中国北西部における住宅のエネルギー利用効率向上に関する研究

翟, 亮亮
九州大学大学院人間環境学府空間システム専攻博士後期課程

赤司, 泰義
九州大学大学院人間環境学研究院都市・建築学部門

住吉, 大輔
九州大学大学院人間環境学研究院都市・建築学部門

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中国北西部における住宅のエネルギー利用効率向上に関する研究

A Study on Energy Efficiency Housing Technologies in North-Western China

翟　亮亮*，赤司泰義**，住吉大輔**
Liangliang ZHAI*, Yasunori AKASHI** and Daisuke SUMIYOSHI**

As the biggest developing country, China is undergoing a dramatic increase of energy consumption and greenhouse gas emission that comes with the rapid progress of urbanization. In order to pursue a sustainable development and as an answer to the climate change, the Chinese government has devoted great effort by developing and revising building design standards, setting specific scenario plan for energy conservation, and strengthening legal measures to guaranteeing the execution of these policies. The aim of this paper is to justify the effects of the new policies on energy conservation and CO_2 emission reduction. This paper introduces a demonstration project as an example of building technology improvement and innovation which fulfills the requirements of the new design standards. The effect of energy saving in this project has been proved. However, further studies are necessary to understand the broader effects of new technologies and policies on larger scales of development of society and on growing cities.

Keywords: *Energy efficiency, house technologies, greenhouse gas emission, policies, design standards*
エネルギー効率，　住宅技術，　温室効果ガス，　政策，　設計基準

1 Introduction

1.1 Background: Increasing rate of urbanization rate and corresponding energy consumption

Urbanization is undergoing rapid growth in the whole world, including China. According to the UN-HABITAT's prediction, two thirds of the world's population will live in urban area in 2050.

As reported by the National Bureau of Statistics of China, the urbanization rate in China was 19.8% in 1980, and increased to 51.27% in 2011. It is the first time that the number of urban residents exceeds the number of rural residents in Chinese history. In 10 years the percentage will possibly increase to between 55% and 60%.

Urbanization is an important index that shows the development level of the society, however, the process is so fast that many problems occur, such as a dramatic increase of construction areas, more and more intense heat island effect, and a growing demand of energy and resources, etc.

As the development of the economy increases, the energy consumption of the whole country is inevitably increasing as well. Architectural energy consumption takes a big part in this process. In the life cycle of buildings, energy consumption is divided into:

- 20%: Production of building material
- 60%: Use and maintenance
- 20%: dismantling and waste treatment

In the use and maintenance phase, about 25.5% of the total commercial energy of the whole society is consumed.

1.2 The Chinese government's enthusiastic promotion of energy-saving policies

Since one of the most severe problems of the fast urbanization is the radical increase of energy consumption, the government has devoted great efforts in policies and trade standards to reduce energy consumption.

Firstly, the government established laws and ordinances since 1998 to reassure the status of building energy conservation. The main contents of these publications are listed in Table 1.

Secondly, under the Central Government, the Ministry of Housing and Urban-Rural Development (MOHURD) is taking charge of the field of construction activity, which has been developing and revising design standards since 1986. A whole system of energy efficiency for different types of buildings has been built up since then. The main content of this development is shown in Table 2.

Specifically the energy consumption of buildings built

*Department of Architecture, Doctoral Courses
空間システム専攻，博士後期課程
**Department of Architecture and Urban Design
都市・建築学部門

under the general residential design standards (or representative residential buildings) during 1980~1981 was set as a baseline. For new constructions, energy consumption in the use-phase should be less than the baseline by a certain percentage. The higher the percentage is, the more energy the new buildings will save. According to Table 2, the required reduction percentage has been raised from 30% to 50% in the standard issued in 2005.

Besides, in order to supervise the application of these standards and institutions, the Ministry of Housing and Urban-Rural Development has issued development plans every five years for building energy conservation since 1980s, called Five-Year-Plan, what is constantly and orderly adjusting the design standards for energy efficiency, and helped with promoting technology improvement. In the latest Five-Year-Plan, the 12th Five-Year-Plan, the required reduction percentage has been raised to 65% starting from 2010. This Five-Year-Plan emphasizes these aspects:

- Energy-efficient reconstruction for existing buildings in north China;
- Renewable energy technologies;
- Building energy efficiency technologies in rural areas.

Table 1 The Initiation and Development of Legislation Regulation

Year	Law and Ordinance	Main Contents and Purposes
1998	Energy Conservation Law	In the fourth chapter the status and content of building energy conservation is clarified as one of the three major aspects of energy conservation.
2008	Building Energy Conservation Ordinance	The building energy issue has been raised separately in this ordinance. Since then one special scenario plan for building energy conservation has been conveyed every year.
2009	China's policies and actions to address climate change	This ordinance suggests the long term target that by 2020 greenhouse gas emission should be reduced to 40%~45% from the emission level of 2005.
2011	Scenario of controlling of greenhouse gas emission in the 12th Five-Year-Plan	This plan targets the following reductions until 2015: -The reduction of green house gas emission by 17% (of the emission in 2010). -The reduction of energy consumption of the whole society by 16% per unit of GDP (1 unit of GDP is 10 thousand Yuan RMB). -Non-fossil energy consumption should reach 11.4% of the primary energy consumption.

Table 2 Design Standards of Building Energy Efficiency Issued by MOHURD

Year	Name	Main content	category
1986	JGJ 24-86 Thermal design code for civil building	The first design standard that covers the content of energy conservation design. Measures include: control area of windows; enhance air tightness; reduce coefficient of heat transfer; avoid open aisles and stairs in north region; etc.	Trade standard
1986	JGJ 26-86 Energy conservation design standard for new heating residential buildings	If take the energy consumption of buildings designed under common standards in 1980 as a baseline, the new constructed residential buildings should save 30% of energy of the baseline.	Trade standard
1987	GBJ 19-87 Design code of heating, ventilation and air conditioning system	First comprehensive design standard for energy saving of heating and cooling systems of buildings.	National standard
1995	JGJ 26-95 Revised version of "Energy conservation design standard for new heating residential buildings(1986)"	Based on the aim that new constructed residential building should save 50% of energy from the baseline of local common design in 1980. (30% by building efficiency and 20% by heating system efficiency)	Trade standard
2005	GB50189-2005 Design standard for energy efficiency of public buildings	After the standard system for residential buildings is completed, the requirements for newly constructed public buildings has been raised in this version of standard; 50% of the energy should be saved, compared with the baseline of local common designs in 1980.	National standard

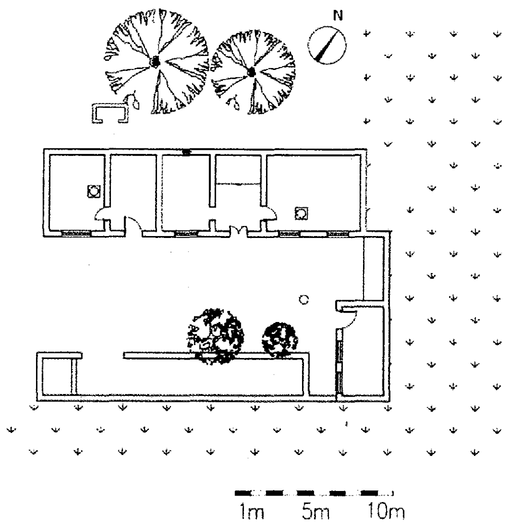
* MOHURD: Ministry of Housing and Urban-Rural Development of the People's Republic of China

1.3 Objective of the study

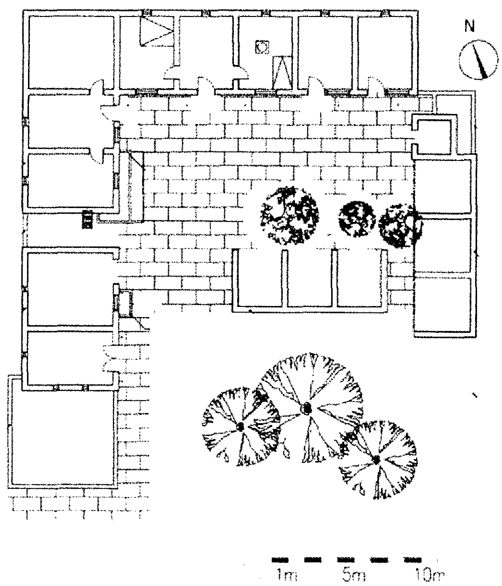
As we have discussed above, the legislation system, the technology and the policies of building energy conservation are constantly updated in China in order to catch up with the pace of development of the society. Different types of regulations require more and more percentages of energy reduction in new constructions and existing buildings. The baseline is the energy consumption of buildings built under common design standards in 1980s.

Before the 1980s, the concerns of design standards were more about function and cost but unfortunately not much about the environment or indoor comfort. For instance, there was no requirement for insulation of the envelope in the northern area of China, so that the mass of buildings were built with only 240mm thick brick walls. These buildings consume a huge amount of heating energy in winter, while the indoor comfort is poor. There is a considerable potential of energy conservation from this baseline.

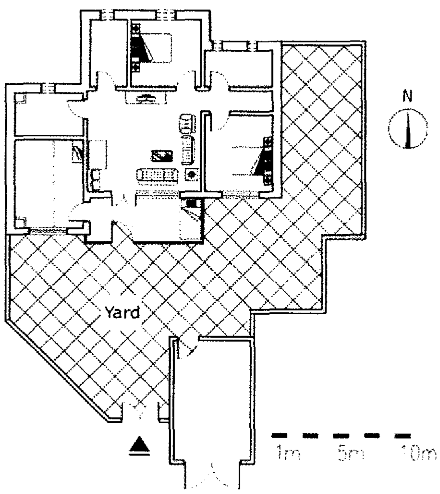
The basic purpose of this paper is to clarify the effects of policies concerning energy conservation; furthermore, to compare the effects of the new design standards with the earlier versions. One example is introduced in this research. It is a demonstration project funded by the National Key Technology R&D Program in the 11th Five-Year-Plan of China, "Developing the Renewable Energy Utilization Technologies for Rural Housings in Ningxia". In the local region, existing houses were built under earlier versions of design standards. But in this project, new constructions were built under the new design standards. In addition, several features that combined traditional and new technology for conserving energy were applied in the construction. In order to measure the effects of these new technologies based on the new design standards and policies, questionnaires and physical environment tests were carried out.



a. Traditional House



b. Modern House



c. New House

Fig. 1 Typical Master Plans of the Three Types of Houses

2 Outline of the local situation

2.1 Climate condition in the local area

Ningxia Hui Autonomous Region is located in the inner continent of North-east China. With a typical cold and dry desert climate, both daily and annual ranges of temperature are huge. The solar radiation is intensive. The temperature is moderate in summer and very cold in winter. The village of this project, Zhang village, is about 9 km away from the capital city of Ningxia, Yinchuan City, which is located in the center of Yinchuan plateau. In this climate, it is not difficult to achieve indoor comfort in summer if the ventilation condition is satisfying. However in transition seasons and winter, heating is needed to keep warm.

2.2 Situation of local houses

Zhang village is an agricultural village with 574 households. The existing households in Zhang village can be categorized into two types according to the time and construction style, namely traditional houses and modern houses. Examples of building plans of these two types are represented by plan a. and b. in Fig. 1.

Traditional houses include two houses built more than sixty years ago and two houses built within forty years which used local vernacular materials and followed the traditional construction. Houses in the Ningxia Hui region share certain characteristics. First, the envelopes of the houses are made from thick rammed earth. The master plan shows a square shape in a closed form to hold against the strong wind in winter. The structure consists of wooden column frames and flat roof tops. The Kang, a traditional horizontal radiation heating system widely used in large regions of China, is built in the bedrooms. During daytime in winter, stoves are used for heating and cooking and the fuel is usually firewood or straw.

With these characteristics they can resist the severe climate to a certain distant and provide residents a safe living shelter; nevertheless many problems exist so it cannot fulfill the demands of modern life.

The modern houses were the majority in the village; most of which were built within the last twenty years. Usually they were planned by house owners themselves, and built with industrial materials and modern construction.

2.3 The features of the new houses

In the project, a residential block of 86 new houses was planed and around 20 houses were built in the first stage of the project. These houses were designed according to the features of the local climate. Furthermore they inherited and developed the merits of traditional houses, and took full consideration of the demands of their residents as well, in order to show the local people a more sustainable way of construction.

The major features of the newly designed houses shall be listed below:

Table 3 Heat Transfer Coefficient in Design Standards and Houses

	Version / Type	Heat transfer coefficient of envelope(W/(m²·K))
Design standards	JGJ 24-86	1.70
	JGJ 26-86	1.28
	JGJ 26-95	1.16~0.82
Demonstration project	Traditional house	1.42
	Modern house	1.51(north), 2.11(other directions)
	New house	1.05(south), 0.38(other directions)

1) The new design standard requires the heat transfer coefficient of external walls to be smaller than 1.16 W/(m²·K). In the new houses, compound materials are used on the north, east and west sides' wall. The material is composed with 250mm thick grass bricks and 240mm thick airbricks. The grass bricks are compressed straw bricks. The materials are all from the local region, so that transportation expenses are low. The grass bricks can also help to reduce heating energy consumption. A comparison of the thermal performance of the building envelopes is shown in Table 3. New houses have the best insulation among the three types of buildings, which surpass the requirement of the new design standards as well.

2) It is encouraged to use solar energy in proper form in regions with rich solar resources. In the region where Zhang village locates, the annual solar radiation is 5711 to 6096 MJ/ (m² · a), and the annual hours of sunshine are above 3000 hours. There are plenty of solar energy resources in this region to be used in architectures. In the new houses, a glass sunroom is attached on the south side of the house. In winter, heating energy can be reduced by using the supplement heat gained from the sunroom. The top of the sunroom is a slope so that more heat can be collected to heat the air inside.

3) According to the new policies, effective vernacular building technologies are recommended to be conserved and improved in new constructions. As a traditional heating facility, the Kang[*1)] is kept as bed especially for aged people and children in the new houses. As an improvement the position of the Kang's stove was

Table 4 Comparison of Construction among Three Types of Houses

Envelop construction	Traditional House	Modern House	New House
External wall	Rammed earth, 400mm	Brick, 240mm; Or with 370mm brick wall on the north side.	North, east and west sides: Compound wall with grass brick 250mm and airbrick 240mm,490mm South: airbrick, 370mm
Internal wall	Rammed earth, 400mm	Brick, 240mm	airbrick, 240mm
Ceiling	Wooden frame flat rooftop covered with reed mat, straw, and 200mm straw earth	Wooden frame covered by straw earth; or reinforced concrete board covered by straw earth.	Reinforced concrete board covered by straw earth and tiles.
Floor	Pebble, 200mm deep as foundation, paved with clay brick tiles.	Cement covered by floor tiles.	Reinforced concrete board paved with floor tiles.
Windows	Wooden frame with single-layer window. 1300mm×1500mm in the south wall, and 500mm×600mm in the north wall.	Wooden frame ingle-layer window; or aluminum slide window.	Vinyl frame with double-layer window. 2100mm×1700mm in the south wall.
Door	Wooden double swing door. A cotton blanket is hanged on the door as curtain to keep warmth in winter. A bamboo curtain is hanged to shade solar radiation and keep insects out in summer.	Wooden door; or iron door	Vinyl frame with wood door wrapped with steel cover.
Others	Kang directly connected with cooking stove.	Kang directly connected with cooking stove.	Kang separated with cooking stove. Sunroom with aluminum frame and double –layer glass.

Table 5 Subjective evaluation of indoor thermal comfort of three types of houses

	Winter			
	Air Temperature	**Relative Humidity**	**Air Tightness**	**Indoor Air Quality**
Traditional House	Comfortable in Kang-room; Cool in other rooms.	Comfortable.	Poor. Strong cold air infiltration, from doors, windows, and their frames.	Poor. Suffer from cooking fuel dust.
Modern House	Comfortable in Kang-room; Cold in other rooms.	A little bit humid.	Fairly poor. Cold air infiltration from door and window frames.	Fairly good.
New House	Warm in Kang-room, living room, bedroom; cool in storage room and kitchen.	A little bit dry in Kang-room; comfortable in other rooms.	Very good. No feeling of air infiltration.	Very good.
	Summer			
	Air Temperature	**Relative Humidity**	**Ventilation**	**Indoor Air Quality**
Traditional House	Cool.	Comfortable.	Good cross ventilation.	Poor when cooking.
Modern House	Hot in all rooms.	Humid.	Natural ventilation in rooms with openings; poor ventilation in others.	Fairly good.
New House	Hot in sun-room; warm in living room; comfortable in other rooms.	Comfortable.	Good natural ventilation.	Very good.

changed. In the traditional houses, a Kang itself is both a bed and a stove. People fill the Kang's stove with firewood through a small opening directly at the bottom of the Kang, and light the firewood just inside of the Kang-bedroom. The smoke pollutes the indoor air and causes breathing problems sometimes. In the new houses the stove of a Kang was moved into the kitchen. Only the warm air flows in pipes through the Kang for heating the Kang-bedroom.

Besides, several other features are applied according to the new design standards and policies. Rammed earth was widely used in traditional houses as wall material. In new houses, this ecological material is used as insulation of the rooftop. To improve the thermal performance and air tightness of openings, the frames of windows and doors were changed to vinyl in the new houses. Biogas ponds are built at the back of courtyards, which help digesting planting waste. The biogas is used as fuel for the kitchen stove.

2.4 Comparison of new houses with local existing houses- the traditional houses and the modern houses

In order to clarify the improvement of the new houses, we did a field survey concerning master plans, constructions, clothing of residents, and subjective comfort feelings of three types of houses in the village. Interviews and questionnaires were carried out to gather information. A comparison of certain aspects including the plan, the construction and the indoor environment was done.

(1) Master plan and construction

In the traditional house, the living space is often mixed up with working space. In the new plan, functional spaces are separated according to different household structures and their individual needs. Courtyard spaces are planned for the need of farming tools and device storage. In this way a better organization is achieved. See plan c. in Fig. 1.

One typical sign of traditional houses is the use of vernacular materials, which are cheaper due to reduced transportation costs. However these materials are considered to be symbols of poverty for local people.

In new houses, however, vernacular construction techniques were improved and adopted to make newly built houses more environment-friendly. These improvements are listed in Table 4.

(2) Subjective thermal comfort

Concerning the insulation level, the new houses show the highest level of insulation, followed by the traditional houses and the modern houses. How do the residents feel about the indoor environment of their houses throughout the year? In order to answer this question, we carried out questionnaires about the "subjective thermal comfort feeling" of 46 households in one team[*2)] of Zhang village. These questionnaires covered all three types of houses: 4 traditional houses, 20 new houses, and 22 modern houses. In the questionnaires, people were asked about what clothes they wear at home, their living schedule and the operation schedule of their heating systems, their feeling of thermal comfort. The most frequently answered results are summarized in Table 5.

As shown in the results, new houses have the most comfortable environment while modern houses have the lowest level of indoor comfort.

3 Indoor physical environment tests

In the second stage of field survey, in order to clarify the thermal performance of traditional houses and new houses, indoor physical environment tests were conducted. The aim of the tests is to study the difference between both types and justify whether the new house has better thermal environment.

3.1 basic situation of both tested houses

(1) The traditional house

It was a 114.24 m^2 and 2.8m high rammed earth building built 60 years ago. The house faced south-south west. The ratio of window to wall on the south direction was 0.12. There was a small high window on the north wall but no openings were found on east or west walls. The doors were wooden and windows were wooden framed with a single layer of glass.

The inhabitants of the traditional house were a 6-person-family, including one aged couple, one young couple and two children. It was a house of five rooms in one line with a front yard to keep cattle and store farming tools. In the five rooms, from the left side, the first room was the bedroom of the young couple, heated by a stove; the second room was their sitting room. The third room was a storage room without heating; the forth room was a Kang bed-room of the old couple which was used as bedroom in winter, heated by the Kang. The one room at the right end was a mixed functional room, which was used as a bedroom in summer; and as a living room,

Fig.2 Test object 1 – the traditional house

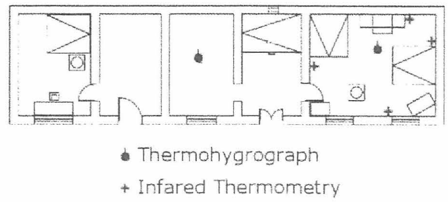


Fig.3 Test setting in the traditional house

Fig. 4 Test object 2 – the new house

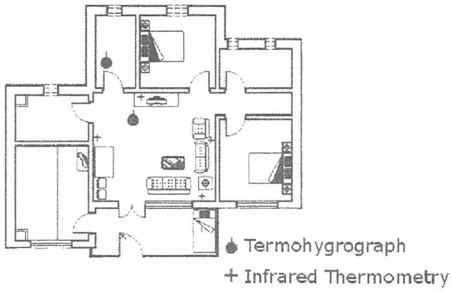


Fig.5 Test setting in the new house

kitchen, and study room for children. The room is even used as a laundry room in winter when it is too cold to wash in the court yard. This room has a stove for both heating and cooking. In the test, we chose the living room as a heating room and the storage room as a non-heating room in the traditional house to set thermo hygrographs, as showed in Fig. 2and Fig. 3.

In winter, the owner starts to fill the Kang with firewood at 21:00 for overnight heating and, adds new firewood at 8:00 to keep the room warm until noon. They start the stove at 10:00 and 18:00 temporarily for cooking.

(2) The new house

The family living in the new house was an aged couple. They moved in the house since March 2007. It was a south-faced 124.8 ㎡ compound-enveloped house. The ratio of window to wall on the south direction was 0.27. Small high windows for daylight were installed on the north wall. There are no windows on the other walls.

In this building, each room is attached to the heating system. The heat is supplied by a stove in the kitchen. The heating system operates for 14 hours every day in heating season, from morning till evening. During night a Kang is used for heating instead of the heating system.

For the test, the storage room in the north side was chosen as non-heating room, and the living room in the south side was chosen as heating room to set the thermal hygrograph, as showed in Fig.4 and Fig. 5.

3.2 Design of the tests

The tests were carried out in typical weather, sunny, no cloud in the sky and windy conditions. The testing period was from 8:00 on 11th to 8:00 on 12th, December, 2008. The test parameters are shown in Table 6.

Parameters of the tests included outdoor temperature, indoor temperature, inner wall surface temperature, and indoor air flow. The indoor air flow shows the indoor air quality. The other parameters show the comprehensive thermal environment. The combination of the test results and residents' subjective feeling, allow an objective and general analysis.

In the tests, the air temperature was measured in both of the heating and the non-heating rooms, every 10 minutes for a period of 24 hours continuously. The inner wall surface temperature was measured in the sitting rooms only, during day time, from 8:00 to 18:00. It was conducted every 30 minutes, manually.

Table 6 Thermal Environment Test Method

Testing items	Instrument	Instrument parameter	Operation & time step
Indoor/outdoor air temperature	175-H2 self-recording thermo hygrograph	OTR: -20.0~70.0 ℃; Precision: +/-3.0%	Automatic recording, 24h, every 10 min
Inner wall surface temperature	MT4 Infrared thermometry	Range:-18~260 ℃; Precision: +/-1%	Manual recording during daytime, every30 min
Indoor air flow	CASSLER IAQ thermal comfort equipment	Range: 0.06~2.50m/s; Precision: +/-0.05m/s	Automatic recording during daytime, every 10 min

3.3 Results of test

(1) Air temperature

According to Fig.6 and Fig. 7, the fluctuation of the outdoor air temperature was efficiently reduced in both new and traditional houses.

The diurnal range of the outdoor temperature was 12 K, while the highest temperature was only 5℃. On the contrary, the diurnal range of the indoor temperature was no more than 5 K.

Moreover, the thermal insulation of the new house is better than the traditional house. In the new house, the average room temperature is higher than 10℃ in all the rooms; while it was more than 5℃ in the traditional house.

(2) Wall surface temperature

Wall surface temperature was conducted in the living room. This room was only used during daytime in winter, so the test was also carried out during daytime. That's why there was no data during night. In the test we measured surface temperature of all of the 4 walls, ceilings and floors in the living rooms of both houses, and calculated the average temperature of each living room for a comparison. From Fig. 8 we can see that the diurnal range of inner surface temperature was only 2.5 K in new house and 3.4 K in the traditional house; both are way smaller than the outdoor air temperature. The average inner wall surface temperature in the traditional house was 12.59℃ while it was 14.66℃ in the new house. That explained why people feel stronger cold radiation inside of the traditional house than in the new house. It justified that both envelopes are good at insulation and retaining stable indoor thermal environment. Also, the new house has better thermal performance than the traditional house.

(3) Indoor air flow

The indoor air flow was tested in the middle of the living room, 1 meter high. Fig. 9 shows that the average indoor air flow was 0.042 in the traditional house and 0.032 in the new house. Since the windows and doors were used for

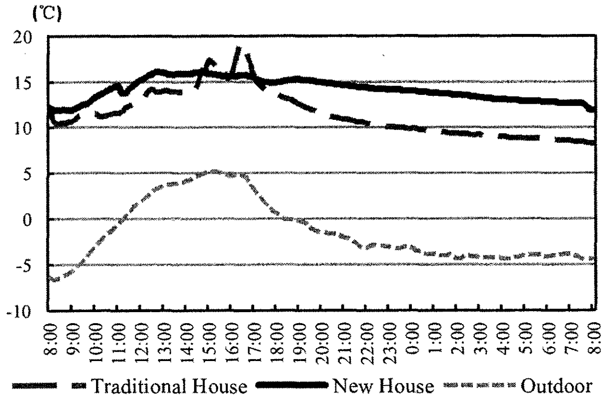


Fig.6 Air Temperature of Heating Rooms

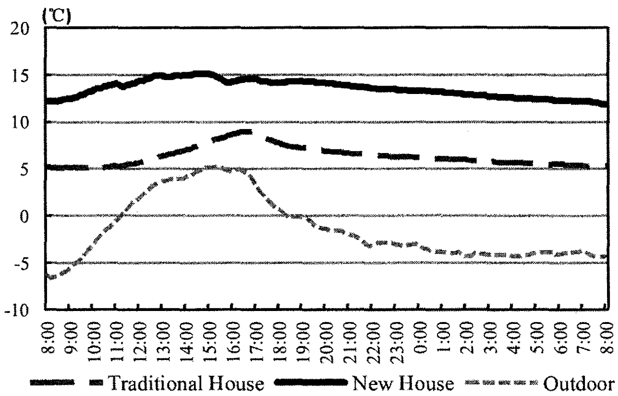


Fig.7 Air Temperature of Non-Heating Rooms

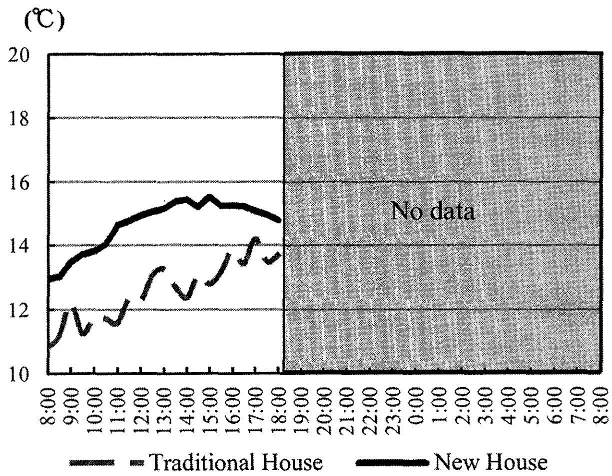


Fig. 8 Average Inner Surface Temperature of Living Rooms

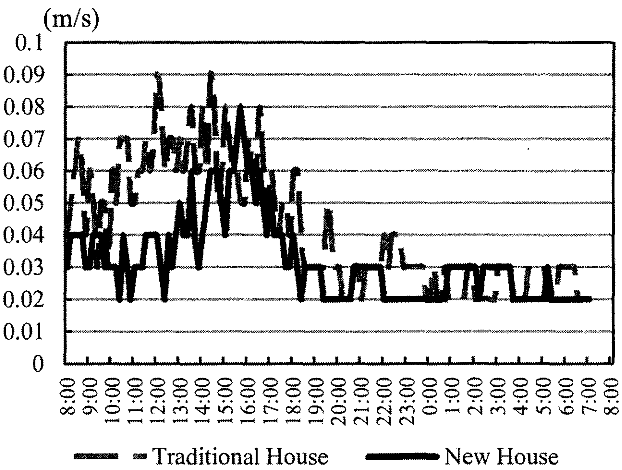


Fig. 9 Indoor Air Flow

more than 30 years already, the air flow in the traditional house was mainly caused by cold air infiltration. In contrast to that, air temperature in the new house was higher, so the air flow won't cause uncomfortable coldness.

4 Conclusions

This paper discussed the initiation and development of Chinese building energy regulation. There was no special regulation for energy conservation in the field of construction until 1980s. The requirements of earlier standards were not as strict as those of the latest standards. Therefore if compare with thermal performance, the modern houses built follow the earlier standards were even poorer than the local traditional houses. It was the purpose of this research to find out the effects of the new standards and policies. The new houses were designed to fulfill the requirements of the new standards. Through the tests of indoor physical environment, the indoor comfort is proved to be better in the new houses than in the traditional houses. The technologies applied in this project improved the quality of living environment for local people, compared with existing houses in the local region.

Concerning the future research, there are questions that are not answered. What kinds of technologies that are applied to new constructions are more effective? How to improve the design standards? What measurements deserve a subsidy from the nation? How is the effect of the new policies on the society as a whole? In order to answer these questions, new methods of evaluation and assessment are needed.

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Note:

*1) Kang is short for "Kang bed-stove", a traditional bed with a stove and pipes inside for heating. For further information: http://en.wikipedia.org/wiki/Kang_bed-stove

*2) In China, a village is usually consists with a sub-unit "production team", which is divided by the location.

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