ENERGY CONSUMPTION ANALYSIS OF AN ELEVATED TRADITIONAL CHINESE KANG

Zhi Zhuang Ph.D Candidate[1, 2]
Yuguo Li Ph.D[2]
Xudong Yang Ph.D[3]
Bin Chen Ph.D[4]

[1] Building Environment and New Energy Resource Laboratory, Dalian University of Technology, Dalian, Liaoning, China, zhgzhi@gmail.com
[2] Department of Mechanical Engineering, The University of Hong Kong, Hong Kong, China, liyg@hku.hk
[3] Department of Building Science, School of Architecture, Tsinghua University, Beijing, China, xyang@mail.tsinghua.edu.cn
[4] Building Environment and New Energy Resource Laboratory, Dalian University of Technology, Dalian, Liaoning, China, chenbin8911@yahoo.com

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Summary

Heating of rural houses now constitutes 25% of total building energy consumption in China. Hence, the transition and new technologies for rural home heating is considered as the top priority for managing future building energy consumption in China. Chinese kang, the most traditional and widely used heating and sleeping bed system, has been regarded as a potentially sustainable and energy-saving solution.

In this paper, we integrated a macroscopic heat transfer and airflow model of an elevated kang system into the existing Chinese building environmental system simulation and analysis software-DeST. The new integrated software can serve as a design and energy analysis tool for rural houses with the elevated kang heating. The basic methodologies and mathematical model for the elevated kang are presented and some preliminary results obtained from simulations of a typical house in northern China are also discussed.

1. Introduction

With the rapid economical development and urbanization in China, the living environment of people in rural areas has received increasing attention. Rural house heating (including biomass energy) constitutes now 25% of total building energy consumption in China. Hence, transition and new technologies for rural home heating is considered as the top priority for managing future building energy consumption in China.

The Chinese kang has been used for home heating for more than 2500 years (Men 2004). There are currently nearly 200 million people using this kind of heating system in northern China. Figure 1 illustrates a typical arrangement of an elevated kang heating system. It utilizes the residual heat of fume from the cooking stove, and uses the kang body to release heat to indoor environment. Kang plates, often made of materials with high thermal storage capacity, can store heat and maintain a heating period of several hours or more and also create local warm climate under the blanket for sleeping. Chinese kang has been regarded as a kind of potentially sustainable heating system, although its design has been mainly based on the experience of craftsmen. Investigations have shown the potential of energy-saving while providing a comfortable indoor thermal environment by the elevated kang, the latest design of kang (Chen et al. 2007). The performance of some of the buildings using these systems has been reported by, among others, Yang (1963), Deguchi and Sanda (2002). These reports, however, often lack the information about the likely effect of key parameters on the heating energy requirements of a building with such a system. For example, there appear to be no studies that identify clearly the contribution of the kang alone to the overall energy savings of the building. Thus, a thermal analysis tool for buildings with kang systems is needed for designing the kang in a house.

In this paper, the macroscopic thermal and airflow model of the elevated kang is developed at the first, and the approach of integrating the kang model with a building energy simulation software (DeST) is given. The thermal performance of the elevated kang and its effect on indoor environment in a typical house in northern China are investigated by applying the tool developed.

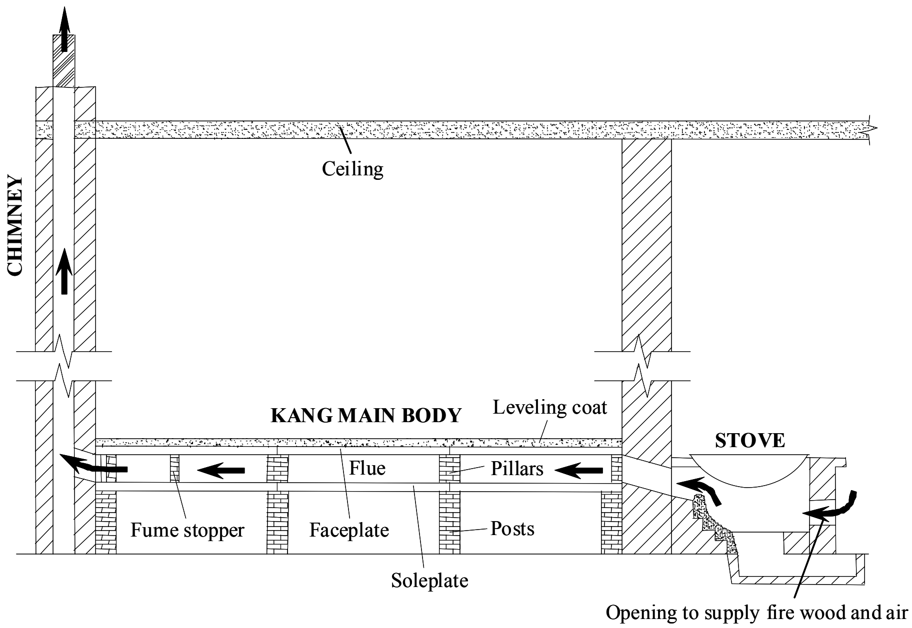


Figure 1 Schematic representation of a typical elevated kang system

2. Approach

A mathematical model for a house integrated with an elevated Chinese kang (HIEK) heating system has been developed for building energy simulation, which was validated using the test data (Zhuang, 2007). Because the heat transfer and airflow between smoke and kang plates is a coupling process, it is more adaptive to analyze the elevated kang using the macroscopic method. The entire elevated kang heating system is divided into three zones, Zone 1 (stove), Zone 2 (kang main body) and Zone 3 (chimney), as shown in Figure 2.

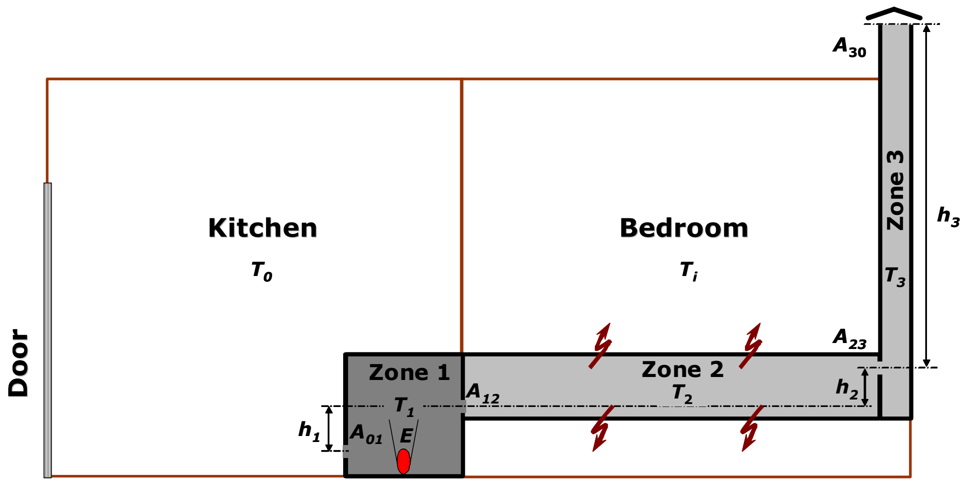


Figure 2 The general notation for the macroscopic model of elevated kang heating system

Considering the relatively small sizes of space in kang heating system, the uniform air temperature in each zone is assumed, which is often adopted in building thermal analysis. This approach enables relative, if not absolute, predictions of the effects on heating energy requirements to be made. The proposed program is mainly developed for researchers or experts. For building designers its use is, however, severely limited due to some shortcomings such as inconvenient input and output methods. If this model is integrated into available building simulation software, it can be used to investigate alternative operational strategies and to determine kang system performance for a range of climates. Due to the fully development of building energy simulation techniques over the past decades, several programs are widely used with mature techniques and friendly visual interface, like Designer's Simulation Toolkit-DeST (Tsinghua University DeST Group, 2006).

DeST is a simulation tool for building thermal performance & HVAC developed by Tsinghua University during 1990s, and now widely used in Chinese building industry. The approach taken in this project was hence to integrate the proposed kang model into the DeST software.

The core issues on integration are the input and output linkage between the kang model and the DeST software. The output parameters from DeST such as indoor air temperature, solar radiation and building envelope surface temperatures are used as inputs for the kang module. The heat release from a kang should be transferred to DeST likewise at each time step. Another item noticed is to deal with the inconsistent time step. In this project the outputs from DeST with the time step of 1hour are linearly interpolated into 60 parts and input the kang model with the time step of 1 minute. The integrated DeST-k can predict the indoor air temperature, heating load, heat release from kang plates, surface temperatures of kang plates, mass flow rate of kang system and so on.

3. Case setup and simulation details

The design for buildings with the elevated kang heating system is to achieve or check the two main aims: firstly people often lie on the kang plates to sleep, and the kang needs to be felt thermally comfortable. Thus the surface temperature of kang plates should be maintained within the range of 25-30^{o}C (Guo, 1998). The heat input pattern can be controlled to regulate the surface temperature, such as changing the heat source power, firing time and firing duration. Besides, the kang configurations like plate thickness and materials also affect the surface temperature. The second design aim is to efficiently utilize the heat input of kang to improve indoor thermal environment. That needs to improve the heat release and heat storage capability of kang and the thermal physical level of building itself such as enhancing insulation, decreasing building air infiltration, or installing auxiliary heating systems. The integrated DeST-k can serve as a useful tool for energy analysis of buildings with elevated kang heating systems to obtain the design aims described above.

A base case house with elevated kang heating was selected for case study, see Figure 3. Note that this building was representative of commonly found homes in rural area in northern China from surveys (Zheng, 2007). The total building area was 66m^2, and the heating area was 33m^2.There were two bedrooms with one living room between them. The living room was mainly used as kitchen and dining place. The elevated kangs were placed in each bedroom for heating. The parameters of one bedroom are listed in Table 1. The TMY data provided hourly climate data. Shenyang, the capital city of Liaoning province in Northeast China, was chosen as the base location. The elevated kang was 3.0 m long and 2.0m wide with often used concrete kang plates. The base plate thickness was 60mm. For heat transfer from the slab surface to the room, a combined linearized radiation and convection heat transfer coefficients were used. The convection coefficients were obtained from recent experimental results, and the heat power of smoke into the kang body was fixed at 35KW during firing time (Zhuang, 2008). There were three firing times during a day, at 6:00 am., 12:00 am. and 18:00 pm., lasting for 90 minutes respectively. It should be noted that heat release from the stove is not included in the following simulations.

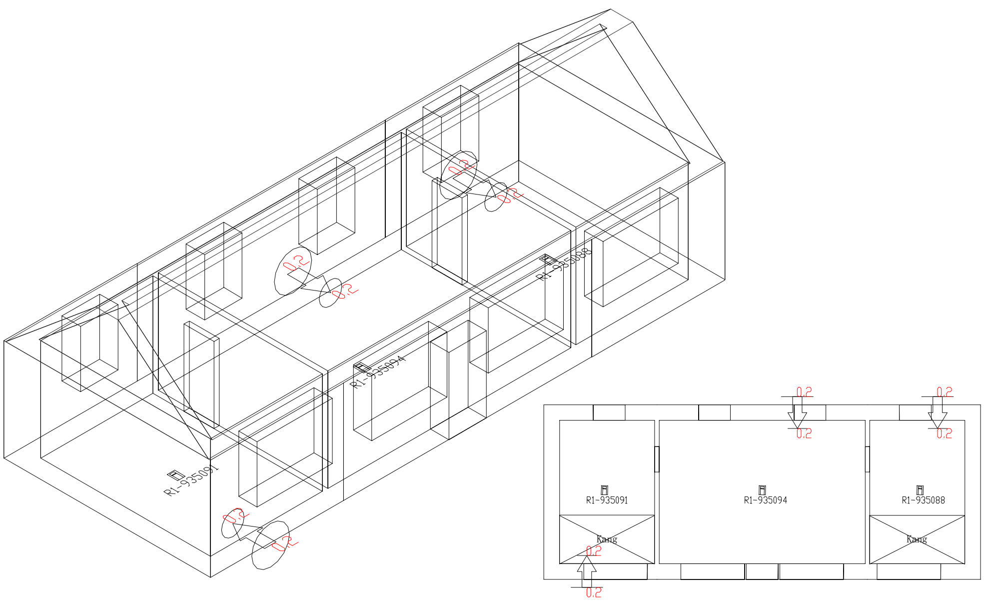


Figure 3 Layout of a typical rural house in northern China

Table 1 Materials, dimensions and assumptions used in the base room

Item	Description
Room size (L×W×H)	5.0 m×3.3m×2.7m
External wall construction	370mm clay brick with 20mm plaster layer
Internal wall construction	120mm clay brick with 10mm plaster layer either side
Roof construction	10mm tile, 160mm clay with 80mm straw
Ceiling construction	10mm plasterboard
Floor construction	50mm concrete with 100mm soil
South window construction	Single, 6 mm thick, plain, size: 2.0m×1.8m
North window construction	Single, 6 mm thick, plain, size: 1.5m×1.0m
External door construction	Timber framing, size: 2.0 m×1.0m
Internal door construction	Timber framing, size: 2.0 m×0.8m
People	2×64W/person, from 18:00 pm. to 6:00 am.
Lights	60W, from 18:00 pm. to 22:00 pm.
Air change rate	2 ACHs (ACH is a short of “air change per hour”)

Performance sensitivities to a variety of parameters were determined by changing the inputs to the base case model. Various simulations were performed to investigate the effects of kang configuration, building insulation, room air change rate and climate on indoor thermal environment and heating load. Three different plate thicknesses (40, 60 and 80 mm) were arranged. These dimensions are typical of the sizes used in an elevated kang. To evaluate the insulation effect, only the external walls were insulated by adding 100mm polystyrene panel outside. Four different room air change levels were assumed, namely 0.5, 1, 2 and 4 air changes per hour (ACH), to represent the range of ventilation rates most likely to be used in a residential building. The effect of climate on performance was investigated by running the models described above using climatic data for three different capital cities in northern China listed in Table 2. All the simulations were performed only in the heating season. Considering the low living level in most rural families in China, the design indoor air temperature for heating was fixed at 14 °C, which is often adopted in passive heating building design.

Table 2 The climate in three locations during the heating season (National Meteorological Information Center and Department of Building Science of Tsinghua University 2005)

Location	Shenyang	Beijing	Xi’an
Heating degree days (base 14°C)	3063	1978	1572
Average temperature in the coldest month	-11.46 °C	-3.83 °C	-0.35 °C
Average temperature in the coldest day	-17.50 °C	-10.00 °C	-3.45 °C

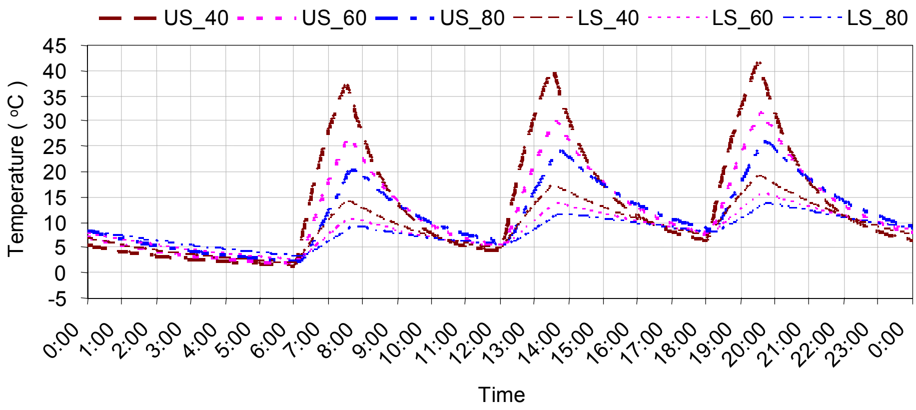
4. Results and discussion

4.1 Thermal performance of the elevated kang

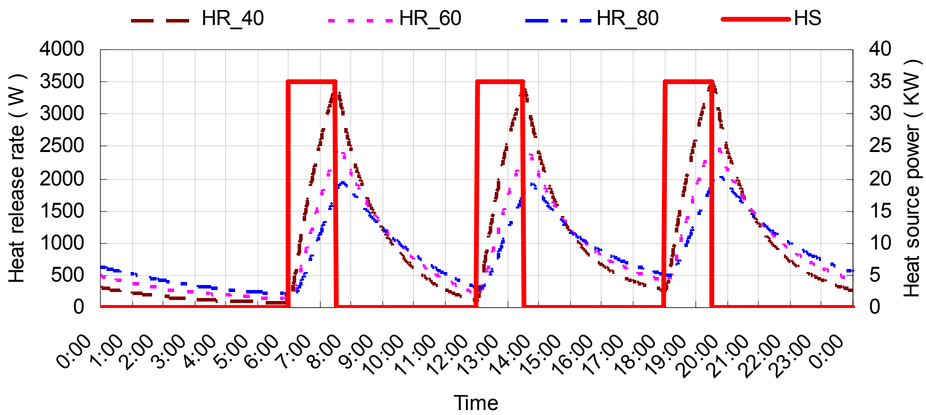
The thermal performance of the elevated kang can be investigated from its thermal responses. The change of surface temperatures of kang plates with three different plate thicknesses during one day is shown in Figure 4(a). It can be obviously seen that the upper surface temperatures of top plate fluctuate a lot due to the firings. The amplitudes of them decrease from about 30 °C to 15 °C as the plate thickness increases from 40mm to 80mm. The thicker plate has more thermal capacity which helps to moderate the change of temperature. While considering body thermal comfort requirement, the recommended thickness is 40mm leading to upper surface temperature within the range of 25~30 °C in most of time. The amplitudes of lower surface temperatures of bottom plate are relatively small, within 10 °C in all cases. This is mainly caused by the low heat convective coefficient at the inner surface of bottom plate (Zhuang, 2008).

The heat release from kang plates directly describes the heating capability. From Figure 4(b), it is found that a decrease in plate thickness results in an increase of transient heat release during the firing periods. For example, the maximum transient heat release rates with 40, 60 and 80mm thick plates are 3500 W, 2596 W and 2070W respectively. By calculation, the heat efficiencies, the ratio of total heat release to heat source power, are 15.4%, 14.1% and 13.3% for the kang with plate thicknesses of 40, 60 and 80mm respectively.

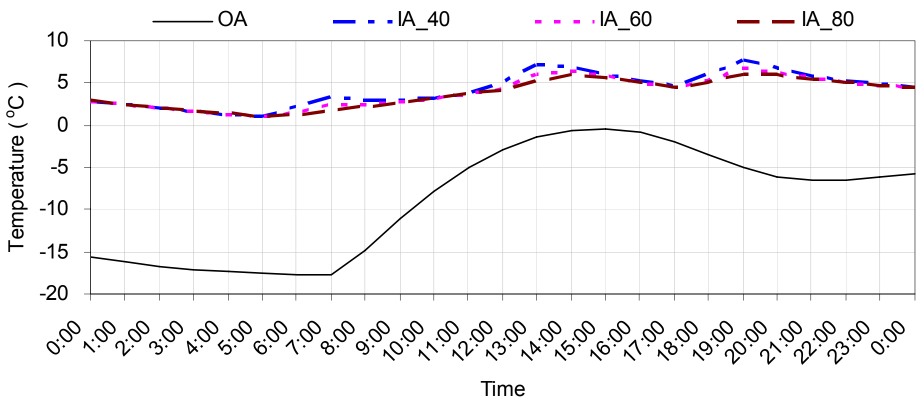
Figure 4(c) illustrates that the indoor air temperature can be maintained above 2 °C under the kang heating despite of the lowest outdoor air temperature of -18 °C. The thickness of kang plates has little effect on indoor air temperature, which only changes somewhat during the firing periods. The main reason is that the change of total heat release from kang is relatively small comparing to building heat demand.



(a) US: upper surface, LS: lower surface



(b) HR: heat release, HS: heat source



(c) OA: outdoor air, IA: indoor air

Figure 4 Dynamic thermal response of the elevated kang during one day

4.2 Effect of the elevated kang on indoor air temperature

Figure 5 shows the indoor air temperature frequency distributions for different proposed cases. For case NIWK, the indoor air temperature is the basic result telling the current thermal level of rural building without insulation, and even 8.2% of indoor air is lower than -2.0 °C. There is an urgent need to improve indoor thermal environment. The effect of building insulation on indoor thermal environment can be evaluated with case NIWK and case WIWK. By adding wall insulation described above (for case WIWK), the indoor air temperature can be further improved by about 2.0 °C. Besides, the indoor air temperature distribution of case WINK is better than case NIWK. It can be said that insulation plays an important role in improving indoor air temperature, even better than using the kang heating system. For case WIWK, 13.5% of indoor air is still lower than 2.0 °C, which may be caused by the uniform heat input of kang at the fixed times. The heat supply is not completely based on the requirement.

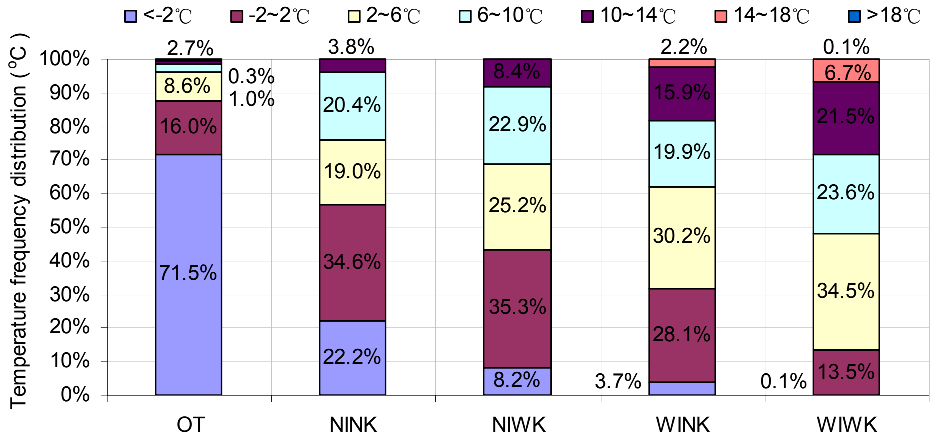


Figure 5 Indoor air temperature frequency distribution with and without kang heating and wall insulation (OT: outdoor air temperature, NINK: no insulation and no kang, NIWK: no insulation and with kang, WINK: with insulation and no kang, WIWK: with insulation and with kang)

4.3 Effect of ACH on indoor air temperature of room with elevated kang heating

Figure 6 gives simulation results of the room with four ACHs under the elevated kang heating. The air infiltration of room greatly affects the indoor environment in cold regions. For airtight room with ACH of 0.5, the indoor air can be kept above 6 °C in 99.5% of heating reason.

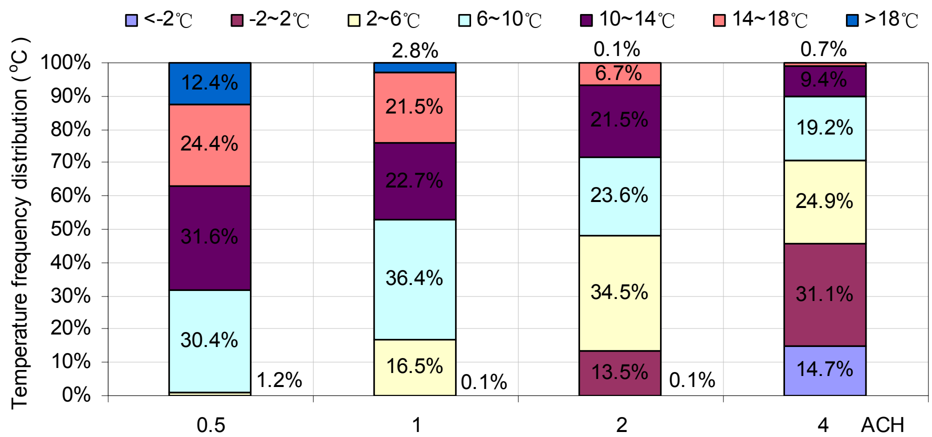


Figure 6 Indoor air temperature frequency distribution under different ACHs

4.4 Effect of the elevated kang on building energy consumption

Table 3 lists the cases of various simulations described above for the heating load prediction. Predictions of heating energy and peak demand as a result of using the kang heating system and wall insulation are summarized. A brief discussion of the use and meaning of the simulation results is presented below.

Table 3 List of simulation results for a room with an elevated kang system

Case	Location	ACH	Heating energy (KWh/m^2)	Peak heating load (W/m^2)
NINK	Shenyang	2	201.64	149.09
NIWK (base)	Shenyang	2	133.09	143.15
WINK-1	Shenyang	2	149.95	121.39
WINK-2	Beijing	2	66.01	83.37
WINK-3	Xi'an	2	67.37	66.40
WIWK-1	Shenyang	2	86.13	115.03
WIWK-2	Beijing	2	33.07	70.12
WIWK-3	Xi'an	2	19.2	53.41

Figure 7 compares the heating load index under kang heating and building insulation. The heating load index per square meter is decreased from 54.8 W/m^2 to 40.7W/m^2 by the elevated kang when the external walls have no insulation, saving 25.7% of heating load. By adding wall insulation, the energy saving by the elevated kang is improved by 5.8%, providing 31.5% of heating load. It illustrates that the elevated kang can contribute more energy savings as the building is better insulated. While the total heat release from kang is slightly affected by the building insulation, the heat efficiencies of the kang body are 14.22% for external wall with insulation and 14.24% for external wall without any insulation.

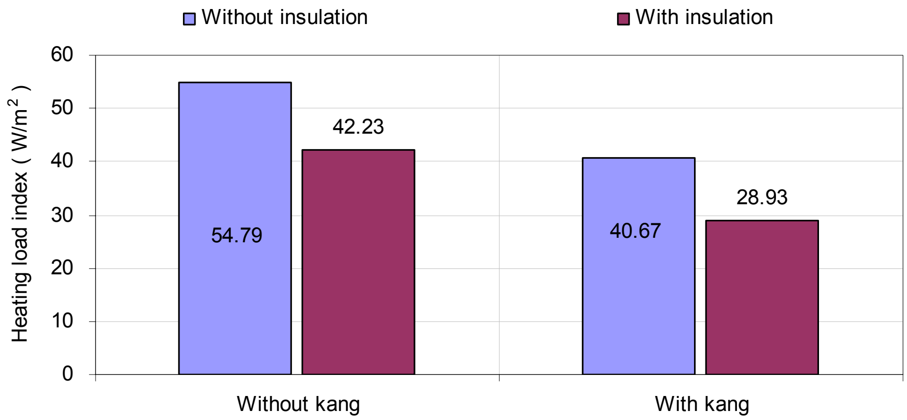


Figure 7 Comparison of heating load index under kang heating and building insulation

4.5 Effect of climate on building energy consumption of room with elevated kang heating

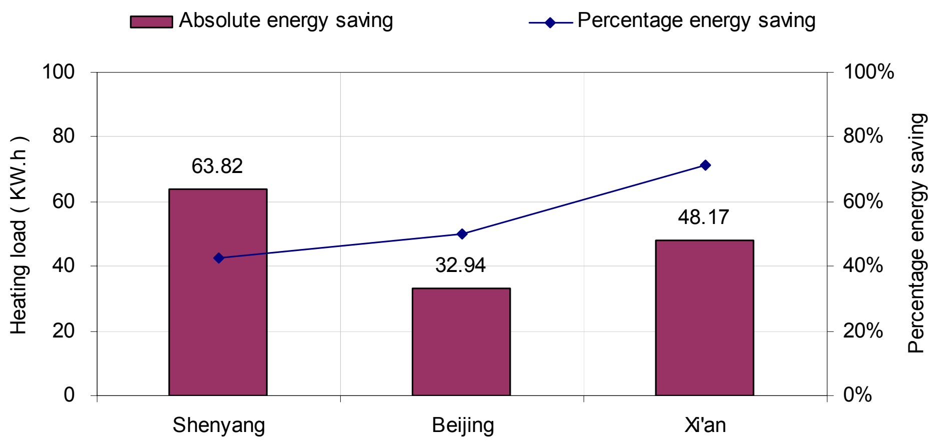


Figure 8 Predicted heating energy savings by the elevated kang in three climates

The heating capability of the elevated kang in various climates is investigated. Three representative regions in Northeast China, North China and Northwest China respectively are selected. Overall it is important to understand that it is not possible to identify a “best” system for any particular location. In this paper the judgment depends on how much the heating energy consumption is reduced. The absolute energy saving is defined as the difference between heating load for room using a traditional air-conditioning system and the auxiliary heat energy required as using the elevated kang to reach the designed indoor air temperature. The percentage saving is a convenient indicator of system performance, which evaluates the heating potential of the kang system. From Figure 8, the elevated kang is the most effective in reducing heating energy consumption in areas with the climate like Xi’an, 71.5% of heating load can be provided by the kang alone. It is also interesting to observe that 49.9% of annual heating load is saved for the Beijing climate. However, the annual heating load saving in this location is 51.6% of the result in Shenyang area.

5. Conclusions

Chinese kangs have been widely used in northern China as a potentially sustainable heating system. The elevated kang model has been integrated into a building energy simulation software (DeST) to predict the indoor air temperature and energy consumption for houses with the elevated kang heating. The performance of this system in a typical rural house has been predicted under different proposed cases to investigate the effects of kang configuration, building insulation, room air change rate and climate on indoor thermal environment and heating load.

The simulations show that the indoor air temperature can be improved under the kang heating, and building insulation plays an important role in further improving indoor air temperature. The heat supply of kang should be based on the requirement to maintain continuous indoor thermal level. The heating performance of the system is not very sensitive to the thickness of kang plates. The air infiltration of the room greatly affects the indoor thermal environment in cold regions. The elevated kang can contribute more energy savings if the building is better insulated. The elevated kang system offers either energy and/or peak load savings in almost all locations investigated. It is the most effective in reducing heating energy consumption in areas with the climate of Xi’an, 71.5% of heating load can be provided by the kang alone. These results support the general consensus that the elevated kang system is suitable for climates with not too cold regions. For the extreme cold regions, the design indoor air temperature cannot be achieved only by the kang heating system. Further research is needed to fully explore other controls parameters and strategies for kang system.

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