Title
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Publication Date
1992-06-01

LBL-33098
UC-350
Preprint

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

Submitted to ENERGY, The International Journal

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Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

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LBL-33098
UC-350

ENERGY CONSERVATION STANDARD FOR SPACE HEATING IN CHINESE URBAN RESIDENTIAL BUILDINGS

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This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Building Systems and Materials Division of the U. S. Department of Energy under Contract No. DE-AC03-76SF00098.

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Abstract

With the rapid growth of housing construction and increasing concerns about energy demand in the last decade, the Ministry of Construction released in 1987 a draft energy standard for new residential buildings in cities where central heating is required. The first half of this paper describes the current housing stock in China, its energy consumption, and the engineering method and economic assumptions used to develop the energy standard. Since the Ministry energy standard serves only as a general guideline on energy efficiency, as of 1991 most local governments are still in the process of writing detailed rules and regulations conforming to the basic standard. The second part of the paper finds that the steady-state calculational method of the Ministry standard agrees well with the results of dynamic DOE-2 building energy simulations, and uses the DOE-2 program to evaluate the specific conservation measures proposed by the local Beijing version of the energy standard.

Energy Conservation Standard for Space Heating in Chinese Urban Residential Buildings

by

Siwei Lang † and Yu Joe Huang ‡

1. Introduction

To house its huge population, China has a residential building stock that is, in absolute terms, one of the largest in the world. According to government statistics, the total floor area of residential buildings in the cities alone has reached 7 billion m^2 by 1991, or roughly half that of the U.S. residential stock. Furthermore, with the changes in government priorities in 1979, the rate of new construction has skyrocketed nearly nine-fold compared to the previous years.

Since 40% of the urban population live in areas that require winter space heating, Chinese residential buildings are major energy users consuming 11% of the total national energy output just for space heating. Due to their poor thermal characteristics, these buildings are energy intensive, even though the indoor comfort conditions are generally not comparable to those in the West. With the rapid growth of new housing, this energy demand for space heating can be expected to increase in coming years. Within the last decade, the Chinese government has shown increasing concern about energy efficiency and has asked the Ministry of Construction to develop an energy standard for residential buildings in areas that require central heating. A draft version of this energy standard was released in 1987 and is now undergoing review and modification.

The objective of this paper is to give an overview of the energy-use characteristics of the Chinese housing stock, describe the draft building-energy standard, and evaluate the potentials for energy conservation using a dynamic building energy-analysis computer program.

2. Current Situation of Building Energy Consumption

China is a vast country with considerable differences in weather from the south to the north. The floor area of buildings in the north of China that require winter heating amounts to roughly 50% of the total building stock in the nation. Based on the climate severity and the current economic situation, the government has defined a *Central Heating Zone* within which space heating is mandated. This *Central Heating Zone* includes all

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locations where the so-called "heating season", defined as those days when the average daily outdoor temperature for any five successive days is lower than or equal to 5 C, has more than 90 days in a year. As shown in Figure 1, this zone includes north, northeast, and northwest China. Figure 1 also shows the heating degree-days lines based on an indoor temperature of 18 C and accounting for only those days falling within the heating season.[1] The number of heating degree-days shown is, therefore, lower than if they had been calculated with a constant base temperature as done in many other countries.

2.1. *Size of Building Stock*

Although the land area within the mandated *Central Heating Zone* makes up almost 70% of the entire nation, much of this in the northwest and the west is very sparsely settled, as illustrated in Figure 2.

According to official government statistics,[2] the existing building floor area in cities in the whole country is about 7,000 million m^2 (75 billion ft^2), of which 3,070 million m^2 (33 billion ft^2), or 44%, is in cities in the Central Heating Zone. As defined by the Ministry of Construction, "cities" include all urban areas down to the county seats, as well as special tourist sites, transportation centers, or important mining and industrial locations. There are several reasons why the Ministry of Construction distinguishes between buildings located in "cities" and the remaining 80% located in the countryside. For city dwellers, the government, despite recent market reforms, by-and-large provides the funds for residential construction in what is known as the "State-owned System". Because of this, the government is able to influence, if not dictate, the construction process. However, the rural population does not fall into this system and, historically, have been responsible for both the funding and construction of their dwellings. This was by using the so-called "Collectively-owned System" or, in recent years, private resources. Because these buildings fall outside of government jurisdiction, it is difficult for government agencies to even get detailed information, let alone control their construction. In addition, most rural construction is still done using traditional materials and methods and are not amenable to the application of standard energy conservation techniques.

Table I shows the amount of existing urban floor area in the Central Heating Zone by the end of 1990 separated into various major building sectors. It is evident that the residential building sector represents by far the largest sector with about 1,650 million m^2 (17.8 billion ft^2) of floor area.

Since the early 1980s, the rate of building construction in China has increased dramatically, with about 150 million m^2 (1.6 billion ft^2) of new residential buildings added in cities in the whole country each year. By comparison, the rate of residential construction in the first three decades was only around 17 million m^2 (180 million ft^2) per year.[3] From 1979 to 1990, the amount of new residential buildings in the cities reached 1,500 million m^2 (16.1 billion ft^2), and the average living floor area, i.e., living rooms and bedrooms, per capita has increased to 7.1 m^2 (76 ft^2) by 1991.[3] The current Eighth Five-Year Plan (1991-1995) will add another 650 million m^2 (7.0 billion ft^2) of residential buildings in the cities of the whole country.[2] This means an average construction rate of about 130 million m^2 (1.4 billion ft^2) of residential buildings each year. On an

Figure 1. Central Heating Zone and degree-day map of China

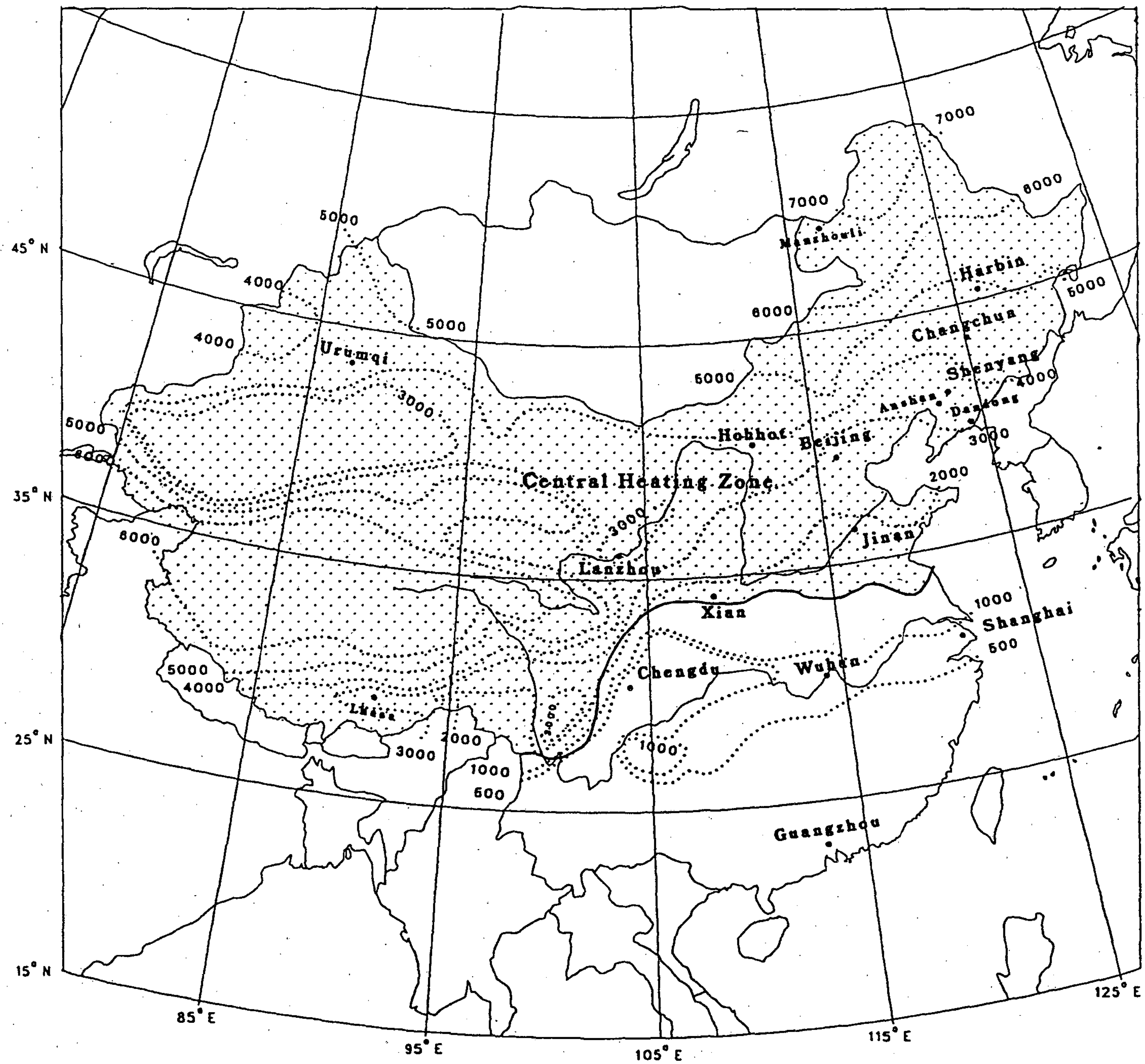


Figure 2. Chinese cities with population above 100,000

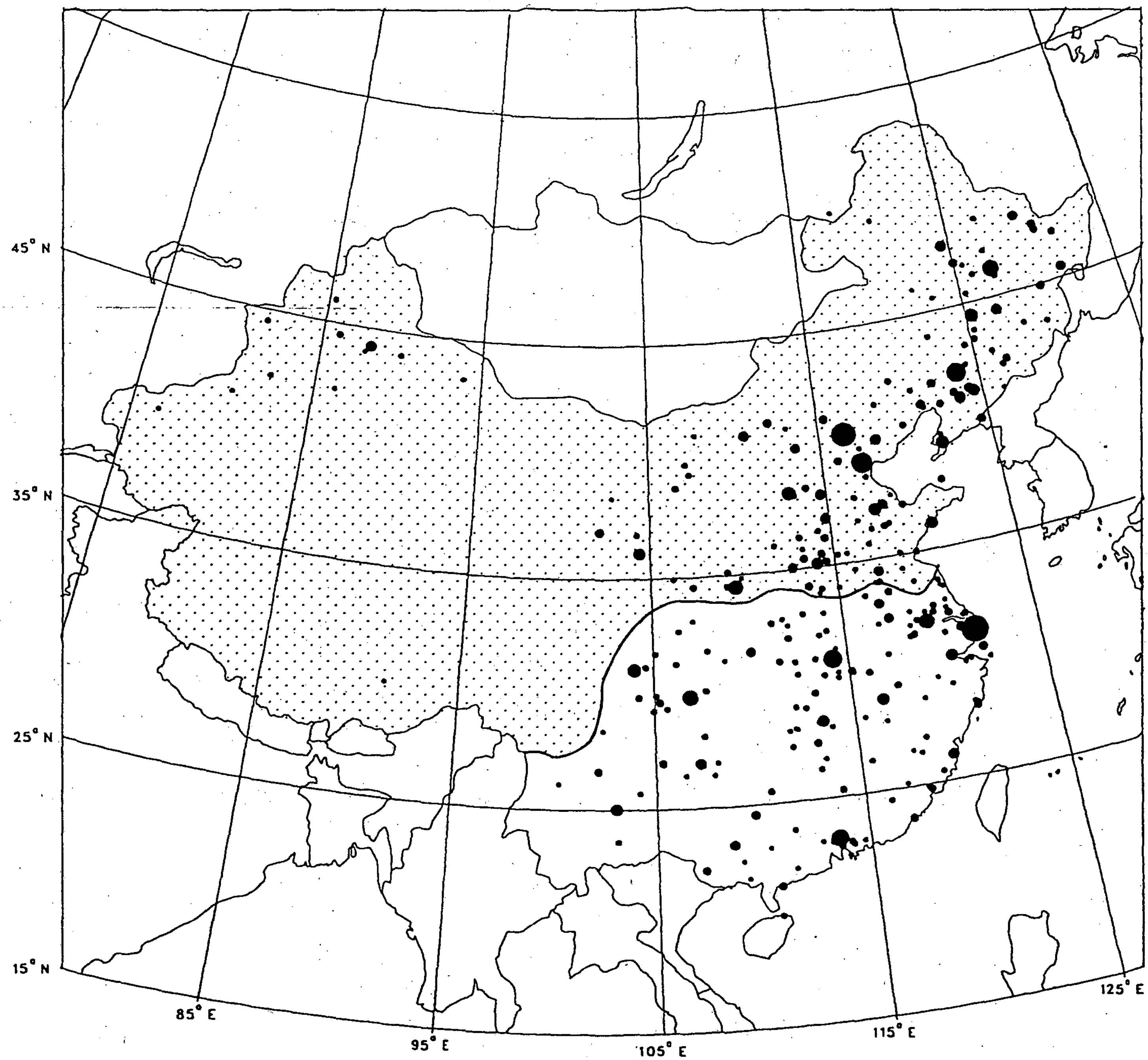


Table I. Total floor area of building stock in cities in the Central Heating Zone (at the end of 1990).

Building sector	Floor area (10^6 m^2)	Percentage (%)
Residential	1,650	53.8
Industrial and communications	900	29.3
Commercial	230	7.5
Scientific and educational	50	1.6
Offices	160	5.2
Others	80	2.6
Total	3,070	100.0

absolute basis, this construction rate is half that of the United States, but on a per urban capita basis it is 25%.† Based on the rough proportion of residential to non-residential buildings shown in Table I, it is estimated that the total amount of building construction in the Central Heating Zone will be about 120 million m^2 (1.3 billion ft^2) per year.

2.2. *Types of Residential Construction*

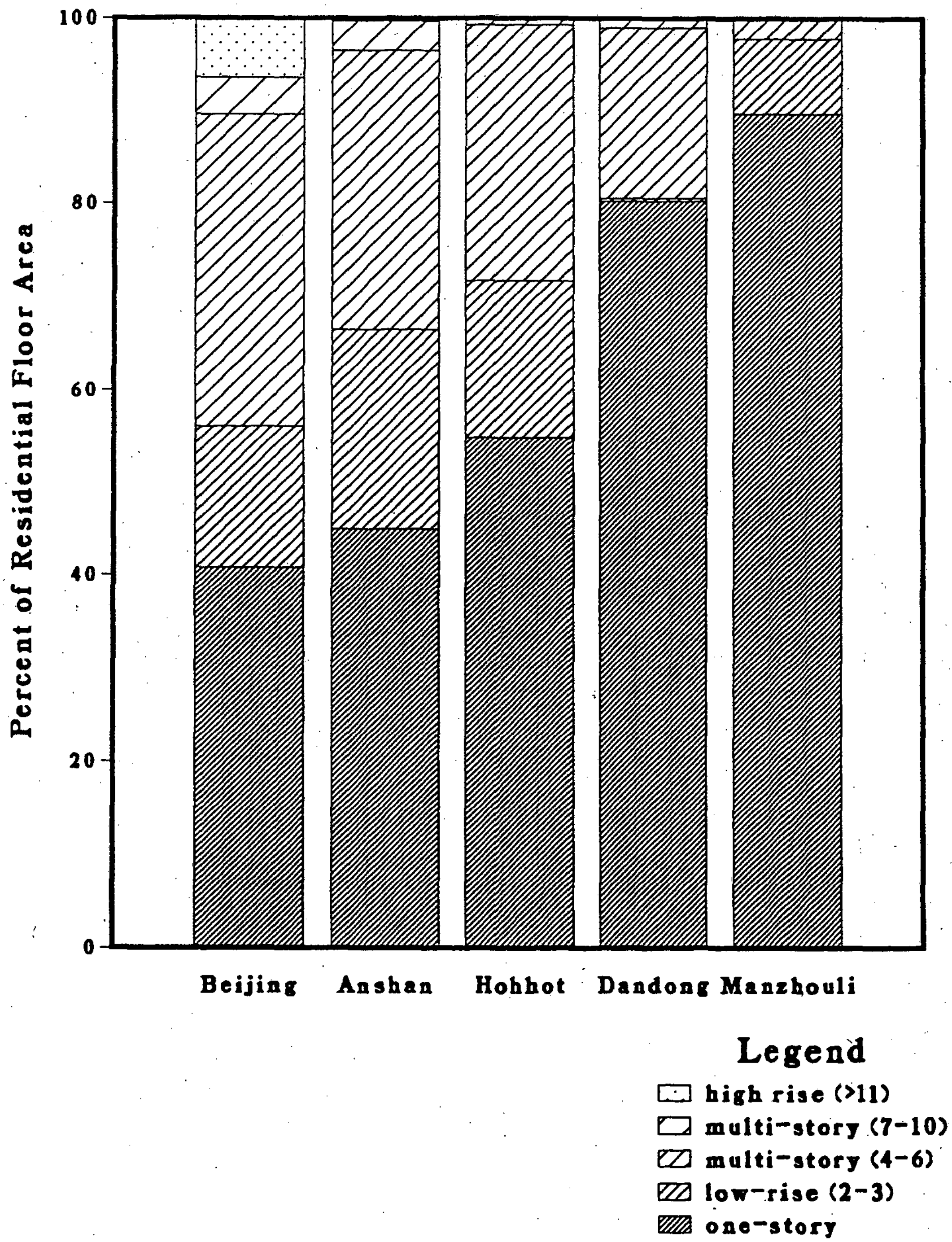
The residential building stock in Chinese cities can be categorized as either one-story, low-rise (2-3 stories), multi-story (4-6 and 7-10 stories), or high-rise buildings (greater than 11 stories). In general, most of the existing old residential buildings are traditional one-story or low-rise buildings. It has only been in the last decade that large numbers of new multi-story and a few high-rise buildings have been built in the larger urban areas. Figure 3 shows that the percentages of each type of residential building in five representative cities in descending order of size: Beijing, Anshan, Hohhot, Dandong, and Manzhouli.[4] Beijing has a non-agricultural population of over five million, Anshan about a million, Hohhot and Dandong both about half a million, and Manzhouli about a hundred thousand. ‡

In Beijing, nearly half of the residential stock (44%) is comprised of buildings of four stories or more, but only 6% are high-rise buildings. In the four smaller cities, one-story buildings predominate, making up from 45% in Anshan to nearly 90% in Manzhouli. The prevalence of one-story buildings in the small towns is less a result of lower population pressures than of reduced construction activity. Since post-1949, residential construction is universally multi-storied. These one-story buildings are invariably older

† Based on the 1987 Residential Energy Consumption Survey (RECS), the U.S. has 90.5 million housing units with an average floor area of 160.9 m^2 (1732 ft^2). From 1980 to 1987, 11.3 million housing units with an average floor area of 158.1 m^2 (1702 ft^2) was built.

‡ Population figures for Chinese cities are generally inflated because their jurisdictions also include large areas of the surrounding countryside, necessitating the distinction between the "agricultural" and "non-agricultural" population figures.

Figure 3. Residential building types in various cities



buildings built prior to the establishment of the People's Republic. There are significant numbers of 4-6 story buildings in the medium to large cities, ranging from 30% in Anshan to 18% in Dandong. Interestingly, there are more multi-story than low-rise (1-3 stories) buildings in all cities except Manzhouli. Both types can be built using the same materials and technology, but the multi-story ones are more economical. The scarcity of high-rise buildings is due to the need for more advanced materials, mechanized construction techniques, and the added expense of adding vertical transportation.

2.3. *Heating Systems and Indoor Temperatures*

In Chinese residential buildings, space heating is typically supplied by either stoves or central hot water systems supplied by boilers or power cogeneration. The stove is a traditional heating system that is gradually being replaced. Although the percentage of buildings heated by stoves is steadily decreasing, they still make up the majority, especially in the smaller cities and towns. In the central heating system, hot water is generated by a boiler or cogeneration plant, almost all are coal-burning and distributed to radiators in the living spaces through a distribution network. The boilers have capacities of less than 4-6 ton/hour (2791-4187 kW) in most cities. In newer residential areas, district heating systems linking many buildings are often used.

At present, hydraulic and heat unbalance in the pipeline system is very common. Frequently, the water flow through the network and the radiators under actual operation do not conform to the designed flow. As a result, some rooms are underheated, while others are overheated. To maintain adequate temperatures in the underheated rooms, operators will compensate by supplying more heat than necessary, resulting in energy waste. The small capacity of the boilers also causes lowered efficiency during operations.

The actual indoor temperatures of residential buildings in the Central Heating Zone are quite low compared to those in Western countries. For buildings heated by central hot water systems, the indoor temperatures typically range from 16 to 18 C. For buildings heated by stoves, the indoor temperatures are generally much lower, from 10 to 16 C. Chinese residential buildings also do not have domestic hot water supply systems.

2.4. *Energy Consumption for Space Heating*

The amount of energy used for space heating in the Central Heating Zone is shown in Table II.[4] The total energy used for heating and air conditioning in the whole country is 110 million tons of standard coal equivalent, of which 94.1 million tons, or 86%, are consumed for space heating in the Central Heating Zone. Of the rest, 1.1 million tons are used for cooling, 2 million tons for space conditioning in other parts of China, primarily the use of fans for cooling or stoves for heating, and 1.8 million tons for heating and air conditioning in commercial buildings. Lastly, rural buildings in the Central Heating Zone account for 11 million tons of standard coal energy use for space heating.

Table II. Energy use for space heating in the Central Heating Zone .

Floor area by sectors (10^6 m^2)	Residential (1,650)		Industrial & communications (900)		Commercial (230)		Education, offices, & public (290)	
Heating mode	radi-ator	stove	radi-ator	stove	radi-ator	stove	radi-ator	stove
Floor Area (10^2 m^2)	410	1240	500	400	60	170	100	190
Percentage (%)	25	75	55	45	25	75	35	65
Energy use for heating per m^2 (kg coal/year)	30	18	60	45	20	15	30	25
Energy use for heating (10^6 tons/year)	12.30	22.30	30.00	18.00	1.20	2.25	3.00	4.75
Subtotal (10^6 tons/year)	34.60		48.00		3.75		7.75	
Total (10^6 tons/year)	94.1							
Total energy use by sector (10^6 tons/year)	52.0 †		299.0		6.0		16.5	
Heating energy use as a pct. of total energy	66.5		16.1		62.5		47.5	

† Total daily energy use for residents

Table III shows that, currently in China, 23.2% of the total national energy production is expended either for space conditioning, building construction, or the production of building materials. The energy used for construction means that which is expended each year at the construction sites to construct buildings. The energy used for building materials means that which is expended each year to fabricate the bricks, cement, steel, etc.

Table III. Total energy consumed by the building sector in China.

Energy usage	10^6 tons of coal equivalent	Pct. of total national production
Total national energy production	985.7	100.0%
Energy used in the building sector		
for space conditioning	110.0	11.2
during building construction	12.7	1.3
for production of building materials	105.0	10.7
Subtotal	227.7	23.2%

3. Building Energy-Conservation Measures

Efforts in building energy conservation in China were launched comparatively later than in the West. Since 1982, the former State Energy Commission has entrusted the former Ministry of Urban and Rural Construction and Environment Protection with the assignment of energy conservation in buildings.† The China Academy of Building Research, a research institute under the Ministry of Construction, has undertaken to compile a residential building energy standard entitled, "The Standard for Energy Conservation Design of Civil Buildings (Housing Heating Division)".[5] For brevity, we will refer hereinafter to this document as simply the "Standard". The Standard was approved by the Ministry of Construction in March 1986, with trial use beginning in August 1986.

The Standard focuses on multi-story residential buildings, because (i) residential buildings comprise the largest building sector with greater numbers being built in recent years and (ii) multi-story buildings are the predominate type among all residential buildings. The energy conservation target defined by the Ministry of Construction is divided into two phases. The Phase One goal is to reduce the average heating energy consumption of new residential buildings designed before 1993 by 30% compared with the baseline energy consumption of buildings designed in 1980/1981. The Phase Two

† The State Energy Commission was abolished in 1982 and its tasks absorbed first by the State Economic Commission, and then in 1987 by the State Planning Commission. In 1988, the Ministry of Urban and Rural Construction and Environmental Protection (MURCEP) was renamed the Ministry of Construction (MOC).

goal is to reduce the average heating energy consumption of new residential buildings designed in 1993-2000 by 50% compared with the baseline energy consumption.[5]

The current Standard addresses only Phase One of the Ministry's plan. Of the 30% energy savings goal, 20% will be achieved by better thermotechnical design and 10% by better heating system design. This means that, on average, the heating load per m^2 in new buildings should be reduced by 20%.

3.1. Standard for Energy Conservation Design of Civil Buildings (Housing Heating Division)

The Standard has six parts: (i) general principles, (ii) degree-day number in heating season and indoor calculation temperature, (iii) heat consumption index of building and estimation of heating energy consumption, (iv) thermotechnical design in building, (v) design of heating system, and (vi) economic evaluation. The following will focus primarily on the thermotechnical design of the building.

A. General Principles

The aim for compiling the Standard is to put the national energy conservation policy into effect and put an end to the state of high energy consumption for space heating and poor indoor thermal environment conditions in residential buildings in the north of China, and to control energy consumption for space heating within a certain level under the circumstances of satisfying occupant needs, construction quality and economic principles. This Standard applies only to the energy consumption for space heating. The stipulations for other energy consumptions in buildings shall be in accordance with other standards.

B. Degree-Day Number and Indoor Calculation Temperature

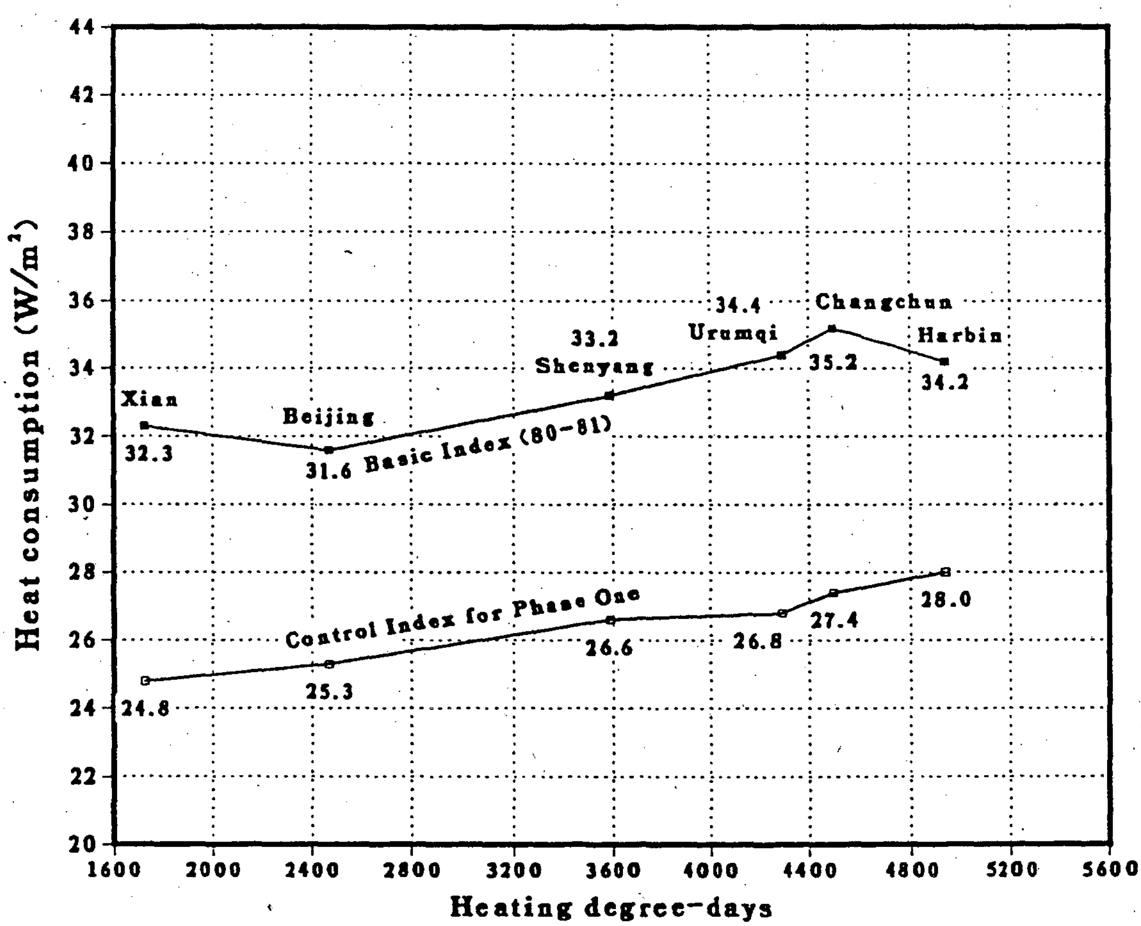
The Standard stipulates maximum allowable indices for heat consumption and for the overall heat transfer coefficients of the envelope in residential buildings for different regions. The design indoor temperature for the bedroom and living room is 18 C. The calculation temperature for estimating heating energy consumption is 16 C, which is considered the average temperature of the entire building. The isolines for heating degree-days during the heating season lines are shown in Figure 1.

C. Maximum Allowable Heat Consumption and Estimating a Building's Heating Energy Consumption

The heat consumption for a building in different regions shall not exceed the values shown in Figure 4. The building heat consumption is calculated from the relation

$$Q_H = (Q_{HT} + Q_{Inf} - Q_{IH}) / (24\,Z \times A_o), \tag{1}$$

Figure 4. Maximum allowable heat consumption for different cities



where Q_H = heat consumption index of the building (kWh/m^2), Q_{HT} = heat loss by transmission (kWh/year), calculated from

$$Q_{HT} = 0.024\sum_{i=1}^{m}\varepsilon_i \times K_i \times F_i(Dd_i + \Delta t \times Z), \quad (2)$$

K_i = overall heat transfer coefficient of the building component i (W/m^2 x K), calculated according to "Specification for Thermal Design of Civil Buildings JGJ 24-86".[6], † ε_i = solar correction coefficient of K_i, depending on the solar absorption listed in Table IV, ‡ F_i = area of the building component i (m^2), Dd_i = heating degree-days during Heating Season (C x d) (shown in Fig. 1), Δt = difference between the base temperature (18 C) used for calculating degree-days and the average indoor temperature (16 C) for a typical residential building, Δt = -2 C, Z = number of days in the Heating Season (day/year), A_o = building floor area (m^2), Q_{Inf} = heat losses by infiltration and ventilation (kWh/year) calculated from

$$Q_{Inf} = 0.024C_p \times \gamma \times N \times V(Dd_i + \Delta t \times Z), \quad (3)$$

C_p = specific heat capacity of air (0.28 K x h / Kg x K), γ = density of air (Kg/m^3), N = number of air change per hour (N=0.5 after the Standard is applied), V = infiltration rate (m^3) (V is 0.6V_o for buildings with unheated stairwells and 0.65V_o for buildings with heated stairwells, where V_o is the volume enclosed by the exterior of the building envelope, Q_{IH} = heat gain by internal heat (people, cooking, lighting, and appliances, etc., in kWh/year), calculated from

$$Q_{IH} = 0.024q_{IH} \times Z \times A_o, \quad (4)$$

q_{IH} = internal heat gain per m^2 per hour, assumed to be 3.8 W/m^2.

The heat consumption in coal equivalent is calculated according to

$$Q_C = Q_H \times 24Z/(q_c \times \eta_1 \times \eta_2), \quad (5)$$

where Q_c = total annual coal consumption for heating (Kg/m^2 x year, standard coal), Q_H = average heat consumption during heating season (W/m^2), Z = number of days in heating season (day/year), η_1 = average efficiency of heat distribution in the outdoor pipeline system (η_1 is 0.85 before and 0.90 after application of the Standard), η_2 = average efficiency of boiler operation (η_2 is 0.55 before and 0.60 after application of the Standard), q_c = heat content in standard coal (q_c is 8.14 x 10^3 W x h/Kg).

†This document is a parallel design standard that mandates minimum thermal resistances for each building component based on the climate severity.

‡ The "Solar Correction Coefficient" utilizes a technique originally developed in Germany to account for solar heat gain in degree-day calculations by modifying the K-value of the building envelope.

Table IV. Solar correction coefficient E_i, W/m^2–K.

	Window (including glass part of balcony door)					Exterior wall (incl. opaque part of balcony door)			Roof
City	Overall heat transfer coefficient	Balcony	S	E,W	N	S	E,W	N	Horizontal
Xi'an	6.40	yes	0.69	0.80	0.86	0.79	0.88	0.91	0.94
	(single pane)	no	0.52	0.69	0.78				
Beijing	6.40	yes	0.57	0.78	0.88	0.70	0.86	0.92	0.91
		no	0.34	0.66	0.81				
	3.26	yes	0.50	0.74	0.86				
	(double pane)	no	0.18	0.57	0.76				
Lanzhou	6.40	yes	0.71	0.82	0.87	0.79	0.88	0.92	0.93
		no	0.54	0.71	0.80				
	3.26	yes	0.66	0.78	0.85				
		no	0.43	0.64	0.75				
Shenyang	3.26	yes	0.64	0.81	0.90	0.78	0.89	0.94	0.95
		no	0.39	0.69	0.83				
Hohhot	3.26	yes	0.55	0.76	0.88	0.73	0.86	0.93	0.89
		no	0.25	0.60	0.80				
Urumqi	3.26	yes	0.60	0.75	0.92	0.76	0.85	0.95	0.95
		no	0.34	0.59	0.86				
Changchun	3.26	yes	0.62	0.81	0.91	0.77	0.89	0.95	0.92
		no	0.36	0.68	0.84				
	2.09	yes	0.60	0.79	0.90				
	(triple pane)	no	0.34	0.66	0.84				
Harbin	3.26	yes	0.67	0.83	0.91	0.80	0.90	0.95	0.96
		no	0.45	0.71	0.85				
	2.09	yes	0.65	0.82	0.90				
		no	0.43	0.70	0.84				

D. Thermotechnical Design of the Building

General Guidelines

The building shall be located as much as possible in a place with limited wind loads and with the possibility of utilizing passive solar energy. It is advantageous for the main facade to face south for reducing heating energy consumption. The building's Shape Coefficient (surface-to-volume of the building) shall be less than 0.30. The stairwell shall have doors and windows for locations where 1500<- Dd_i <2200; the stairwell shall have wall insulation but is unheated for locations where 2200<- Dd_i <3500; the stairwell shall be heated and have a sheltered entrance for locations where Dd_i >-3500.

Design of the Building Envelope

The roof shall be better insulated, and its total thermal resistance increased by at least 20% compared to the minimum total thermal resistance stipulated in the "Specification for Thermal Design of Civil Buildings" (see footnote on previous page). The total thermal resistance of the exterior wall shall conform with both the stated maximum allowable average overall heat transfer coefficient in the next section, and the minimum total thermal resistance and insulation levels stipulated for light structures in the "Specification for Thermal Design of Civil Buildings" (see footnote on previous page).

The overall heat transfer coefficient for the windows and the glass portion of the balcony door shall be as follows:

Number of heating degree-days	Maximum allowable K_G	
	North-facing	Other orientations
Dd_i<2200	6.40	6.40
2200 <- Dd_i < 3500	3.26	6.40
3500 <- Dd_i < 4500	3.26	3.26
4500 <- Dd_i < 5500	2.09	3.26
Dd_i >-5500	2.09	2.09

The Window-to-Wall Ratio (including the glass portion of the balcony door) shall not exceed 20% for north-facing walls, 30% for east- and west-facing walls, and 35% for south-facing walls. Windows and balcony doors shall have tight air seals. The volume of infiltration per linear meter between the casements and the panes shall not exceed 2.5 $m^3/h \times m$ for low-rise and multi-story, and 1.5 $m^3/h \times m$ for high-rise residential buildings. The lower opaque part of the balcony door shall be insulated, with a thermal resistance of 0.58 $m^2 \times K/W$) for a door with a single-glazed window and 0.74 $m^2 \times K/W$) for one with a double-glazed window.

The following thermal bridges shall be insulated: floors located over an unheated basement in locations where the number of heating degree-days (Dd_i) is greater than 2000, and the perimeter edge of floors that are in direct contact with the ground in heated residential buildings where the number of heating degree-days (Dd_i) is greater than 4500.

E. Maximum Allowable Overall Heat Transfer Coefficient for the Envelope

The average overall heat transfer coefficient (K_m) of the envelope shall not exceed the maximum allowable indices shown in Figure 5 as a function of the number of heating degree-days. Depending on the "Shape Coefficient" (SC), i.e., the Surface-to-Volume Ratio, of the building, the average overall heat transfer coefficient of the building has to be reduced as follows:

for 0.30 <- SC < 0.32, reduce K_m by 5%;
for 0.32 <- SC < 0.34, reduce K_m by 10%;
for 0.34 <- SC < 0.36, reduce K_m by 20%.

Furthermore, if the main facade of the building faces east/west, the average overall heat transfer coefficient of the building shall also be reduced 5%. The recommended overall heat transfer coefficients K_i for different building components that meet the overall Maximum Allowable K_m shown in Figure 5 are listed in Table V.

The average overall heat transfer coefficient of the envelope is calculated according to

$$K_m - \sum_{i-1}^{m} K_i \times F_i \,/\, F_o \qquad (6)$$

where K_m = average overall heat transfer coefficient of the envelope($W/m^2 \times K$), K_i = overall heat transfer coefficient by component, including the roof, exterior wall, window, balcony door, exterior door, floor slab, etc., and interior walls and doors next to an unheated stairwell ($W/m^2 \times K$), F_i = Component area (m^2), and F_o = Total area of envelope with heat transfer (m^2).

F. Economic Analysis

Two methods are used to calculate the payback period for the extra investment of the energy conservation measure.

i. Fixed payback period calculated according to

$$n - I/A \qquad (7)$$

where n = fixed payback period in years, I = extra investment for energy saving in

Figure 5. Maximum Alloweable Overall Heat Transfer Coefficients for Different Cities

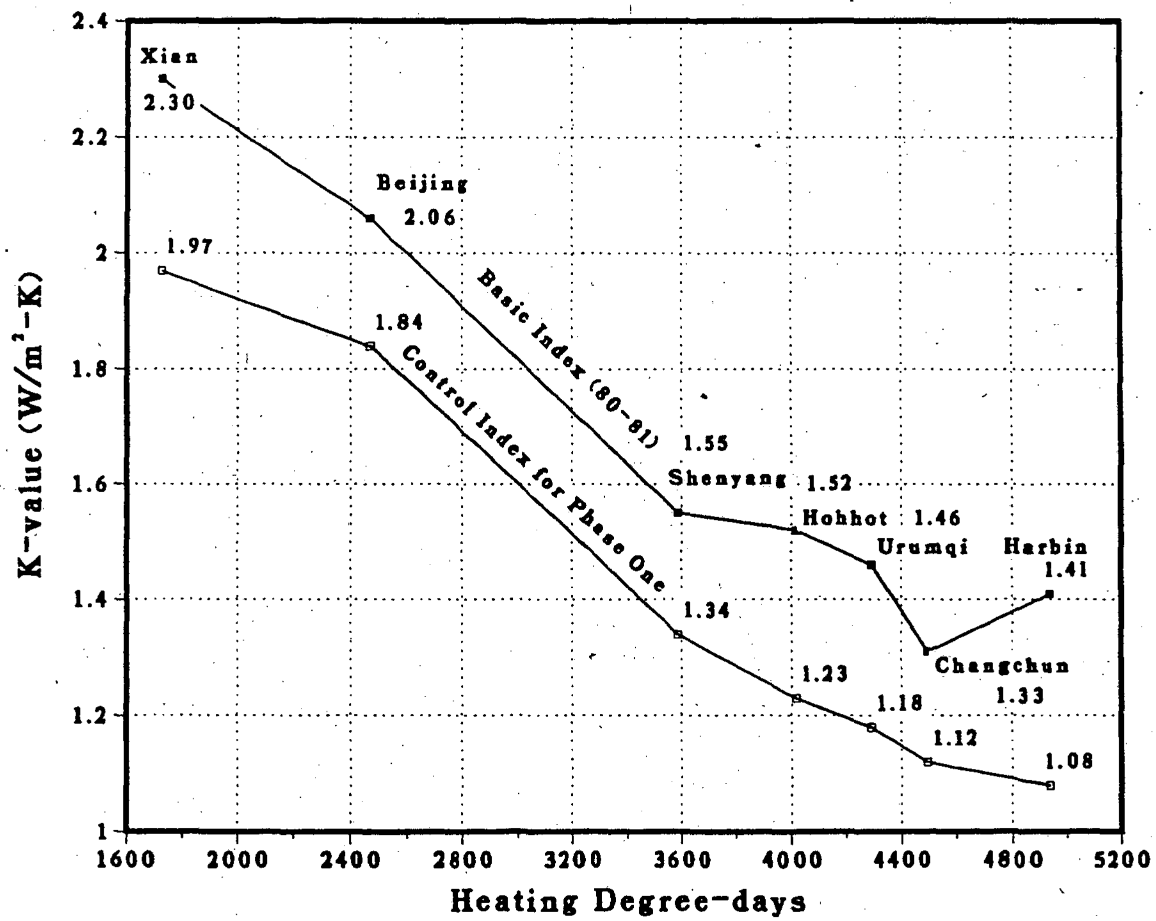


Table V. Recommended average overall heat transfer coefficient K_i (W/m^2-K).

City	Average overall heat transfer coefficient (K_m)	Roof (K_R)	Exterior wall (K_W)	Window (including glass part of balcony door): South (K_G·S)	Window (including glass part of balcony door): East, West (K_G·E,W)	Window (including glass part of balcony door): North (K_G·N)	Opaque part of balcony door (K_B)	Ground contact: edge (K_{F1})	Ground contact: interior (K_{F2})	Exterior door (K_D)	Stairwell interior wall ($K_{S\text{-}W}$)	Apartment door ($K_{S\text{-}D}$)
Xi'an	1.99	1.00	1.60	6.40	6.40	6.40	1.72	0.52	0.30		1.83	2.91
Beijing	1.84	0.91	1.28 1.61	6.40	6.40	6.4 3.26	1.72	0.52	0.30		1.83	2.91
Lanzhou	1.72	0.85	1.05 1.35	6.40	6.40	6.40 3.26	1.72	0.52	0.30		1.42	2.91
Shenyang	1.34	0.60	1.05	3.26	3.26	3.26	1.36	0.52	0.30		1.42	2.91
Hohhot	1.15	0.70	1.00	3.26	3.26	3.26	1.36	0.52	0.30	5.82		
Urumqi	1.10	0.68	0.94	3.26	3.26	3.26	1.36	0.52	0.30	5.82		
Changchun	1.03	0.67	0.3	3.26	3.26	3.2	1.36	0.32	0.30	3.26		
Harbin	1.08	0.64	0.73 0.84	3.26	3.26	3.26 2.09	1.36	0.52	0.30	3.26		

Renminbi (RMB, the Chinese currency), A = annual benefit of energy saving in Renminbi (RMB).

ii. Dynamic payback period calculated according to

$$n' - \ln \frac{A}{A - I \times i} / (\ln(1+i)) \tag{8}$$

where n' is the dynamic payback period in years.

The required payback periods are shown in Table VI.

Table VI. Required payback periods

Building type	Economic calculation method	
	Fixed	Dynamic (2.4% annual interest rate)
Multi-story	9 years	10 years
High-rise	14 years	15 years

note: payback periods are calculated using an energy cost of 94 Renminbi (RMB) per ton of standard coal.

3.2. *Progress in Building Energy Conservation*

A circular about how to implement the Standard and compile local detailed rules and regulations was issued in 1987 by the former Ministry of Urban and Rural Construction and Environmental Protection, the State Planning Commission, the former State Economic Commission, and the State Building Material Bureau. Although these agencies advocated the rapid adoption of steps to improve building energy efficiency, up until 1990 the rate of implementation has been slow. The approach of the recently renamed Ministry of Construction has been to disseminate the Standard as a generalized statement of energy efficiency standards, which local governmental agencies can then use as a basis to develop detailed rules and regulations suited to local construction practices and climate conditions. For example, the Standard specifies the calculational method and the required Maximum Allowable Heating Consumption or Overall Heat Loss Coefficient. The detailed local rules and regulations are then responsible for providing recommended designs and strategies that meet those standards.

By 1991, the following cities and provinces had compiled, issued, and executed local detailed rules and regulations: the cities of Beijing and Harbin; the provinces of Heilongjiang, Jilin, Liaoning Shaanxi, and Gansu; and the Inner Mongolia Autonomous Region. The following provinces and cities are in the process of compiling local rules and regulations: the city of Tianjin; and the provinces of Hebei, Shanxi, Qinghai, and Ningxia; and the Xinjiang Autonomous Region.

The city government of Beijing announced on August 26, 1990 that, after Jan. 1, 1991, all new civil buildings must be designed in accordance to the published local rules and regulations. This is the first instance in China of the mandatory enforcement of an energy conservation rule and regulation.

By 1991, about 100,000 m^2 of demonstration energy-efficient residential buildings had been built in Beijing, Tianjin, Harbin and other cities. In Beijing, a demonstration residential district was built in the Asia Athletic Village with a total floor area of 132,000 m^2 and designed for 30% energy savings. In Harbin, a demonstration district is being built with a total building floor area of 144,000 m^2, half of which is designed for 30% energy savings and the other half for 50% energy savings.

To further promote their construction, the government has agreed that, after Jan. 1, 1991, energy-efficient buildings will be exempt from the 5% tax on capital expenditure.

3.3. *Main Problems Faced in Promoting Building Energy Conservation*

Although a number of demonstration buildings have been built, the actual implementation of the Standard has been realized to a great extent only in a few cities. The main problems with a wider implementation of the Standard are (i) the legislation of building energy conservation is imperfect. There is at present a single Standard covering only heated residential buildings. Although this Standard was approved by the Ministry of Construction in 1986, it is still a trial Standard and is implemented to a great extent only in a few cities. (ii) The supervision and enforcement mechanism for the Standard have not been developed. (iii) Scientific and research efforts have not been sufficient to meet the technology needs for building energy efficient buildings. At present, there is still a shortage of applicable construction methods, conservation designs strategies, and methods for retrofitting existing buildings. There is also a need for improved calculational methods to show the benefits of energy conservation strategies.

4. Heat Consumption Calculation using DOE-2

In the past two years, Chinese officials have given increasing attention to the topic of building energy conservation. The Standard, which is now in trial form and undergoing review, will be expanded to include conservation strategies for Phase Two and will eventually become a national standard. A four-month visit to Lawrence Berkeley Laboratory by Mr. Lang in late 1991 permitted the authors to use a dynamic building energy simulation program, DOE-2, to analyze the energy consumption of a prototypical Chinese residential building, compare the simulation results to the steady-state calculations of the Standard, and evaluate the feasibility of achieving the Phase One goal of a 30% reduction in heating energy use using typical energy conservation strategies.

DOE-2 is a well-known computer program developed at Lawrence Berkeley Laboratory that uses the response factor method to simulate dynamically the heating and cooling loads, or energy consumption, of a building hour-by-hour depending on its physical and operational characteristics, and the outside weather condition as described by a weather file.[7,8] For this study, the authors have used the DOE-2.1D version of the program.

This sample study was done to demonstrate the applicability of DOE-2 for analyzing Chinese residential buildings and to show how this program can be used to promote and advance the state of knowledge about building energy conservation strategies in China.

4.1 Analysis of Energy Consumption of Baseline Building

The energy saving goal of the Standard is based on the baseline energy consumption of residential buildings designed in 1980/1981. In order to obtain this baseline energy consumption, the "80-Residential-2" building, which was designed in 1980 for the Beijing area, was chosen as the Baseline building for this analysis. Both the measured heat (and coal) consumption and the calculated consumption using the steady-state heat transfer method detailed in the Standard were reviewed or carried out.

A. Baseline Residential Building

The "80-Residential-2" building is a typical six-story apartment building with four or six entrances, and brick and concrete construction is used as the prototypical multistory residential building.[9] The main facade of the building is assumed to face south, and the stairwells are assumed to be unheated. The plan and south elevation of the building are shown in Figure 6. The building has a total floor area of 3258.8 m^2 (35,077 ft^2) and a volume of 8749.4 m^3 (308,983 ft^3). Its Shape Coefficient (surface-to-volume ratio) is 0.28. Sections of the exterior walls, roof, and interior wall are shown in Figure 7. The windows are single-glazed with steel frames.

B. Comparison of DOE-2 Results to Standard Calculation Method

In order to verify the calculation methods, the heating load of the baseline residential building was calculated using the same inputs with the two calculation methods (steady-state Standard method and DOE-2) and then compared to each other as well to the measured data. Table VII lists the U-values of envelope components, while Table VIII and Figure 8 compare the results from the two methods. For the DOE-2 simulations, an hour-by-hour weather file is needed. A weather tape following the Typical Meteorological Year (TMY) procedure was developed using weather data for Beijing from 1951 to 1980. Since calculations are needed only for the heating load, the DOE-2 simulations were done for the Heating Period, which runs from November 12 to March 17 in Beijing.

The DOE-2 simulations are done with the same input assumptions as used in the steady-state calculation for the Standard. The internal heat gain from people, cooking, appliances, etc. is modeled as 3.8 W/m^2. The average hourly air change rate from

Figure 6. Plan and south elevation of baseline residential building

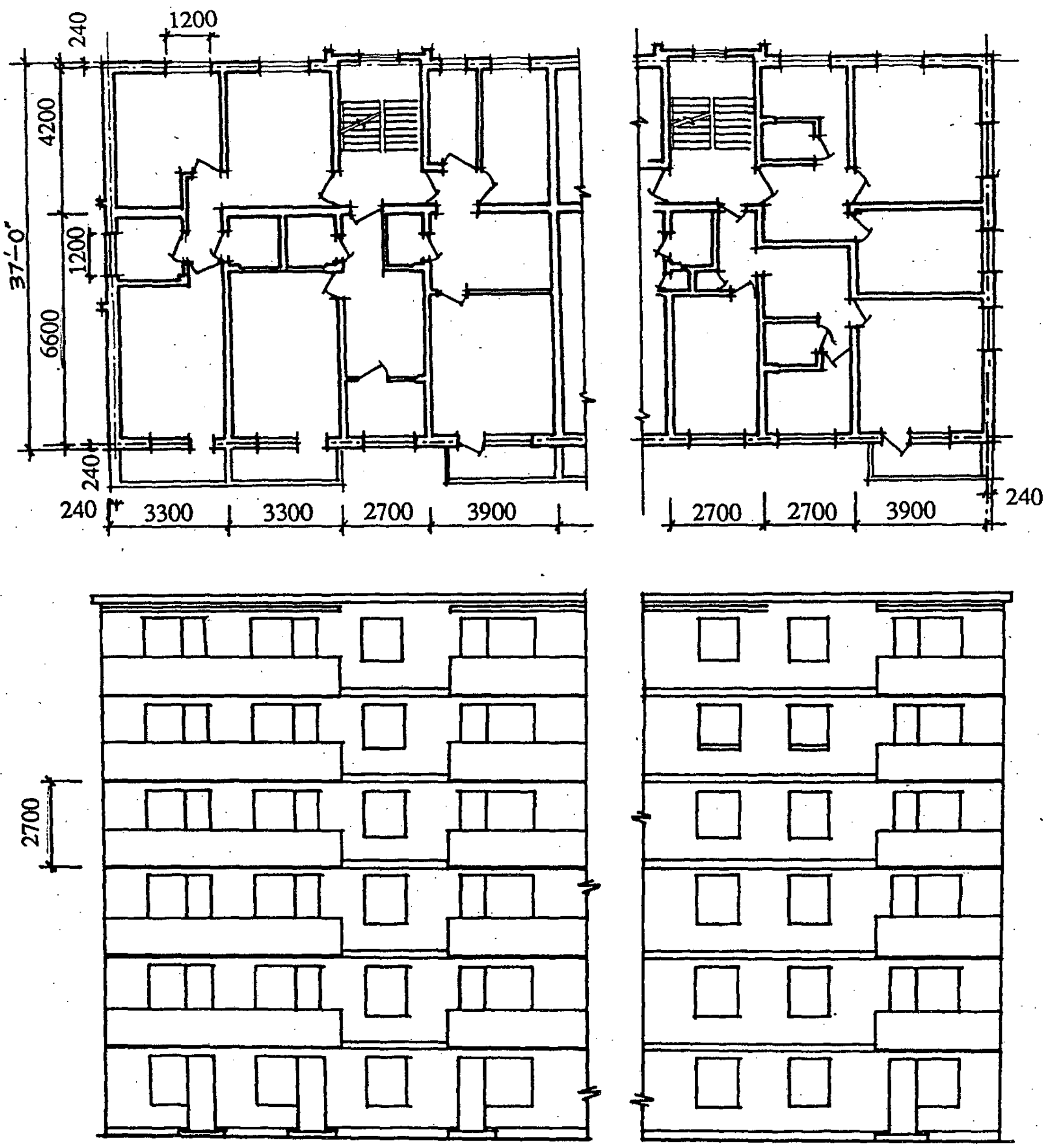
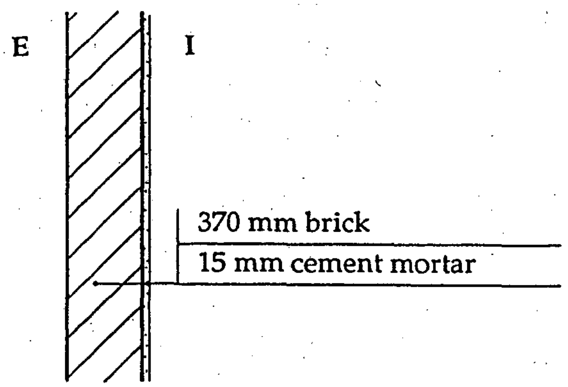
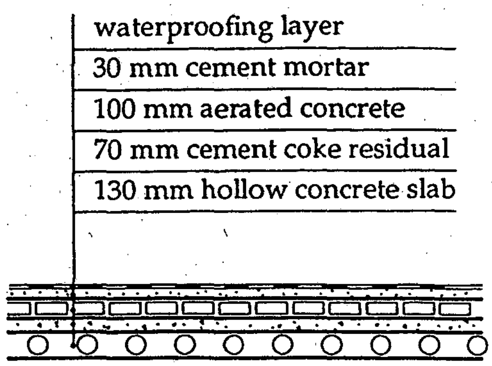


Figure 7. Baseline residential building wall and roof construction

Exterior wall



Roof



Interior wall

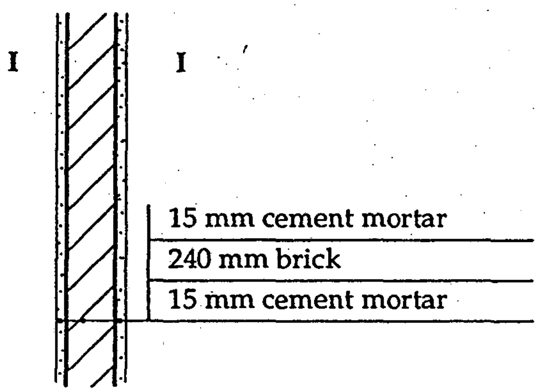


Figure 8. Comparison of heat losses computed by DOE-2 and the standards methods

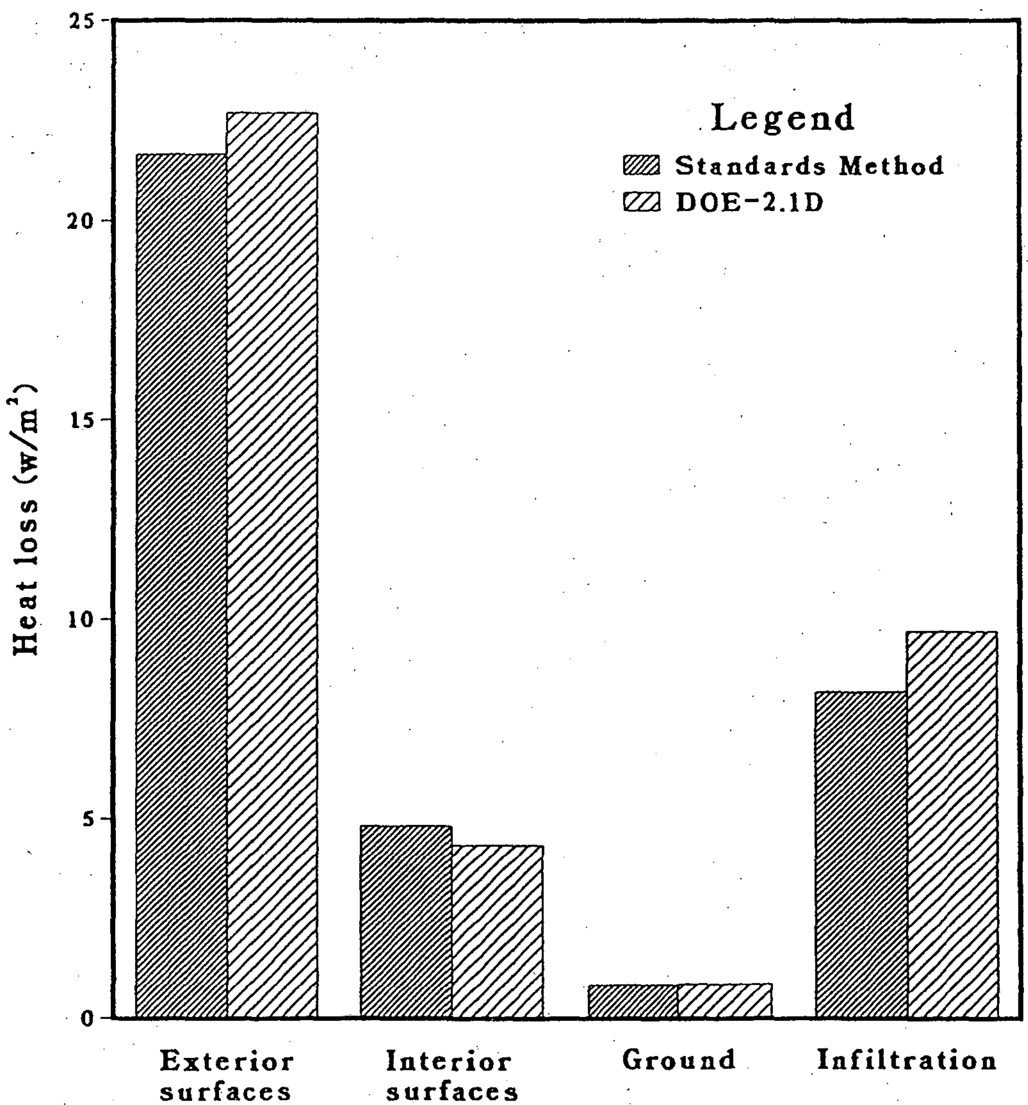


Table VII. U-value of components for baseline case.

Component	Construction	U-value (W/m^2–K) Steady-State	U-value (W/m^2–K) DOE-2.1D
Exterior wall	Solid brick (370mm)	1.57	1.580
Roof	Flat hollow concrete	1.26	1.188
Exterior window	Single pane	6.40	6.028
Ground	Soil	0.30	0.456
Interior wall	Solid brick (240mm)	1.83	2.215
Interior Door	Wood	2.91 *	
Balcony Door	Plate Steel	6.40 *	
Mean U-value		2.06	1.852

* Values used in DOE-2.1D input file.

Table VIII. Comparison of DOE-2 results and the Standard calculation method.

<table>
<tr><th rowspan="2"></th><th colspan="3">Heat loss</th><th>Heat gain</th><th colspan="3">Heat loss</th><th>Heat gain</th><th rowspan="2">Total heat load (Q_H)</th></tr>
<tr><th>Wall</th><th>Roof</th><th>Glass</th><th>Solar</th><th>Interior wall</th><th>Ground</th><th>Infil-tration</th><th>Internal</th></tr>
<tr><td rowspan="2">Steady-state</td><td>9.09</td><td>3.05</td><td>9.51</td><td rowspan="2"></td><td rowspan="2">4.82</td><td rowspan="2">0.82</td><td rowspan="2">8.19</td><td rowspan="2">3.48</td><td rowspan="2">31.68</td></tr>
<tr><td colspan="3">21.65</td></tr>
<tr><td rowspan="2">DOE-2.1D</td><td>15.42</td><td>3.30</td><td>10.87</td><td>6.92</td><td rowspan="2">4.32</td><td rowspan="2">0.84</td><td rowspan="2">9.69</td><td rowspan="2">3.48</td><td rowspan="2">34.04</td></tr>
<tr><td colspan="4">22.67</td></tr>
</table>

infiltration has been modeled at 0.6 of the building volume. Since the Standard calculation method uses the concept of Solar Correction Coefficients to adjust for the effects of oolar radiation on the heating load, we have compared the net heat loss calculated by the steady-state method through walls, roofs, and windows to that from DOE-2, instead of attempting a component-by-component comparison (see Table VIII).

The heat consumption of the Baseline building (Q_H) is 31.68 W/m^2 using the steady-state calculation of the Standard, while it is 34.04 W/m^2 using the dynamic DOE-2 simulation. For comparison, the measured heat consumption of a "80-Residential-2" building in Beijing was 32.76 W/m^2 in the 1982-83 heating season and 40.90 W/m^2 the following 1983-84 heating season.[10] It is apparent from Tables VII and VIII and Figure 8 that the calculated heat consumption agreed within 7.4% using the two methods, and that they should be regarded as compatible. According to the DOE-2 simulation, the peak heating load of the building is 106.69 kW or 62.36 W/m^2 and occurred at 7 a.m. in late January when the outdoor dry bulb temperature was -13.3 C. This DOE-2 peak load conforms quite closely to the commonly accepted design heating load for Beijing of 64 - 70 W/m^2.

C. Analysis of Energy Conservation Strategies

Retrofit of the Baseline Building

For Beijing, the mandated maximum allowable heat consumption for Phase One of the Standard is 25.3 W/m^2 (see Fig. 4). Figure 9 shows the heat losses through different building components of the Baseline building in Beijing as calculated by the DOE-2 program. The largest source of heat loss is the exterior wall, followed by the windows, infiltration, and then interior walls next to unheated stairwells. Adding insulation to the building shell is an effective energy conservation strategy, but there have been concerns that changing windows from single- to double-glazed might reduce not only heat loss, but also beneficial solar heat gain and cause a loss of comfort. Since Chinese buildings are of brick and concrete construction, the heat loss due to infiltration depends almost entirely on the air-tightness of the windows and doors.

For this study, the following typical energy conservation strategies have been explored: (i) insulating the 370 mm (14.5 in) thick brick exterior wall, as well as the 240 mm (9 in) thick brick interior walls next to stairwells, by using 30 mm (1 in) of cement perlite mortar instead of the common cement mortar on the inside, and increase the resistance of the opaque part of the balcony door (current U-value: 1.72 W/m^2 x K); (ii) changing the windows in east, west, and north-facing orientations from single- to double-glazed, except in the stairwells; (iii) changing the windows in all orientations from single- to double-glazed windows except in the stairwells; and finally (iv) all of the above measures combined.

The results for the DOE-2 analysis of the four strategies are listed in Table IX. It is obvious that insulating the walls can greatly reduce energy use, with the heat consumption reduced by 14%. Perlite is a relatively cheap insulation material in China and is used in cement perlite mortar with the ratio of perlite to cement of 3:1. After a first layer

Figure 9. Heat losses computed by DOE-2 for the baseline building

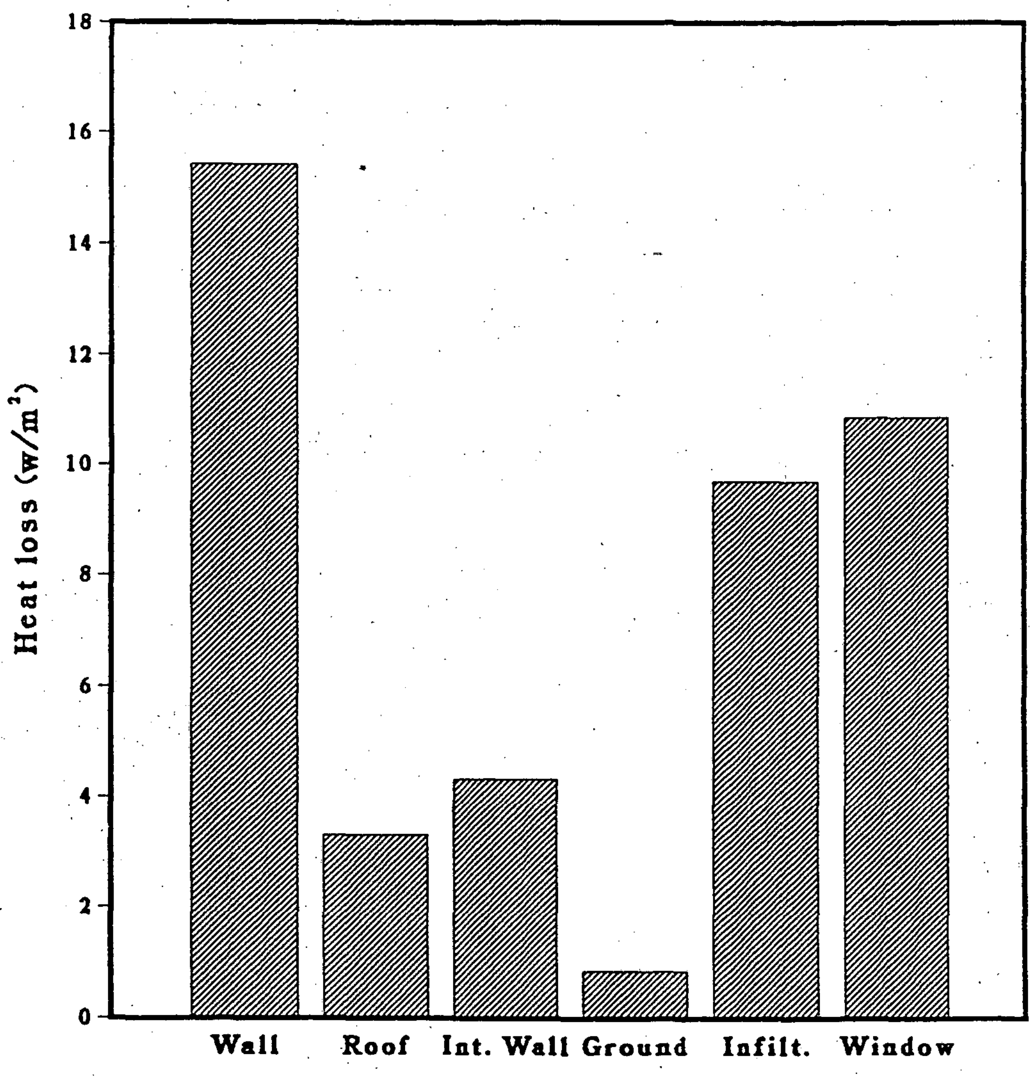


Table IX. Comparison of DOE-2 results for four energy-conservation strategies (W/m²).

		Base-line	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Heat loss	Exterior wall	15.43	11.58	-	-	11.68
	Interior wall	4.32	3.13	-	-	3.16
	Window	10.87	-	8.34	5.61	5.69
Heat gain	Solar	6.92	-	6.76	6.05	6.06
Reduction of heat loss from windows		-	-	2.53 (23.6%)	5.26 (48.4%)	5.18 (47.7%)
Reduction of solar heat gain		-	-	0.16 (2.3%)	0.87 (12.6%)	0.86 (12.4%)
Total heat load (Q_H)		34.05	29.26 (14.1%)	31.76 (6.7%)	29.85 (12.3%)	24.98 (26.6%)

Table X. Heat losses and gains for Phase One case (W/m²).

Heat loss						Heat gain				Q_H
Wall	Roof	Interior wall	Ground	Infil-tration	window	Solar	Occu-pancy	Light-ing *	Equip-ment	
7.11	2.66	4.88	0.86	9.99	8.56	5.53	3.93	1.65	0.38	22.56

* includes cooking.

of 20 mm (0.8 in) is plastered, a steel net is added and then a second perlite/cement layer about of 10-15 mm (0.4-0.6 in) thick is added. The U-value of the exterior wall is thereby reduced from 1.52 W/m^2 to 1.10 W/m^2.[11]

Changing the single-glazed windows, including those facing south, to double-glazed ones in the Beijing climate can also significantly reduce energy use by 7 to 12 %, with only a negligible reduction of solar heat gain. If Strategy Four is used, the heat consumption will be further reduced by 27% to 24.98 W/m^2. This would make the baseline building meet the Phase One requirement with a dynamic payback time of two to three years.[12]

Phase One Conservation Strategies from the Beijing Local Standard

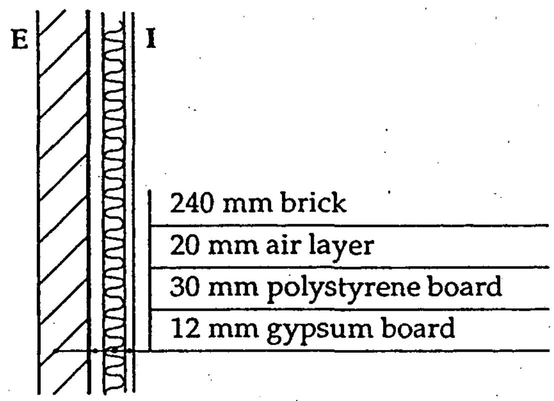
In order to put the Standard into effect, the Capital Planning Commission and Urban Construction Commission of Beijing (hereafter referred to as CPC/UCC) in 1988 approved a set of local detailed rules and implementation regulations for the Beijing area.[12] This local document is more specific than the Ministry Standard and contains recommended construction details for the exterior walls, roofs, and interior walls, samples of which are shown in Figure 10.

The authors have used DOE-2 to analyze the energy consumption of the Phase One construction recommended by the Beijing CPC/UCC using the Baseline building described earlier. For the simulations, the following space conditions have been assumed : (i) an average indoor temperature of 16 C (61 F), (ii) ten occupants (three families) per apartment, (iii) monthly electricity consumption per family for lighting and appliances of 60 kWh, and (iv) monthly city gas usage per family of 30 m^3 for cooking. City gas has a heat content of 4.65 kWh. Of this amount of heat, 70% is assumed to be exhausted, leaving only 30% left in the room as heat gain, (v) an average hourly air change rate of 0.6, taking into consideration requirements for indoor air quality and the growing proliferation of kitchen exhaust fans, and (vi) an average hourly air change rate of five in the stairwell.

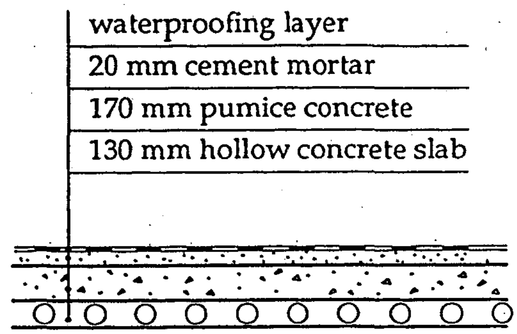
The DOE-2 simulations results are shown on Table X and Figure 11, with the heat loads of the original Baseline building also shown for comparison. The resultant heat consumption of 22.6 W/m^2 is below the maximum allowable value of 25.3 W/m^2 stipulated by the Standard. Infiltration makes up the largest component of heat loss, followed by the window, interior walls facing stairwells, exterior walls, and then the roof. The building peak heating load was 77.5 kW or 45.3 W/m^2 and occurred at 6 am on Feb. 8 (outdoor dry bulb temperature -17.2 C). To study potential further improvements in energy conservation, a parametric study has been done reducing the air change rate, also changing the south windows into double glazed windows adding further insulation to the interior walls and roof, and changing the location of the exterior wall insulation from inside to outside. All of these strategies are applied to a building built according to the Phase One Standard for Beijing.[12]

Figure 10. Phase One conservation strategies

Exterior wall



Roof



Interior wall next to stairwell

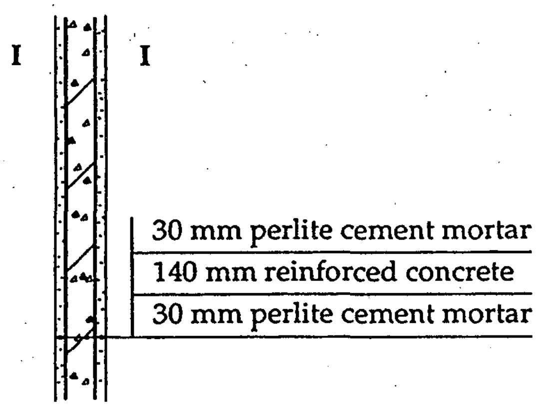
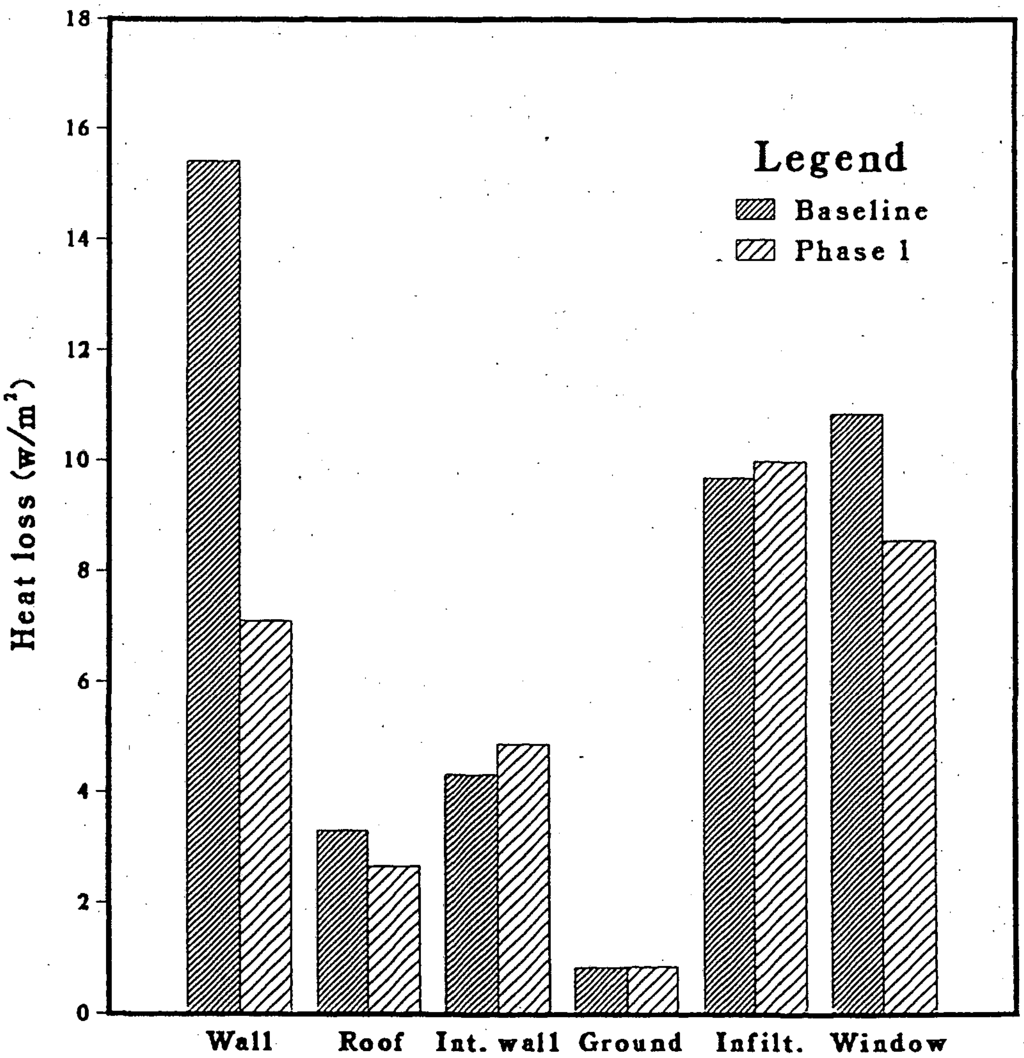


Figure 11. Comparison of heat losses for the baseline building and the Phase One strategy



Air Change Rate

It is obvious that the heating energy consumption will increase as the infiltration air change rate goes from 0.5 to 0.75. As the rate changes from 0.5 to 0.6 and 0.75, the heating consumption will change from 21.04 to 22.56 and 24.84 W/m^2, respectively. All of these heating consumptions are still in the acceptable range for Phase One of the Standard (Fig. 12).

Strategy One - Double Glazed South-facing Windows

According to Phase One of the Standard, in Beijing windows facing north, west, and east must be double-glazed, but those that face south can be single-glazed. As shown in Table XI, changing from single- to double-glazed windows on the south-facing windows reduces heat loss by 2.76 W/m^2 (32%), while the solar heat gain is reduced by only 0.59 W/m^2 (11%). This causes the building's heat consumption to be reduced from 22.56 W/m^2 to 20.44 W/m^2 (9.4%), with a dynamic payback period of 3 years.[12]

Strategy Two - Interior Wall Insulation

In Beijing, stairwells are generally unheated which results in heat loss through the interior wall adjacent to a stairwell. Table XI shows the result of changing the construction of the interior wall from concrete and cement perlite mortar to 200 mm (8 in.) of aerated concrete. This causes the heat loss through the interior wall to decrease from 4.48 W/m^2 to 2.37 W/m^2 and the heat consumption of the building from 22.56 W/m^2 to 20.67 W/m^2 (8.4%). Since the costs of regular and aerated concrete are nearly the same, we recommend that aerated concrete be used for interior walls adjacent to stairwells.

Strategy Three - Added Roof Insulation

In this strategy, the Phase One roof insulation of pumice concrete is replaced by a 50 mm (2 in.) layer of polystyrene, as illustrated in Figure 13. As shown in Table XI, this will reduce the building's heat consumption by 4.6% from 22.56 W/m^2 to 21.52 W/m^2. The dynamic payback period is 6 years.[12]

Strategy Four - Added Exterior Wall Insulation

In this strategy, the wall insulation is placed on the outside of the exterior wall instead of the inside, as shown in Figure 14. As shown in Table XI, this will reduce the building's heat consumption by 3.6% from 22.56 W/m^2 to 21.75 W/m^2. The dynamic payback period is 7 years.[12]

Table XI. Parametric study for Phase One case (w/m^2)

		Phase One case	Strategy 1	Strategy 2	Strategy 3	Strategy 4
Heat loss	Exterior wall	7.11	-	-	-	6.29
	Interior wall	4.88	-	2.37	-	-
	Roof	2.66	-	-	1.59	-
	Window	8.56	5.80	-	-	-
Heat gain	Solar	5.53	4.94	-	-	-
Reduction of heat loss from windows (%)		-	2.76 (32.2%)			
Reduction of solar heat gain (%)		-	0.59 (10.7%)			
Total heat load (Q_H)		22.56	20.44 (9.4%)	21.52 (8.4%)	22.75 (4.6%)	(3.6%)

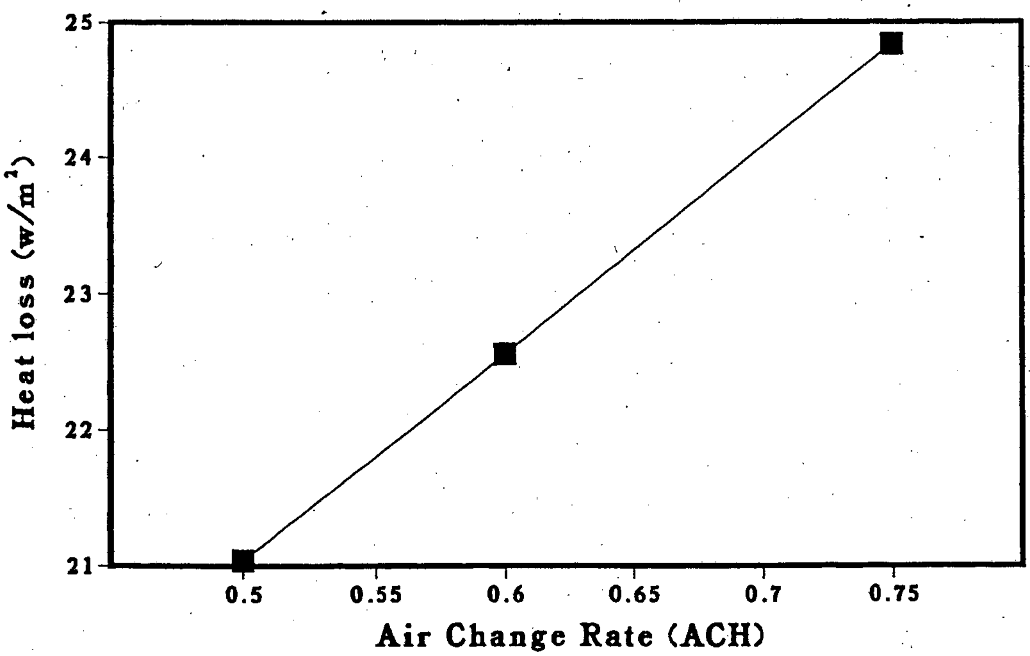


Figure 12. Heat loss as a function of the Air Change Rate

Figure 13. Strategy Three roof construction

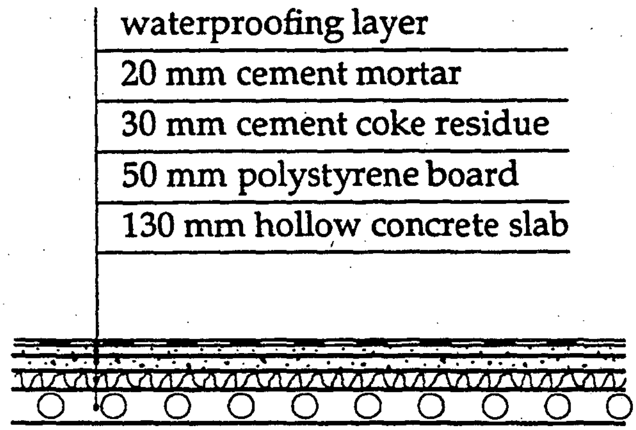
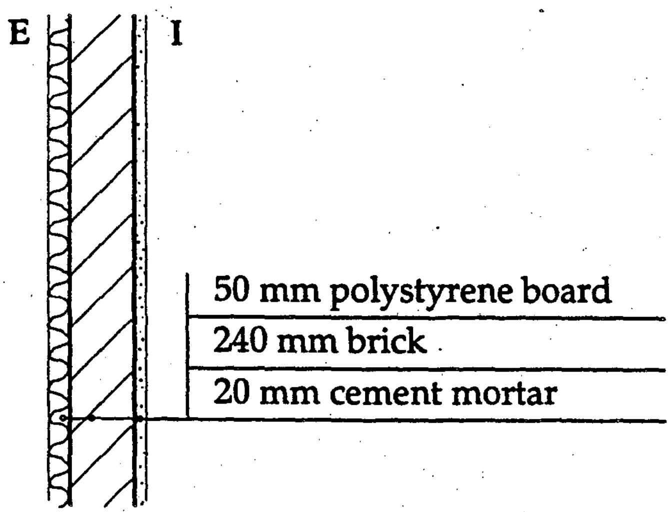


Figure 14. Strategy Four wall construction



5. Conclusions

(i) Heating is required in buildings in the north of China for as much as five months in the winter. The area of the official Central Heating Zone includes about 70% of China's land area and about 40% of the building stock. The energy used for heating and cooling represents 11.2% of total national energy production. Compared with the U.S. and Europe, the energy use per m^2 is about three time higher, but the indoor comfort conditions are worse. (ii) The first energy conservation standard for space heating in urban residential building in China was approved in 1986 by Ministry of Construction. Since Jan. 1, 1991 all new civil buildings in Beijing region must be designed in accordance to the local rules and regulations of the Standard. (iii) The heat consumption of a baseline residential building has been calculated using the steady-state heat transfer method of the Standard and the hourly dynamic response-factor method represented by the DOE-2 program. The results are quite consistent (7.4%) and also in accordance with measured data. (iv) Parametric studies using DOE-2 have shown that it is possible to reduce heat consumption by 20% by using 30 mm (1 in) of cement perlite mortar on the inside of exterior walls and interior walls facing stairwells and changing the windows from single-glazed to double-glazed (except those in the stairwell), thereby meeting the Phase One requirements of the Standard. The dynamic payback period is 2 to 3 years. The study also showed that changing south-facing windows to double-glazed can also be important for reducing the heat loss in the Beijing area. (v) The strategies recommended in the local rules and regulations of Beijing will satisfy the heat consumption values given in the Standard. Further analysis shows that using aerated concrete on interior walls adjacent to unheated stairwells will further reduce heat consumption by 8.4% without additional cost. In addition, it was shown again that double-glazed windows facing south are cost-effective, producing savings of 9.4% and a short payback period of three years.

6. Acknowledgements

The authors would like to thank M. Levine, program leader of the Energy Analysis Program of Lawrence Berkeley Laboratory for his support and encouragement, and H. Zhang of the Department of Architecture of Qinghua University and currently a visiting scholar at the University of California for reviewing this paper and drawing the architectural illustrations. This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Building Systems and Materials Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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