Housing Design for Lower Domestic Energy Use

Exemplified by multi-storey buildings in Beijing

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Part 1

1 Introduction

The objective of this study is to analyse the energy use of typical households in multi-storey housing areas and to develop recommendations for appropriate design of new housing and improvements in existing housing areas, in urban regions with a climate similar to Beijing.

Problem

In 1999 the world's total energy production was 9.8 million TOE[1], an increase of 13% over the previous decade. Energy use was 9.7 million TOE, of which 19% (309 kgOE per capita) was within the residential sector.

In Beijing the energy use for space heating is about 38 kg coal per m^2 during the heating season, which is roughly three times as much as in industrialised countries with similar climates.

The pattern of energy use by households changes as housing improves and becomes more modern. Traditionally cooking and heating were often done with solid fuel such as wood and coal, while electricity was mainly used for lighting. Energy end-use is different today in low and middle income urban households, where there is an increased demand for air conditioning with a rising standard of living. It is also becoming more common to use electricity for other activities in the home, many of them income-generating.

Several surveys have shown that improving thermal comfort is a high priority for many households. It is therefore likely that rising living standards will lead to increased use of energy. Energy also gets more and more expensive, especially in countries where energy subsidies are being reduced or removed. These factors mean that households using a lot of energy will have to reallocate their family budgets in the future.

There is a lot of urban housing under construction in China, and in many developing countries. Lack of energy-conscious design today will therefore have serious effects for many years to come.

Higher energy use and comfort creates a demand for efficient and reliable supply, and environmental concerns lead to the use of cleaner energy sources. Therefore, a conscious energy supply policy and relevant guidelines for housing design, based on life-cycle cost, will have great impact on social well-being and economic development.

Method

This study consists of:

- Field studies in multi-storey apartment buildings in the Beijing region.
- Documentation of existing housing stock, urban population statistics and household economy.
- Documentation of climate, design, materials and techniques, and domestic energy use patterns.
- Computer simulations of energy use in standard type apartments.
- Literature survey.
- Compilation and synthesis of the collected information.

Organization of the report

This report consists of two parts.

- Part 1, written by Hans Rosenlund, includes: Chapter 1, introduction to problem and method; Chapter 2, general considerations about household energy use patterns and principles of climatic design of buildings; Chapter 3, recommendations.
- Part 2 describes the case study of China, and Beijing in particular. He Jianqing and Sun Guofeng participated in the field study and supplied the main data for Chapter 4: a background to housing, energy and climate. In Chapter 5 a residential area is presented, and its energy use and saving potentials are analysed by Hans Rosenlund.

1 Tons of Oil Equivalent.

2 General considerations

This study focuses on energy use at household level – especially housing design and its effects on energy use. This chapter presents a background and a basic framework for the understanding of the issue.

Household energy use

There are great variations in the world's residential energy use[2]: in 1999 the average for developing countries was only 212 kgOE/capita (China: 233), while developed countries used 651 kgOE/capita (North America: 913). Even if the per capita residential energy use in China remained only one fourth of North America's, its increase over the previous decade was 29% – almost twice of that of North America!

Within a household energy is mainly used for:

- *Heating and cooling of the living space:* boilers/heaters/ radiators, air-conditioners
- *Ventilation for comfort and hygiene:* fan-driven systems
- *Lighting:* fluorescent, incandescent, low-energy
- *Cooking and food preservation:* stove, fridge/freezer, food processor, coffee maker, tea kettle
- *Laundry:* washing machine, dryer, iron
- *Hot-water for hygiene and washing:* water heater
- *Appliances:* TV, radio/music, computer, vacuum cleaner, hair dryer.

An example of a planning instrument for dimensioning the energy supply is shown in Table 1. Equipment can have a wide range of performance in how much energy they use. New appliances might be classified according to energy efficiency, and may even be subsidised, which definitely raises public awareness.

Primary energy sources for these needs may be:

- *Fossil:* petroleum, coal, LPG, natural gas
- *Biofuel:* wood, peat, vegetable oil, methane
- *Nuclear*
- *Renewable:* sun, wind, hydro.

These sources may be directly used to produce heat or mechanical power, or transformed into electricity. Production could be local small-scale or remote large-scale. Especially for the latter, there could be great losses in the distribution systems.

The environmental effects of different energy sources are often debated. Transforming coal to electricity for example creates more CO_2 in the end-use than burning the coal directly. Different sources may also be more suitable for specific use. To take solar energy as an example: solar energy is excellent for hot-water production using simple techniques; however, the physical environment imposes restrictions and it is difficult to apply solar heating in high-rise buildings.

Table 1
Beijing Contemporary Planning Index of Infrastructure and Energy (1990s).

	Electricity W/m^2	Heating W/m^2	Hot water W/m^2	Gas/ Natural Gas $m^3/m^2 \times d$	Water $l/m^2 \times d$	Sewage/ Drainage $l/m^2 \times d$
Ordinary House	30–40	58	5.8	N/A	6.5	6.2
Luxury House	40–50	93	11.6	2.2*	7–10	6.7–9.5
Business Bldg	50–80	58	5.8	0.02	10–15	9–13.5
Commercial Bldg	60–200	93	5.8	0.03	7–16	6.3–14.4
Hotel	40–80	93	17.4	0.06	17–20	16.2–19
Hospital	50–80	76	11.6	0.02	14–18	12.6–16.2
University	30–50	58	5.8	0.02	15	13.5
School	15–30	58	5.8	0.02	6–10	5.4–9
Kindergarten	15–30	76	11.6	0.04	6–10	5.4–9

* m^3/**household** × d

Climate and comfort

Climatic elements

Air **temperature** (°C, °F or K), or dry bulb temperature (DBT), is generally available in meteorological records. The wet bulb temperature (WBT) is the temperature level where vapour saturation occurs (see below).

Energy is transported from higher to lower temperatures (sensible heat), e g through a building envelope, whose thermal properties decide the amount transferred.

Air **humidity** may be specified as absolute humidity, but more commonly as *relative humidity* – RH (%) which describes the portion of vapour in relation to saturation. Hot air can contain more vapour than cold, and when the limit – the dew point – is reached the surplus condenses as water.

Vapour may be added to the air by people (breathing and perspiration) and by activities like cooking and washing. When water changes state (evaporates or condenses) heat is absorbed or released, which is referred to as *latent heat*.

Wind is the most irregular and varying component of the climate. It is locally affected by topography, vegetation and surrounding buildings, and closeness to the sea may create on and off-shore winds. The wind is described by its speed and direction, summarized in frequency diagrams, wind roses.

Air infiltration has a major influence on buildings' heat balance and is affected by the size and direction of openings, cracks, window sealing, etc.

The **sun** may be described as the 'engine' of climate since it supplies a large amount of energy to the earth. The sun's path is regular and the location of the sun depends on the latitude and the time of the year. The season also determines the total amount of irradiation through the length of the day. High altitudes experience more intense solar radiation due to less absorption in the relatively thinner layer of atmosphere.

Short-wave solar radiation is divided into a direct (I_D) and a diffuse (I_d) part. The relation between these varies with the sky conditions, where humid air, pollution or overcast skies increase the diffuse part.

2 UNDP/UNEP, World Bank, World Resource Institute.

Reflection from the ground and adjacent buildings, as well as shading by surrounding objects, affect the total amount of solar radiation reaching a building. Direct insolation through openings has strong influence on the energy balance, while the effect of radiation at opaque parts depends on their absorptivity and thermal properties.

Energy is also dissipated *from* the earth *to* the sky by long-wave **heat radiation**. This portion is affected by air and sky conditions, where cloudiness and pollution have a decreasing effect. Heat radiation exchange also occurs between objects near the ground, e g from hotter to cooler building elements.

Precipitation may vary considerably between seasons in different climates and also over shorter periods. Precipitation often reduces air temperatures, and may cause direct cooling or indirect by evaporation.

Other phenomena related to the climate are hail, frost, thunder, fog/smog, rain/dust/sandstorms, hurricanes and earthquakes. These affect the design of buildings, but may have less importance due to their lower frequency.

Climate types

The climate is classified into several types, where the main types are **cold**, **temperate**, **hot-arid** and **warm-humid** (or equivalent expressions). A range of subgroups exists, e g mountain and maritime variations. On the local scale the *microclimate* may differ much from the 'official' climate, recorded by meteorological stations, because of the specific topography, vegetation, lakes, surrounding constructions, etc. In cities the *urban climate*, affected by its geometry, changed surface properties, shading, wind protection, pollution, heat production, etc, is often different from that of the hinterland. Most climates also include *seasonal* variations.

Beijing has a cold climate as described further in Chapter 4 under the section on Climate.

Thermal comfort

The human body exchanges heat with its environment through conduction, convection, radiation (short and long wave) and evaporation/condensation (latent heat). Factors influencing the heat balance are *environmental*, such as air and mean radiant temperatures, vapour pressure and air motion, but also *individual*, e g metabolic rate (Table 2) and clothing (Table 3). The body's thermal equilibrium must be maintained within narrow limits for survival, and the range of comfort is even narrower.

Table 2
Metabolic rates at some different activities (average for adults). 1 met = 58 W/m² body area. Source: ASHRAE Handbook.

Activity	*Metabolic rate* *met*	*(W)*
Sleeping	0.7	75
Sitting	1.0	105
Standing relaxed, office/school work	1.2	125
Standing, light – medium activity	1.6–2.0	170–210
House cleaning	2.0–3.4	210–350
Walking (level, 3–6 km/h)	2.0–3.8	210–400
Dancing, gymnastics	2.4–4.4	250–460
Pick and shovel work	4.0–4.8	420–500
Running (15 km/h)	9.5	1,000

Table 3
Thermal properties of some clothing combinations (1 clo = 0.155 m²K/W). Source: ASHRAE Handbook.

Clothing	*clo*
Nude	0
Shorts	0.1
Walking shorts or knee-length skirt + short sleeve shirt	0.3–0.4
Trousers or knee-length skirt + long sleeve shirt	0.5–0.6
Trousers or knee-length skirt + long sleeve shirt + jacket	0.7–1.0
Knee-length skirt + long sleeve shirt + half slip + pantyhose + long sleeve sweater or jacket	1.0–1.1
Men's heavy three piece business suit	1.5
Men's heavy suit + wool overcoat	2.0–2.5

Comfort is a subjective experience, and a 'comfort zone' is established by the votes of a population in an experimental situation. A number of scales have been developed, of which the DISC index (ASHRAE 1997) expresses degrees of discomfort rather than comfort. The most common definition of the 'comfort zone' is DISC ±0.5, which means that 80% of the population is satisfied, although extended limits to DISC ±1, i e 70% satisfied, could be proposed for situations where resources are limited. There is also evidence for geographical and seasonal adaptation related to monthly mean temperatures, and psychological factors, such as expectations, have also been found to play an important role for comfort sensation.

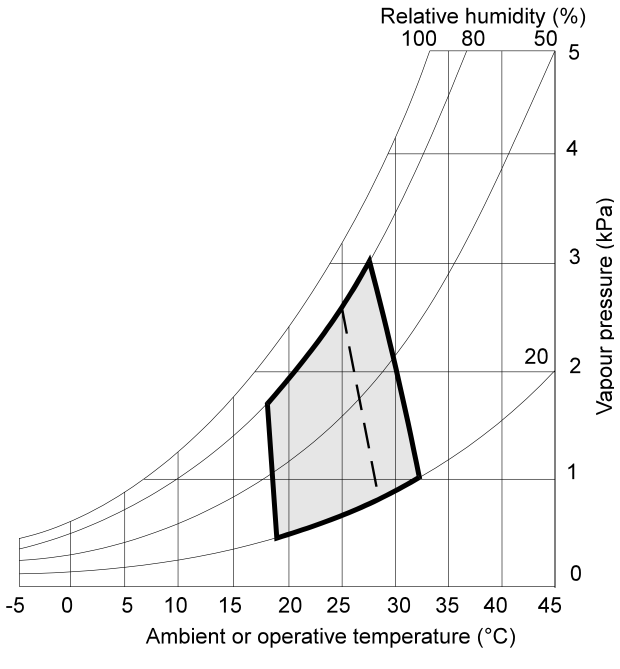


Figure 1
An example of a comfort diagram for: DISC ±0.5; 0.6–1.0 clo (upper and lower limits respectively); 1 met; v=0.1–0.5 m/s (the higher value to the right of the dashed line). After Markus and Morris (1980), where 55 combinations of parameters can be found.

Building design

Designing a building is a process which includes giving it its main architectural features, choice of building materials and design of technical systems. Finally, attention must be given to the users. The following are some considerations when it comes to energy use. A more elaborate description of the design process is given in Rosenlund (2001).

Architecture
The architectural design of the building may include the following factors.

Form
By form is meant the building's main proportions, scale/volume, attachment, etc. In multi-storey buildings, the location of the apartment within the building strongly affects the energy use. For example, a top-corner position has a larger proportion of external walls than a position in the middle of the building. The storey height also affects the overall envelope surface and the interior volume.

Orientation
The orientation of the building's main facades and openings determines the access to solar radiation. During the cold season, solar access is important for passive heating, while during hot periods, adequate shading may create comfort. Thus, shading devices (fixed or movable), topography and surrounding objects must also be taken into account.

Ventilation
Similar to orientation above, the ventilation (for structural heating/cooling, comfort, health, moisture removal) depends on form, openings and orientation. Window design is important, and additional devices for wind-catching or weatherproofing may also be considered.

Building materials
The choice of building materials is one of the most obvious factors affecting energy use in buildings[3]. All building materials possess both thermal resistance and thermal capacity (inertia) in different proportions. These properties are more or less the opposite of each other, and there are three factors influencing them.

Density (ρ, kg/m^3): the lighter the material the more insulating; the heavier the more heat storing.

Conductivity (λ, W/mK) is the ability to conduct heat. Insulating materials have low conductivity.

Specific heat capacity (c_p, Wh/kgK), or the volumetric heat capacity (VHC = $c_p\rho$ Wh/m^{3}K), indicates how much energy can be stored in the material.

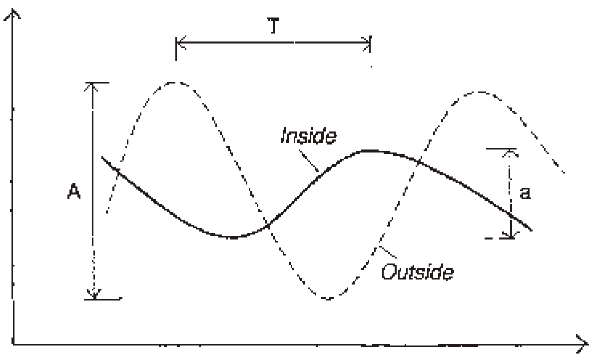


Figure 2
The concepts of time lag (T) and attenuation (a/A).

Table 4
Thermal properties for some common building materials. Local variations may occur, especially in relation to moisture content. This table is compiled from several sources and presents a span of each property.

Material	*Density kg/m³*	*Conductivity W/mK*	*Specific Heat Wh/kgK*
Adobe blocks	1,000–1,700	0.3–0.8	0.28–0.30
Aluminium	2,700–2,800	160–200	0.25
Burnt clay bricks	1,200–2,000	0.42–0.96	0.25–0.30
Clay	1,600–2,000	0.45–0.9	0.22–0.24
Concrete	2,200–2,400	1.2–2.0	0.23–0.30
Cork, expanded	115–200	0.043–0.052	0.47–0.58
Lightweight concrete	200–1,600	0.08–0.80	0.27–0.31
Mineral wool	20–300	0.034–0.049	0.18–0.21
Polystyrene	15–130	0.033–0.039	0.47
Polyurethane	30	0,026	0.47
Sand	1,500–1,700	0.40–0.50	0.23
Steel	7,800	50–60	0.13
Stone	2,000–2,800	1.3–3.5	0.20–0.25
Wood	500–900	0.14–0.16	0.66–0.76

The combination of thermal properties has influence on the *time lag*, the time from outside to inside maximum surface temperature; the *attenuation*, the proportion of inside to outside temperature amplitude (Figure 2); and the *diffusivity*, the conduction rate ($\lambda/c_p\rho$ m^2/h), of building elements. These properties strongly affect the indoor climate.

Surface properties of building materials are *absorptance*, which is the ability to absorb short-wave, visible light and *emittance*, the ability to emit long-wave, heat radiation. Absorptance relates to colour, and values between 20% for white paint and 95% for black surfaces are practically applicable. Emittance relates more to surface structure, and is normally around 85–95% for building materials except for new metal surfaces, which may have 10–30% emittance. Consequently, a light-coloured rendering reflects most of the solar radiation but may emit a great deal of heat to a clear night sky.

The *thermal resistance (R-value)* of a material layer is calculated as its thickness divided by the conductivity (d/λ). The overall thermal resistance of a building element is the sum of the R-values of each layer of the element, including the so-called film resistance of the air layers close to the element's outer surface (0.03–0.04 m^{2}K/W depending on wind) and inner surface (0.11–0.16 m^{2}K/W for non-reflective materials, depending on position and heat flow direction). The *thermal transmittance (U-value)* is the reciprocal of the thermal resistance.

$$R_{tot} = 1/U = R_{in} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \ldots + \frac{d_n}{\lambda_n} + R_{out} \qquad \text{Eq 1}$$

For complex elements, e g stud walls, the average U-value may be calculated as the proportional average of the U-values for each part.

3 This study does *not* include energy *embodied* in building materials (see Der-Petrossian and Johansson, 2001).

Table 5
Absorptance and emittance of some building materials (based on various sources).

Material		Absorp-tance (a) %	Emit-tance (e) %
Aluminium sheet	New	20–40	10
	Oxidized	30–50	20–30
Burnt clay bricks	Cream	30–50	85–95
	Yellow	55	90
	Red	65–80	85–95
Concrete	Light	45–70	85–95
	Dark	90	90
Paint	White	20–30	85–95
	Light grey	30	90
	Light green	50–60	90
	Medium grey/yellow/orange	55	90
	Light brown/grey/red	65–70	90
	Dark brown/red/green	80–90	90
	Black	85–95	85–95
Steel sheet	Galvanized, new	30–65	15–30
	Galvanized, oxidized	80	20–40
	Rusty	60–85	60–90
Stone	White marble	50	85–95
	Limestone	60	85–95
White-wash	New	10–15	85–90
	Weathered	20–30	85–90
Wood	Pine	60	90–95

Systems
In addition to the building itself, there are normally systems for heating and/or cooling. *Passive* systems include, e g, solar collectors and sun spaces for heating, and evaporative, radiative, heat capacity, and shading systems for cooling. There is a wide variety of *active* systems for heating and air-conditioning on the market.

Users
The users of the building play an important role, affecting the energy use. Their actual presence and use of equipment for work, entertainment, cooking and lighting create additional internal heat loads, varying over the day/week/year. Further, setting of thermostats and regulators, opening windows, etc directly affect energy use. All these factors have to be taken into account when estimating a building's

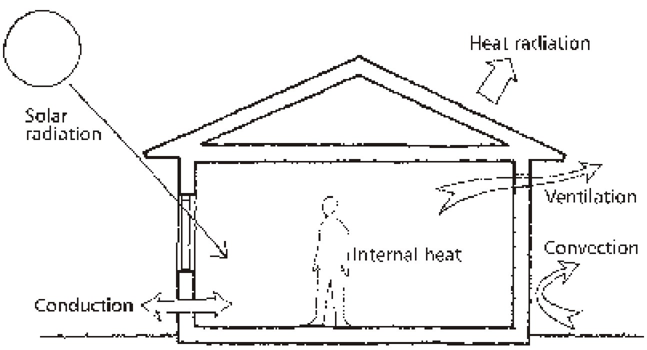


Figure 3
Thermal balance of a building.

energy use. Typical profiles for different building occupation or activity are often developed.

Energy calculation methods

Even if heating and cooling stages may occur, a building is in thermal balance in the long run, meaning that the sum of all incoming, outgoing and internally produced energy equals zero. The energy flow is in the form of radiation (short-wave visible solar and long-wave invisible heat), conduction (direct flow through solids), ventilation and convection (transport via air).

Simple tools
Simple tools for energy calculations are generally based on steady-state models, not taking, for example, heat storage capacities into account. These may give reasonably accurate results for climates and seasons with one-directional heat flow, e g during a plain heating season.

Degree-days
A simple way of describing the severity of a climate is through the degree-days method. Define the base temperature as the indoor set-point for heating (normally 18–20°C) or cooling (normally 20–27°C). Calculate the average outdoor temperature (normally by averaging minimum and maximum). Accumulate these over time by multiplying the temperature difference with the number of days. If the outdoor average is lower than the base temperature, the product is called heating degree-days *(HDD)*, if it is higher you get cooling degree-days *(CDD)*.

The degree-days can thus be used for estimating a building's total energy demand. For that purpose we have to convert to degree-hours *(DH)* by multiplying by 24. The energy demand could be described as:

$$Q_{total} = Q_{cond.} + Q_{vent} - Q_{int.heat} - Q_{sol.gain} \quad \text{Eq 2}$$

or

$$Q_{total} = DH \times (\sum UA + 1206v) - Q_{int.heat} - Q_{sol.gain} \quad \text{Eq 3}$$

***Note**: ± signs are dependant of flow direction and heating/cooling case!*

DH is the number of heating or cooling degree-hours. The *conduction* part is the sum of *UA* (W/K), the product of the thermal transmittance and the area of each part of the envelope. Corrections should be made for surfaces towards the ground. The *ventilation* part includes the volumetric heat capacity of air and the rate v (m^3/s). *Internal heat* must be accumulated over the whole period. *Solar gain* is dependent on sunshine, orientation, latitude, season, glazing area and property, shading factor, etc, but could be given as a correction factor to the windows' thermal resistance.

An example of a heat balance calculation is shown in the box on page 17.

Computer simulations
The energy balance and requirement of a building may well be studied by computer simulations. There are computerized versions of many simple calculation methods, but more useful is the possibility of running dynamic calculations, taking into account internal thermal storage and loads, detailed insolation, etc.

An organized way to study the energy balance by computer tools is to carry out a *parametric study.* Hence, each building parameter may be systematically evaluated in terms of its effect on the energy balance.

In the case study in Chapter 5, a parametric study with the powerful *DEROB-LTH* software (Kvist, 2003) is presented.

Regulations

Regulations may be divided into two main categories.

- **Prescriptive** regulations set detailed criteria, give technical guidelines and may also propose definite solutions. Typical elements in such regulations are maximum thermal transmittance of walls, floors and roofs, maximum window sizes, limits for ventilation rates, etc. However, this type of regulation does not promote innovation in the building industry and design. In the worst case each element of a building has to be chosen from a catalogue of standard type drawings. This reduces the role of the designer to combining these approved elements.
- **Performance based** regulations give the designer the tools to verify that the building is able to perform the different functions for which it was designed. The specifications often range from qualitative objectives to quantitative criteria and verification methods. These generally more advanced regulations often require special tools and higher skills of the designer.

Even though performance based regulations are considered the most modern, prescriptive regulations are in some cases simpler to apply and enforce. Most regulations are a mixture of the two types. In some cases the designer may choose between using one or the other.

The Swedish code (see box) is an example of regulations that have changed from fully prescriptive to mainly performance based, but where details are of prescriptive nature and alternative calculation methods are possible. Also the most recent Chinese regional regulations include such options, see further Chapter 4.

Swedish Building Regulations

The Swedish building regulations specifiy in the 9th chapter, *Energy Economy and Heat Retention*, the requirements for reduction of heat losses. For complying with these there are two alternatives.

Alternative 1

This method includes three requirements (here presented for housing only):

- **Requirement 1**: Overall thermal insulation and transmission losses, F_s:

  $$F_{s,\,required} = 0.16 + 0.81 \times A_{windows} / A_{envelope}$$

  where the maximum window area to be taken into account is 18% of the heated floor area of the building. Note that this does not mean that the *actual* window area is restricted.

  For each building element a practically corrected thermal transmittance, $U_{corrected}$, is calculated or, more normally, found in manufacturer specifications.

  These are then adjusted if the element is towards the ground, or if the indoor base temperature deviates from 18°C. For windows, the U-value may be reduced according to direction (N: –0.4; E/W: –0.7; S: –1.2) or with 0.7 for all windows irrespective of direction. The resulting $U_{adjusted}$ for each building element is multiplied with its area.

  Next step is to calculate the thermal bridges (punctual and linear) and possibly correct these for deviating indoor temperature.

  Finally, the obtained transmission losses,

  $$F_s = \frac{\sum (U_{adjusted} \times A) + \sum (Thermal\ Bridges)}{A_{envelope}}$$

  should be lower than the required, defined above.
- **Requirement 2**: The building envelope shall be so airtight that the average air leakage rate at a pressure difference of ±50 Pa does not exceed 0.8 l/s per m^2 envelope.
- **Requirement 3**: Buildings heating the ventilation air with more than 2 MWh annually, using essentially oil, coal, gas, peat or electricity, shall have special arrangements (e g heat exchanger, heat pump or solar heating) which reduce the energy requirement of the building by ≥50% of the energy needed for heating the ventilation air.

Alternative 2

It is allowed to show by *tradeoff calculation* that the energy requirement for space heating, domestic hot water and heat recovery does not exceed the requirements above. However, the surface related heat loss, F_s, shall not exceed the values required above by more than 30%.

If the building does not need special arrangements in accordance with Requirement 3 above, only 50% of the calculated energy saving may be taken into account if such arrangements are nevertheless installed.

Swedish Board of Housing, Building and Planning (2002).

3 Recommendations

There is no ultimate solution for a sustainable or low-energy design. Each case is unique; each site has its own conditions and each climate sets its limits. Further, esthetic, cultural, functional, technical and economic aspects have important influence on building design. Hence, recommendations on climatic design have to be very general. Nevertheless, we will attempt to set an order of priority or check-list to reduce energy use in buildings. In this study we focus on multi-storey apartments in Beijing, but some recommendations may have wider application.

It is clear that climatic design has to be considered at an early design stage, and be integrated in the design process to be efficient, since much of it deals with choice of building materials and form of building, openings, orientation, etc. There is a multitude of more or less advanced tools, of which this study only pointed at a few. Further development of these tools is still necessary to integrate them better into the designer's toolbox.

New construction is very intensive in China and in many developing countries. However, not all buildings are new; there is a huge stock of existing buildings which often need retrofitting to be more energy efficient. Some of the recommended actions below may be more suitable in this respect.

General ranking

The parametric study in Chapter 5 gives indications of the effect and magnitude of some often used energy-saving measures. Given the limited frame of the study, the saving potentials, shown in Table 6, are very approximate. However, they may be grouped into the following tentative ranking list.

1 Different means of ***reducing ventilation*** and air infiltration rates are generally very effective at a low or no cost. Much of the effect depends on the users' behaviour. Creating awareness about the high economic benefits of keeping windows closed may be successful. Weather stripping does not cost much and should be affordable to any tenant or owner. The common sliding windows often cause air leakage, and other types, e g hinged windows, should be considered. Ventilation reduction is suitable in any kind of building, but individual metering of heating energy is a booster for success.

2 A moderate ***insulation*** of the building envelope is standard in new construction in Beijing today, but increased insulation capacity would probably still be economically positive. More important is, however, to retrofit the older building stock, which totally lacks special insulation materials. For practical reasons additional insulation can be applied on the inside, even if much of the desirable thermal storage capacity thereby is lost. The highest savings is when the ventilation is kept low. Special attention should be paid to top-floor and top-corner apartments, as well as other housing forms with higher envelope-to-volume ratio (form factor), where additional insulation may be required. Otherwise these apartments tend to be less attractive, especially if energy is individually metered and prices rise.

3 ***Double glazing*** is also standard in new construction in China, but many old buildings have single-glazed, metal-framed windows. Replacing these is not technically difficult, and would improve U-values but also result in more air-tight apartments. The effect is however limited if not combined with envelope insulation.

4 Increased ***south-facing glazed area*** is efficient in combination with envelope insulation and decreased ventilation. However, even if allowing a higher degree of solar energy into the apartment, these large glass areas need to have better insulation value (3-glass), to reduce conductive heat loss. This measure is less suitable for retrofit, since it most probably includes changes in the building structure. Balcony glazing may be a way of increasing solar heating and at the same time increasing the usable living area.

It is thus obvious that realising all relevant recommendations is possible with short pay-back periods.

Table 6
Matrix of different energy-saving actions. Tentative savings for typical multi-storey apartments (middle of building) in the Beijing climate, based on the computer simulation study in Chapter 5.

		Cost level				*Suitable for*		
							Retrofit by	
Action	*Typical saving*	*No*	*Low*	*Medium*	*High*	*New building*	*User/ Tenant*	*Owner/ Manager*
Ventilation reduction (keeping closed)	50–70%	×				×	×	
Weather stripping of windows	50–70%		×			×	×	×
Envelope insulation (moderate)	16–37%			×	×	×		×
Double-glazing	11–31%		×	×		×		×
Larger south windows (2 × size, 3-glass)*	up to 30%			×	×	×		
Larger south windows (2 × size, 2-glass)*	up to 8%			×	×	×		

* *For low ventilation rates.*

Different building types

Relating to the typical multi-storey buildings from different time periods in Beijing, described in Chapter 4, recommendations for each type is summarized below.

Retrofitting

Buildings built before 1995
Highest priority should be to reduce ventilation by weather stripping of the untight windows, which could save up to 50% energy. If this is achieved by also changing windows to double-glazed with insulated frames, the energy saving effect will be even higher. More complicated and expensive is envelope insulation, but in combination with the above measures, it may save a substantial amount of energy – up to 80%.

Buildings built after 1995
Buildings complying with the first new energy regulations generally have some envelope insulation and double-glazed windows. Most essential here is to keep the ventilation low through good weather stripping (saves up to 70%), and possibly to improve roof and gable insulation to make edge and top apartments more energy efficient and thus attractive.

New buildings

Most important for new construction is to increase the south-facing glass area compared to today's practice. If triple-glazing is used, a saving of 30% is realistic. Summer overheating should be prevented by adequately designed shading devices. Today's thermal insulation standard is too low and increased overall envelope insulation should be very profitable economically.

Policy

Even if large improvements have been made over the last decade, today's energy regulations in China still stipulate only moderate energy-saving techniques. Much more energy would be possible to save in the colder zones by, e g, increasing envelope insulation. This would however require a more conscious life-cycle cost perspective, where investments in building construction and services are balanced against the running costs. Pay-back periods are likely to shrink with increasing energy prices. Some improvements in building design are at low or even no cost, and may permit an indoor comfort level with small or even no investment in active systems.

Besides the necessity to update thermal regulations, a prerequisite for effective energy-saving is public awareness and economic incentives. In apartment buildings this has to be created through individual metering of all kinds of energy.

Part 2

4 Background

This chapter gives a general background to urban housing policies in China over the past decades. It presents typical buildings in Beijing and their energy use and a review of the development of energy regulations up to now.

Urban housing in China

This section presents China's process of urbanisation and urban housing.

Urbanisation
Urbanisation in modern China passed through several stages.

1949–1958
The implementation of a 3-year rehabilitation of the national economy and the first 5-year plan, large scale development of national industry and rapid development of the urban economy resulted in a sharp rise in the urban population – from 11 to 16%.

1959–1963
During this unstable period with drastic ups and downs in social and economic life ("the great leap forward"), a large number of farmers poured into cities – far more than China's national economy could support. Decisive measures to mobilize these farmers back to the countryside resulted in a sudden drop in the urban population.

1964–1977
A stagnant period in which the policy of strict control over urban population caused it to decrease slightly.

1978–1997
Changes in the urban administrative system resulted in a large rural population residing in cities and towns being included in the total urban population statistics. The expansion of urban industry and the so called 'Rural Industrialisation' played an important role in the fast growth of urban population. Also newly designated counties and towns mushroomed into the urban areas of existing municipalities.

1998–
Following the end of 'housing distribution' from the employer to employees, the housing market developed rapidly. The area of urban dwellings constructed remains over 200 million m^2 per year. Besides the massive housing construction, a future urbanized society is also formed.

Prediction
According to recent domestic and international views, the urbanization level in China will rise to 45% in 2010, 55% in 2025, and up to 75% in 2050. This is higher than the prognosis from 2001, shown in Figure 4, and it seems plausible since the actual 2005 level is already higher than predicted.

Urban housing reform
Before 1978, the State had responsibility for urban housing development. Most of the funds needed for housing

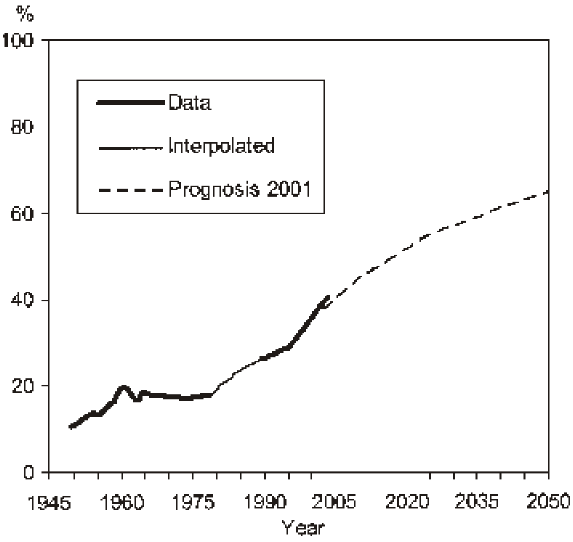


Figure 4
Urbanisation level in China. Most values around 1979–88 are interpolated since the administrative systems changed, and statistics became unreliable. There is already a discrepancy from the 2001 prognosis, indicating a higher future urbanisation rate. This is also supported by recent studies, estimating 75% urbanisation by 2050.

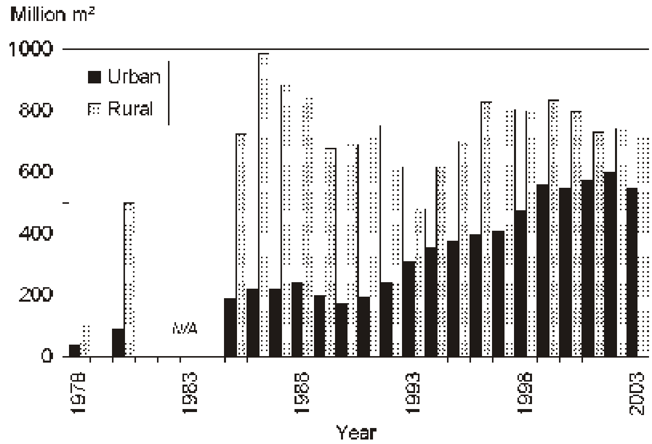


Figure 5
New residential construction in China: urban and rural.

Source: China City Development Report 2001–02.

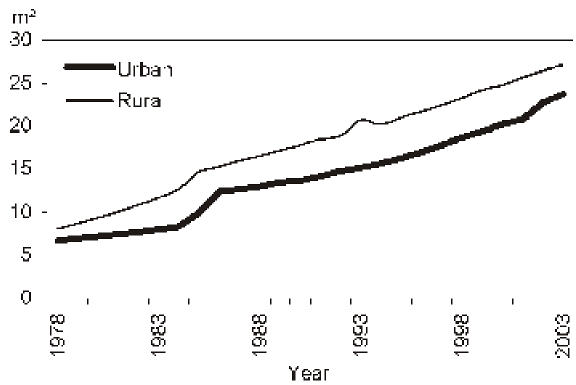


Figure 6
Per capita living space: rural and urban.
Values for 1981–84 are interpolated.

Source: China City Development Report 2001–02.

Figure 7
Multi-storey building from the 1970s, Beijing.
Poor insulation and air tightness.

construction were allocated by the Central Government, while the proportion of investment from enterprises or work units was very low, and that from collectively owned businesses and individuals was even lower. Housing was allocated by government employers to their staff. The standard average built area was only 4 m^2 per capita. This system could be characterized as *low salary, low rent, and high subsidies*.

The rents were far too low to cover maintenance costs, and country could not afford to finance the system. It resulted in an irrational consumption structure of both the individual and the society, and encouraged people to demand more and better houses. There were also other negative impacts: housing management departments had little initiative, and the construction and building material industry was under-developed.

Since the financial resources of the Central Government were limited, initiatives from other sectors were mobilised; a preliminary reform of housing investment, construction, allocation, exchange, and consumption was implemented in 1978. Several stages can be identified after that.

1978–1984 Housing construction depended mainly on government investment or finance. Housing development was directed by government.

1985–1988 Following the fast growth of the national economy, a real estate sector emerged in urban areas. A new housing policy promoted different sectors such as central and local government, enterprises and the private sector to participate in housing construction and investment.

1989–1990 Housing construction faced a shortage of investment, especially in infrastructure and public facilities. Central Government tried to stimulate investment by putting old public houses onto the market. A land development tax was introduced.

1991–1995 Housing construction was promoted by real estate development, often based on foreign investment, which reflected the nation wide economic growth characteristic of that time.

1996–1998 *Housing is the growth point of national economy* became a common view. Many state enterprises supported the real estate market by purchasing of large volumes of housing for their employees. When the advantages of employer-provided housing declined, the housing shortage turned into a surplus.

1999– Industrialisation of the building sector resulted in massive housing construction. The view has changed “From Building to Housing”.

The multi-sector participatory system for housing development established today allows national and local governments, enterprises, collectives, and the private sector to invest in housing. Urban housing construction has thus changed from self-construction by enterprises or working units to development and management by specialist real estate companies.

Investment management has also changed from each enterprise collecting money for its construction plan, towards real estate developers using their own credits to invest, and establishment of real estate finance systems.

Only 5–8% of housing and infrastructure investment comes from the national budget. The collective sector keeps 5% of the urban housing construction stock, while the private sector stands for 48% of housing construction investment.

Figure 8
New high-rise apartment buildings, Beijing.

Prediction of future urban housing development
According to the prediction of the *9th National Five-Year Plan* and the *Years of 2010 Plan*, the annual urban housing construction would reach 240 million m^2 during 1996–2000. In reality 370 million m^2 of new housing was built in 1996, and 320 million m^2 in 1997. From 2000–2010, the plan predicted 3.2–3.6 billion m^2 new housing will be built, but the number is now expected to be 4.9 billion. The reasons are as follows.

1 Pressure from a large population.
2 Densification and renewal of existing urban areas, due to limited land and infrastructure.
3 Improved living standards; some current housing is very poor.
4 A continuation of the same high rate of new construction as in recent years.

Energy use

Energy production and consumption over 40 years are shown in Figure 9. There is a clear trend of increase in both, but around the turn of the millennium there was a drop, especially in production which has not yet caught up with consumption.

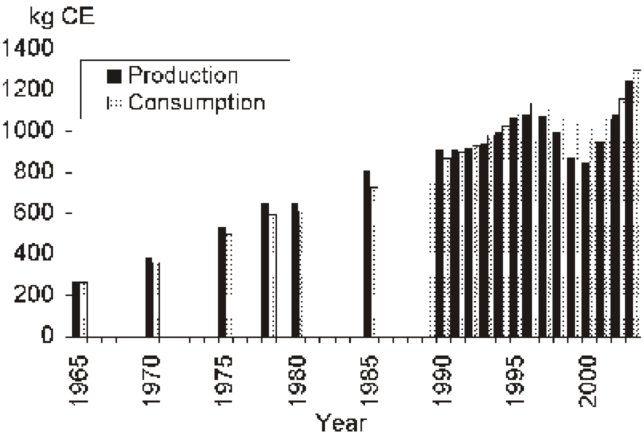


Figure 9
Total energy production and consumption per capita in China (in kg Coal Equivalent).

Sources: China Development Report 2001–02, China City Development Report 2001–02, and China Statistical Yearbook 2004. (Sporadic data before 1990).

Energy use in the residential sector is from several sources (Figure 10), and electricity and LPG (Liquefied Petroleum Gas) in particular are increasing.

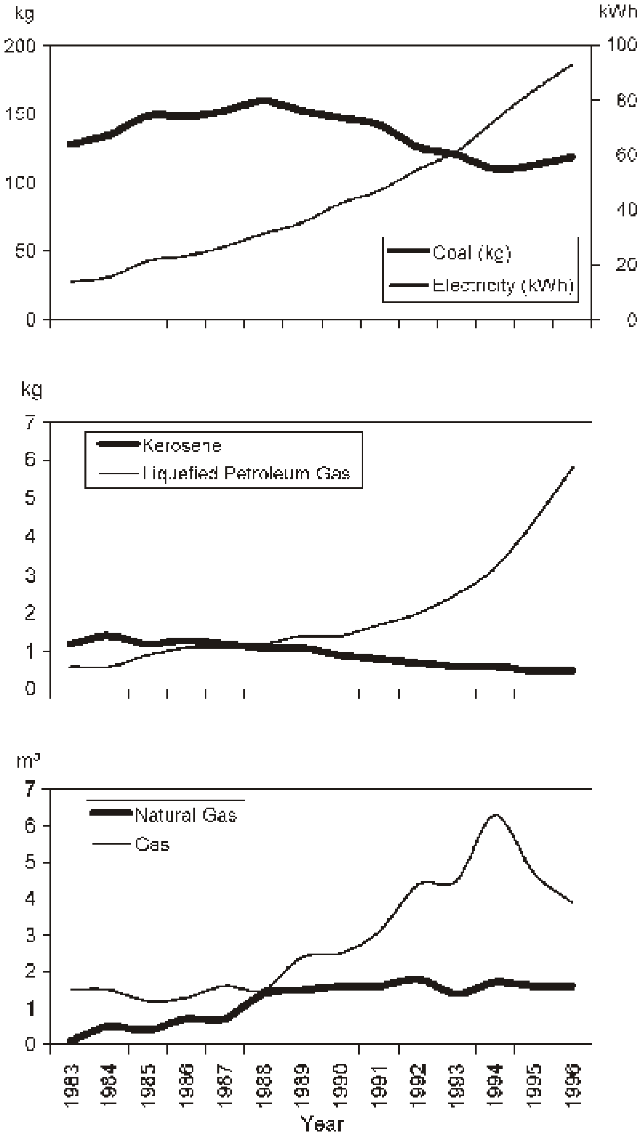


Figure 10
Residential energy use per capita in China.

Source: China City Development Report 2001–02.

Climate

China is divided into five climatic zones, see Figure 11: the *very cold* and *cold* zones in north and west, where space heating is a main requirement; a *warm* climate in south-west; a composite *hot summer and cold winter* climate in the mid-latitudes; and the *hot summer and warm winter* in the south, where space cooling is essential.

Beijing lies within the cold region, where January temperatures normally range from –9°C to +1°C. Nevertheless the summer period is hot with normal temperatures of 21–30°C in July. See Figure 12.

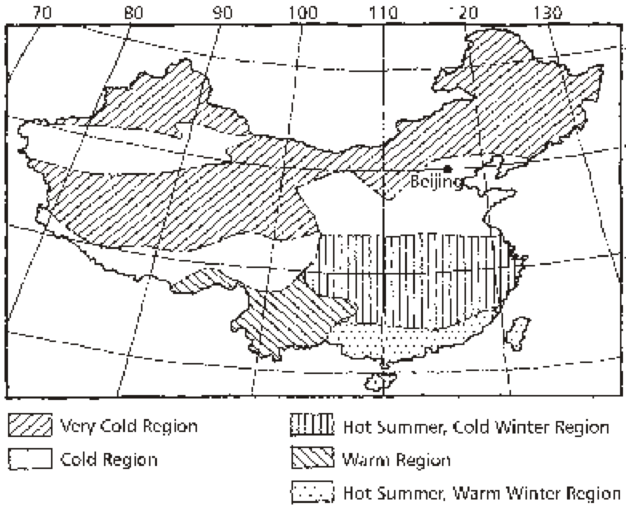


Figure 11
Climatic zones of China.

Policy

The policy document *Sustainable Development of the Residential District*[4] includes two topics relevant to household energy use.

Providing appropriate housing to everybody

Since housing standard is important for the middle-income Chinese family, the government is giving priority to

4 The 10th chapter of *Population, environment & development in 21st century in China.*

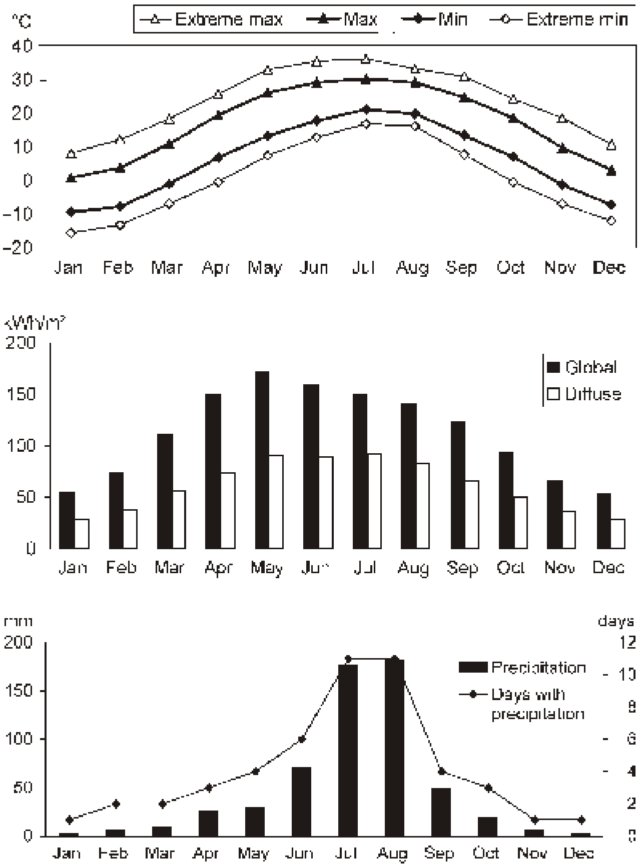


Figure 12
Climatic data for Beijing. Upper chart shows a normal year's maximum, average and minimum temperatures, middle chart shows solar radiation, and the lower chart shows rainfall data.

Source: Meteonorm.

increase investment in the housing industry. There are still 5 million families living under 'poor conditions' according to Chinese standards. The ratio of 'acceptable' housing is only 46% in urban areas over the whole country: much housing is poor quality (including poor thermal insulation) and under poor management.

Energy conservation and enhancing the efficiency of energy use

The energy use in 1990 within the residential sector was about 113 million TCE (not including the production of building materials), or 11.5% of the total energy use in the country. Up to 1999 it increased to 233 million TCE (about 27% of the total energy use) which was far more than expected. Further, the average efficiency of energy use in the building industry in China is only about 30%.

During the heating season the energy use is about 38 kg coal per m^2, which is roughly three times that in developed countries with similar climates. A shift from emphasizing building investment, which today results in poor building envelopes and insulation, to introducing a life-cycle cost perspective could result in more sustainable construction.

Energy conservation design standards

The cold district of China includes the northwest, north and northeast, where the average temperature is below 5°C during more than 90 days per year. This is usually called the *heating needed region* and covers about 70% of China. At the end of 1990, there were 3.1 billion m^2 urban building in this region, of which 54% was residential. Including dormitories, nursery schools, hotels, etc, there are over 1.8 billion m^2 residential buildings needing heating. Smaller cities and towns have more single-storey and lower multi-storey buildings, while in bigger cities more high-rise and higher multi-story housing appeared in recent years. Single and lower multi-storey housing is estimated to use 10–30% more energy, given the same type of envelope and insulation.

As emphasis was put on building investment costs, there were no adequate codes for energy use before 1986. This resulted in poor building envelopes and consistently high energy use for space heating.

Adamson (1986) made computer simulation studies of a residential building in the climate of Beijing, and found a typical annual heating requirement of 96 kWh/m^2 during the heating period, November–March. Recommendations for an optimal passive design included high interior thermal storage capacity, low ventilation rates (except during summer nights), large, double-glazed, south-facing windows without shading, and a well-insulated building envelope. These recommendations would shorten the heating period by two months and reduce the annual heating to 21 W/m^2, a saving of 78%. A *moderate* decrease of ventilation rate and increase of wall insulation, together with a second window pane, would save 50%.

Most of the population, about 75%, living in the northern towns and small cities still get their winter heating through stoves with very low heating efficiency, about 15–25%. In big cities the most common heating system (84%) is scattered boiler stations, of which 90% have a capacity lower than 50,000 m^2. Almost all these boilers work seasonally and intermittently, with very low efficiency and load, about 40%.

In recent years, with the fast economic development, the government has put more emphasis on environment, energy saving and improvement of residential conditions. For the cold regions of China, the Ministry of Construction introduced a two-step strategy in 1986 for energy conservation in buildings, the *Energy Conservation Design Standard for Heating in New Residential Buildings*.

The first step (enforced in 1993–1996) aimed to save 30% energy compared to a typical "base building" designed in 1981. All new heated and air conditioned public buildings had to be designed according to this energy-saving standard, requiring a minimum insulation of the envelope. However, this code was not fully applied in northern China.

The second step (1996–2000), decreed in 1995, for new heated and air conditioned residential and public buildings raised the energy saving target to 50%, where improvements to the envelope account for about 30% and the heating system for another 20%.

The 30% saving through building design should be achieved mainly by north-south orientation, no main rooms towards the prevailing winter wind direction, a shape coefficient (envelope to space volume ratio) preferably below 0.30, and staircases with windows and thermal insulation in colder regions.

Figure 13
Apartment building from the 1980s. Single-glazed unsealed windows with steel frames.

Table 7
Overall heat transfer coefficient (U-value, W/m²K) of building envelopes in China and some developed countries (reflecting the situation around the mid 1990s).

States			*Roof*	*Exterior Wall*	*Window*
China	Beijing	First code (1986)	0.91	1.28	6.40
		Second Code (1995)	0.80, 0.60	1.16, 0.82	4.00
	Harbin	First code (1986)	0.64	0.73	3.26
		Second code (1995)	0.50, 0.30	0.52, 0.40	2.50
Sweden	Old code	Southern (incl. Stockholm)	0.20	0.30	2.00
Canada		Degree-days of heating period equals to Beijing	0.23 (flammable) 0.40 (unflammable)	0.38	2.86
		Degree-days of heating period equals to Harbin	0.17 (flammable) 0.31 (unflammable)	0.27	2.22
Denmark			0.20	0.30 (<100kg/m³) 0.35 (>100kg/m³)	2.90
U.K.			0.25	0.45	3.30
Japan	Tokyo		0.66	0.87	6.51
Germany			0.22	0.50	1.50

To allow 20% energy conservation in the heating system, housing areas should use electric heating plants and district boiler stations as the main source, and surplus heat from factories if available. New large urban residential districts should build concentrated boiler stations of minimum 7.0 MW, serving at least 100,000 m², and designed as around-the-clock hot-water heating systems.

A target of the second step standard was that the cost of improving envelope insulation and window/door air-tightness should not exceed 10% of the whole investment, and have a pay-back period of less than 10 years.

The total energy saving in buildings from 1993 to 2000 was estimated to 41 million TCE, and after 2000 more than 10 million TCE *annually.*

Table 7 compares overall heat transfer coefficients of building envelopes between China and some other countries around the mid 1990s.

Table 8 shows the significant parameters for the heating period in Beijing.

Current energy conservation design code for Beijing

In 2004 a new Design Standard for Energy Efficiency of Residential Buildings (DBJ 01-602-2004) was enforced for Beijing. It targets an energy saving of 65% compared to the 1980 standard.

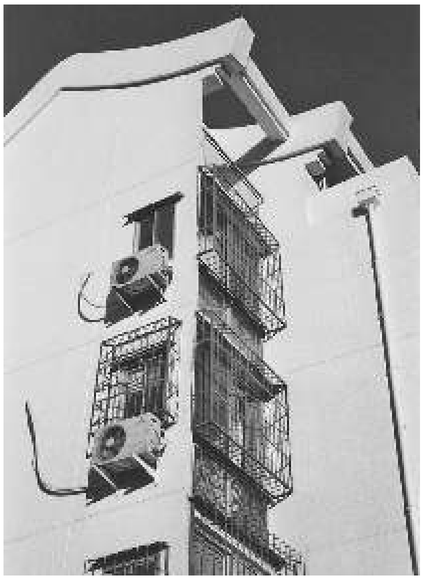
Table 8
Outdoor average temperatures and heating degree days (HDD) in Beijing for indoor base temperatures 12–20°C. Summary for the heating period (November to March). Based on Zhang and Huang 2004.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Σ*
T_{ave}	*–4.6*	*–2.2*	*4.5*	*13.1*	*19.8*	*24*	*25.8*	*24.4*	*19.4*	*12.4*	*4.1*	*–2.7*	*HDD*
HDD_{20}	763	622	481	207	6				18	236	477	704	3,045
HDD_{18}	701	566	419	147						174	417	642	2,743
HDD_{16}	639	510	357	87						112	357	580	2,441
HDD_{14}	577	454	295	27						50	297	518	2,139

For bedrooms and living rooms the design temperature for heating is 18°C, maintaining a maximum ventilation of 0.5 ACH. For cooling, correspondingly 29°C and 1.0 ACH should be used. For natural ventilation, a rate of 10 ACH is assumed.

The average energy load for heating, taking boiler efficiency and distribution network losses into account, should not exceed 32 W/m² floor area for medium and high rise buildings.

Figure 14
New multi-storey building in Beijing. Comfort and safety are high priority.



Simple Energy Calculation

The heating energy need of the apartment of the Case Study is here estimated by a simple, steady state calculation according to:

$$Q_{total} = DH \times (\sum UA + 1206v) - Q_{int.heat} - Q_{sol.gain}$$

(See Eq 3)

The number of Heating Degree Days based on 18°C indoors (HDD_{18}) is 2,743 (Table 8), which makes (× 24 h) 65,832 HDH.

The external surfaces of the apartment are: 36.3 m² wall with U = 0.54 W/m²K, i e UA = 19.6 W/K; 6.9 m² window with U = 2.0 W/m²K, giving UA = 13.8 W/K. Thus total ΣUA = 33.4 W/K.

With an area of 66 m² and a room height of 3 m, the total apartment volume is 198 m³. Ventilation is set to 0.5 ACH in the 'tight' model (see Table 14), i e 198 × 0.5 / 3,600 = 0.028 m³/s.

The internal heat load, described in Table 13, adds up to 7,400 Wh/day. During the heating period (151 days) this gives 1,117,400 Wh.

If the solar gain is *not* taken into consideration, the yearly need for heating would be:

$$Q_{total} = 65{,}832 \times (33.4 + 1206 \times 0.028) - 1{,}117{,}400 - 0 = 3{,}264{,}839 \text{ Wh or } 49 \text{ kWh/m}^2.$$

The alternative ventilation rates of 1 and 2 ACH gives 83 and 149 kWh/m² respectively.

Comparing with the simulation results in Figure 33, the latter are slightly lower which difference could be explained by the solar gain not taken into account in this calculation.

According to the new regulation the following criteria must be met:

- The index of heat loss from a building should not exceed 14.65 W/m², and is calculated as follows:

$$Q_H = Q_{HT} + Q_{vent} - Q_{IHL} \qquad \text{Eq 4}$$

Q_{HT} is the conductive heat transfer loss (W/m²), and should be calculated as:

$$Q_{HT} = \frac{\Delta t}{A_{floor}} \sum_{i=1}^{n} \varepsilon_i \, U_i \, A_i \qquad \text{Eq 5}$$

Δt is the outdoor-indoor temperature difference. For Beijing the mean outdoor temperature during a heating season of 125 days is –1.6°C and the base indoor temperature for calculation of heat loss index is 16°C, giving Δt = 17.6°C.

A_{floor} is the building's floor area (m²).

For each building element (i = 1…n):

ε_i is a correction factor, see Table 9,

U_i is the element's average heat transfer coefficient (W/m²K),

A_i is the element's area (m²).

Q_{vent} are the ventilation losses. These are set to 1.92 V_o/A_{floor} when staircases have no space heating, else to 2.08 V_o/A_{floor}. V_o is the building's volume (m³).

Q_{IHL} is the gain from internal heat load from people and appliances, and is set to 3.8 W/m².

- The shape coefficient of the building (envelope to space volume) should not exceed:
  - 0.30 for high-rise dwellings,
  - 0.35 for multi-storey dwellings,
  - 0.45 for low-rise dwellings.
- Limitations of the heat transfer coefficient, U (W/m²K), are shown in Table 10.
- Maximum allowed window to wall area ratio is shown in Table 11.

Table 9
Values of the ε_i correction factor depending on the element's orientation.

		South	East/ West	North	Horizontal
External walls and doors		0.70	0.86	0.92	
Double-glazed windows	with balcony	0.50	0.74	0.86	
	without balcony	0.18	0.57	0.76	
Roof					0.91

Table 11
Maximum allowed window to wall area ratio.

Orientation	Maximum window to wall area ratio
South	0.50
South-East	0.35
Other directions	0.30

New energy efficiency management

Beginning in 2006, a new state Provision regulates 30 terms relevant to energy efficiency. Key issues are renewable energy use, promotion of energy efficient technology and products, building retrofit solutions, and real estate development. New focus areas are operation and maintenance, and energy efficient urban planning. These goals should be achieved through improved management and supervision, multi-level implementation plans, energy auditing, quality control, metering and pricing reforms, approval and penalty systems, and capacity building and R&D.

A Renewable Energy Law was also acted in 2006. The law aims to promote the use of hydro, solar, wind and biomass energy through favourable pricing, loans, taxes, and grid priority. It includes support for research and pilot projects, implementation in remote areas, and development of local manufacturing and marketing. The aim is that renewable energy should reach 30% of the national power capacity in 2030.

Table 10
Maximum allowed U-values (W/m²K).

Dwelling type	Roof	External wall with exterior insulation	External wall with interior insulation	External glazing	Balcony door lower panel	Externally exposed ground floor	Upper floor of unheated space
5-storey or above	0.6	0.6	0.3	2.8	1.7	0.5	0.55
4-storey or below	0.45	0.45	N/A	2.8	1.7	0.5	0.55

5 Case study

This case study illustrates a typical example of modern housing in China. Though many high-rise buildings are constructed in the largest cities and there are even some attempts to build single-family houses for upper middle-class people, the medium-rise, multi-storey apartment buildings still represent the bulk of new urban housing in China.

After a general description of the housing area, apartment types and building technique and service, the energy use of one typical apartment is analysed and design options for improvement are discussed.

Figure 15
Exterior environment, Xin Kang, Beijing.

Description of the area

The *Xin Kang* residential district is located in the northern suburbs of Beijing. It includes about 270,000 m^2 living area and 20,000 m^2 service area, much of it under construction at the time of the field visit in the end of 1998.

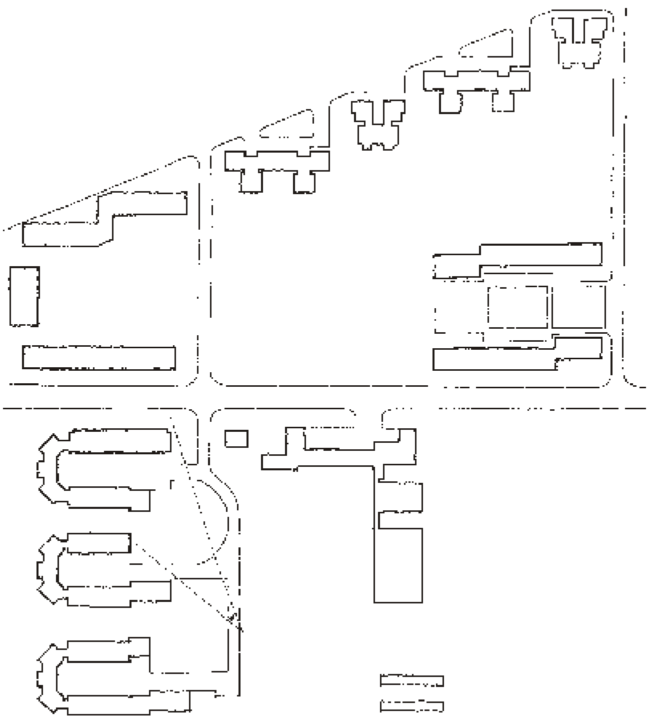


Fig. 16
Area plan, Xin Kang. The photo spot of Figure 15 is indicated.

About 60,000 m^2 flat area is in multi-storey buildings, 4–5 storeys high; the rest is in high-rise buildings.

The target group is lower middle income people, and apartment prices are around 3,000 RMB[5] per square meter.

Apartment types
The apartments are open-space type, where the inhabitants arrange partition walls and details themselves. Sizes vary from 66 m^2 to over 200 m^2, with an average of 81 m^2.

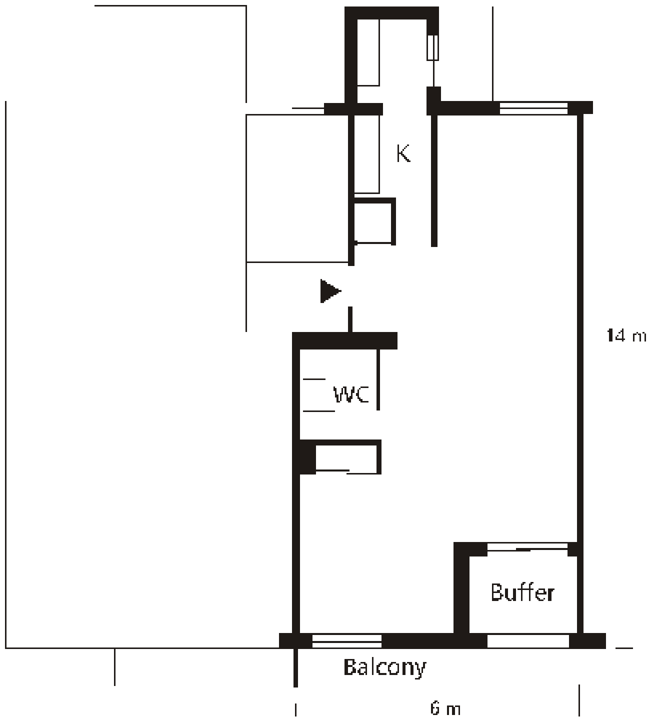


Figure 17
An open-space apartment in Xin Kang. Smallest size 66 m^2 intended for division into livingroom and 2–3 bedrooms.

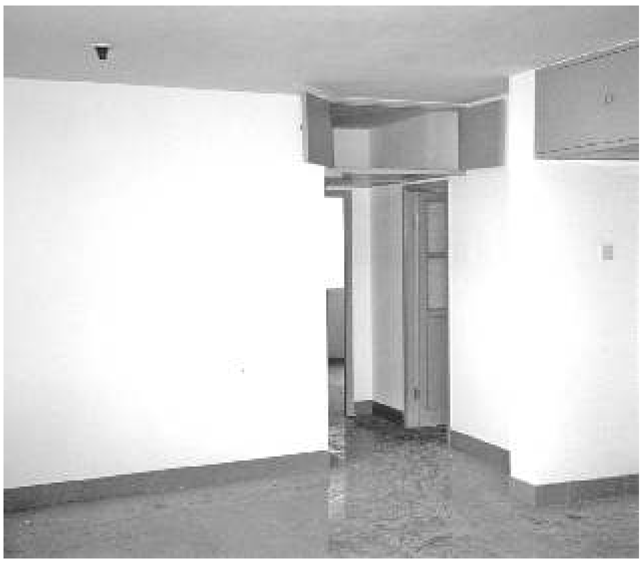


Figure 18
Open-space apartment.

5 About US$360.

Figure 19
Buffer space.

Figure 20
Glazed balcony.

Figure 21
Kitchen.

Figure 22
Bathroom.

Figure 23
Air exhaust fan in the bathroom.

Building technique
The buildings in Xin Kang comply with the latest energy saving regulations. This means that external envelopes (also towards staircases) include a thermal insulation layer and that windows are double-glazed and with improved air-tightness (sliding plastic frames).

Table 12
Building elements, Xin Kang, Beijing.

Building element Layers outside → inside	*Dimension (d) mm*	*Conductivity[1] (λ) W/mK*	*Thermal resistance[2] (R) m^2K/W*	*Thermal transmittance[3] (U-value) W/m^2K*
External walls				*0.54*
Polystyrene/cement blocks	60	0.05	1.20	
Hollow clay bricks	240	0.50	0.48	
External Roofs				*0.69*
Polystyrene/cement blocks	60	0.05	1.20	
Prefab. concrete panels	140	1.70	0.08	
Intermediate slabs and walls				*4.0*
In-situ cast concrete	140	1.70	0.08	
Ground slabs				*0.43*
Ground			1.50	
Polystyrene/cement blocks	30	0.05	0.60	
In-situ cast concrete	80	1.70	0.05	
Windows				*2.0*
Double-glazed, plastic frame				

1 Estimated 2 d/λ 3 Including film layers 0.17 m^2K/W.

Figure 24
External wall insulation of cement-bound polystyrene blocks, used in part of Xin Kang, Beijing.

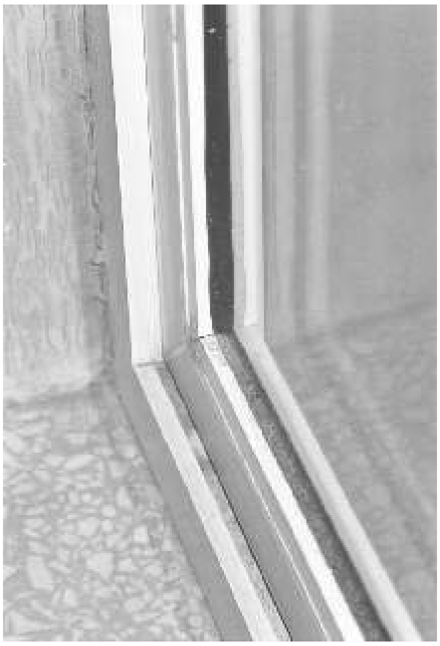


Figure 25
Double-glazed window in plastic frame with sealing.

Services

All heating in Xin Kang is by natural gas. Some apartments have individual gas boilers, but most is by central heating from a district boiler. No cooling is supplied, but could be arranged by electric air-conditioners, though electricity is dimensioned only to 40 W/m^2 according to planning index. All heat, gas and electricity are individually metered.

Figure 26
Gas-powered central heating station in Xin Kang, Beijing.

Figure 27
Heating meters.

Figure 28
Gas meter.

Figure 29
Floor heating and radiator – two systems applied in Xin Kang, Beijing.

Figure 30
Individual gas boilers are installed in some apartments in Xin Kang.

Climatic analysis

The apartment in Figure 17 has been analysed with the thermal simulation program *Derob-LTH* (Kvist, 2003). The baseline model is shown in Figures 31 and Figure 32. The apartment is oriented North–South and has adjacent apartments all around, representing an apartment in the middle of a building.

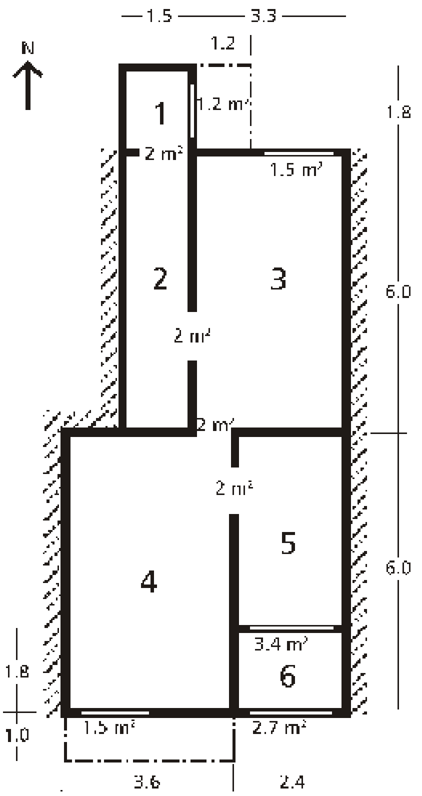


Figure 31
Plan model of the 66 m² standard apartment in Figure 17 with kitchen (vol 1 and part of 2), entrance (part of vol 2), living room (vol 3,) two bedrooms (vol 4–5) and sun space (vol 6). Window areas are indicated, as well as internal openings. The baseline case is oriented with the kitchen towards north and with adjacent apartments above, below and on both sides.

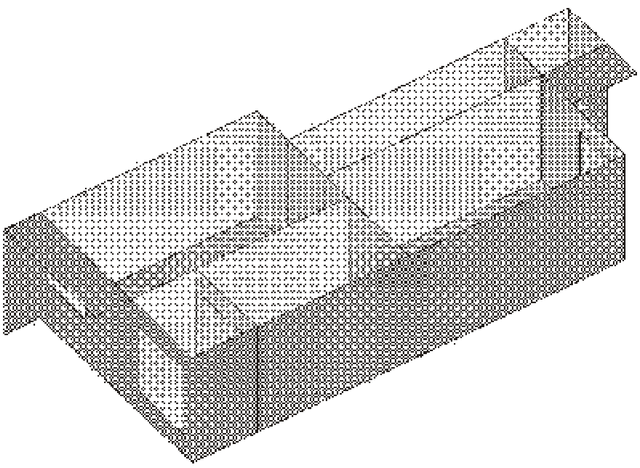


Figure 32
3D simulation model of the apartment.

Material and construction data is taken from Table 10. Surface absorptivity is set to 70% for external surfaces and floors, and 30% for other internal surfaces.

Occupation pattern and resulting internal heat load of five persons is estimated according to Table 13.

Table 13
Internal heat loads from five occupants and appliances.

Volume	Hours*	Load (Wh/h)	Comment
1	07–08	100	Making breakfast
	18–19	200	Making supper
2	18–19	100	Arrival after work, etc.
3	18–21	500	Living room occupation incl TV
	22–08	100	One person sleeping (grandparent?)
4	22–08	200	Two persons sleeping (parents)
5	20–08	100	One person sleeping (child)
6		0	No significant occupation

** 07–08 means 07:00–08:00, i e one hour load.*

It is not possible to predict the minimum ventilation rate occurring in the baseline apartment. Firstly, infiltration differs over time depending on changing wind speed and direction, resulting in pressure differences between facades. Secondly, the user behaviour (opening/closing windows) strongly affects the air changes. All cases have been simulated with three different ventilation rates assumed when the building is closed. These rates should roughly correspond to untight (2 ACH[6]), rather tight (1 ACH) and very tight (0.5 ACH) windows. Rates lower than 0.2 ACH are not recommended for health reasons, but 0.5 ACH was set here as the lower realistic limit. When the windows are open, a rate of 10 ACH is assumed.

Simulations were run for a full year, based on a thermal reference year generated by the software Meteonorm. Set-point for heating was 18°C and for cooling 27°C. There were no maximum limits defined for heating or cooling power, which means that the equipment will generate as much as is instantly needed. The energy use presented in the results below is the *output* energy, which might differ from energy input needed depending on the equipment's coefficient of performance (COP).

Table 14
Ventilation rates in Air Changes per Hour (ACH). 'Open' means 10 ACH and 'closed' means 0.5, 1 or 2 ACH depending on case, see results.

Volume	Hours	Ventilation (ACH)	Comment
Winter, Sep 1 – May 31			
1–6	00–24	Closed	Heated at 18°C
Summer, Jun 1 – Aug 31			
1–2, 6	18–08	Open	
	08–18	Closed	
3–4	22–09	Open	
	09–22	Closed	Air-conditioned at 27°C
5	20–09	Open	
	09-20	Closed	Air-conditioned at 27°C

6 ACH = Air Changes per Hour, i e how many times the room's total air mass is exchanged every hour.

Results

Energy use

The yearly heating and cooling demand for the baseline case – the existing apartment in the middle of the building – is shown in Figure 33 for the three different minimum ventilation rates. We see clearly that cooling energy is negligible. The main issue for energy saving in Beijing climate is thus concentrating on reducing the heating demand.

The potential for energy saving by reducing ventilation is striking. The tightest apartment has an energy use of about 30% of the untight one.

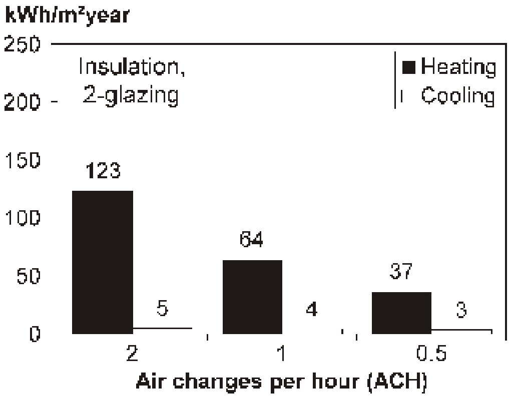


Figure 33
Yearly heating and cooling demand per square metre for an insulated apartment (middle of building) with double glazing. This case represents the baseline, existing building.

If we compare with older building types from the 1970s and 1980s, we see that the positive influence of the insulation materials in the outer walls is also evident. Removing the insulation layer from the actual apartment, leaving only 24 mm brick walls (increasing the U-value from 0,54 to 1,5 W/m^2K), we see in Figure 34 that the saving by insulation is 16% in the untight, 25% in the medium, and 37% in the tight apartment. The effect of insulation is thus greater if ventilation is kept low. Combining reduced ventilation and insulation can give as much as 74% energy saving.

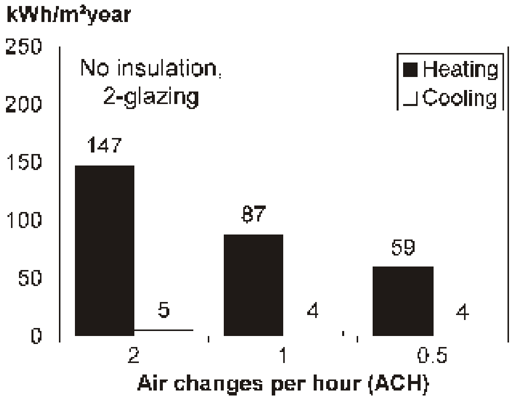


Figure 34
Yearly heating and cooling demand per square metre for a non-insulated apartment (middle of building) with double glazing.

The saving effect of double, compared to single glazing is, for the insulated case, between 13% in the untight, and 31% in the tight apartment, see Figure 35. For the uninsulated building the corresponding saving is only 11–22%, see Figure 36.

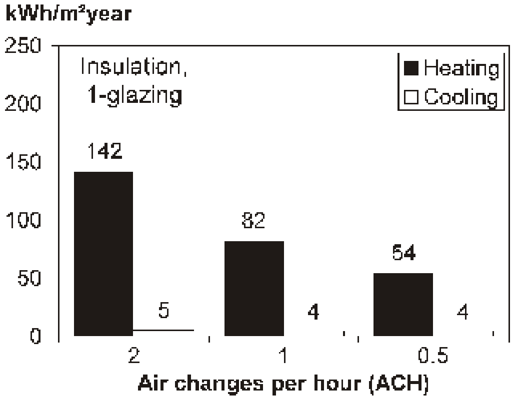


Figure 35
Yearly heating and cooling demand per square metre for an insulated apartment (middle of building) with single glazing.

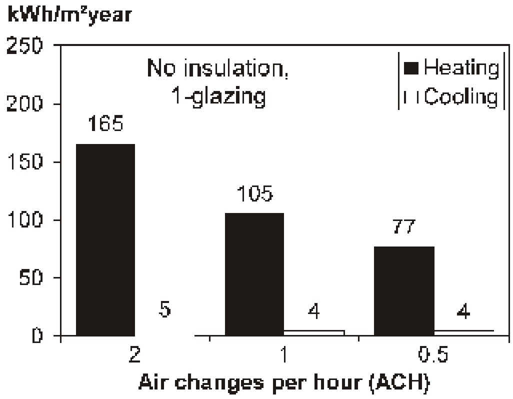


Figure 36
Yearly heating and cooling demand per square metre for a non-insulated apartment (middle of building) with single glazing. This is a typical building from the 1970–80s.

All cases above have displayed three cases of ventilation rates; high, medium and low. From these cases it can be concluded that reducing the ventilation to ½–¼ generally saves 30–70% energy. We can also see that the existing flat in Xin Kang (Figure 33), assuming that the ventilation is kept at a minimum, uses only 23% as much energy as an older non-insulated, single-glazed, untight apartment from the 1980s (Figure 36).

One way of further reducing the heating need is to increase solar gains. In Figure 37 the size of the south facing windows are doubled. Only the low-ventilation apartment is calculated. Its heating need is slightly reduced compared to the baseline case, but the cooling need increases, making the total energy need equal to the baseline case. However, the cooling need could probably be eliminated by either opening windows, thus increasing the ventilation, when overheating occurs or apply moveable or accurately dimensioned shading devices. Coated glasses also reduce the cooling need, but would give an adverse effect in winter.

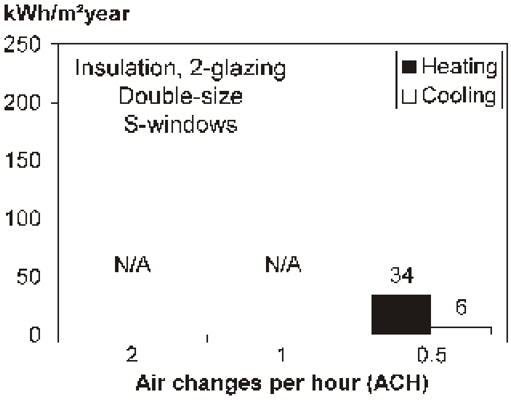


Figure 37
Yearly heating and cooling demand per square metre for an insulated apartment (middle of building) with double glazing and double-sized south windows.

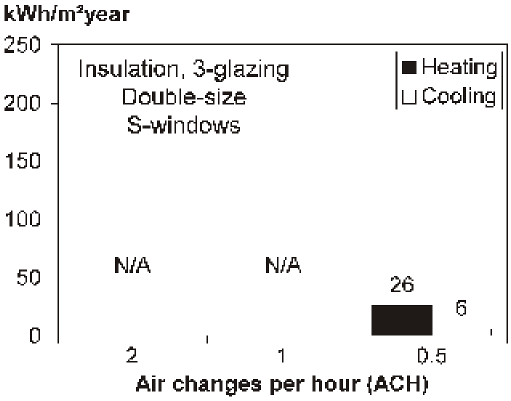


Figure 38
Yearly heating and cooling demand per square metre for an insulated apartment (middle of building) with triple glazing and

In Figure 38 all external windows have been provided with triple-glazing, giving a reduction in heating need of 24% compared to the case with large, double-glazed windows above.

Special attention should be paid to top-floor and top-corner apartments, requiring additional insulation in their comparatively larger envelopes. Figure 39 shows that the baseline apartment placed in the top-corner position increases its heating demand from 37 to 138 kWh/m^{2}year – almost four times. A top-corner uninsulated, single-glazed

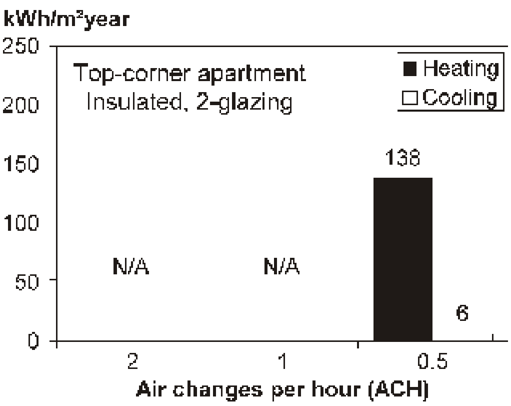


Figure 39
Yearly heating and cooling demand per square metre for an insulated apartment (top corner of building) with double glazing. Except for its top-corner placement this case is equal to the baseline, Figure 33.

apartment consumes 364 kWh/m^{2}year or almost five times a corresponding middle apartment. All these cases have the minimum ventilation.

The cases above are only some, but important, parameters. The influence of internal heat storage capacity, other orientations, forms of apartment, room height, etc, are also possible to study through computer modelling.

Passive climatisation

What would be the resulting indoor temperatures if no energy at all was used for heating and cooling? Figure 40 shows absolute maximum, minimum and average indoor temperatures in the uninsulated, single-glazed apartment with high minimum ventilation rate. Comparing with the insulated, double-glazed, low-ventilated apartment in Figure 41, the latter have higher minimum and average temperatures, while the maximum temperatures are still the same.

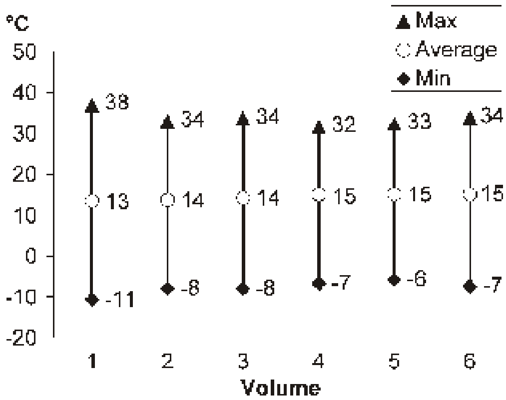


Figure 40
Uninsulated, single-glazed apartment with high minimum ventilation rate. Maximum, average and minimum temperatures over a year in the six volumes.

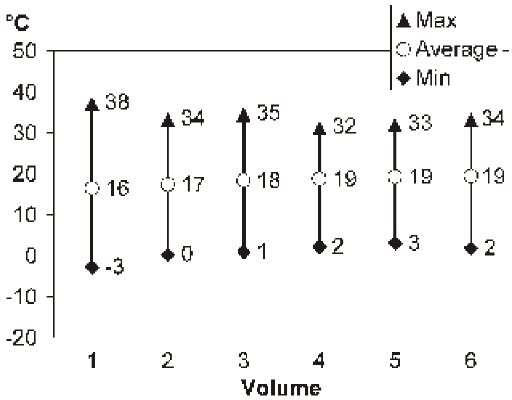


Figure 41
Insulated, double-glazed apartment with low minimum ventilation rate. Maximum, average and minimum temperatures over a year in the six volumes.

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