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China's Building Energy Use

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Table of Contents

1	Background	3
2	Annotated Bibliography	4
2.1	English-Language Sources.....	4
2.2	Chinese-Language Sources	12
2.3	International Building Energy Reference Materials	18
2.4	Data Overview	19
3	General Findings	25

China Buildings Energy Use: Annotated Bibliography

1 Background

Buildings represent an important and increasing component of China's total energy consumption mix. However, it is difficult to assess accurately the total volume of energy consumed in buildings owing to deficiencies in China's statistical collection system and the lack of national surveys. Officially, residential and commercial energy use account for 19% of China's total consumption. This measure, though, omits many commercial and residential buildings that belong to units that are categorized under the industrial, agricultural, construction or other sectors of the economy. Chinese academics estimate that the buildings sector actually accounts for 23% of total energy use and will exceed 30% by 2010 (Liang, et al. 2007). Beyond data uncertainties, current figures exclude the energy used in the mining, extraction, harvesting, processing, manufacturing and transport of building materials as well as the energy used in the construction of buildings.

This annotated bibliography aims to review the existing major literature available in English and Chinese (including Japanese research published in Chinese) to determine the type, nature and scope of available building energy use data, including embedded energy (production of building materials and construction energy) and operations energy (end-use equipment use of energy). A wide range of sources were reviewed and include on-going projects in China metering building energy use in the residential and commercial sectors. As well, relevant international reports on issues not covered directly in the sources about China were reviewed, including such topics as building lifetime, building material intensity, and energy use changes between dense and dispersed residential settings, among others.

The research was carried out both in the US and in China. These articles were mostly in English. In addition, a Chinese-speaking researcher reviewed on-hand Chinese yearbooks and other publications. Although some material, such as the China Statistical Yearbook is published in Chinese and English, most, such as the Yearbook of China Building Materials Industry, is available only in Chinese. The researcher also compiled related LBNL publications. Inside China, a Chinese-speaking researcher with a background in building energy studies interviewed a number of experts in the field, such as Dr. Jiang Yi at Tsinghua, Wang Lan at the China Building Materials Association, and others, who provided her both with published materials and details of ongoing metering and survey projects.

Each of these sources is listed below both in summary format, followed by tabular details of the content of each source. The summaries are grouped into English-language sources, Chinese language sources, and finally international reference sources.

2 Annotated Bibliography

2.1 ENGLISH-LANGUAGE SOURCES

1. Bressand, Florian; Zhou, Nan; Lin, Jiang. 2007. "Energy use in commercial building in China: Current situation and future scenarios," *Proceedings of the European Council for an Energy Efficient Economy (ECEEE) 2007 Summer Study*, pp.1065-1071.

Data sources: China National Bureau of Statistics (NBS); Lawrence Berkeley National Laboratory (LBNL) China End-use Energy Model.

Geographic and sector scope: China commercial building energy use 2000-2020.

Core argument: commercial energy consumption in current NBS statistics is underestimated by 44% and fuel mix is misleading; energy efficiency improvements will not be sufficient to offset strong increases in energy (particularly electricity) intensity in commercial buildings.

2. Brockett, Debbie; Fridley, David; Lin, Jieming; Lin, Jiang. 2002. "A Tale of Five Cities: The China Residential Energy Consumption Survey," *Proceedings of the American Council for an Energy Efficient Economy (ACEEE) Summer Study on Building Energy Efficiency*, August 2002.

Data source: 5-city, 251-household comprehensive survey of Chinese household energy use, taken in the cities of Beijing, Guangzhou, Shanghai, Yixing, and Shenyang.

Geographic and sector scope: Eastern China urban residential energy consumption.

Core argument: The findings support the current policy to emphasize development of minimum efficiency standards for household equipment, as energy consumption from these sources are a significant portion of the household energy budget.

3. Chen, Shuqin; Li, Nianping; Jun, Guan; Xie, Yanqun; Sun, Fengmei; Ni, Ji. 2007. "A statistical method to investigate national energy consumption in the residential building sector of China," *Energy and Buildings*, 40 (2008): 654-665.

Data source: end-use data for 60 households in a "representative city with middling economic level"; more detailed data were collected based on a single representative household.

Geographic and sector scope: residential building energy consumption in a single, unspecified urban sample; article includes quantitative data on end-use and unit-area energy consumption by fuel per month, seasonal HVAC usage, and daily consumption by end use.

Core argument: China's current residential building energy use data are too fractured and incomplete: article outlines the structure of a proposed new national statistical system of residential building energy consumption. Case study data are presented to illustrate proposed system and the authors' qualifications for administration.

4. Fernandez, John E. 2007. "Resource Consumption of New Urban Construction in China," *Journal of Industrial Ecology*, 11 (2): 99-115.

Data sources: survey of more than 50 residential, commercial, and industrial buildings in the U.S., Europe, Canada, and Japan (for building energy shares); survey of "typical Chinese construction" (for material input requirements); secondary literature.

Geographic and sector scope: national urban analysis based on residential, commercial, and industrial building-type material intensity analysis; select review of published Yangtze Delta analysis.

Core argument: building design and operation technology should be integrated with urban planning to save energy and resources.

5. Gao, Weijun; Wang, Xingtian; Li, Haifeng; Zhao, Penglin; Ren, Jianxing; Toshio, Ojima. 2004. "Living Environment and energy consumption in cities of Yangtze Delta Area," *Energy and Buildings* 36: 1241-1246.

Data source: NBS, Urban Statistical Yearbook of China, 1992-2000; Shanghai municipal statistics.

Geographic and sector scope: Yangtze Delta (eastern China) urban areas; residential consumption of coal gas, LPG, electricity, and total energy are qualitatively reported with sporadic quantitative data interspersed into the text.

Core argument: most of the article is a review of published NBS data; concluding argument is that planning should be used to avoid a property bubble, particularly in Shanghai.

6. Guan, K.; Feng, K.; and Zeng, S.X. 2001. "Urban housing reform and development in China," *Building Research and Information* 29(4): 286-292.

Data source: NBS; secondary literature.

Geographic and sector scope: China national-level analysis of urban residential building; includes historical and forecast floor area demand data; socio-economic breakdown of new urban housing.

Core argument: urban residential building growth accounted for 0.57% of national GDP in 1998; continued construction will generate growth in related services.

7. Huang, Yu Joe; Canha, Antonio; Rosenfeld, Arthur H., and Dien Tseng. 1982. "Energy Efficiency in Chinese Apartment Buildings: Parametric Runs with the DOE.2 Computer Program," Lawrence Berkeley Laboratory Report LBL-15183.

Data source: Primary source construction cost, efficiency, and weather data obtained from Chinese personal contacts; secondary literature.

Geographic and sector scope: "typical design" low-rise urban residential building (4 stories) in Beijing and Shanghai.

Core argument: North-wall insulation and reduced infiltration improves comfort and generates more rapid social and economic benefits than achieving the same heating levels through increased coal production.

8. Huang, Yu Joe. 1989. "Potentials for and Barriers to Building Energy Conservation in China," Lawrence Berkeley Laboratory Report LBL-27644.

Data source: NBS; primary research; secondary literature.

Geographic and sector scope: Urban residential and commercial buildings in East and Northeast China, particularly Shanghai, Beijing, Harbin, and Suzhou.

Core argument: Computer simulations demonstrate that energy efficient boilers and building designs are economically cost-effective in Northeast China.

9. Kwok, R.Y. 1980. "Construction Technology and Building Materials in the People's Republic of China," *Habitat International* 5.3-4:323-335.

Data source: Official Chinese government media; secondary literature.

Geographic and sector scope: China urban residential buildings: built space and investment.

Core argument: Urban residential construction suffers from financial constraints, lack of modern building materials, low technology, and lack of qualified labor.

10. Lang, Siwei; Huang, Yu Joe; and Levine, Mark. 1992. "Energy Conservation Standard for Space Heating in Chinese Urban Residential Buildings," (unpublished LBNL report).

Data source: Ministry of Construction published data; primary research.

Geographic and sector scope: Urban residential buildings in "central heating zone," with Beijing case study. This zone subsequently relabeled "cold" and "very cold."

Core argument: article quantifies cost payback of various methods used to improve energy efficiency according to 1991 standard.

11. Lang, Siwei. 2004. "Progress in energy-efficiency standards for residential buildings in China," *Energy and Buildings*, 36: 1191-1196.

Data source: Ministry of Construction published building standards; primary research.

Geographic and sector scope: Urban and rural residential buildings in "cold and very cold" regions of China.

Core argument: Building energy efficiency standards should be revised to corresponding international levels, for example to include air conditioning. Government funding should be established for energy-efficient buildings. Heating payment system must be reformed to foster competition and create rational end-use incentives. Evaluation and certification system is essential for energy-efficient technology and products.

12. Liang, Jing; Li, Baizhan; Wu, Yong; Yao, Runming. 2007. "An investigation of the existing situation and trends in building energy efficiency management in China," *Energy and Buildings* (forthcoming).

Data source: 13,125 questionnaire surveys (10,236 residential; 2,889 institutional); anecdotal results and overview data provided throughout the article.

Geographic and sector scope: 22 provincial capitals and major cities; predominantly in the "hot summer cold winter" climate zone; government and residential buildings.

Core argument: Survey data show the most effective way to reduce building heating, air conditioning, and lighting energy use by 50% (compared to buildings built in the 1980's) as stipulated by regulation GB 50189-2005. Suggested mechanisms include: increased regulation of large-scale public buildings; legislation compelling property developers to educate consumers on the energy efficiency labeling system; training of skilled construction and installation workers; installation of thermostats and a metering systems.

13. Liu, Feng. 1993. "Energy Use and Conservation in China's Residential and Commercial Sector: Patterns, Problems, and Prospects," Lawrence Berkeley Laboratory Report LBL-33867.

Data source: NBS; primary research; author estimates; secondary literature.

Geographic and sector scope: China urban commercial, and urban and rural residential buildings.

Core argument: Report provides a comprehensive assessment of residential and commercial energy usage; suggestions include increased emphasis on electricity conservation, energy price reform, strengthened standards enforcement, increased investment, and improved international cooperation.

14. Ma, Laurence J C. 2002. "Urban transformation in China, 1949-2000: a review and research agenda," *Environment and Planning A* 34: 1545-1569.

Data source: Secondary literature.

Geographic and sector scope: China historical urbanization.

Core argument: article provides a qualitative, planning-oriented review of urban dilapidation between 1949 and 1978, and urban renewal and growth after 1978.

15. NBS. 2007a. *China Energy Statistical Yearbook 2006*. Beijing: China Statistics Press.

Data source: NBS integrated national and provincial-level data from the State Statistical Bureau, the Energy Bureau of the National Development and Reform Commission, and the First National Economic Census.

Geographic and sector scope: National and provincial-level data are provided for industry (including construction), commercial, and residential (urban and rural) energy consumption by fuel.

Core argument: N.A.

16. NBS. 2007b. *China Statistical Yearbook 2006*. Beijing: China Statistics Press.

Data source: NBS integrated national and provincial-level data from the State Statistical Bureau and the First National Economic Census.

Geographic and sector scope: National and provincial-level data are provided for industry (including construction), commercial, and residential (urban and rural) consumption and production. Construction start and sales data are published by floor space area. Residential end-use data are published in terms of appliance ownership per household. Rural residential building material content published annually. Residential demolition data can be derived from built area and annual newly built floor space.

Core argument: N.A.

17. Rousseau, David; and Chen, Yi. 2001. "Sustainability options for China's residential building sector," *Building Research and Information* 29(4): 293-301.

Data source: Secondary literature.

Geographic and sector scope: Material and energy sustainability of urbanization in China is reviewed vis-à-vis American development models.

Core argument: If China is to achieve sustainable development, new urban development must be more efficient than Western cities.

18. Tyler, Stephen R. 1994. "Household Energy Use in Asian Cities: Responding to Development Success," *Atmospheric Environment* 30(5): 809-816.

Data source: survey research from 5 countries and 12 cities; LBL databases; secondary literature.

Geographic and sector scope: Urban residential energy use in 5 countries and 12 cities in East Asia. Chinese cities include Beijing and Nanning.

Core argument: Article reviews shift from energy fuel to household electricity use with urbanization; it then outlines policy mechanisms useful for improving electricity usage efficiency.

19. Wang, Z.; Bai, Z.; Yu, H.; Zhang, J.; Zhu, T. 2004. "Regulatory standards related to building energy conservation and indoor-air-quality during rapid urbanization in China," *Energy and Buildings*, 36: 1299-1308.

Data source: Ministry of Construction standards; NBS; secondary literature.

Geographic and sector scope: China urban residential and commercial.

Core argument: Ex post facto description of building energy-saving and indoor-air-quality standards in China.

20. Wei, Yehua Dennis. 2005. "Planning Chinese Cities: The Limits of Transitional Institutions," *Urban Geography* 26(3): 200-221.

Data source: Hangzhou City statistics; secondary literature.

Geographic and sector scope: Hangzhou urban residential and commercial buildings.

Core argument: Institutional reform will facilitate rational, economically-integrated urban growth in China.

21. Wirtshafter, Robert M and Song-ying, Chang. 1987. "Energy conservation in Chinese housing," *Energy Policy*, April, pp.158-168.

Data source: Primary case study research and secondary literature.

Geographic and sector scope: Urban and rural residential building energy usage in Zhengzhou, Henan Province, China.

Core argument: Conventional Western solutions for energy conservation must be adjusted and adapted to be effective in improving Chinese residential building energy efficiency.

22. World Bank, Asia Alternative Energy Programme and Energy and Mining Unit. 2001. *China: Opportunities to Improve Energy Efficiency in Buildings.*

Data source: Tsinghua University surveys and Ministry of Construction data; secondary sources; NBS.

Geographic and sector scope: China urban and rural commercial and residential buildings.

Core argument: Two-handed approach is necessary to combine heat metering and billing, and supply system modernization, together with more aggressive development of energy efficient buildings.

23. Xu, Ming; Zhang, Tianzhu. 2007. "Material Flows and Economic Growth in Developing China," *Journal of Industrial Ecology* 11(1): 121-140.

Data source: NBS; author estimates; secondary literature.

Geographic and sector scope: article compares physical aspects (e.g., total material requirements) of China's economy with those of select developed and developing countries.

Core argument: Analysis of China's material consumption efficiency from 1990 to 2002 illustrates the effects of macropolicies that defined the Eighth, Ninth, and Tenth Five-Year Plans. Material flow accounting is necessary for understanding the physical dimensions of economic development.

24. Yao, Runming; Li, Baizhan; Steemers, Koen. 2005. "Energy policy and standard for built environment in China," *Renewable Energy*, 30: 1973-1988.

Data source: NBS; Ministry of Construction, Energy Conservation Center; Secondary literature.

Geographic and sector scope: China urban and rural residential and commercial buildings.

Core argument: Energy efficiency policy revisions will help China achieve its five-year-plan economic and environmental goals.

25. Yoshino, Hiroshi, S. Guan, Y.F. Lun, A. Mochida, T. Shigeno, Y. Yoshino, et al. 2004. "Indoor thermal environment of urban residential buildings in China: winter investigations in five major cities," *Energy and Buildings*, 36: 1227–1233.

Data source: field surveys; NBS; secondary literature.

Geographic and sector scope: Urban residential buildings in 5 Chinese cities.

Core argument: Thermal insulation and air tightness are important for building thermal energy efficiency.

26. Yoshino, Hiroshi; Yoshino, Yasuko; Zhang, Qingyuan; Mochida, Akashi; Li, Nianping; Li, Zhenhai; Miyasaka, Hiroyuki. 2006. "Indoor thermal environment and energy saving for urban residential buildings in China," *Energy and Buildings*, 38: 1308-1319.

Data source: survey questionnaires and field measurements; secondary literature.

Geographic and sector scope: China urban residential buildings with a 9-city focus.

Core argument: Energy used to heat indoor spaces can be halved by installing thermal insulation and properly sealing the building.

27. Zhang, Qingyuan. 2004. "Residential energy consumption in China and its comparison with Japan, Canada, and USA," *Energy and Buildings*, 36: 1217-1225.

Data source: Ministry of Construction standards; NBS; secondary literature.

Geographic and sector scope: Urban residential energy consumption in China is compared with that of Japan, Canada, and the U.S.

Core argument: Annual China urban household energy consumption varied between 11 and 24 GJ in 1997. Household final coal consumption declined while electricity and gas have been growing.

28. Zhu, Yingxin and Lin, Borong. 2004. "Sustainable housing and urban construction in China," *Energy and Buildings*, 36: 1287-1297.

Data source: Ministry of Construction; NBS; primary research; secondary literature.

Geographic and sector scope: China urban residential buildings.

Core argument: Execution and enforcement of buildings standards is unsatisfactory and China's construction sector is not sustainable. Limited academic progress gives hope for improved sustainability.

2.2 CHINESE-LANGUAGE SOURCES

29. Chen, Chen; Pan, Yiqun; Huang, Zhizhong, and Lou, Zhenfei. 2006, *The Establishment and Application of Commercial Building Information Database for Shanghai*, Shanghai Energy Conservation Supervision Center, 2006

Data source: building survey through questionnaire in 95 commercial buildings in Shanghai in 2005, collected energy consumption data in the last few years.

Geographic and sector scope: 95 commercial buildings in Shanghai. Surveyed items include building characteristics, HVAC system, operation schedule, and energy consumption by fuel type.

Core argument: Commercial building energy intensity in Shanghai has increased from 148.3 kWh/m² in 1998 to 172.6 kWh/m² in 2005, by 16%. This survey is just a beginning of the establishment of Shanghai commercial building information database, next step would be to enrich and improve the business information database construction and function of the content and use of statistical analysis and data mining and other advanced data processing means, ultimately allowing users to access the web-based database

30. China Academy of Building Research (CABR), and Chongqing University, 2001. *Design Standard for Energy Efficiency of Residential Building in Hot Summer and Cold Winter Zone*, JGJ 134-2001. 2001.

Data source: standards

Geographic and sector scope: heating degree days and cooling degree days in major cities in the hot summer and cold winter zone

Core argument: It stipulated energy saving standards for residential buildings.

31. China Building Material Industry Association (CBMIA), 2006. *China Building Material Industry Yearbook*, China Building Material Industry Yearbook Publishing Company, 2007.

Data source: statistics through the Building Material Industry Association.

Geographic and sector scope: relevant policy documents, work of each building material industry associations, industry economic operation status, standards and patents, national projects, summary of general status of the industries in each province, autonomous regions, and financial information of key enterprises, and the basic statistics. Building material industry includes cement industry, glass industry, ceramic industry, etc.. In addition, energy intensity, emissions, and other basic technical and

economic indicators of average NSP cement kilns and flat glass and comparisons to international level are also included.

Core argument: 77.37% of the building material products are used in construction. New construction and retrofitting floor area will be 10.8 billion m² by 2020. In the last few years, the real estate industry has achieved 20% annual growth. Newly added housing floor area is 0.6 billion m² in urban areas, 0.7 billion m² in rural areas, and 0.7 billion m² for public and industrial buildings now.

- 32.** China Meteorological Bureau Weather Information Center (CMBWIC), and Tsinghua University, *China Building Thermal Environment Analysis Special Weather Database, 2005*. China Building Industry Publishing Company.

Data source: hourly weather data from major observatories in China, for some observatories that do not have hourly data, Tsinghua University has developed a method to interpolate or calculate hourly data.

Geographic and sector scope: It includes data from 270 observatories in 30 provinces and autonomous regions across China. Data cover temperature, wind speed, humidity, solar radiation, atmospheric pressure and heating degree-days.

Core argument: the data is from 1971 to 2003, it comes with a CD. The data can be used for choosing typical weather year, and then be used for building energy simulation.

- 33.** Jiang, Zhongtian; Yoshino, Hiroshi; Watanabe, Toshiyuki; Yoshino, Yasuko; Zhang, Qingyuan; Gao, Weijun; Tonooka, Yutaka; Kumagai, Kazukiyo; And Hayama, Hirofumi. 2007. "Investigation on the Current Energy Consumption of Urban Residential Buildings in China" (in Japanese), *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, AIJ*, September 2007

- 34.** Jiang, Zhongtian; Yoshino, Hiroshi; Watanabe, Toshiyuki; Yoshino, Yasuko; Zhang, Qingyuan; Gao, Weijun; Tonooka, Yutaka; Kumagai, Kazukiyo; And Hayama, Hirofumi. 2007. "The Survey of the Use of Cooling&Heating Systems And Energy Consumption Of Urban Apartments In China" (in Japanese), *The Society of Heating Air-Conditioning and Sanitary Engineers of Japan*, May, 2007.

Data source: survey of electricity and gas consumption, and living pattern in 350 households China from January 2006 to January 2007. A comparison of the energy consumption in Japan and China were made.

Geographic and sector scope: residential building energy consumption in typical urban apartment housing in 7 cities across the country, which represent 4 prototypical climate zones.

Core argument: peak electricity consumption occurs in the summer across the country, housing in southern cities use more gas for cooking than northern cities. Total household energy consumption in some city can be significantly higher than other cities, mostly attributed to higher cooking energy and cooling energy demand. Annual cooking energy use in Chongqing is twice as much as that of Nanjing, and is 60% that of Tokyo. Cooling energy consumption in Chongqing is three times that of Nanjing and Tokyo. Heating and water heating energy consumption in both Nanjing and Chongqing are approximately 10% and 20% that of Tokyo respectively.

35. Kang, Yanbing, and Wei, Qingpeng, 2005. "Analysis of the impacts of building energy efficiency policies and technical improvements on China's future energy demand", *International Journal of Global Energy Issues*, Volume 24, Number 3-4, pp280 – 299. 2005

Data source: unclear

Geographic and sector scope: residential and commercial energy consumption. Residential is broken out by north, transition area, and south.

Core argument: it has building floor areas, and the projection to 2020, space heating load, heating technologies in northern China and their projections. It also has energy consumption and projection by fuel and by end use, by commercial and residential. Fuel consumption by end use is also included.

36. Li, Zhengrong; Peng, Jiao; Wang, Baohai; and Yan, Yibiao. 2005. "Survey on energy consumption and operation management status of public buildings in Shanghai", *Heating Ventilating & Air Conditioning*. Issue 5, 2005

Data source: through survey conducted by Tongji University and Shanghai Construction Commission in 2003, in order to form basis to facilitate further development and implementation of [Shanghai area public building energy conservation design code]

Geographic and sector scope: public building energy consumption and building management in Shanghai. Public building includes 12 prototypes of building such as office, retail, healthcare and educational buildings. The survey was done in 32 high-rise buildings, with higher composition of office building and hotels.

Core argument: The floor area of public building in Shanghai has reached 86.96 million m², with an annual growth rate of 9.44% in recent five years; Among the 32 surveyed high-rise buildings, office building and hotel building together account for 88% of the total, and they are mostly built after 1990. HVAC system uses 40 to 60% of the total energy, and lighting uses 10 to 20%. 80% of the air conditioning fuel is electricity, and 8% uses NG.

37. Long, Weiding; Zhang, Peihong; Zhong, Ting. 2003. "The Status and Development of Residential Air Conditioning Energy in Shanghai", <http://www.china5e.com/dissertation/newenergy/20030820173043.html>.2003.

Data source: through survey in 780 households in Shanghai in 2001 conducted by Tongji University

Geographic and sector scope: Appliance saturation rate in Shanghai's middle class households.

Core argument: The saturation rates of major appliances are much higher than that in NBS' statistics. Some family even has as much as 7 air conditioners. The AC saturation in Shanghai is higher than any of the regions in the U.S., but much of those are Room ACs. However, the usage time is low, and annual average usage time is approximately 800 to 900 hours.

38. Long, Weiding. 2006. *The status of Residential energy consumption and energy conservation in China*, Speech at China Building Energy Conservation Net, <Http://www.k211.com>. 2006.

Data source: Tongji University and Shanghai Building Science Academy jointly conducted survey in 10,000 households in Shanghai in 2004

Geographic and sector scope: residential building energy consumption Shanghai. The talk mentioned the electricity consumption and average energy consumption in 10,000 households.

Core argument: Building energy consumption in Shanghai only accounts for 13.7% of the total energy because of low space heating energy use. Average household primary energy use in household in Shanghai is 973 kgce, about 13.7 kgce/m², which is one third or one fourth that of the energy use in the U.S. The electricity consumption is also significantly lower than the U.S. level, and space cooling electricity use accounts for one third of the total electricity consumption. Some policy suggestions include: The trend of growth in building energy consumption can not be easily changed, but its elasticity to floor area should be controlled; Building envelope insulation should be further improved; Market access approval measure for new air conditioners and rebate for purchasing more efficient air conditioners should be adopted; promote the use of solar thermal water heater and heat pump water heater.

39. Ministry of Construction (MOC)'s ongoing survey in public building in 32 provinces or cities

Data source: national survey in public building in 32 provinces or cities

Geographic and sector scope: It will cover at least 20 government office, and 20 public buildings in each region for the major cities, and more than 10 buildings each for smaller cities. It also covers 13 types, and the buildings are all more than 20,000 m². The survey includes building characteristics and building energy consumption by fuel. The MOC just started doing it, and has commissioned local Construction Commissions and Building Research Institutes to do the questionnaire and data collection. The data should be collected by the end of 2007 for major cities and sometime in 2008 for smaller cities.

Core argument: no results yet

40. NBS, 2007c. 2006 China City Statistical Yearbook, China Statistics Press.2007.

Data source: statistics through Bureau of Statistics.

Geographic and sector scope: covers all mid-large cities in China, has population, residential Gas and LPG consumption, electricity consumption, number of hospitals, theaters, schools, number of employees by sector

Core argument: Statistical compilation

41. Tsinghua University Building Energy Conservation Research Center, 2007. *Annual Report on China Building Energy Efficiency*. China Building Industry Publishing Company, 2007.

42. DeST, Tsinghua University China Energy Consumption Information Center (<http://bdb.dest.com.cn/>) (through interview)

Data source: on going and planned survey of electricity consumption and building characteristics in China since 2000. Real-time electricity use metering for some typical buildings. Not all online data accessible.

Geographic and sector scope: Residential : on going and planned survey of electricity consumption and building characteristics in 1000 urban households each in Beijing, Shenzhen, Shanghai, Chongqing in China since 2000. On going rural household energy consumption survey in 2707 households in 417 villages in 16 provinces. (interview, not included in the book). Commercial: survey in electricity and gas consumption in 583 buildings in Beijing and other regions (Beijing 409, other region 174). It includes 14 prototypes of buildings; some buildings have real-time metering and directly report to Tsinghua DeST group.

Core argument: energy consumption particularly heating energy consumption in China varies by region; however, excluding heating energy, the electricity consumption across the country does not differ very much; fuel mix and total energy consumption in urban and rural area are different; commercial building energy consumption significantly

varies by type and size of the building, particularly due to the type of HVAC system, and energy intensity is much lower than that of the developed countries.

43. Nie, Deliang. 2002. "The Potential Analysis of Energy Conservation in Shanghai Public Buildings", *ENERGY TECHNOLOGY*, Vol. 23, No. 3 June, 2002

Data source: energy consumption of public buildings by end use by fuel in Shanghai in 1999 was derived from statistic and some sample surveys. Data source for total number of building by type are not clear. Average energy use by technology and potential energy saving is estimated.

Geographic and sector scope: total number of high-rise office, retail and hotel buildings, school classrooms and hospitals in Shanghai. Also estimates of average HVAC systems, average efficiencies, lighting energy use, elevator and other equipment electricity use.

Core argument: Electricity consumption accounts for 70% of the total energy consumption in public buildings in Shanghai, and space heating and cooling energy account for 35% of the total. The energy saving potential from HVAC system is 30%, 16% from efficient lighting, 20% for elevators, and 10% for other equipments.

44. Yu, Hang; Liu, Shujuan; Li, Yiyu; and Yu, Lang. 2007. "Investigation Energy Consumption from Living Conditions, Habits of Residents in Shanghai".
<http://www.secidc.org.cn/newscontent.asp?id=709>

Data source: questionnaire survey in 315 households in Shanghai conducted by Tongji University

Geographic and sector scope: residential building in Shanghai. Surveyed items include basic information of the households, energy consumption and appliance usage pattern

Core argument: major fuel use in Shanghai is electricity and gas. Electricity consumption is high in the summer, but is not low in the winter either because of the air conditioner uses for heating. More use of coal gas than natural gas throughout the year. Usage patterns are included.

45. Zhou, D., Dai, Y., Yu, C., Guo, Y. and Zhu, Y., 2003. *China's Sustainable Energy Scenarios in 2020*, China Environmental Science Publishing Company.

Data source: some are from existing survey, some are from the statistics, government plan, and some are estimates.

Geographic and sector scope: Both residential and commercial sector, with end use broken out by technology or fuel. It has energy intensities, efficiency of the technologies and penetration rate. Residential is broken out by urban and rural; space

heating is further broken out by three climate zones. Commercial is broken out by 5 types of the building.

Core argument: Based on a bottom-up model populated with data and information for modeling energy consumption from end use and the projections. It incorporated three scenarios that are all based on different level of energy efficiency policies. The results show that more effective and strengthened policy would significantly reduce the energy consumption in China, whereas a policy failure would lead to much high energy consumption. The model requires detail of the data that doesn't exist in statistics or in published documents; a lot of the data are estimated. The data are outdated, and some data lack elaboration.

2.3 INTERNATIONAL BUILDING ENERGY REFERENCE MATERIALS

46. Cole, Raymond J. 1999. "Energy and greenhouse gas emissions associated with the construction of alternative structural systems," *Building and Environment* 34: 335-348.

Data source: General worker-hour data from a published primary source and project-specific data from surveys and telephone interviews.

Geographic and sector scope: Canada on-site construction industry.

Core argument: Relative to wood and steel, concrete structural assemblies require an order of magnitude more energy and greenhouse gas emissions.

47. Norman, Jonathan; MacLean, Heather L.; Kennedy, Christopher A. 2006. "Comparing High and Low Residential Density: Life-Cycle Analysis of Energy Use and Greenhouse Gas Emissions," *Journal of Urban Planning and Development* 132(1): 10-21.

Data source: two case studies; secondary literature.

Geographic and sector scope: Urban residential buildings in Toronto, Canada.

Core argument: Low-density suburban development is more energy and GHG-intensive than high-density urban core development on a per-capita basis.

2.4 DATA OVERVIEW

	Bressand, et al. (2007)	Brockett, et al. (2002)	CABR (2001)	CBMIA (2006)	Chen, et al. (2006)	Chen, et al. (2007)	CMBWIC (2005)	Fernandez (2007)
Data Vintage	2000-2020	1999	N.S.	2006	2005	2005	1971-2003	2005
Data Source	National statistics, literature.	Questionnaire surveys	Weather data	National statistics	Questionnaire survey	Two surveys	Collected weather data	Two surveys; secondary literature
Sector	Commercial	Residential	Residential	Building Material Industry	Commercial	Residential	N/A	Residential, commercial, & industry
Region	China	China cities	China cities	China	Shanghai	China	China key cities	China
Climate Zone	N.S.	Hot summer and cold winter	Hot summer and cold winter	N.S.	one	N.S.	All kinds	N.S.
Urban/Rural	N.S.	Urban	N.S.	N.S.	N.S.	Urban	N.S.	Urban
Building Type	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	Six-floor building
Metric	Unit energy consumption by fuel & end-use.	Unit energy consumption by fuel & end-use.	Heating and cooling degree-days	Tech. & econ. indicators: cement & glass	Building characteristics; energy by fuel	Unit area energy consumption by fuel; end-use consumption.	Heating degree-days, thermal parameters	Material intensity
Building Vintage	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Area	Annual sector projections	City-level data for 1999.	N.S.	2006	monthly	N.S.	hourly	Annual sector projections
Fuel Consumption	All fuels	All fuels	N.S.	Energy intensities for cement & glass	All fuels	Unit-area consumption for gas & electricity	N.S.	Electricity
End Use	Intensity	Appliance	N.S.	N.S.	N.S.	Appliance	N.S.	N.S.
Building Lifespan	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	125 years
Demolition	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N/A	Resource use

Note: N.S. is Not Specified

	Gao, et al. (2004)	Guan, et al. (2001)	Huang, et al. (1982)	Huang, et al. (1989)	Jiang (2007)	Kang (2005)	Kwok (1980)
Data Vintage	1999	1998	1982	1988	2006-2007	2000	1979
Data Source	NBS	NBS, secondary literature	Primary research; secondary literature	NBS; primary research; secondary literature	Survey & measurement	N.S.	China official media
Sector	Residential & commercial	Residential	Residential	Residential & commercial	Residential	Residential & commercial	Residential
Region	Eastern China	China	Shanghai & Beijing	East & NE China	7 cities	China	China
Climate Zone	N.S.	N.S.	N.S.	East & NE China	Cities in different zones	Three zones for residential	N.S.
Urban/Rural	Urban	Urban	Urban	Urban	urban	Urban/rural	Urban & rural
Building Type	N.S.	N.S.	Low-rise (4 stories)	N.S.	Apartment complex	Average	N.S.
Metric	Inter-city consumption	Share of GDP	Energy consumption & cost savings in typical unit.	Cost of conserved coal (investment cost : coal conserved)	Energy by fuel & living pattern	Aggregated energy by fuel and by end use	Built area and investment
Building Vintage	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Area	Historical floor area	Historical & projected floor area	144 square-meter unit	48 square-meter unit	2006 to 2007 data	One Data point	Annual historical built area
Fuel Consumption	All fuels	N.S.	Coal	Coal & total energy	All fuel	All fuel	N.S.
End Use	N.S.	N.S.	Heat	Heat	By end use	By end use	N.S.
Building Lifespan	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Demolition	N.S.	N.S.	N.S.	N.S.			N.S.

	Lang, et al. (1992)	Liang, et al. (2007)	Long (2006)	Lang (2004)	Li (2005)	Liu (1993)
Data Vintage	1990	2006	2004	2003	2003	1991
Data Source	Ministry of Construction	13,000 survey questionnaires	survey	Ministry of Construction standards	survey	NBS; published surveys
Sector	Residential	Public (government & residential)	Residential	Residential	public	Residential & commercial
Region	North and Northeast China	China	Shanghai	North & central China	Shanghai	China
Climate Zone	“Central heating zone”	Primarily “hot summer cold winter”	one	Cold & very cold	one	All
Urban/Rural	Urban	Urban	urban	Urban & rural	N/A	Urban & rural
Building Type	N.S.	Survey sample data	N.S.	N.S.	13 types high-rise	N.S.
Metric	Unit area energy consumption	Policy and standard effectiveness	Aggregated energy consumption	Unit area energy consumption	Aggregate energy consumption	Energy end-use by fuel and technology
Building Vintage	N.S.	Survey sample data	N.S.	1980-2003	Mostly after 1990	N.S.
Area	1991 baseline	N.S.	N.S.	1990s data	N.S.	N.S.
Fuel Consumption	Total energy	Aggregate policy goals	electricity	Total	All fuels	All fuels
End Use	Heating	N.S.	N.S.	Heating	Air conditioning and lighting	Appliance unit energy consumption
Building Lifespan	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Demolition	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

	Ma (2002)	MOC (2007)	NBS (2006)	NBS (2007a)	NBS (2007b)	NBS (2007c)	Nie (2002)	Rousseau, et al. (2001)
Data Vintage	2000	2007	2006	2005	2005	2005	N.S.	1999
Data Source	Secondary literature	survey	Statistic	NBS surveys & censuses	NBS surveys & censuses	NBS surveys & censuses	Estimate & statistic	Secondary literature
Sector	N.S.	Large Public building	Commercial, & Residential	Residential, commercial, & industry (including construction)	Residential, commercial, & industry (including construction)	Residential & commercial	Public buildings	N.S.
Region	China	China/provinces/cities	All key cities	China provinces	China provinces	Major Chinese cities	China Shanghai	China
Climate Zone	N.S.	many	Various	N.S.	N.S.	All	one	N.S.
Urban/Rural	Urban	N/A	urban	Urban & rural	Urban & rural	Urban	N/A	Urban
Building Type	N.S.	13 types large building	Number of hospitals, schools	N.S.	N.S.	N.S.	High-rise	N.S.
Metric	Urban consistency with other socialist cities	Building characteristics & energy	Urban development	Energy by fuel	Area, price, & material	Energy by fuel	Energy saving potential estimates	Resource and energy intensiveness of urbanization
Building Vintage	N.S.	May be	N/A	N.S.	N.S.	N.S.	N.S.	N.S.
Area	N.S.	annual	N/A	N.S.	Annual	N/A	N.S.	N.S.
Fuel Consumption	N.S.	All fuels	All fuels	All fuels	Fuel by sector	Gas, LPG, electricity	electricity	N.S.
End Use	N.S.	N.S.	N/A	Sector by fuel	Household appliances	N/A	N.S.	N.S.
Building Lifespan	N.S.	N.S.	N/A	N.S.	N.S.	N.S.	N.S.	N.S.
Demolition	N.S.	N.S.	N/A	N.S.	Area derivable	N/A	N.S.	N.S.

	Tsinghua University	Tyler (1994)	Wang, et al. (2004)	Wei (2005)	Wirtshafter, et al. (1987)	World Bank (2001)	Xu, et al. (2007)
Data Vintage	2000-2007	1990	2000	2002	1984	2000	2002
Data Source	Survey & measurement	Surveys & literature	Ministry of Construction standards & secondary literature	Hangzhou City statistics; secondary literature.	Case study data; secondary literature	Tsinghua University surveys and Ministry of Construction data; secondary sources; NBS	NBS; author estimates; secondary literature
Sector	Commercial & Residential	Residential	Residential & commercial	Residential & commercial	Residential	Residential & commercial	Macro-economy
Region	China cities	East Asia	China	Hangzhou, China	Zhengzhou, Henan, China	China with selected cities	China, with international comparisons
Climate Zone	Cities in different zones	N.S.	N.S.	N.S.	Hot summer cold winter	All	N.S.
Urban/Rural	urban & rural	Urban	Urban	Urban	Urban & rural	Primarily urban	N.S.
Building Type	specified	N.S.	N.S.	N.S.	N.S.	Sectoral breakdown	N.S.
Metric	Energy by fuel	Energy end-use by fuel	Energy consumption & indoor air quality	Urban planning effectiveness in meeting housing demand.	Material and energy intensiveness of buildings	Various energy, economic, and policy metrics	Material consumption efficiency of economic development
Building Vintage	N.S.	N.S.	Pre-1980's, 1980's, and 1990's	N.S.	N.S.	N.S.	N.S.
Area	monthly	N.S.	Breakdown by vintage	N.S.	Total built area for Henan	Historical by type and climate zone	N.S.
Fuel Consumption	All fuels	All fuels	Breakdown by vintage	N.S.	Total energy	All fuels	Total material inputs
End Use	By end use, some cooling technologies	Quantitative data by fuel and technology	Limited	N.S.	Limited	Selected data by province	N.S.
Building Lifespan	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Demolition		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

	Yao, et al. (2005)	Yoshino, et al. (2004)	Yoshino, et al. (2006)	Yu (2007)	Zhang (2004)	Zhou (2003)	Zhu, et al. (2004)
Data Vintage	2001	2002	1998-2004	2006	1997	1998	1999
Data Source	NBS; Ministry of Construction	Survey research.	Survey questionnaires & field measurements; secondary literature	questionnaire	Ministry of Construction; NBS; secondary literature	Survey & estimates	Ministry of Construction; NBS; primary research; secondary literature
Sector	Residential & commercial	Residential	Residential	residential	Residential	Commercial & Residential	Residential & commercial
Region	China provinces	China: 5 cities	China: 9 cities	Shanghai	China, Japan, Canada, & U.S.	China	China; Anhui case study
Climate Zone	All zones	3 zones	All zones	One	All	Three in residential	N.S.
Urban/Rural	Urban & rural	Urban	Urban	urban	Urban	urban & rural for residential	Urban
Building Type	N.S.	Specified	Specified	specified	N.S.	Specified for commercial	N.S.
Metric	Energy efficiency	Residential thermal energy efficiency	Residential thermal energy efficiency	Energy by fuel	Household energy consumption	Energy by fuel and end use	Sustainability of construction materials, practices, and building operation.
Building Vintage	N.S.	Specified	Specified	N.S.	N.S.	N.S.	N.S.
Area	Historical, projected, & cumulative	Specified	Specified	monthly	N.S.	average	Aggregate
Fuel Consumption	All fuels	N.S.	N.S.	All fuels	All fuels	All fuels	Aggregate
End Use	Specified	Heating	Heating	N.S.	Data by fuel and technology	By end use and technologies	Limited modeling
Building Lifespan	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Demolition	N.S.	N.S.	N.S.		N.S.		N.S.

3 General Findings

Overall, China's building sector is very poorly characterized in national statistics and the academic literature. On the national level, data sources and series are sparse. The national statistical system, which is increasingly oriented to financial measures of performance, reports only a few series of relevance, including new construction floor space of residential buildings, new construction floor space of non-residential buildings (apparently excluding industrial floor space), average per-capita living space in urban areas, average per-capita living space in rural areas, and a breakdown of material types used in rural residences (brick, wood, tile), and some statistics on household expenditures for energy. The "commercial" sector is not explicitly identified in any of the series—the "non-residential" balance of total construction thus includes commercial, government, and other public sector buildings. These series are all available on an annual basis; no monthly series were found.

The energy data series includes residential consumption by fuel (coal, oil products, natural or coal gas, electricity, heat) by rural and urban breakdown but excludes non-commercial energy consumption in rural areas. The "commercial" sector (wholesale, retail trade, and hotels and restaurants) includes consumption by fuel in units that formally are considered part of the "commerce" sector of the economy; the "Other" sector includes energy consumption by fuel in government and other buildings, while further building energy use is included (but not explicitly) in the Transport, Storage and Post sector, and Construction, Industry and Agricultural sectors, to the extent that commercial establishments run by units under these sectors of the economy exist.

The national series on industrial energy use includes consumption by fuel in 39 industrial subsectors, but the subsectors are presented at a level at which it is not possible to equate energy use with individual building materials. For example, energy use in the cement industry is included in "Manufacturing of Non-Metallic Mineral Products", which would also include gypsum production for drywall use, among other mineral products. Further, no material flows could be found, and experts at the China National Building Materials Academy were unaware of any data or studies that indicated the proportion of each sectors' output that went to building construction.

Sectoral and subsectoral energy consumption data are available only on an annual basis, and publication is usually 18-24 months after the year reported has ended.

Further, there are no national series on energy end-use, such as lighting, heating, cooling, or refrigeration, within buildings.

An increasing number of studies, however, have focused on smaller scale surveys of commercial and residential energy use, providing partial data on end-use energy consumption lacking from the national data. Of the surveys reviewed, some focus on just one city (Shanghai and cities in the Lower Yangtze region appear to be most favored locations), while others cover up to 34 cities, including urban residential, rural residential, and commercial use. Some surveys include only electricity use, while others included all energy forms, including district heat. One looks at only thermal comfort in apartments. Only two surveys explicitly

distinguish low-rise and high-high residential units, but no “total building” energy use was provided in association. “Commercial” building types covered included retail establishment, hospitals, schools, and other public buildings (increasingly, in China, including in the scope of the building codes, commercial and government buildings are being grouped together as “public buildings”)

All of China’s climate zones are included among these surveys, although the “Cold” and “Hot Summer/Cold Winter” cities appear to be most represented. Heating degree day data are available for 370 cities, but cooling degree day data are available only for each of the building code climate zones, as reported in the building code itself.

The survey data are “snapshots” and do not provide time series for the location. Further, it is not clear that the survey methodology used in different studies is compatible, possibly affecting the comparability of results for the same city.

No data are available on commercial building numbers by city, so it is not possible to determine the top 25 cities with the most commercial establishments (it is possible that city governments may know these figures in terms of total commercial establishments, but they are not included in provincial, national, or urban statistical compilations.)

A number of on-going efforts promise to provide a much larger dataset of building energy use for analysis in the future. In particular, Tsinghua University, under Dr. Jiang Yi, has surveyed 1000 households in 4 cities and 2707 households in 417 villages, and is metering AC electricity use in 30 urban households; partial results of this work have been published. They have also surveyed 583 large (>20,000 m²) public buildings (mostly in Beijing) for electricity and natural gas use by end-use; partial results of this work is available online (in Chinese, with registration) at <http://bdb.dest.com.cn/index.php>. Similarly, the Shanghai Energy Conservation Service Center (SECSC) under Lou Zhenfei has surveyed 95 commercial buildings, but the work has not included metering. At present, the Ministry of Construction has launched an effort, in part supported by the Energy Foundation, to survey large (>20,000 m²) in 32 provinces and cities, including government and other public buildings. Results are not yet available.

In general, there appears to be a growing body of data that would allow a fairly good characterization of energy end-use in different building types around China, particularly residential buildings, based on a single time frame. Almost completely lacking are the “upstream” components of building energy use in the production and construction phase. Aside from the national average energy intensity of cement production and of flat glass production reported by the Building Materials yearbook, no information was found concerning material intensity of buildings, average materials use per building type, or building construction energy use. Data on average building lifetime are also lacking.