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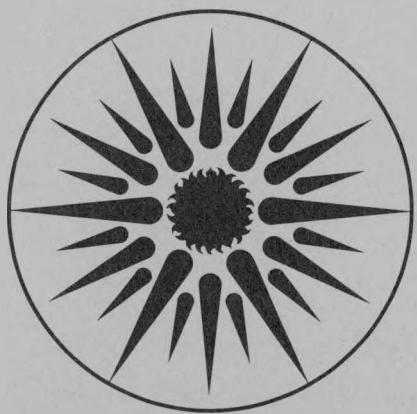
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### Potentials for and Barriers to Building Energy Conservation in China

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**POTENTIALS FOR AND BARRIERS TO  
BUILDING ENERGY CONSERVATION IN CHINA**

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**Presented at:**

**The Western Economic Association International Annual Meeting  
"Comparing Energy Technologies: Private and Social Costs"  
South Lake Tahoe, California  
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# POTENTIALS FOR AND BARRIERS TO BUILDING ENERGY CONSERVATION IN CHINA

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## ABSTRACT

*China is distinct among developing countries in having significant heating loads over much of the country. With nearly half of the urban residential buildings located in climates colder than Washington, there is a large demand for space heating that will skyrocket if the current building boom continues. With the exception of hotels and offices catering to foreigners, space heating energy use is constrained by mandated coal allocations that result in partially heated buildings with indoor temperatures significantly below design conditions.*

*This underheating masks to a significant extent the energy savings from more energy efficient boilers and building designs. Even so, computer simulations show that such conservation strategies can reduce current energy use by 40%, while dramatically raising indoor temperatures. Economic calculations comparing energy savings to increased construction costs are skewed by the unmet heating loads as well as government-subsidized coal prices that are below actual costs. From the perspective of building owners and managers, building energy conservation is still economically attractive in the cold Northeast, with a Cost of Conserved Coal half that of the subsidized coal price, but difficult to justify in terms of economic payback in Beijing or Shanghai.*

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## INTRODUCTION

For the past decade, China has one of the fastest growing economies in the world, with a real growth rate of nearly 10% a year between 1978 and 1987. To fuel this growth, the Chinese economy has been consuming increasing amounts of energy, from 293 million tons of coal equivalent (1 tce = 29.3GJ) in 1970 to 845tce by 1987, ranking it third in the world. A distinctive feature of China's energy consumption is its strong reliance on coal, which makes up 75% of the primary fuel source (SYB 1988). Although China has the largest hydroelectric potential in the world and significant oil reserves, for the foreseeable future China's energy needs will continue to be met by coal. Recent Chinese projections have put Chinese annual energy demand in the year 2000 between 1.3 to 2.4 billion tce (Smil 1988). Such a large increase in energy, and particularly coal, consumption has profound implications not only on China, but also on the world economy and the global environment. Some researchers have even expressed concern that increased coal burning in China will accelerate global warming.

The above government forecasts were based on an unchanged energy-to-GDP ratio and a projected economic growth termed by Deng Xiaoping as "...achieving moderate wealth by the year 2000". The economic effort required to meet this expected demand is prodigious and possibly unsustainable. Although China's energy production has risen by a respectable rate of 5.2% per year between 1981 and 1987 (Zhu 1988), energy shortages have become increasingly severe in the past two years. The official party newspaper stated last fall that electrical shortages in 1987 idled a quarter of the nation's industrial capacity and caused losses of 400 billion Yuan (RMRB 1988). A report this year estimated that a fifth of China's industry has been idled by coal shortages (AWSJ 1989), while another projected a potential shortage of 100 to 200 million tce of coal by the year 2000 (Xie 1988). Even if China's coal industry is able to meet this increased demand, the environmental impacts on acid rain and air quality due to such a drastic increase in coal burning might well be unacceptable.

To address these problems, Chinese have begun to recognize the benefits of reducing demand through the more efficient use of energy. In 1985, the government made conservation a key part of China's energy strategy, and announced a goal of quadrupling the economy by the year 2000 with only a doubling of energy consumption. This goal is potentially possible given China's current energy inefficiency and waste, but it will require a major effort which one researcher put at the replacement of at least half of all current fixed assets (Smil 1988). The challenge to China is to distinguish between

conservation and curtailment, and reduce energy waste while expanding services and raising standards of living.

This paper will give an overview of the energy efficiency of China's economy, but will concentrate on that of the rapidly increasing number of residential and commercial buildings. Combining reported energy consumptions with computer simulations of building performance, the paper will evaluate the energy efficiency of China's residential building stock, potential energy savings with improved construction, and the economic and societal trade-offs compared to alternative methods to provide the equivalent energy needs. The paper will discuss the effects on the current structure in China of building construction and ownership, and energy pricing on energy conservation, and the perceptual problems with improving building energy efficiency when indoor comfort conditions are non-optimal.

## **I. AN ENERGY INEFFICIENT ECONOMY**

The People's Republic of China currently is perhaps the most wasteful user of energy among all major nations. In 1982, the energy-to-GNP ratio (MJ/US\$) of China was 60, double that of the Soviet Union (30), 2.3 times that of the U.S. (26), and four times that of Japan (15) (Smil 1988). Although these comparisons are rough due to uncertainties in currency exchange rates, they do indicate that energy utilization efficiency in China is very poor. There are a variety of political and economic reasons for this high energy intensity. From 1949 to 1978, Chinese planners followed the Soviet development model in stressing energy-intensive heavy industries. As a result, the industrial sector dominates China's total energy consumption to a much greater degree than in the developed countries or even newly industrialized nations such as South Korea. In 1980, industry consumed 66% of all primary energy; by 1985, this percentage has dropped to 60% (Zhu 1988). Furthermore, the energy efficiency of most of China's industries is substantially below Western or Japanese standards due to out-of-date technology and poor management. For example, Chinese mills consume from 50% to 100% more electricity as Western or Japanese mills to produce a ton of raw steel (Smil 1988).

Another cause for China's low energy utilization is a pricing structure that does not reflect the true costs of energy production. The artificially low coal prices represent a large financial burden on the government and reduce the incentive for the economy to invest in conservation. Traditionally, disparities between energy supply and demand have been controlled through rationing. In the industrial sector, fuel shortages resulted in

work stoppage or reduction; in the commercial and residential sectors, they result in curtailment and reduced indoor conditions.

Since 1978, the government has attempted to rectify this disparity by raising coal price substantially and permitting a two-tiered pricing scheme of subsidized and unsubsidized (or "market") prices (Table 1). The differential between these prices can be as much as a factor of two, while unofficial spot prices are even higher based on demand and availability. Although these increased prices have reduced the disparity between price and cost, the artificiality of the pricing scheme has not helped in clarifying the true price of coal. Moreover, in spite of the price hikes, state coal mines are still operating at a loss and subsidized annually by the central government by more than 1 billion Yuan (the official exchange rate in 1989 is Y3.73 = \$1.00) (Zhou 1988).

In 1985, the Chinese government declared conservation a key element of their energy policy, and announced a goal of quadrupling the economy by the year 2000 while only doubling the energy consumption. To date, China's conservation efforts has concentrated on improving the energy efficiency of her industries. This is a logical strategy given the disproportionate energy use and waste in the industrial sector. However, as the economy evolves from centrally-planned to a more market-oriented one, the energy efficiency of China's potentially gigantic commercial and residential sectors will become increasingly important.

Under the comparatively liberal policies since 1980, China has witnessed a rather dramatic shift of economic priorities from heavy industries and defense to meeting consumer demands. Starting from very low bases, the saturation of domestic appliances such as televisions, fans, and washing machines in Chinese cities is now approaching that of other East Asian cities a decade ago. For example, the saturation of refrigerators and color televisions in Beijing, rose from 1.7% for both in 1981 to 61.5% and 50.0% respectively in 1986 (Zhang 1988). The rapid increase in appliances is mirrored by a building boom of apartments, offices, and hotels that is evident to any recent visitor to China. The total urban building stock is expected to increase from 2 billion m<sup>2</sup> in 1984 to 3.3 billion m<sup>2</sup> by 1990. The increase in the residential portion of the building stock is even more dramatic, from 1 billion m<sup>2</sup> to 1.78 billion m<sup>2</sup> for the same years (Guo 1986) .

This rapid expansion of the domestic and commercial sectors is gradually changing China's energy consumption pattern. During the Sixth Five Year Plan period (1981-1985), average electrical consumption as a whole rose by 6.7% annually, while that for "civil daily life", i.e., residential consumers, rose by 13.2% annually (Zhang 1988). The share of total energy consumed in households has risen from 18% in 1980 to 22% in

1985 (Hu 1988) and is now approaching 25%. This is lower than the 32% in the U.S., but already higher than that of Japan (21%) and the Soviet Union (19%) (Smil 1988). This evolving energy picture indicates that energy efficiency of the domestic and residential sectors will be increasingly important in determining whether China can overcome her present energy shortage and realize the goals of an expanding and energy-efficient economy.

## II. ENERGY USE IN THE RESIDENTIAL BUILDING SECTOR

On an aggregate level, the Chinese buildings industry is one of the largest in the world, with an annual construction rate of 150 million m<sup>2</sup> for urban residential building alone. (The focus of this paper throughout will be on urban buildings under the supervision of the Ministry of Construction. There are approximately 2.4 times as much floor area in rural houses, whose construction varies greatly by region and whose fuel use characteristics are little known.) On a per capita basis, however, China continues to have an acute housing shortage. The average floor area per person is only 3-5 m<sup>2</sup>, depending on the city. Prior to 1982, building funds were distributed by the government to *work units*<sup>1</sup>, which in turn contracted *construction companies* for the construction. Since economic policies were liberalized in 1982, apartments can now be sold rather than contracted, creating a real estate market of sorts and even the appearance of speculative buildings. This change has stimulated the construction industry, but also created strong disincentives against energy conservation by loosening government controls, and rewarding those that build as quickly and cheaply as possible. A major difference from the American real estate market, however, is that the purchasers are generally work units rather than individuals. The work units, in turn, distribute apartment units to their constituents.

The overwhelming majority of the residential buildings in Chinese cities are five to seven story apartment blocks with uninsulated brick walls, and concrete floor and roofs. The only construction characteristics that can be regarded as conservation features are the use of thicker walls (37cm instead of 24cm) and double-pane windows in the colder provinces northeast of Beijing.

Space heating is mandated by the government for important public buildings, hotels built for foreigners, and typical residential buildings for cities with more than 90 days of below 5°C average daily temperature (Guo 1986). Air-conditioning is found in tourist hotels and high-rise offices, but is almost nonexistent in Chinese residences due to

inadequate electrical circuits and high electricity prices. The saturation of electric fans in residences, however, is very high (97.5% in Beijing, and 132% in Shanghai) (Hu 1988).

The floor area of urban residential buildings falling in the mandated heating region is around 500 million m<sup>2</sup>, about half of the national total (Lang 1984). In the older buildings, heating is provided by coal stoves. In new construction, it is typically supplied by hot water district heating systems with a central boiler house servicing from 5 to 20 apartment blocks. The boilers are all coal-fired, with typical efficiencies around 50% and an additional 7% heat loss through the distribution system (Guo 1986). The boilers are manually operated, and there are no individual controls in the apartment units.

In a typical U.S. home, the indoor temperature is kept fixed within a narrow dead-band so that its space conditioning energy use becomes a function of the building thermal integrity, equipment efficiency, and climate severity. In China, however, energy use (or rather, energy supply) is constrained and the indoor temperatures allowed to float. The local government in each city prescribes the length of the Heating Period and the amount of coal allocated for space heating. In Beijing, the Heating Period is from November 12th to March 16, and the allocated amount of coal is 17.5 to 20 kg/m<sup>2</sup>; in Harbin the Heating Period is from October 15th to April 14th, and the allocated amount of coal is 40 kg/m<sup>2</sup> (author's notes 1985). In Zhengzhou, whose climate barely falls in the defined Heating Zone, families are given 124kg of coal for cooking and space conditioning combined (Wirtshafter 1988).

The prescribed Heating Periods and coal allocations for each city generally reflect local requirements, but are not determined objectively and are subject to political pressures. For example, in Harbin, the Heating Period was shortened by a month and the coal allocation reduced in the mid-Sixties as part of a "conservation program" (Guo 1985). Although engineering calculations are based on indoor temperatures of 18°C (64°F), only a small fraction of Chinese residential buildings are maintained at that temperature, with 10-12°C during the winter not uncommon. Ironically, buildings in the colder regions are heated more adequately due to tradition and necessity, while those in the central parts of the country have the lowest winter indoor temperatures.

Prior to the 1980's, work units had no recourse to additional coal should they run out before the end of the Heating Period. With the loosening of economic controls and the creation of coal markets, they are now able to purchase or barter for additional coal, albeit at higher prices. These changes have also made it difficult to determine the total coal consumption in Chinese residential buildings.

### III. ENERGY EFFICIENCY OF CHINESE RESIDENTIAL BUILDINGS

The energy efficiency of Chinese residential buildings and the indoor conditions resulting from constrained heating can be estimated using building energy simulation programs. The author has simulated the energy use of a typical Chinese residential building in three Chinese cities (Beijing, Harbin, and Shanghai) using the DOE-2.1D program<sup>2</sup>. Harbin has very cold winters and mild summers, Beijing has cold winters and hot summers, and Shanghai has mild winters and very hot summers (see map in Figure 1). The prototype building was developed in a previous study on China (Huang et al. 1984) and shown in Figure 2. The simulations were done for three assumed operating conditions: (1) heating thermostat held at 18°C (64°F) at all times, (2) heating thermostat held at 18°C during the mandated Heating Period for each city, and (3) heating fuel consumption constrained to the allocated amounts of coal for Beijing and Harbin, and no heating at all in Shanghai. The first duplicates U.S. indoor conditions (typically held at 70°F or 21°C); the second is the theoretical condition mandated by Ministry of Construction; and the third approximates typical conditions in Chinese residential buildings.

The DOE-2.1D simulations give the *heating loads* for the building, i.e., amount of heat input required to maintain assumed indoor conditions. These loads should be divided by the heat output of the fuel source and the efficiency of the system to estimate the amount of consumed coal. Since only low grade coal is used for space heating, a heat content of 5000 kcal/kg has been assumed (Guo 1985). The net efficiency of the heating system has been estimated as 46.5% based on a monitoring study in northern China (Guo 1986). The simulated heating loads and estimated coal consumptions for the three assumed operating conditions are shown in Table 2.

For comparison, Table 2 also gives the heating loads and fuel consumptions (assumed to be natural gas) for prototypical multifamily buildings of various vintages in three U.S. cities with similar climates. The loads for these U.S. buildings are taken from an unrelated study done for the Gas Research Institute (Ritschard and Huang 1989). Boston has about the same heating degree-days as Beijing, Minneapolis 85% that of Harbin, and Washington D.C. the same as Shanghai.

Comparisons of the energy consumption of Chinese and U.S. buildings in Table 2 are meaningful only for the fully heated cases with comparable indoor conditions. These show that the Chinese apartment buildings are somewhat more energy efficient than pre-1940's U.S. buildings, but require from two to three times as much energy per floor area as current U.S. construction to maintain the same indoor conditions.

If we consider cases where the heating energy is constrained by coal allocation, the energy consumption for the Chinese buildings decreases by 40 to 60%, but at the penalty of significantly reduced indoor temperatures. For these partially heated conditions, the concept of *unmet heating degree-days* is useful. This term is similar to *heating degree-days* but tabulated using the indoor rather than the outdoor temperature. At a base temperature of 18°C (64°F), which corresponds to the lower limit of the human comfort zone, the number of *unmet heating degree-days* indicates the cumulative amount of discomfort experienced by building occupants.

Table 2 shows that a typical apartment in Beijing has 811 unmet heating degree-days, of which 173 occur outside, and 638 during the Heating Period. Since the Beijing Heating Period is 125 days long, the average indoor temperature during that time is 12.9°C (18 - 638/125) or 55°F. The simulation for Harbin shows that the allocated 40 kg/m<sup>2</sup> of coal in a typical building results in 1077 unmet heating degree-days and an average indoor temperature of 12.1°C (53°) during the Heating Period. For Shanghai there is no space heating, but 619 unmet heating-degrees according to the DOE-2 simulations. Assuming that these occur over three winter months, the average indoor temperature during that time would be 11.2°C (52°F), or lower than those in Beijing and Harbin.

The previous analysis indicates that on the basis of equivalent comfort, Chinese residential buildings have energy efficiencies similar to those of pre-1940's brick multifamily buildings in the U.S. However, due to curtailed heating, their energy use intensities are smaller than such American buildings by a factor of two or more. Current U.S. multifamily construction, however, maintains constant indoor comfort but use less fuel than typical Chinese buildings in the equivalent climates.

#### **IV. CONSERVATION POTENTIAL IN CHINESE BUILDINGS**

In the 1984 paper, the author made parametric simulations of the energy performance of the same prototypical multifamily building in Beijing and Shanghai with various conservation measures and calculated their simple payback times and *Costs of Conserved Coal* (Huang et al. 1984). (The *Cost of Conserved Coal (CCC)* is the ratio of the investment cost to the conserved amount of coal. In calculating CCC, a real annual interest rate of 6% and a lifetime of 30 years were assumed. If CCC is less than the price of coal, one should invest in conservation. If CCC is more expensive than the price of coal, one should burn coal and expand production to meet needs.) The costs of the

conservation measures were estimated by a Chinese co-author, and the international market price of coal of Y109.5/ton (= \$35/ton in 1989) was used for the economic calculations. The building simulations were done using a constant heating set point of 18°C.

The study concluded that in Beijing reducing air infiltration and insulating the north wall were highly attractive conservation measures with a combined simple payback time of less than 6 years and a CCC of Y29/ton (Table 3). Making the windows double-glazed had a simple payback of 12 years and a CCC of Y79.4/ton, while insulating the south wall had a long payback time of 22 years and a CCC of Y146/ton.

In the five years since that analysis, the unsubsidized coal price in China has risen to the international price quoted, thereby making the use of that price in the paper less controversial in retrospect. Although the estimated costs for the conservation measures need to be corrected for infiltration, their relative magnitudes are generally still valid, although overshadowed by bigger uncertainties about product availability. Based on information gathered during a four-month visit in 1985, the greatest deficiency in the earlier analysis lies in the assumption of a constant 18°C (64°F) heating set point. Since typical Chinese residential buildings have unmet heating loads, adding conservation features will not necessarily lower energy consumption, but rather, improve indoor comfort conditions.

To investigate the energy and comfort impacts of conservation measures, DOE-2.1D simulations were repeated for the prototypical residential building in the three selected cities with a conservation package for each city based on the 1984 study. As in the base case simulations, three different operating conditions were considered: constant 18°C heating, 18°C heating during the Heating Period, and heating limited to the fuel allocation for that city. The last condition was not simulated if the coal allocation was sufficient to meet the second operating condition.

For Beijing, the conservation package included reduced infiltration, insulated north wall, and double-pane windows. For Harbin, it included reduced infiltration and insulated walls on both the north and south, double-pane windows being a typical construction. For Shanghai, the conservation package includes only reduced infiltration through tighter doors and windows. In addition to building shell improvements, an improved heating system with an efficiency of 60% was also considered.

The results for these "energy-efficient" buildings are shown in Table 4. If only heating system improvements are considered, buildings in Beijing and Harbin will still be operating under the constrained heating mode. Assuming that building managers will continue to burn the available coal unless comfort conditions are reached, there will be

no reductions in energy use. However, due to better energy utilization, the boilers can now be operated an hour or two longer each day, reducing the number of unmet heating degree-days and raising average indoor temperatures by 1°C or more.

If both heating system and building shell improvements are considered, the buildings can be heated at a constant 18°C for the entire Heating Period in both Beijing and Harbin *and* still use 39% and 41% less coal, respectively. In addition to the coal savings, average indoor temperatures will be raised by 5°C (9°F) in Beijing and 6°C (11°F) in Harbin. In Shanghai, there are no energy savings simply because there is no base case heating coal consumption. However, the improved building thermal integrity will raise winter indoor temperatures by 2°C.

Using the same methodology as in the 1984 paper, CCC and simple payback times can be calculated for the energy-efficient designs in Beijing and Harbin. Since there is no reliable data on the costs for improved boilers, only the building shell improvements were considered using the estimated 1984 costs multiplied by 1.33 to account for the effects of inflation.

For Beijing, the energy efficient design yields a very high CCC of Y112/ton.

$$\begin{aligned} \text{CCC} &= \frac{\text{annualized cost of investment}}{\text{annual saved coal}} & [1] \\ &= \frac{\text{Y716} * 1.33 * 0.0725}{4.3 \text{ kg coal/m}^2 * 143.6\text{m}^2} = \text{Y.112/kg} = \text{Y112/ton} \end{aligned}$$

The simple payback time is 14 years if calculated using a unsubsidized coal price of Y110/ton (presumably closer to the real cost), and 24 years if calculated using the subsidized coal price of Y65/ton.

$$\begin{aligned} \text{Simple payback} &= \frac{\text{Conservation cost}}{\text{annual energy savings}} & [2] \\ &= \frac{\text{Y716} * 1.33}{4.3 \text{ kg coal/m}^2 * 143.6\text{m}^2 * \text{price/kg coal}} \end{aligned}$$

The main reason for the high CCC and long payback times is that much of the improved energy efficiency went to meeting unmet heating loads and raising indoor comfort conditions. In addition, any economic incentive to conserve energy at the work unit level is diluted by their access to subsidized coal up to the allocated amount of 20kg/m<sup>2</sup>. Unless a work unit has been purchasing large amounts of unsubsidized coal to keep their constituents content, it would be looking at a less than compelling payback time of 20-25 years! In such a socio-economic environment, energy efficient buildings should be regarded as an improvement in living standards with a bonus of some

reductions in energy consumption.

In Harbin, the same calculation yields very different numbers due to the smaller conservation cost and the longer Heating Period. Since walls in Harbin are already two bricks thick, adding insulation requires only that a cavity be added between the two courses of bricks for the poured perlite. The CCC is Y30/ton, much lower than even the subsidized price of coal.

$$\text{CCC} = \frac{\text{Y}410 * 1.33 * 0.0725}{9.0 \text{ kg coal/m}^2 * 143.6\text{m}^2} = \text{Y}0.030/\text{kg} = \text{Y}30/\text{ton} \quad [3]$$

Even using the subsidized coal price of Y65/ton, the energy efficient building has an attractive simple payback time of 6.5 years. At the unsubsidized coal price, the simple payback time is shortened to a little over 3 years.

$$\text{Simple payback} = \frac{\text{Y}410 * 1.33}{9.0 \text{ kg coal/m}^2 * 143.6\text{m}^2 * \text{price/kg coal}} \quad [4]$$

These indices show that from an economic point of view, the energy efficient building design is justified for Harbin even using the subsidized coal price and ignoring its clear benefits on thermal comfort.

## V. BARRIERS TO IMPROVING ENERGY EFFICIENCY IN CHINESE BUILDINGS

The above analysis has shown that in the colder cities in Northeastern China (Manchuria) with long winters, energy efficient buildings can be justified on standard economic criteria, and promoted as a way to reduce coal consumption and improve indoor comfort. However, in the rest of China, constrained heating and subsidized coal prices combine to make energy efficient buildings appear superficially uneconomical to building owners and operators. From a societal point of view, it can be argued that these economic signals are misleading. The marginal cost for increased coal production, including mines and railroads, is probably several times that of even the unsubsidized coal price. J. Walsh of the Jet Propulsion Laboratory estimated in 1982 that this capital cost to be \$275/ton for the U.S. (Huang et.al 1984). Even if China is able to half that cost, it would still be five times the unsubsidized and eight times the subsidized coal prices.

In addition to the lack of clear economic signals, there are socio-political barriers in China that deter building energy conservation. As in other socialist countries, housing and utilities in China are regarded as social welfare rather than commodities. A typical family pays their work unit a nominal Y5 a month (= \$1.34) for rent and nothing for

heating. Typically, they have no control or input over their space heating, and no incentive to improve their building's energy efficiency except to prevent discomfort. For example, occupants in overheated apartments would typically open their windows in the dead of winter.

At the governmental level, building construction and fuel use fall under different ministries with different priorities and little inter-agency co-operation. A Ministry of Energy has been created in the last two years, but its effectiveness in bridging the gap between energy producers and consumers remains to be seen. The Ministry of Construction (MOC, formerly the Ministry of Rural and Urban Construction and Environment Protection) has traditionally stressed quantity over quality and meeting annual quotas for building floor area. In recent years, MOC has paid more attention to building energy use, and published in 1986 a Energy Conservation Standard specifying that new construction should reduce their heat loss coefficient from current practice by 30% in 1990, and by another 30% in 2000 (Guo 1986). The standard, however, is poorly defined and more of an expression of "...goals to be achieved rather than as enforceable minimum levels of compliance" (Wirtshafter 1988). There is no implementation plan, nor guidance on how to achieve these improved heat loss coefficients.

Implementation of building energy conservation is made difficult by the lack or high prices of insulation materials, especially modern industrial products such as fiberglass or styrofoam. For example, the price of perlite quoted to a LBL researcher in 1984 was five times that of imported perlite abroad (Huang et al. 1984). The author was also told in 1985 that the technical level of typical construction workers is low. Most are recent migrants from the countryside with no awareness of building energy issues and unwilling to modify their construction practices. For example, it was felt that even a relatively minor construction detail such as making cavity brick walls for insulation infill would be probably resisted or ignored.

## CONCLUSION

Present construction practices in China are from two to three times less energy-efficient than current U.S. construction. Energy conservation through improved boiler efficiency and better construction can reduce heating loads so that the buildings can be heated to design standards and yet consume approximately 40% less energy. Economic calculations using current Chinese coal prices, however, do not capture the full benefits of this conservation strategy because of current unmet heating loads and subsidized

coal prices. Even so, the calculations show that building energy conservation "pays" in the colder locations, with a Cost of Conserved Coal half that of the subsidized coal price.

Once the true cost of coal is determined, in particular the marginal cost for increased production, building energy conservation can probably be shown to be cost-effective for all buildings in the mandated Heating Zones. A related issue is the need to develop a parameter that can account for improvements in comfort conditions due to building energy conservation.

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## FOOTNOTES

1. The work unit (*danwei*) is the social organization to which a person in China belongs. For a salaried person, this is generally the place of work, but for the unemployed or retired, it can be a neighborhood or co-operative. Membership in a work unit is vitally important, since it determines one's access to housing, health care, and scarce goods such as bicycles.
2. DOE-2.1D is a detailed building energy simulation program that simulates the hourly energy performance of a building based on the input description of the building and equipment, and an hourly weather tape with temperatures, humidity ratios, wind speeds, and solar radiation.

**TABLE 1. AVERAGE COAL PRICES IN TWO CHINESE CITIES**

(unit: Y/ton)

| Year | Shanghai      |                | Suzhou        |                |
|------|---------------|----------------|---------------|----------------|
|      | In-plan price | Out-plan price | In-plan price | Out-plan price |
| 1979 | 37.99         | -              | 45.80         | 56.90          |
| 1980 | 41.75         | -              | 45.80         | 59.90          |
| 1981 | 42.20         | -              | 45.80         | 59.90          |
| 1982 | 42.88         | -              | 45.80         | 80.00          |
| 1983 | 46.63         | -              | 45.80         | 87.00          |
| 1984 | 54.04         | 98.04          | 54.70         | 100.00         |
| 1985 | 63.30         | -              | 62.70         | 115.00         |
| 1986 | 63.72         | 94.72          | 67.40         | 110.00         |

source: Zhou 1988.

**TABLE 2. HEATING LOADS AND ENERGY CONSUMPTIONS FOR PROTOTYPICAL MULTIFAMILY BUILDINGS IN CHINA AND THE U.S.**

| Location    | Vintage    | Construction | N. of Apart-ments | Apart. size (m <sup>2</sup> ) | Oper. condition*  | Load /m <sup>2</sup> (MJ) | Energy /m <sup>2</sup> (MJ) | Coal use/m <sup>2</sup> (kg) | Unmet Heat. Deg-days |
|-------------|------------|--------------|-------------------|-------------------------------|-------------------|---------------------------|-----------------------------|------------------------------|----------------------|
| Beijing     | 1980's     | Brick        | 48                | 47.7                          | 18 const          | 325                       | 699                         | 33.4                         | 0                    |
|             |            |              |                   |                               | 18 HP             | 298                       | 641                         | 30.7                         | 173                  |
|             |            |              |                   |                               | 8 h/day           | 192                       | 413                         | 19.8                         | 811                  |
| Harbin      | 1980's     | Brick        | 48                | 47.7                          | 18 const          | 605                       | 1302                        | 62.3                         | 0                    |
|             |            |              |                   |                               | 18 HP             | 599                       | 1289                        | 61.7                         | 21                   |
|             |            |              |                   |                               | 8 h/day           | 384                       | 826                         | 39.5                         | 1077                 |
| Shanghai    | 1980's     | Brick        | 48                | 47.7                          | 18 const unheated | 150<br>0                  | 325<br>0                    | 15.5<br>0                    | 0<br>619             |
| Boston      | pre-1940's | Wood         | 4                 | 106.2                         | 21 day/           | 607                       | 1012                        | -                            | 0                    |
|             | 1950-59    | Brick        | 4                 | 126.1                         | 18 night          | 388                       | 647                         | -                            | 0                    |
|             | 1980's     | Brick        | 8                 | 85.5                          |                   | 187                       | 267                         | -                            | 0                    |
| Minneapolis | pre-1940's | Brick        | 4                 | 105.0                         | 21 day/           | 702                       | 1170                        | -                            | 0                    |
|             | 1960-69    | Brick        | 4                 | 89.9                          | 18 night          | 471                       | 785                         | -                            | 0                    |
|             | 1970-79    | Brick        | 18                | 88.63                         |                   | 276                       | 394                         | -                            | 0                    |
|             | 1980's     | Wood         | 8                 | 97.5                          |                   | 327                       | 467                         | -                            | 0                    |
| Washington  | pre-1940's | Brick        | 4                 | 80.2                          | 21 day/           | 492                       | 820                         | -                            | 0                    |
|             | 1960-69    | Brick        | 4                 | 83.0                          | 18 night          | 357                       | 595                         | -                            | 0                    |
|             | 1970-79    | Brick        | 24                | 94.9                          |                   | 194                       | 277                         | -                            | 0                    |
|             | 1980's     | Brick        | 24                | 89.9                          |                   | 101                       | 144                         | -                            | 0                    |

\* 18 const = heating thermostat held at 18°C at all hours; 18 HP = heating thermostat held at 18°C during heating season; 6 h/day = maximum 6 hours heating on-time; 8 h/day = maximum 8 hours heating on-time; 21 day/18 night = thermostat at 70°F, with setback to 64°F between 11pm and 7am.

**TABLE 3. COST SAVINGS OF CONSERVATION MEASURES FOR A PROTOTYPICAL RESIDENTIAL BUILDING IN BEIJING (1984 STUDY)**

(values in brackets are the incremental savings for successive measures)

| Measure                            | Annual Load (GJ) | Cumulative Conserv.cost (Y) | Annual Coal Cost (Y) | Simple payback (yrs) | Cost of Conser.Coal (Y) |
|------------------------------------|------------------|-----------------------------|----------------------|----------------------|-------------------------|
| Base case                          | 33.76            | -                           | 151.00               | -                    | -                       |
| Reduce infiltration from 1.0 to 05 | 24.93<br><-8.83> | 50<br><50>                  | 111.51<br><-39.49>   | 2                    | 0.28                    |
| Insulate north wall                | 18.52<br><-6.41> | 230<br><180>                | 82.84<br><-28.67>    | 6                    | 1.40                    |
| Add double glazing                 | 9.58<br><-8.94>  | 716<br><486>                | 42.85<br><-17.53>    | 12                   | 2.71                    |
| Insulate south wall                | 5.66<br><-3.92>  | 1107<br><391>               | 25.32<br><-17.53>    | 22                   | 4.99                    |

source: Huang et al. 1984. note: building energy use numbers differ from later results because only three apartment units were simulated instead of a whole building.

**TABLE 4. HEATING LOADS AND ENERGY CONSUMPTIONS FOR ENERGY EFFICIENT MULTIFAMILY BUILDINGS IN CHINA**

| Location             | Conservation Feature | Oper. Conditions* | Load /m <sup>2</sup> (MJ) | Energy /m <sup>2</sup> (MJ) | Coal use/m <sup>2</sup> (kg) | Unmet Heating Deg-days |
|----------------------|----------------------|-------------------|---------------------------|-----------------------------|------------------------------|------------------------|
| Beijing              | 60% eff. boiler      | 18 const          | 325                       | 542                         | 25.9                         | 0                      |
|                      |                      | 18 HP             | 298                       | 497                         | 23.8                         | 173                    |
|                      |                      | 9 h/day           | 207                       | 447                         | 21.35 †                      | 726                    |
|                      | Energy-eff. design   | 18 const          | 161                       | 346                         | 16.6                         | 0                      |
|                      |                      | 18 HP             | 152                       | 328                         | 15.7                         | 110                    |
|                      | Eff. design & boiler | 18 const          | 161                       | 268                         | 12.9                         | 0                      |
|                      | 18 HP                | 152               | 254                       | 12.2                        | 110                          |                        |
| Harbin               | 60% eff. boiler      | 18 const          | 605                       | 1009                        | 48.2                         | 0                      |
|                      |                      | 18 HP             | 599                       | 999                         | 47.8                         | 21                     |
|                      |                      | 10 h/day          | 438                       | 731                         | 35.0                         | 813                    |
|                      | Energy-eff. design   | 18 const          | 297                       | 639                         | 30.6                         | 0                      |
|                      |                      | 18 HP             | 296                       | 637                         | 30.5                         | 3                      |
|                      | Eff. design & boiler | 18 const          | 297                       | 495                         | 23.7                         | 0                      |
| 18 HP                |                      | 296               | 494                       | 23.6                        | 3                            |                        |
| Shanghai             | 60% eff. boiler      | 18 const          | 151                       | 251                         | 12.0                         | 0                      |
|                      | Energy-eff. design   | 18 const          | 52                        | 111                         | 5.3                          | 0                      |
|                      |                      | unheated          | 0                         | 0                           | 0                            | 269                    |
| Eff. design & boiler | 18 const             | 52                | 86                        | 4.1                         | 0                            |                        |

\* 18 const = heating thermostat held at 18°C at all hours; 18 HP = heating thermostat held at 18°C during heating season; 8 h/day = maximum 8 hours heating on-time; 10 h/day = maximum 10 hours heating on-time.

† This coal consumption is actually slightly above the mandated amount.

Figure 1. Heating Degree Days (Base 18°C) for Heating Period Only

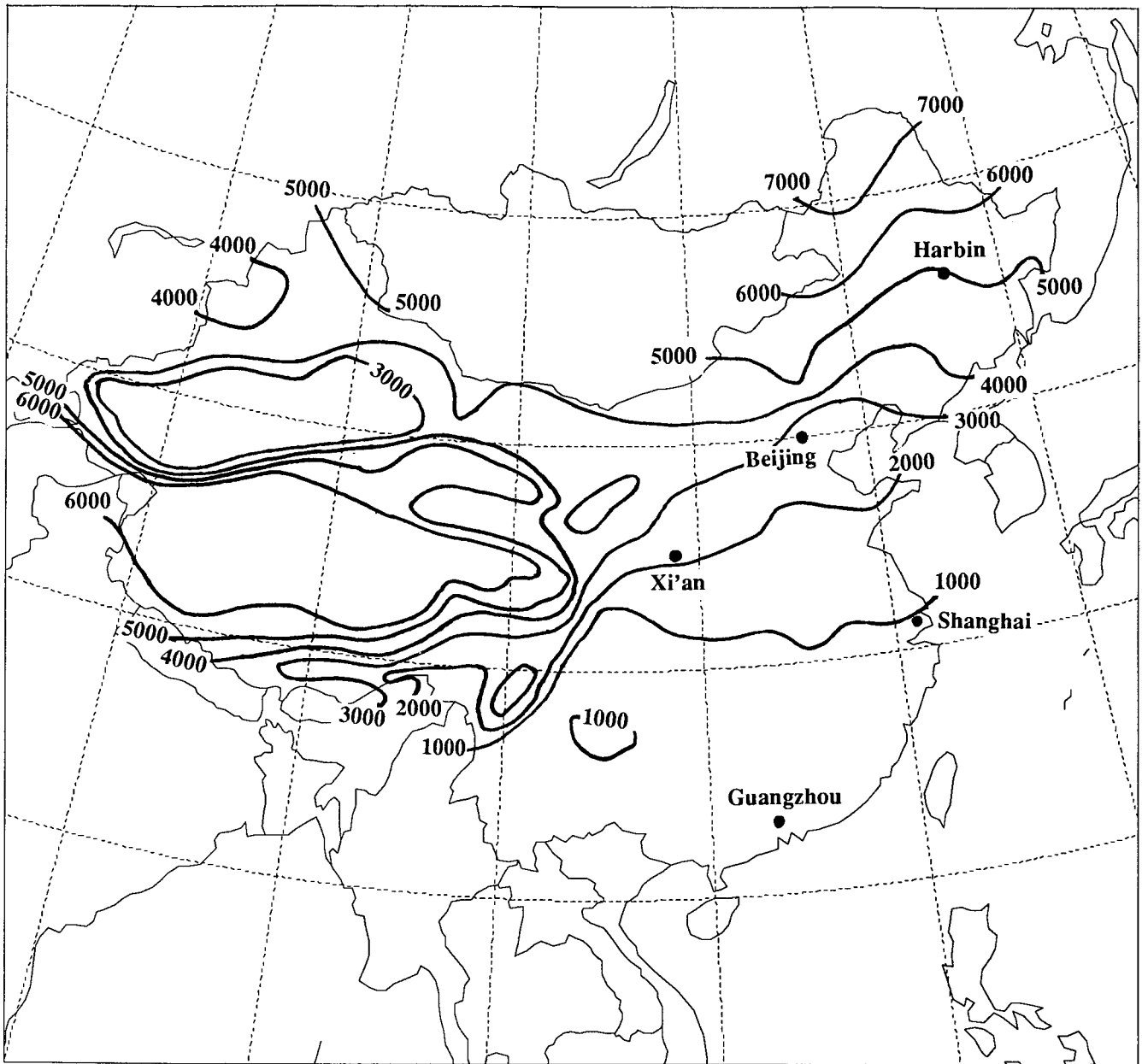
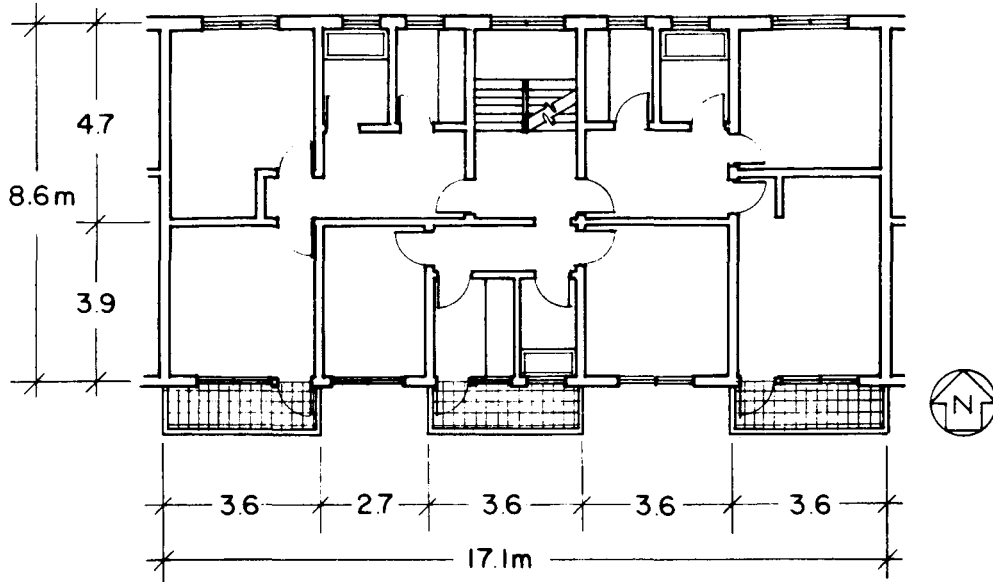


Figure 2. Prototypical Chinese Multifamily Building

|                                |                     |                                 |
|--------------------------------|---------------------|---------------------------------|
|                                | North wall          | South wall                      |
| Wall area                      | 36.0 m <sup>2</sup> | 30.1 m <sup>2</sup>             |
| Windows                        | 11.9                | 12.2                            |
| Doors                          | 0                   | 5.5                             |
| Base case<br>wall construction | 37cm brick          | 24cm brick                      |
|                                | R - 0.70            | R - 0.53 (°C m <sup>2</sup> /W) |



South elevation

XBL 8210-4864