

The impact of updated building design standards on the thermal environment and energy performance of Dwellings in China

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Abstract: Energy demand reduction has become a global issue involving all countries, including China. As major energy consumers in today's society, the need for buildings to be built and operated more energy efficiently is well recognized. In 1995, the national standard on building energy efficiency in China (JGJ 26-95) was refined and updated to become the new residential Buildings standard (JGJ 26-2010) published in 2010. In the new version, many changes have been made to support the construction of more energy efficient buildings in China. For example, in the new standard, all buildings are highly recommended to install personal control on the heating system, such as by Thermostatic Radiator Valves (TRVs), together with 'pay for what you use' tariffs. Previous practice comprised uncontrolled heating with payment based on floor area.

This paper evaluates the impact of updated building design standards on thermal conditions and energy consumption in Chinese residential buildings. In the study, two types of residential buildings have been chosen, one complying with the old Chinese building design standard, while the other complies with the new standard. The study was carried out in seven apartments in each building, with a longitudinal monitoring of indoor air temperature, outdoor air temperature, window position and energy consumption. The impact of the new design standard has been evaluated in relation to a number of aspects, that include building construction, indoor thermal environment, occupant behaviour, thermal comfort and building energy consumption. It is concluded that updating the building design standard has had a positive influence on the building conditions and energy consumption.

Key words: Energy efficiency, building design standard, China, residential buildings

1 Introduction

There is an increasing awareness on the importance of reducing carbon emissions all over the world. China is the second largest country in both energy production and consumption. In the past 20 years, building energy consumption in China has an increasing rate of more than 10% every year (Siwei & Yu, 1993; GB50178-93, 1993; Lang, 2004). According to the official statistics from the Chinese Ministry of Construction, 45% of occupants living in urban areas have been provided with winter space heating. Meanwhile, with the rapid population increase, this will influence China's energy consumption greatly, as nearly 60% of the population is expected to live in urban areas by 2030 (GB50178-93, 1993; Jiang & Hu, 2006).

In 1996, the Chinese government firstly announced an energy conservation design standard JGJ26-95 for new heating residential buildings. This standard focuses on energy efficient measures in order to reduce the energy consumption of residential buildings in China. Since 1996 the development of new residential buildings with central heating systems has started to be guided by the new developed standard. In China, the

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most common heating system in old residential buildings is central heating systems without private control. In the 1996 design standard, the heating control systems have been encouraged to be used for new residential buildings. Generally, China can be separated into five climatic zones (GB50176-93, 1993), namely severe cold, cold, hot summer and cold winter, hot summer and warm winter and moderate as shown in Fig 1. In 2010, the standard was revised and the new version of Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones has a mandatory requirement on the heating system (JGJ26-2010, 2010) namely that it should be installed with household-based heat meters and Thermostatic Radiator Valves (TRVs) for each radiator. In traditional central heating systems, which are operated by constant water flow rate and variable water temperature, there are no heating control systems so occupants can only open their windows to adjust indoor thermal conditions (Xu, et al., 2009). Additionally, the new design standard defines a higher requirement on the thermal insulation of building facades, comparing to the old one.

This paper present the measured impact of different building design standards on the thermal and energy performance of buildings, through a comparison of various aspects (building construction, indoor thermal environment, occupant behaviour, thermal comfort and building energy consumption) of two types of residential buildings developed under different standards.

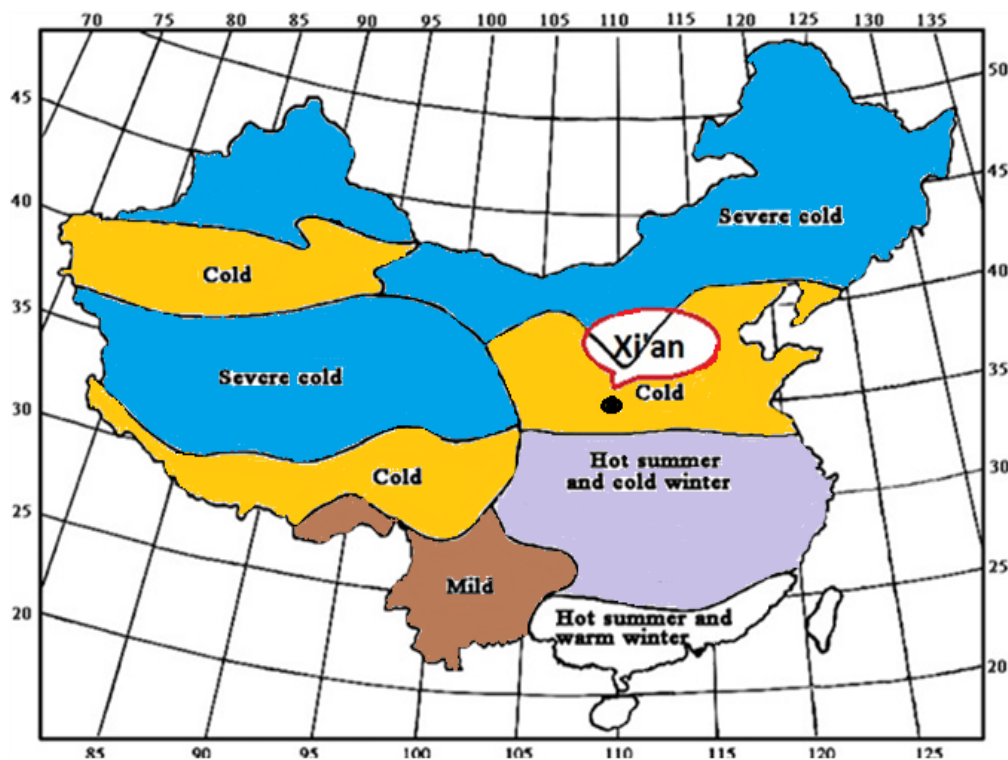


Fig.1 Five climatic zones of China

2 Methodology

2.1 Building description

In this study, two residential buildings with various heating systems were selected: one building was installed with metered and controlled heating systems and the other was not. The investigated buildings are located in

the City of Xi'an in the Shaanxi Province of China, which has a typical cold and dry climate in winter. The two types of buildings are both multi-story residential blocks. The new residential building (Fig 2a) was built after 2011 and the old building (Fig 2b) was built late 1990s. Table 1 lists important definitions of building construction for both old and new buildings.



Fig. 2 (a) The typical investigated old building;

(b) the typical investigated new building

Table.1 The construction and general information of old and new residential buildings

	Old Building	New Building
External Wall	240mm Solid Bricks, Plastering mortar	240mm Cavity Bricks, EPS insulation, Plastering mortar
Window	Single-glazing, Aluminium	Double-glazing, Aluminium
Internal floor/ceiling	Concrete, Roof Bricks, Chalk	Concrete, Roof Bricks, Asphalt
Heating System	Central heating system	Central heating system
Heating Control	No personal control	Personal control by TRVs
Heating payment method	One payment based on Floor Areas	Pay as you go

The old building is heated by a central heating system with constant water flow. The water temperature is controlled by the district heating substation according to the changes of outdoor temperature. Inside the building, there is no direct control from the occupants to the heating system and they can only open the windows or doors to adjust their thermal environment. The new building is heated by a district heating system and it is installed with TRVs on each radiator, so the room temperature can be adjusted within a range based on the requirement of the building occupants.

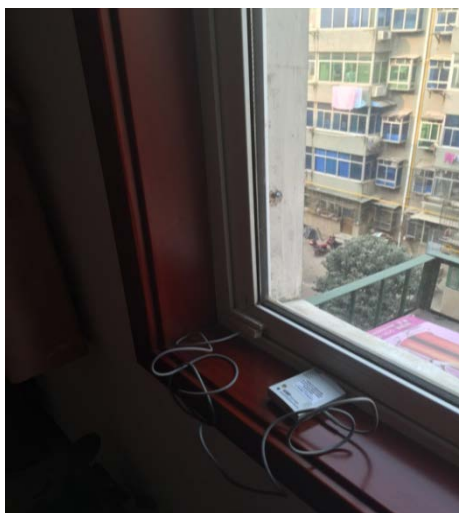
2.2. Data collection methods

In the study, seven apartments from each building were monitored longitudinally between 15 February and 14 March, 2014. The indoor temperature of each apartment was measured and recorded by a Hobo data Logger at an interval of 10 minutes (Fig.3 (a)), in both living room and main bedroom. The measurement location was chosen with a consideration of minimizing the influence of direct sunshine and local heat sources. The

window state was monitored every 0.5 second by a pair of window contactors and the change of window states (either from open to closed, or, from closed to open was instantly recorded by a Hobo U9-001 data logger, as shown in Fig.3 (b). The hydraulic flow rate for the heating system in the old building was monitored by a Portaflow 330 flow meter. Additionally, the water temperatures in both supply and return pipes were recorded at an interval of one hour. Based on the measured flow rate and water temperatures, the heat energy consumed by each apartment in old building was calculated. In each apartment in the new building, an energy meter is installed to measure the heating consumption, as shown in Fig. 3 (c).



(a) Temperature;



(b) Window state;



(c) Heating energy

Fig.3 Measurement devices

2.3. Occupants' survey

There are 14 monitored households from each building, one female and one male in each apartment. The subjective measurement was aimed to collect their thermal sensation in their living space. In the study, each apartment had one male and one female participant, aged between 22 and 57 years. Before the survey, the details of the experiment were described to all participants. Meanwhile, a consent form was issued and how to fill out the thermal sensation questionnaire administered to real participant was explained. During the survey, the occupants were asked to sit in the living room for 45 minutes, and then were asked to report their thermal sensation at the end of the survey. Meanwhile, air temperature, mean radiant temperature, air speed and relative humidity were measured according to the ISO 7726 (ISO 7726, 2001). In order to make sure the participants can clearly understand each question, before the survey the questionnaire was translated into Chinese. The questionnaire includes questions about the participants' age, physical conditions, the culture background, education level, income level and normal lifestyle of each participant, with a further collection of their thermal sensation, thermal preference, clothing insulation and activity level. In this study the insulation of the chair is assumed to be 0.35clo as all participants were sitting on a fabric sofa during the survey.

In order to assess occupants' heating behaviour in the new building, a further questionnaire was distributed to each household, asking them to self-record their heating behaviour (i.e. adjustment of the TRV settings) over a whole week period.

3 Results and discussion

This section compares several characteristics between the old and new buildings, including building insulation level, indoor thermal environment, occupants' window behaviour, energy consumption and occupants' thermal sensation, in order to evaluate the impact of different building design standards on the building performance.

3.1. Comparison of building insulation levels

Table.2 compares the insulation level for both old and new buildings, based on the thermal transmittance (U-value) from design standards. It shows that the old building offers much better insulation than the new building, except the internal floors.

Table.2 The insulation level of living room and main bedroom in each building

	U-Value in Old Building(W/m ² °C)	U-Value in New Building(W/m ² °C)
External Wall	1.69	0.7
Window	5.8	3.7
Floor	2.48	2.28

3.2. Comparison of building indoor thermal environment

According to the monitoring, the variations of indoor air temperature for living room and bedroom in both types of building are shown in Table 3. The mean outdoor air temperature is 8.9°C, the maximum and minimum temperatures are 27.7°C and -1.9°C respectively during the investigation. Table.3 shows that the mean indoor temperature of living room in all old apartments is 22.5°C and the indoor air temperature in new one is 20.7°C which is respectively 1.8°C lower than the value measured in old apartments. Meanwhile the mean indoor air temperature is 21.5°C in main bedroom of old traditional building and 19.6°C in new buildings which is respectively 1.9°C lower than that in old one.

Table.3 The mean indoor air temperature of living room and main bedroom in each building

Residential Building Types	Living Room	Main Bedroom
	Mean Temperature (°C)	Mean Temperature (°C)
Old building	22.6	21.8
New Building	20.8	19.7

Based on the measured data, the indoor air temperature for both the average living room and the bedroom in both buildings are compared in Table 3. From the comparison, it could be found that both the living room and the bedroom temperatures in the old building are higher than those in the new building, agreeing with previous field experiments study (Cao, et al., 2014) carried out the results of indoor air temperature of living room for old traditional central heating residential buildings in Beijing, they compared the two groups of residential buildings, one group of traditional central heating without any control and another one group of new individual boiler heating with control. They carried out the mean indoor air temperature of old buildings were 0.5-3.0°C higher than that of new one. This may reflect that in the new building, occupants prefer a lower indoor temperature to reduce building energy consumption, as indoor temperature has been popularly used to reflect occupants' indoor temperature settings in winter in existing studies (Wei, et al., 2014). What follows is a discussion on the potential reasons for the discrepancy in these results. As mentioned before, occupants can adjust the TRVs of heating in order to satisfy their needs for indoor environment in new residential buildings.

However in old traditional residential buildings, occupants do not have any control devices of heating, they only can open the window or door to adjust the indoor air temperature if the rooms were overheated. For this study, overall the mean indoor temperatures of both living and main bedroom in old are higher than that in new residential building, it reveal that the occupants' behaviour of adjusting TRVs in new one and it also can be seen from questionnaire of adjusting TRVs by occupants. It may be related to the different heating system and heat billing systems, hence the occupants can adjust the TRVs in radiators if the room is overheated or they prefer to use lower heating energy for cost of heat billing.

3.3. Occupants' Window behaviour

The investigations revealed that the occupants are absented from morning 9AM to 5PM regularly during the weekdays. Based on the window devices monitoring, the results showed that overall, the majority of occupants in both types of buildings used to open the window for ventilating during the morning time around 7AM to 9AM when they get up.

Occupants' window behaviour in winter has a dramatic influence on the heating energy consumption of buildings (Wei, et al., 2014). As previous study by Andersen et al. describes, the window opening behaviour has effect on energy consumption (Andersen, et al., 2009). Therefore, occupants' window behaviour in the two investigated buildings is compared in this section. In the study, the parameter used to reflect occupants' window behaviour is the proportion of time during the monitoring period when the window is open. The field measured data reflect that the windows in the old building were opened for 54% of the monitoring time, while they were opened only for 29% of the monitoring time in the new building. This means that occupants in the new building prefer to leave windows closed to reduce heat loss. From the one week self-recording of heating behaviour, it shows that occupants often adjust the TRV settings to adjust the indoor thermal environment.

3.4. Energy consumption

During the survey period, the energy consumption of all 14 apartments in both buildings have been monitored and compared in this section. The results show that the the new building consumed 1328.4 kWh heating energy during the survey period and that in the old building consumed 2427.3 kWh heating energy, leading to an energy saving of 45%.

3.5. Comparisons of occupants' thermal comfort

A main issue to consider when reducing building energy consumption is not to sacrifice indoor thermal comfort. Therefore, in this study, occupants' thermal comfort in both buildings was examined as well, and the results are shown in Figure 4. It reflects that in new buildings, more occupants felt thermally comfortable, comparing to those in old buildings: 14 occupants in new buildings expressed thermal sensation within ± 0.5 , which is the official thermal comfort range defined in ISO 7730 (BS EN ISO 7730, 2005), while in old buildings the number is 14. Therefore, this suggests that although the new building consumed less energy for heating the building in winter, the occupants were more satisfied with their indoor thermal environment than the old building.

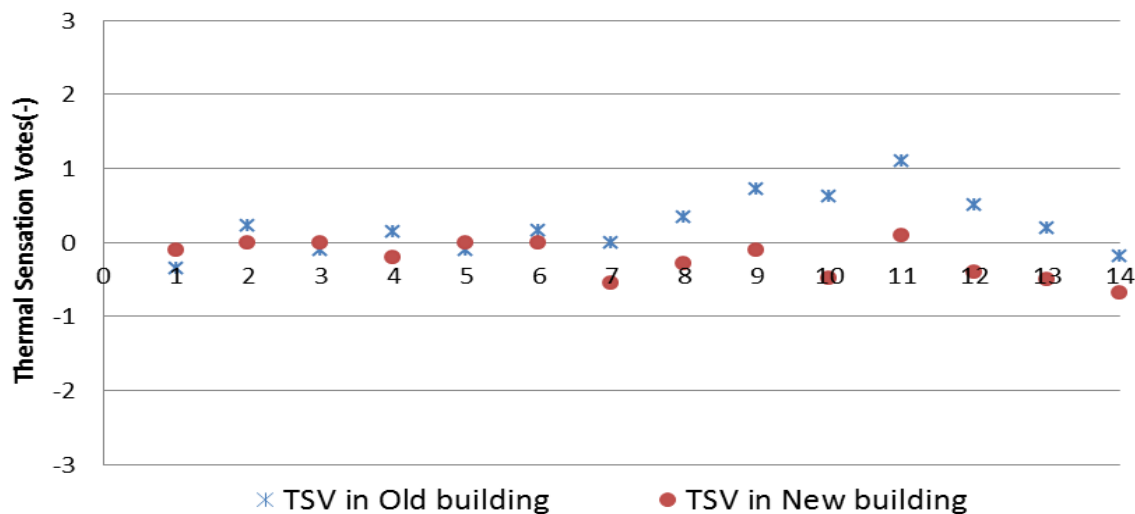


Fig.4 The experimental data of AMV in New and Old apartments

4 Conclusions

In this work, the impact of updated building design standards on thermal conditions and energy consumption in Chinese residential buildings was evaluated. The study was carried out in a new building with personal control on the heating system installed i.e. TRVs, together with 'pay for what you use' tariffs; and in an old building with uncontrolled heating with only one payment based on floor area. There are four main findings associated with this field study:

Firstly from the foregoing, it was observed that the obvious differences between new and old buildings. Occupants in old building only can open the window when they feel uncomfortable, and they only pay once for whole heating period time. However, occupants in new apartments can adjust TRVs to achieve satisfactory indoor environment and they prefer a lower indoor temperature to reduce building energy consumption.

Secondly the investigation showed that the clear differences of occupants' behaviour in new and old apartments and the frequencies of window opened by occupants in old apartments were higher than that in new ones.

Thirdly, research in energy consumption of newer apartments complying with new standard installed new control and heat meter billing systems can lead to 45% energy saving compared with old ones.

Finally, generally occupants in old apartments give higher acceptable evaluation compared to occupants in new apartments. Furthermore more than half occupants prefer to have cooler in old apartments.

Reference

- Andersen, R. V., Toftum, J., Andersen, K. K. & Olesen, B. W., 2009. Survey of occupant behaviour and control of indoor environment in Danish dwellings. *Energy and Buildings*, Issue 41, p. 11–16.
- BS EN ISO 7730, B. S., 2005. *Ergonomics of The Thermal Environments: Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria (ISO 7730)*, British: The European Standard EN ISO 7730:2005 Has Status Of British Standard.

- Cao, B., Zhu, X. Y., Li, M. & Qin, Y. Q., 2014. Individual and district heating: A comparison of residential heating modes with analysis of adaptive thermal comfort. *Energy and Buildings*, Issue 78, pp. 17-24.
- GB 50178-93, P. R. o. C. I., 1993. *Standard of Climatic Regionalization for Architecture(in Chinsese)*. Beijing: GB 50178-93.
- GB50176-93, 1993. *Ministry of Housing and Urban-Rural Development of the Peole's Republic of China, Thermal Design Code for Civil Buidlings, (in Chinese)*, Beijing: China Architecture&Building Press.
- ISO 7726, B. S., 2001. *Ergonomics of The Thermal Environments:Instruments for measuring physcial quantites*, British: The European Standard EN ISO 7726:2001 Has Status Of a British Standard.
- JGJ26-2010, 2010. *Design Standard for Energy Efficiency of Residential Buildings in Sever Cold and Cold Zones*, Beijing: Ministry of Housing and Urban-Rural Development of People's Republic of China; (in Chinese).
- JGJ26-95, 1996. *Energy conservation design standard for new heating residential buildings (in Chinese)*, Beijing, China: Publish House of Building.
- Jiang, K. & Hu, X., 2006. Energy demand and emissions in 2030 in China: scenarios and policy options. *Environmental ecocomics and policy studies*, Issue 7(3), pp. 232-50.
- Lang, S., 2004. Progress in Energy Efficiency Standards for Residential Buildings in China. *Energy&Buildings*, 36(no.12), pp. 1191-1196.
- Lang, S. & Huang, Y. J., 1993. Energy conservation standard for space heating in Chinese urban residential building. *Energy Vol.*, No. 8(18), pp. 871-892.
- Wei, S., Jones, R. & Wilde, P. d., 2014. Driving factors for occupant-controlled space heating in residential buildings. *Energy and Buildings*, Issue 70, pp. 36-44.
- Wei, S., Wang, X., Jones, R. & de Wilde, P., 2014. '*Using building performance simulation to save residential space heating energy: A pilot testing*'. Cumberland Lodge, Windsor, UK ., Windsor Conference.
- Xu, B. P., Fu, L. & Di, H., 2009. Field investigation on consumer behaviour and hydraulic performance of a district heating system in Tianjin. *Building and Environment*, Volume 44, pp. 249-259.