255: Experimental study of a new space heating system combining Chinese Kang and solar energy

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In the present work, a new space heating system has been designed and experiments have been conducted on its performance .The new system consists of a solar Kang system and solar air heaters for room heating. Kang is a kind of heatable brick bed. The solar Kang is heated by circulating hot water which is provided by solar collector. The experiments are conducted in a family house in Qinghai province in the north-west of China. Three different working modes have been tested. 1, Solar Kang working alone. 2, Solar air heaters. 3, Solar Kang and Solar air heaters combined. Kang is heated by circulating hot water from 21:30 to 9:00. The air vents of solar air heaters are open from 9:30 to 16:50 in the afternoon. Results show that the surface of the Kang can maintain a temperature range from 27 ℃ to 38 ℃ during its working hours. The solar Kang can perfectly meet the demand of thermal comfort in the sleeping hours. The performance of air heaters is less ideal. The average air temperature in the room is 8.7 ℃ during the day, 4 ℃ higher than the reference room, 4 ℃ higher than environment temperature.

Keywords: space heating, solar energy, Chinese Kang

1. INTRODUCTION

Energy consumed in buildings accounts for approximately one third of the whole energy consumption, and about 40% of them are consumed in lighting, ventilating, space heating or cooling, and water heating. Therefore, how to reduce energy consumption of space heating, cooling and hot water and how to transform energy supply methods are of great significance for reducing the energy consumption.

In the past decades, solar thermal application has drawn increasing attention and very successfully developed. In 1990s, Yakubu et al. presented an user-experience survey about living in passive solar homes (Li, G., et al., 2014); Zhai et al. analysed two kinds of roof solar collectors and found that the heat collecting efficiency was higher for the double pass than that of the single pass design (Zhai, 2005) . The design of polymer flat plate solar collectors was optimized by Do Ango et al. (Do Ango, 2013). Summers et al. designed and optimized a solar air collector with integrated phase change material storage (Summers, 2012). Tromb wall also showed great potential in energy saving in buildings. (Sun, 2007) As a common point, solar air collectors that serve as passive heating equipment may become inefficient or even infeasible under poor weather condition if thermal storage is not available. So, to economically storage and efficiently use solar energy is as important as collecting the energy. (Tian, 2013)

Winter is very cold in the north of China. Thus space heating during winter is in great demand. In the rural areas of northern China, Chinese Kangs are widely used in nearly 85% of rural homes for space heating. In recent years, Chinese Kang has arouse much research interest. Zhuang et al. (zhuang, 2009) gave a thorough review of the traditional grounded Kang and elevated Kang, including their thermal performance. Ren et al. put forward an up-to-date Kang design (Ren, 2013), with details about the proposed structure, material, construction, performance as well as energy-saving potential. Several scholars developed numerical models for Kang. For example, a thermal and airflow model for elevated Kang was developed by Zhuang et al. (Zhuang, 2009) ; Cao et al. established a set of models to simulate the energy performance of a Kang heating system in Chinese detached house, and accomplished this with experimental field study (Cao, 2009). Traditional fire Kang is composed of a stove, a Kang body and a chimney though the Kang body. The Kang body serve as bed as well as bench. Traditional fire Kang uses biomass fuel as its energy source. By burning wood and straw in the stove, Kang is heated by hot fume which went through the flue in the Kang. The heated Kang body will release heat into the room as well as providing a comfortable sleeping environment. As a method to improve domestic thermal environment, traditional fire Kang is effective and economical, but it also has certain defects. Firstly, there is always serious air pollution during heating season caused by the burning of fuel. And it also presents a safety risk if the ventilation is not ideal. Secondly, fire Kang has low energy efficiency. Thirdly, fire Kang requires a lot of human labour to keep it functioning and the temperature of the Kang body is hard to control.

Solar energy, due to its advantages of renewable and environmentally friendly, is an important alternative to fossil fuels. To improve existing Kang system, a new space heating system combing Kang and solar energy has been designed. The system consists of a solar Kang subsystem and solar air heater subsystem. Solar Kang uses solar energy in place of biomass fuel. By introducing solar energy into the application of Kang, the system is able to meet the demand of indoor thermal comfort with less air pollution, less energy consumption and more convenience for the users.

2. SYSTEM DESCRIPTION AND EXPERIMENTAL SETUPS

2.1 System description

The new system consists of a solar Kang subsystem and a solar air heater subsystem.

The solar Kang system consists of a Kang body, solar collectors, a circulation pump and interconnecting pipework. Solar energy is collected by solar collectors and stored in thermal insulated water tank in form of sensible heat. When Kang needs heating, hot water will be pumped into the water pipe circuit buried in the body of Kang.

The solar air heater subsystem consists of air heaters and air vents. The air vents are built though the south wall to connect the air duct in the solar heaters with indoor space. The air heaters are mounted upon the south wall of the room. The air vents are open during day so the air in the duct of the solar air heaters is heated and brought into the room by natural convection.

2.2 Experimental setups

Experiments on the system are conducted in Guide (101.47 ^{o}E, 36.02 ^{o}N), Qinghai province in the north west of China. Components of the system are manufactured and installed in a family house's bedroom. The room has an area of 20 square meters, including a small kitchen. The outer walls (the south, north and east walls) of the room have extra insulation layers.

The solar collectors are installed on the roof of the house. The collectors used in the experiment are all glass evacuated tube collectors. The collectors have a total area of 4.94 m^2. The volume of the water tanks is 330 L. The Kang body is built in the room 0.6 meters away from the south wall. Kang body is of dimensions 2m by 1.8m by 0.45 m(height), with the following five layers from top to bottom: cement layer (30 mm), sand layer (30 mm), thermal insulation layer (20 mm), and concrete layer(100 mm),as displayed in Fig. 1. a. The vertical surfaces of the Kang body are covered with thermal insulation material. Conductive water pipe is buried in the Kang as shown in Fig. 2. The water pipe in the Kang was arranged in the shape showed in Fig. 1. B. in order to obtain a uniform distribution of temperature for the Kang surface. The pipework connecting the Kang and the water tank is wrapped by insulation material to reduce heat loss.

The solar air heaters are installed on the south wall of the room, as shown in Fig. 2. The two solar heaters have a total area of 4m^2.

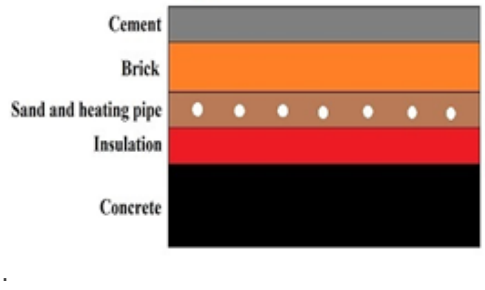

Fig. 1.a: Structure of the Kang body

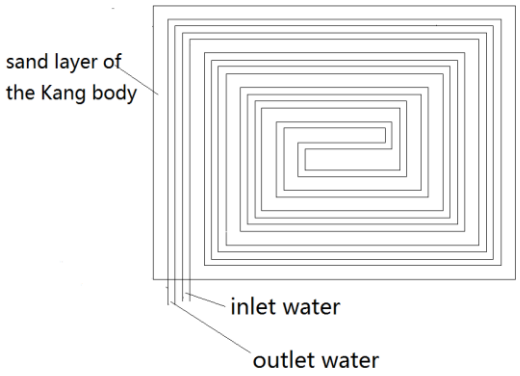

Fig. 1.b: Layout of the water pipe in the Kang

In the experiments, Copper-constantan thermocouples were used to measure the thermal progresses of the space heating system and the room. Nine thermocouples were placed uniformly on the surface of the Kang body, and the temperature of inlet/outlet hot water was measured by two thermocouples attached to the water pipe, as shown in Fig. 3. The temperature in the water tank is measured by a thermocouple placed in the middle of the water tank. Four thermocouples were placed at opening of the air vents of the solar air heaters. 6 thermocouples were placed on the four walls, the roof and the floor. Thermocouples were also used to measure the ambient temperature and the temperature of the reference room.

The flow rate of the hot water which goes through the Kang body was measured and recorded by flowmeter.

Two pyranometers were used to measure the solar radiation quantity received by the solar collectors and solar air heaters. One pyranometer was hanged upon the south wall besides the solar air heaters. The other was placed on the roof of the room beside the solar collector as the same setting angle as the solar collectors.

Fig. 2: Solar air heaters on the south wall

Fig. 3: Thermocouples placed on the surface of Kang body

3 RESULTS AND DISCUSSION

To assess and compare the performance of the two subsystems, three different working modes were tested in the experiments:

1, the solar Kang subsystem and solar air heater subsystem working together.

2, the solar Kang subsystem working alone.

3, the solar air heaters working alone.

Mode 1: The solar Kang subsystem and solar air heater subsystem working together.

During the tests of this mode, the air vents of the solar heaters are open from 9:45 to 16:45. The circulation pump of the solar Kang was on form 21:00 to 9:30. The data used here is from experiments carried out in 29th, December, 2014.

Fig. 4 shows the weather condition and solar radiation of the day. Fig. 5 and Fig. 6 show the working performance of the Kang system and solar air heaters respectively.

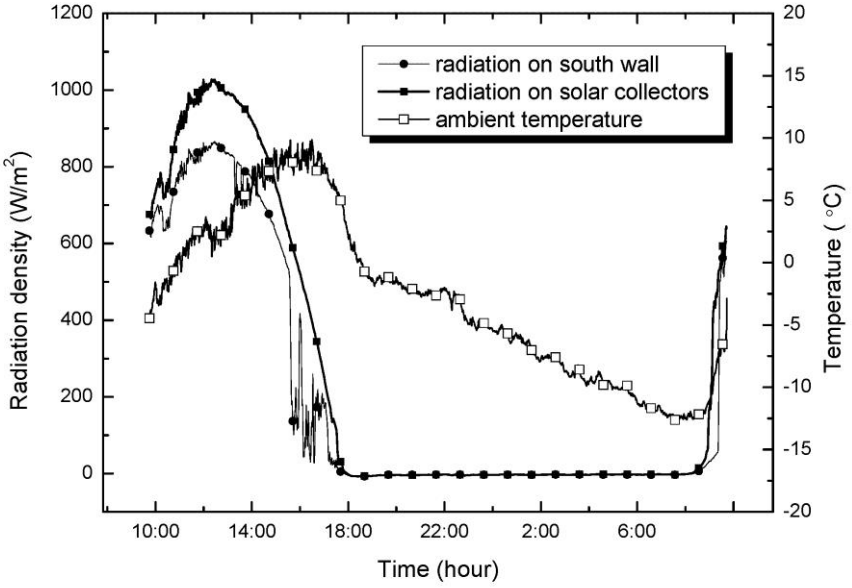

Fig.4: Radiation and ambient temperature in 29th, December, 2014.

In Fig.4 the weather condition and solar radiation of the day is showed. The ambient temperature fluctuates from -12.4℃ to 9.8℃. The average ambient temperature is -2.88℃.

The performance of the solar Kang subsystem

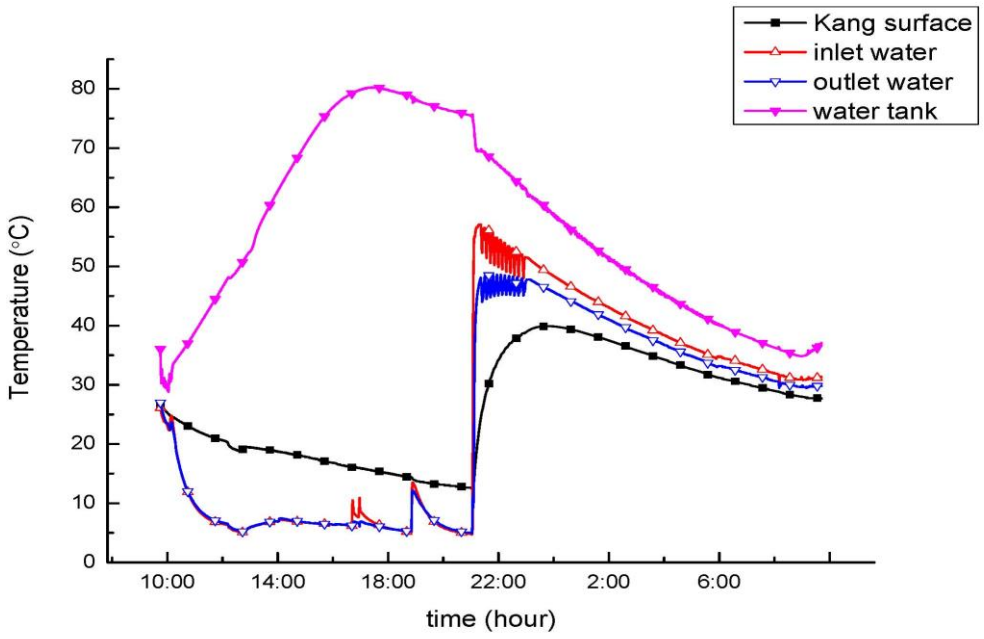

Fig.5 Work condition of the Kang in 29th, December, 2014.

The vibration of the inlet/outlet water temperature showed in Fig.3 is caused by the high temperature protection system, which turns off the circulation pump when the temperature in the water pipe gets too

high. At the beginning, the temperature in the water tank is too high, thus the circulation pump worked intermittently. When the pump is on, the flow rate though the Kang was steadily 0.033kg/s.

The temperature of the Kang surface was obtained by averaging the readings of the 9 thermocouples placed on the surface of the Kang. The graph shows that the temperature of the Kang surface varies from 34.2 ℃ to 27.9℃ from 22:00 to 9:00. The temperature reaches 40℃as its climax at 24:00. The average temperature of the Kang during the sleeping hours is 34.56℃.

The temperature reached 40℃ around 24:00, which is too high for thermal comfort. This problem can be solved by modifying the controlling system of the Kang. To avoid overheating of the Kang, a temperature probe should be placed on the surface of the Kang body, when the temperature on the Kang surface gets too high, the circulation pump should be turned off temporarily.

The solar Kang system provided a heated bed with an average temperature of 34.56℃.The result shows that the solar energy collected by the solar collectors is sufficient to provide a comfortable thermal environment throughout the night. And by heating the Kang body throughout the night, the solar Kang system provided a thermal sleeping environment steadier than traditional Kang.

The performance of the solar air heater subsystem

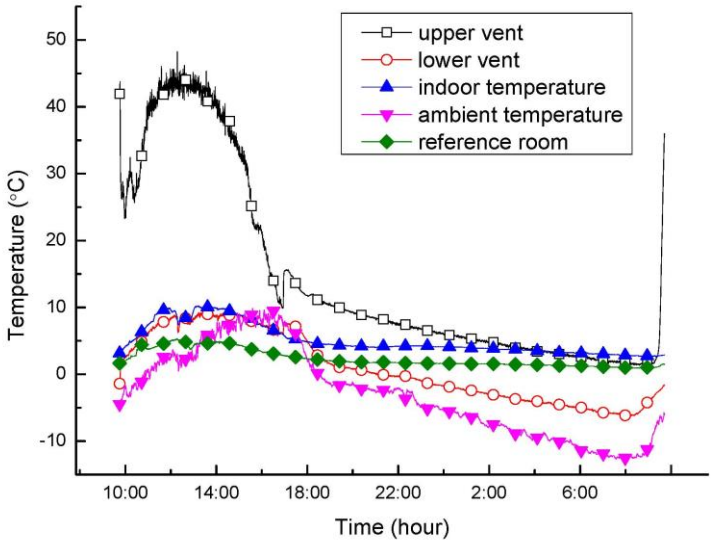

Fig.6: The performance of the solar air heaters in 29th, December, 2014

The indoor air temperature was obtained by averaging the readings of the three thermocouples placed in the middle of the room. The air vents of the solar air heaters were open from 9:45 to 16:45. During these hours, the average indoor air temperature was 8.1℃, while the average ambient temperature was 4℃, and the average temperature in the reference room was also 4℃. The solar air heaters increased the indoor approximately by 4℃.

The performance of the solar air heaters were influenced by the thermal condition of the room. The room is the test is larger than usual bedrooms, and it also has a large window space. The performance of the solar air heaters could be improved by improving the heat insulation of the room.

The result of the experiments shows that the solar air heaters are insufficient to provide a satisfactory indoor thermal environment, but it can still be a prominent auxiliary method for indoor space heating.

Mode 2: The solar Kang subsystem working alone

During the tests of mode 2, the air vents of the solar heaters are closed. The circulation pump of the solar Kang is on from 22:00 to 9:30.The data used here is from experiments carried out in 19th, January, 2015.

Fig.7 shows the weather condition and solar radiation of the day. The ambient temperature fluctuated from -10.7℃ to 9.1℃. The average ambient temperature is -2.9℃.

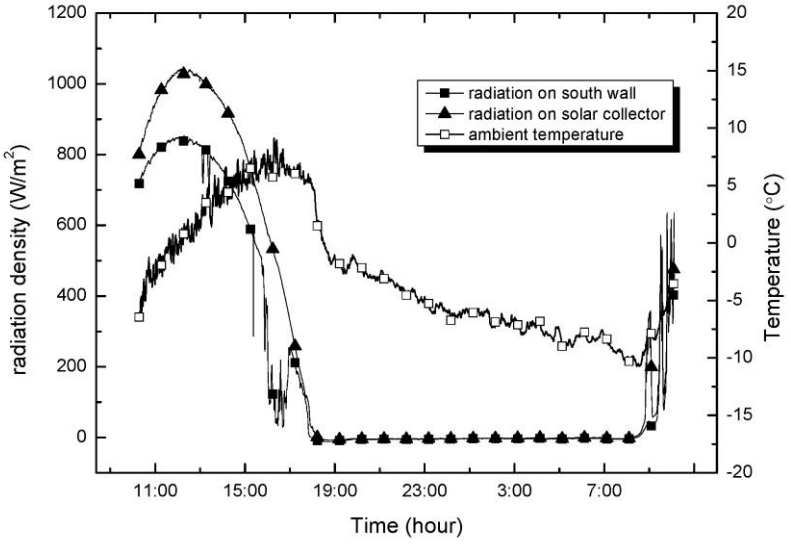

Fig. 7: Radiation and ambient temperature in 19th, January, 2015.

Comparison of Mode 1 and Mode 2

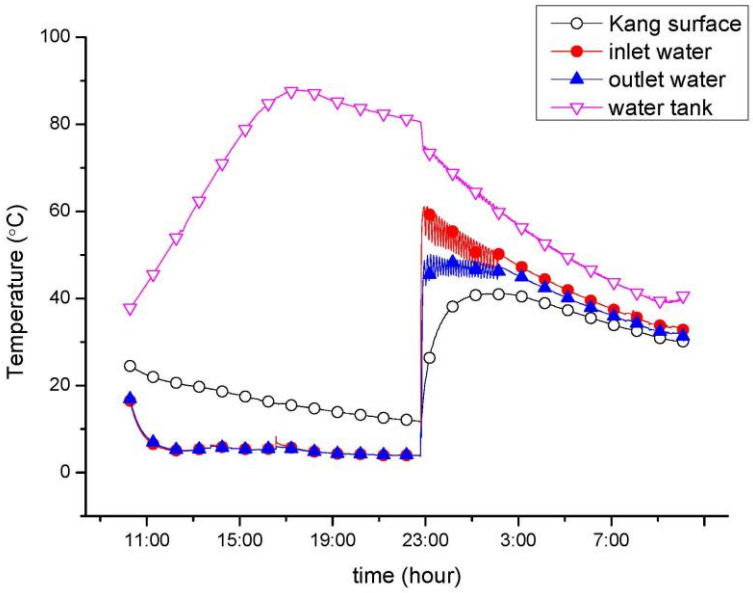

Fig. 8: Working condition of the Kang in 19th, January, 2015.

From Fig.8 it can be seen that the performance of solar Kang subsystem in mode 2 was similar with it in mode 1. The shutdown of solar air heater subsystem does not affect the working of the solar Kang

subsystem. During the sleeping hours, the temperature of the surface of the Kang varies from the average temperature of the Kang surface is 35℃.

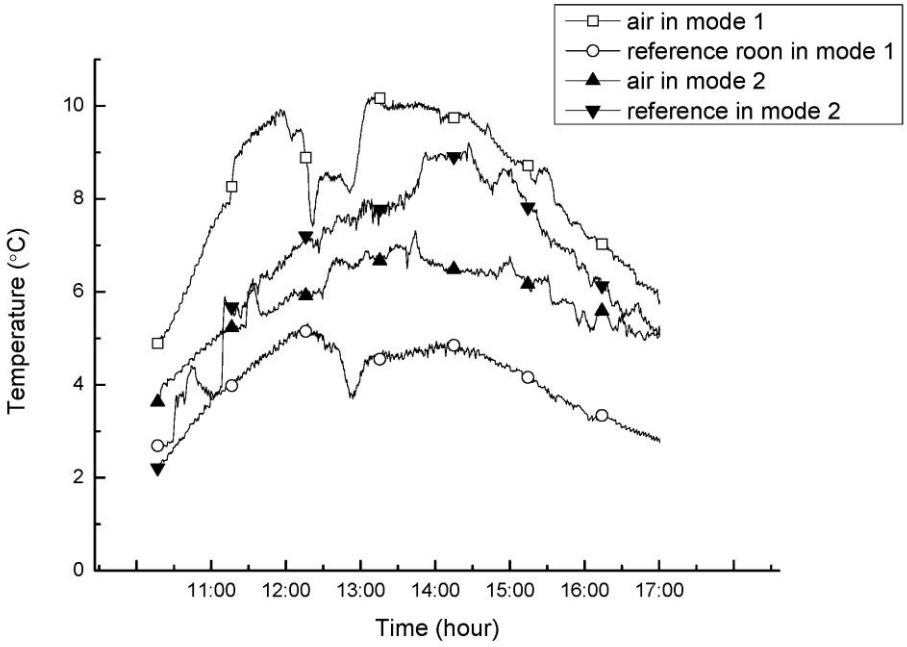

Fig. 9: The indoor air temperature in mode 1 and mode 2 during day

In Fig.9 air temperature in the test room and reference room under mode 1 and mode 2 was compared. In mode 2, the indoor air temperature is lower than the air temperature in the reference room. During the day, from 10:00 to 17:00, the average indoor air temperature of the test room in mode two is 4.5℃， while the average air temperature in the reference room is 6.7 ℃. The average air temperature in the test room in mode 2 is 2.2℃ lower than the reference room. In mode one, the average air temperature in the test room is 4℃ higher than that in the reference room.

The comparison of air temperature in mode 1 and mode 2 shows that the solar air heaters have distinct effect over indoor temperature during the day.

Mode 3： The solar air heaters working alone.

The data is from experiments carried out in 10th, January, 2015.

During the tests of mode 3 the circulation pump of the solar Kang is turn off. The air vents of the solar air heaters are open from 9:50 to 16:50.

In Fig. 10 the weather condition and solar radiation of the day is shown. The ambient temperature fluctuates from 13.4℃ to 10.0℃. The average ambient temperature is -3.6℃.

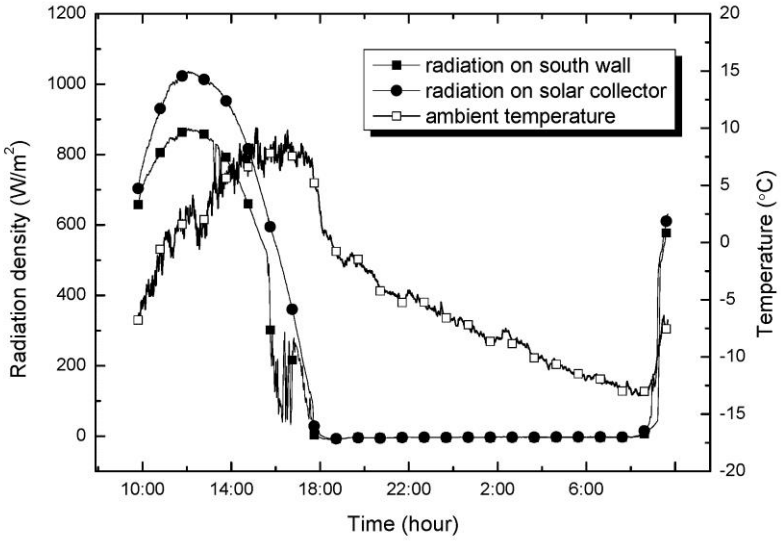

Fig.10: Radiation and ambient temperature in 10th, January, 2015.

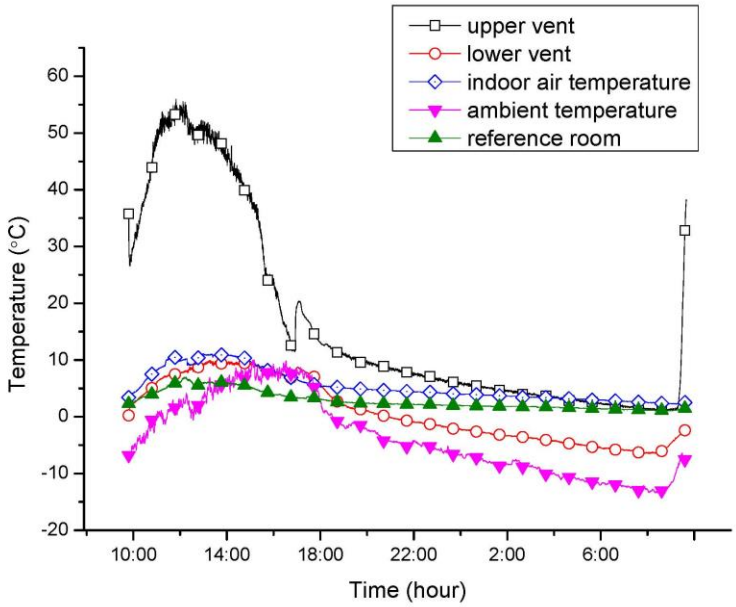

Fig.11: The performance of the solar air heaters in 10th, January, 2015.

During the day, the average indoor air temperature is 8.9℃, while the average ambient temperature is 3.6 ℃, and the average temperature in the reference room is also 4.9℃. The solar air heaters increased the indoor approximately by 4℃.

The air temperature in the test room reached 11℃ as maximum temperature. In The experiments in 10th, January, 2015, the test room maintained an air temperature above 10℃ from 11:30 to 15:00.

The result is consistent with the result of experiments of mode 1.

4 CONCLUSION

A new system combining the solar air heaters with the solar Kang has been successfully developed. Experiments were conducted on the performance of the system. Three different operating modes was tested. Highly encouraging results were obtained.

During the night, the solar Kang can maintain a temperature above 30℃. As a method of providing a comfortable thermal environment for sleeping, the solar Kang is a perfect substitute for traditional fire Kang. Considering solar Kang's advantage in reducing energy consumption and air pollution, it is a distinct improvement to replace traditional space heating Kang system with solar Kang.

While the effect of the solar air heater system is less ideal, it can still be improved in many aspects. In a smaller and better insulated room, the indoor air temperature would be maintained at a higher level.

The thermal environment provided by the system is comfortable and stable. Comparing to traditional fire Kang, this new system is more economical and environment friendly, and the new system can also bring the users a lot convenience for it can work automatically. As a whole, the new system is a very competent and beneficial substitute for the traditional fire Kang system.

5 ACKNOWLEDGED

This study was supported by the National Natural Science Foundation of China (No. 51378483), the Qinghai Province Science and Technology Planning Project (No. 2013-N-544) and DongGuan Innovative Research Team Program (No. 2014607101008).

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