Report On Task 57, Subtask B1: Development of Accelerated Ageing Tests for Evacuated Tube Collectors

2018.11.30

Content

1 Ageing Test under Exposure Conditions

Because of solar irradiation and high temperature, long term exposure affects the thermal performance of ETC. The thermal performance of solar collector has been tested before and after exposure. Four type solar collector has been tested including Flat-plate collector (FPC), Glass-metal sealed evacuated tube collector (GSETC), Heat pipe evacuated tube collector (HPETC), U type evacuated tube collector (UETC) for the comparison of FPC and ETC. The test result could be reference for evacuate tube solar collector.

1.1 Ageing process of ETC

As the largest solar thermal market, there were 477.8 million m^2 solar collectors installed in China in 2017. And Evacuated tube collectors accounts 90% of the market share.

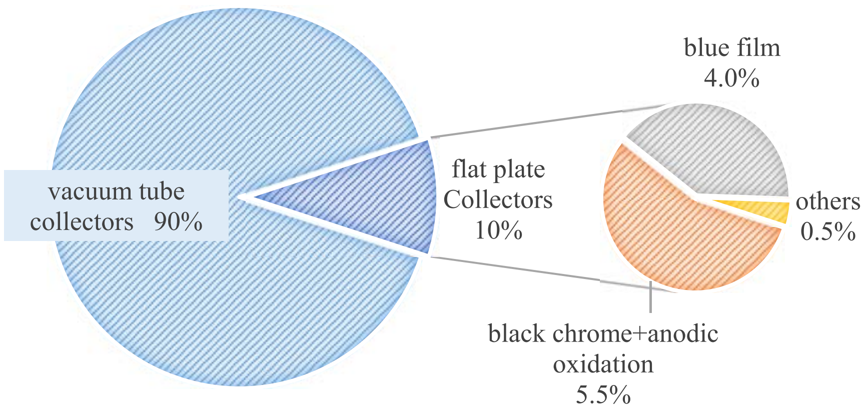


Fig. 1. market share of ETC and FPC in China

Under solar radiation and temperature change, Rubber ring would be harden that led to the joint gap between tubes and Manifold is too large, resulting more heat loss. Insulation material's performance would weaken. And the thermal performance of evacuated tube collectors will change.

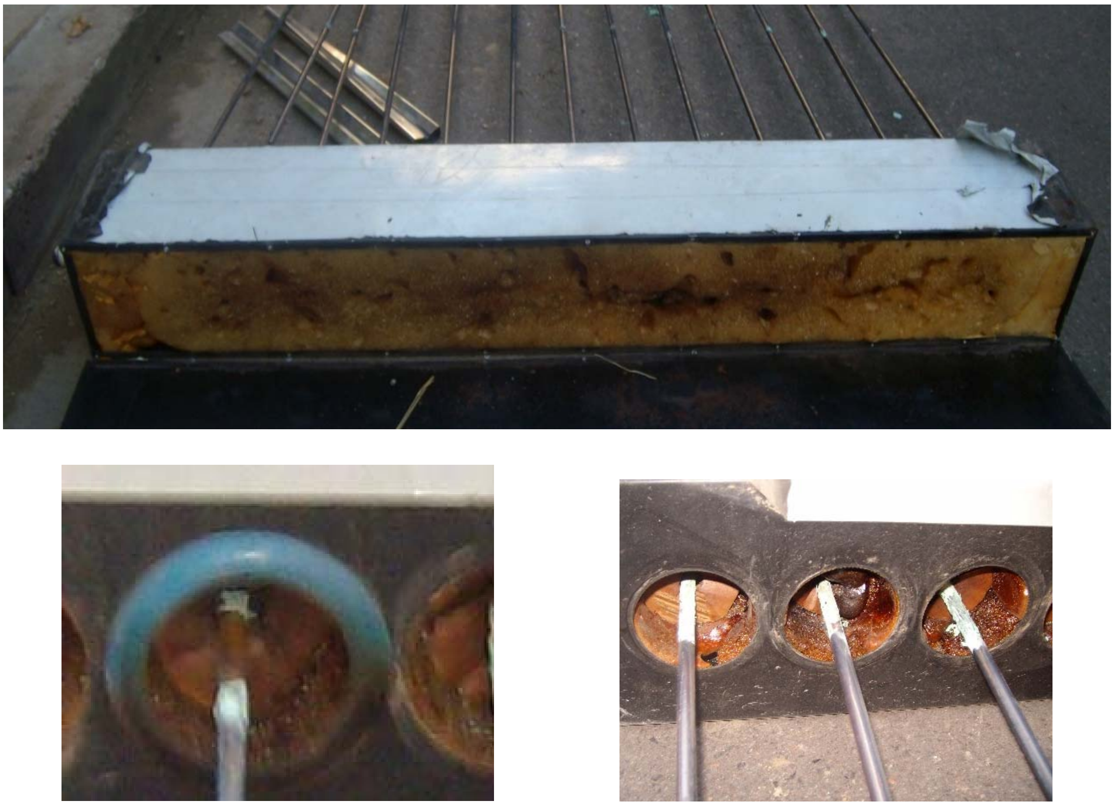


Fig. 2. some ETCs after exposure.

To investigate performance changes under exposure condition, several kinds of ETC were selected to conduct the aging test. FPC had also been tested for comparison. All the work had been carried out by the National Center for Quality Supervision and Testing of Solar Heating Systems (Beijing).

1.2 Specification for tested solar collector

Selected solar collectors were used commonly in China. Four types of solar collectors were tested, including Flat-plate collector (FPC), Glass-metal sealed evacuated tube collector (GSETC), Heat pipe inside evacuated tube collector (HPETC), U type evacuated tube collector (UETC).

Detailed information of FPC in the Tab. 1, others in the Tab. 2.

Tab. 1. specification of flat plate solar collector

Cover material	4mm glass
Layers of cover	Single
Absorber Material	Black Cr

Aperture dimension	1950mmX940mm
Aperture area	1.83 ㎡
Gross area	2.00 ㎡

Tab. 2. specification of evacuated tube collectors

Solar collector	**GSETC**	**HPETC**	**UETC**
Array of tubes	Vertical	Vertical	Vertical
Number of tubes	8	16	16
External diameter of cover tube	102mm	58mm	58mm
Length of tube	2000mm	1800mm	1800mm
Gross area	1.99 ㎡	2.34 ㎡	2.34 ㎡

1.3. Test method

The thermal performance of solar collector had been performed according the Chinese National Standard GB/T 4271[1] and EN 12975-2[2].

1.4. Test conditions

There were more than 100 sets of solar collectors been tested in a year, so tests were started and finished at different day.

The aging test for different solar collector started and finished at different time. Detailed test conditions are listed in the Tab. 3.

Tab. 3. Test conditions

Solar collector	FPC	GSETC	HPETC	UETC
Started day	12th , Jul.	6th, Jun.	14th, Apr.	26th , Feb.
Finished day	8th, Oct.	27th, Oct	12th , Sep.	24th, Oct
Total irradiation on the aperture (MJ/m^2)	1170	1887	1404	1954
Average ambient temperature (°C)	25.2	24.2	26.7	24.3
Duration（day）	88	143	151	241
Daily irradiation (MJ/m^2)	13.6	13.2	9.3	8.1

1.5. Thermal performance test result

After aging test, the thermal performance of solar collectors were all lower, the curve before and after test are listed in the Tab. 4, Fig. 3 to Fig. 6.

Tab. 4. thermal performance before and after test (based on inlet temperature, aperture area)

	FPC	GSETC	HPETC	UETC
Before test	η_a=0.769-5.055T_i*	η_a=0.752-2.462T_i*	η_a=0.768-2.361T_i*	η_a=0.738-2.444T_i*
After test	η_a=0.658-7.669T_i*	η_a=0.737-4.015T_i*	η_a=0.694-7.910T_i*	η_a=0.620-6.438T_i*

Tab. 4 and Fig. 3-6 shows all efficiency (T_i*=0) (curve intercept) dropped down, and all heat loss coefficients of solar collectors were increased after aging test.

In Chinese National Standard, requirement for thermal performance of flat plate collector is η_a=0.72 - 6.0T_i*, for evacuated solar collector is η_a =0.60－3.0 T_i*.Before test, all the test results could satisfy the requirements. After test, all the index , especially the heat loss coefficient, were lower ,and the performance could NOT meet the requirements of Chinese national standard.

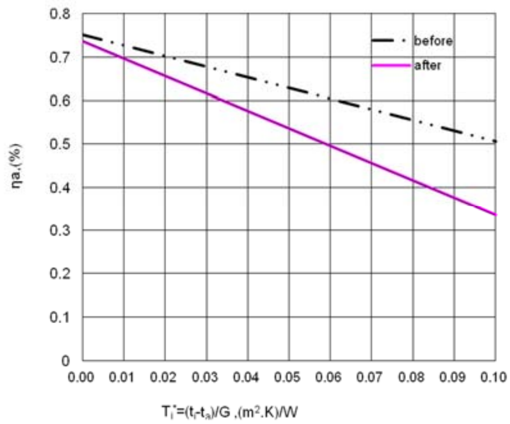


Fig.3. thermal performance change of FPC

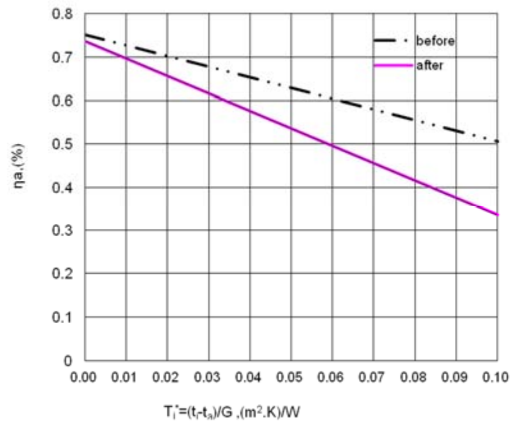


Fig.4. thermal performance change of GSETC

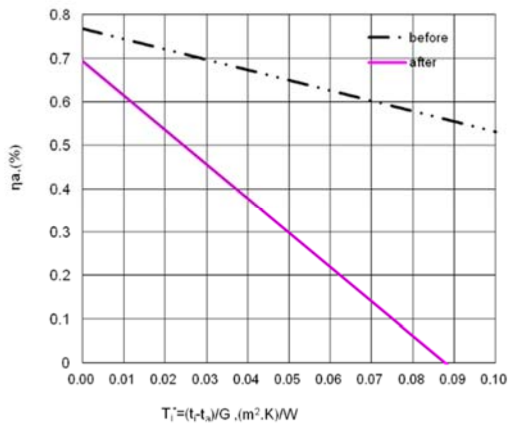


Fig.5. thermal performance change of HPETC

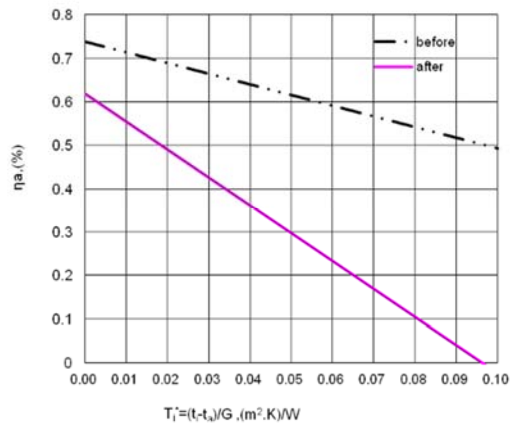


Fig.6. thermal performance change of UETC

1.6. Conclusion

From the aging test result, we can draw a conclusion that the thermal performance of solar collectors were reduced after aging test.

For ETCs, the efficiency (T_i*=0) (curve intercept) dropped little. However, all the heat loss coefficients increased. the heat loss coefficients of GSETC increased from2.462 to 4.015, increased 63.1%, the heat loss coefficients of HPETC increased from 2.361 to7.910, increased 235%, the heat loss coefficients of UETC increased from 2.444 to 4.438, increased 81.6%. Comparing with FPC, the aging test has more significant effect on the performance of ETCs. The possible reason could be that the insulation material, such as the rubber ring, has more influence on thermal performance.

Above test result could be a reference of accelerated aging test method for evacuate tube collectors.

2 Demonstration projects

There were 2 demo projects planned to be finished 1 year before. And the demo project could be used for aging test under different conditions. However, these projects would be delayed. CABR will still go on this work continuously and supply testing report to future’s task.

One of these demo projects is a solar district heating system in Langkazi (Nagarze), Tibet with 23,000 m^2 FP collectors. The other one is a solar district heating and cooling system in Turpan, Xinjiang with 40,000 m^2 collectors.

2.1 Solar district heating system in Langkazi (Nagarze), Tibet

2.1.1 General information

Project: Solar district heating system for Langkazi

Location: Langkazi (Nagarze), Tibet

Scale: Provide heating for 82,600 m^2 houses and buildings

Progress: Under construction, will be finished next year

2.1.2 Project introduction

Langkazi is located in Shannan, Tibet, with an altitude of about 4500m. It belongs to the serve cold and high-altitude region. The annual average temperature is -0.3°C, the coldest temperature would below -30°C. And the winter is about 180 days. There are basically no heating facilities in the existing buildings, and the indoor temperature is very low in the winter especially in the night.

There are about 152,000 m^2 houses and buildings need space heating in Langkazi. The first phase of the project can meet the heating needs of 82,600 m^2 houses and buildings, including government office buildings, commercial office buildings, schools, nursing homes, bus stations, as well as residential buildings.

Fig. 7. Satellite photo of Langkazi, by Google Earth

Fig. 8. Buildings in Langkazi

Fig. 9. Buildings in Langkazi

2.1.3 Systems

Based on the research on temperature and flow balance of solar collector fields in high altitude and low pressure conditions, an optimal design method of solar collectors based on LCC was proposed and applied in the system design. The solar collector field will be the largest in Tibet. According to the implementation conditions of the project site, an easy construction and low cost pit heat storage was designed.

The first phase of the demonstration project has a total investment of 120 million yuan. The solar collector field uses 1680 large-unit flat plate collectors. The total collector area is about 23,000 m^2, and the pit heat storage has a volume of 15,000 m^3. The heating system could satisfy 4.8MW heating demand for 82,600 m^2 houses and buildings.

Analysis results showed that the demonstration project could increase the minimum indoor temperature in winter to 15 °C, and the primary energy consumption for heating could be lower than the constraint value of Chinese National Standard GB/T 51161.

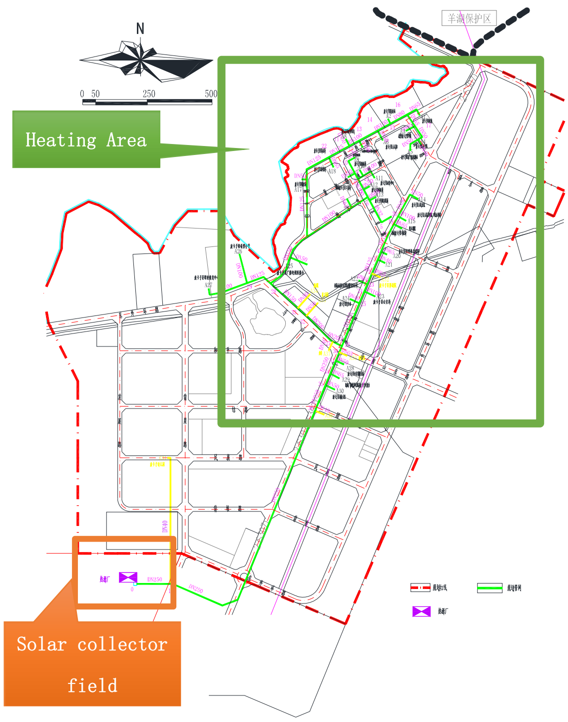


Fig. 10. Solar collector field and the heating area

2.1.4 Progress

The implementation plan for the demonstration project *was approved* on June 8, 2018. The project now is under construction and is scheduled to be completed in 2018. The main progress is as follows:

Fig. 11. Project Department

Fig. 12. solar collector field

Fig. 13. Fundamental of heating station

Fig. 14. Pit heat storage

2.2 Solar district heating and cooling system in Turpan, Xinjiang

2.2.1 General information

Project: Solar district heating and cooling system in Turpan

Location: Turpan, Xinjiang (Northwest China)

Scale: Provide district heating and cooling for 73,500 m^2 houses and buildings

Progress: Under construction, will be finished next year

2.2.2 Project introduction

Turpan is 183 kilometers away from Urumqi, the capital of Xinjiang. Turpan City is the first batch of new energy demonstration cities. The requirement of renewable energy consumption of this city is 30%.

Turpan is a typical continental warm temperate desert climate. There is abundant heat but extremely dry in summer. Therefore, it is known as "Fire Island". Turpan is a famous dry and hot area in China, with an extremely high temperature of 47.8 °C in history. Average annual precipitation is 16.4 mm, and the evaporation is up to 3000 mm. At the same time, Turpan belongs to the Class II region with rich solar resources. The annual solar radiation is 5806.88MJ/(m^2·a), and the annual sunshine hours are 3015 hours.

The project provides space heating and cooling for 73,500 m^2 houses and buildings, including government office buildings, commercial office buildings, and residential buildings.

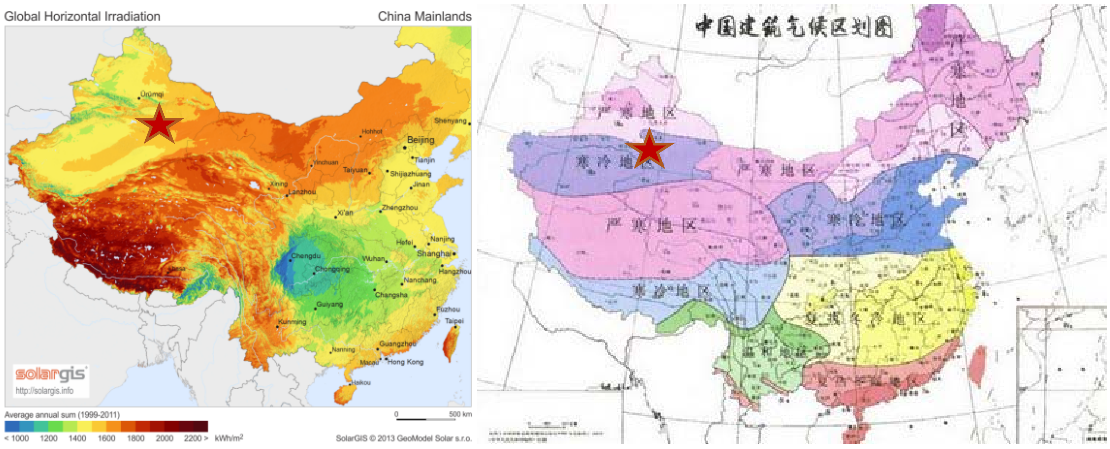


Fig. 15. Solar irradiation and climate zone of Turpan

Fig. 16. Buildings in Turpan

2.2.3 Systems

The project adopted solar heating and cooling system. The system uses FPC or ETC, absorption chiller, indirect heat exchange, and short-term storage tank combined with seasonal heat storage. The solar collector field uses 40,000 m^2 collectors. And the pit storage for seasonal heat storage has a volume of 200,000 m^3. Because the project site has a large pool already, the construction of the pit storage could be cheaper and easier. The system could satisfy heating and cooling demands of 73,500 m^2 houses and buildings.

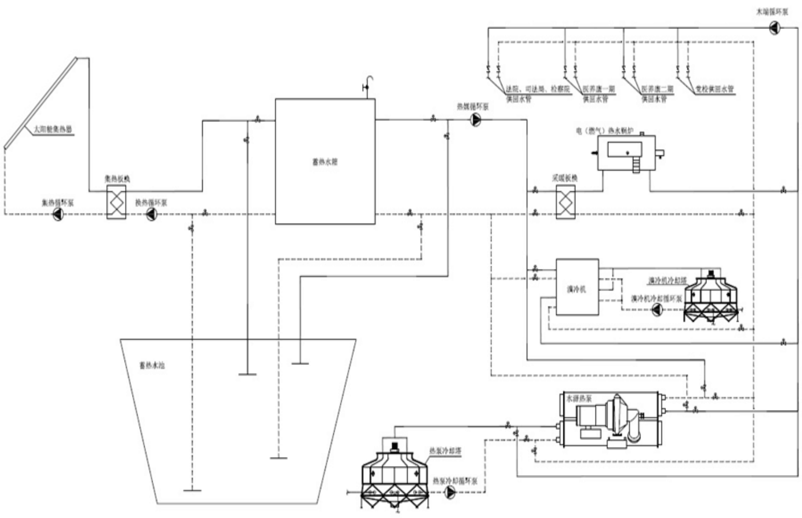


Fig. 17. System scheme

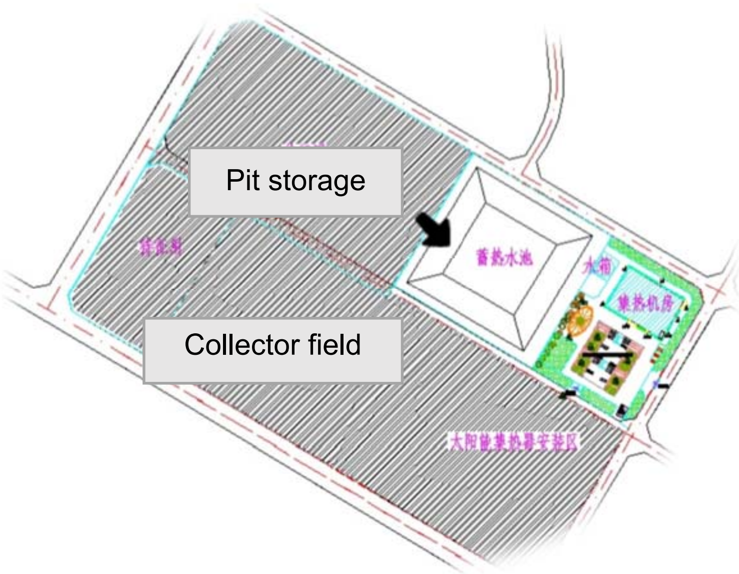


Fig. 18. Project site layout

2.2.4 Progress

The implementation plan for the demonstration project was approved on 2017. The project now is under construction and is scheduled to be completed in 2018.

3 Remote Testing System for Aging test

To test the performance of ETCs in running system, a Low-cost, Flexible, Remote testing system has developed by CABR. Not only collectors' performance, but also the IAQ and EE parameters the system could test.

3.1 Introduction

There is a trend of using locally available renewable energies in residential buildings in rural regions in China. Including the system performance, good indoor air quality (IAQ) and energy efficiency (EE) are two important aspects that need to be considered in designing and operating the heating, ventilation and air conditioning (HVAC) systems for such buildings. It is therefore important to be able to continuously monitor the IAQ and equipment EE parameters. Traditionally, the measurement system is composed of sensors, data log kits and computers for data acquisition, processing and recording. All the components are connected by shield wires for communication. However, conducting multiple field visits to access the data in the computers is often unrealistic for remote buildings in rural regions. In addition, the computers and wires may disturb occupants for long term monitoring and multiple family apartments' measurements.

CABR developed a low-cost IAQ and HAVC equipment energy consumption monitoring system especially for residential buildings in remote rural regions. It could also be used in Remote Aging test. The overall system architecture, the implementation of hardware and network communication protocol, and the appearance of the final prototype product are described.

3.2 Methodologies

Fig. 19 shows the overall system architecture. Measured data is captured by terminal box. and transferred to the local host box. To reduce the wires, this system uses wireless communication between terminal box and local host box. All data is saved in the local host box and submitted to remote server synchronously via internet. The sensor type can be easily redefined depending on the requirements at each measurement site. Additionally, derived parameters and statistical analysis based on the measured data are often needed for controlling and optimizing HVAC equipment operations.

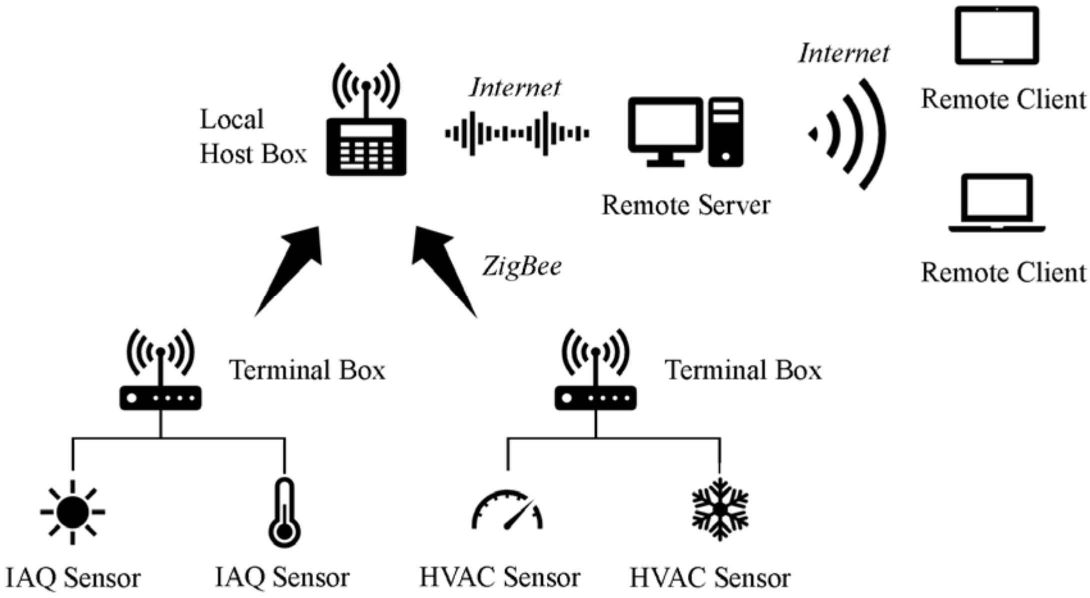


Fig. 19. Topology of the system

The system allows such functions to be easily defined when configuring the sensors. The system can measure multiple individual parameters including IAQ parameters (such as temperature, humidity, concentration of PM2.5, total volatile organic compounds (TVOC) and formaldehyde) and HVAC equipment parameters (voltage, current, power etc.). It accepts both analog and digital signals as inputs. Analog signals are converted to digital signals by A/D convertors.

The reliability for the wireless communication was assessed by comparing three common ways via pilot data acquisition, including Bluetooth, Wi-Fi and ZigBee. It was found that WI-FI mode is more suitable for single family measurement with high data acquisition speed due to the connected terminals limits of routers. For multiple family measurements, WI-FI signal amplifiers have to be used and may not be the best choice. ZigBee is more suitable for multiple room measurements because ZigBee coordinator and routers can set up network up to hundreds of terminals.

3.3 Results and Discussion

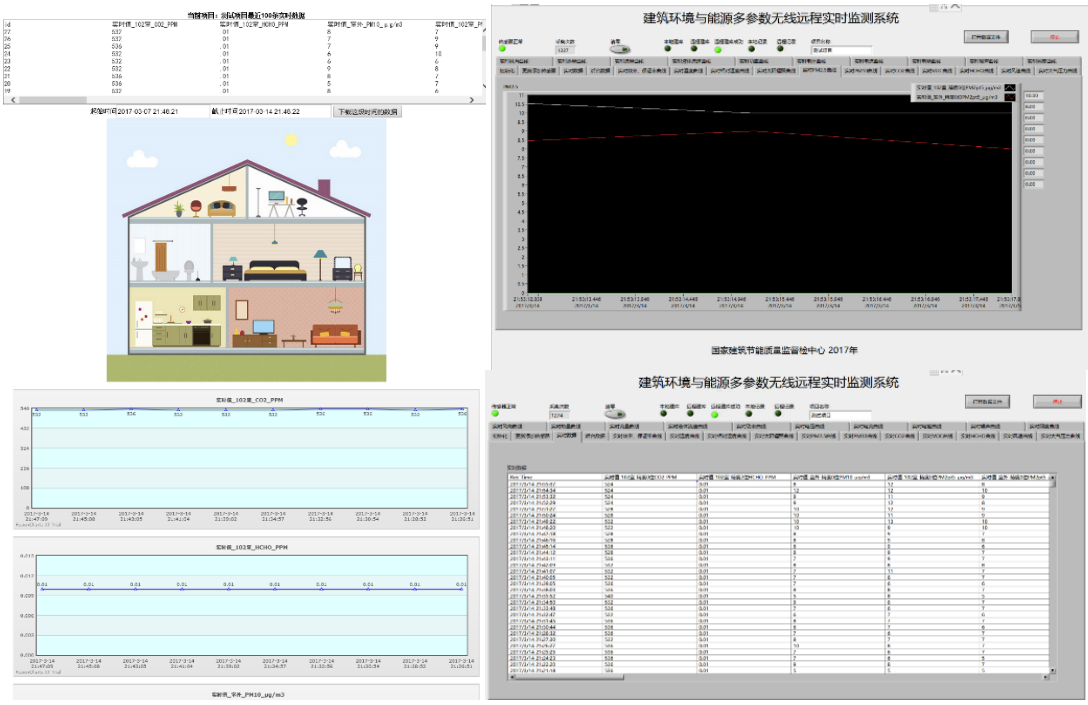
Based on the above methodology, a prototype low-cost wireless sensor network system was developed. Fig.20 shows the system hardware including local host box and terminal box.

Left: terminal boxes with wireless communication kit; **Right:** local host box

Fig.20. System hardware.

The system is composed of one host box with upper computer and wireless communication kit, and up to 32 terminal boxes with wireless communication kit. Each terminal box can connect to several A/D convertors with unique identification address, and each convertor can connect several sensors depending on the sensor type. Commonly used sensors with standard signals in HVAC fields can be applied in this system.. The maximum of address number is 256.

The system can accommodate up to 2,000 sensors. The data recording interval can be defined for each measurement from seconds to hours. To improve the robustness, each component is equipped a lithium battery, and the system can continuously work for more than 8 hours without grid electricity supply. Fig. 21 shows the interfaces for local workstations and remote server. The remote monitoring website allows users to access all the monitoring data and check system running conditions real time without field visits, which is critical for IAQ and EE testing in remote rural buildings.



a. Remote server interface b. Local host station interface

Fig.21 Software interface

The prototype system described above has been tested in a demo project in Beijing, China. For a ten-day monitoring period, results indicate that the measurement errors of this system were less than 0.1%. The standard uncertainty of the measurements can meet the requirement of the Chinese national standards. (GB/T 50801-2013: *Evaluation stand for application of renewable energy in buildings*)

3.4 Conclusions

A low-cost wireless sensor network system for IAQ and HVAC equipment energy consumption measurements has been developed, pilot tested, and proved to function reliably. The system will be firstly used for IAQ and energy supplying testing in remote residential buildings in Tibet farming and stockbreeding areas of Southwest of China.