The Performance of a High Altitude and High Solar Fraction Large-Scale District Heating Project

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Abstract

A large-scale solar district heating project in Langkazi, Tibet, China utilizes a solar thermal system with a pit storage to supply space heating to Langkazi County through a district heating network. The project was constructed by the consortium of Sunrain Group, Solareast Arcon-Sunmark and Beijing District Heating Co., Ltd.

The project is located at 90°40'77.58" E and 28°97'56.13" N with an altitude of 4,600m, where the temperature in winter could reach as low as -30°C and the heating season lasts as long as 251 days.

Total investment of the project is RMB 173 million. With a heating area of 152,000 m^2, the project was implemented in two phases, among which phase I (2018) features a total investment of about RMB 120 million and heating area of 82,600 m^2. Project phase I was completed by the end of November 2018.

Design concept: Overall planning and step-by-step implementation. In the design and construction of phase I, scalable conditions were reserved for future phase II in that the heat exchange station and main heat supply network were built to accommodate the total heating area of 152,000 m^2. The heat exchange station and technical rooms have reserved space for flexible expansion of equipment in future phase II.

Keywords: Large-scale solar district heating system, High altitude, High solar fraction, Langkazi,

1.Introduction

Tibet is a typical plateau and cold region in China, where heating is very important to local residents. However, Tibet lacks traditional fossil energy, and coal and natural gas are scarce. It is inconvenient and expensive to transport from other places, and the pollution is serious. Fortunately, God has given the Tibetans the most precious gift, the sunshine as an alternative energy source. The area is sunny, clean and pollution-free, making it the best source of heat for heating.

In the past few years, there have been many small and medium-sized pilot solar heating projects in Tibet, but almost all failed. The main reasons include that the original design did not fully consider the harsh conditions of local high altitude and low temperature, improper equipment selection, unreasonable construction organization, and no professional operation and maintenance services after the completion of the systems. In this case, using a mature large-scale solar district heating system to provide space heating is the best choice. Langkazi was selected to host the first pilot project.

Langkazi is the highest county under the jurisdiction of Shannan City, boasting an annual solar irradiation of approximately 2,153 kWh/m^2. With No. 307 provincial highway running through the southern and northern regions, the county is a 3-hour drive from Lhasa, capital of Tibet. Here, the temperature in winter is very low. Historically, residents of the county have been burning wood and cow dung for heating, resulting in a harsh indoor environment; in addition, gas and particle emissions are also detrimental to the local fragile ecosystem. At the same time, the lower indoor temperatures in schools, hospitals and homes do not meet the comfort requirements. Therefore, it is necessary to solve the heating problem in the county by providing more advanced heating facilities for local buildings to improve the living conditions of local residents in the cold winter.

doi:10.18086/swc.2019.11.01 Available at http://proceedings.ises.org

Fig. 1: location of Langkazi county (Source: Google Map)

2.System Description

2.1 Design parameters and overview

The key challenge of the design is high altitude of 4,600m. It means the water will be boiling if temperature is higher than 85°C without additional air pressure. The main parameters for the system are as follows:

- *Heating period: Sept. 23 ~ May 31 the following year (251 days).*
- *Average outdoor design temperature in heating period :- 14.4°C*
- *Solar fraction: >90%*
- *Heating supply/return temperature: 65/35°C*
- *Design pressure of pipe network: 1.1MPa*
- *Total heat load: 7.99MW*
- *Heat load of project phase I: 4.3MW*
- *Collector area of phase I: 24,300 m²*
- *Pit storage volume: 15,000 m³*
- *Auxiliary heat source: Electric boiler*

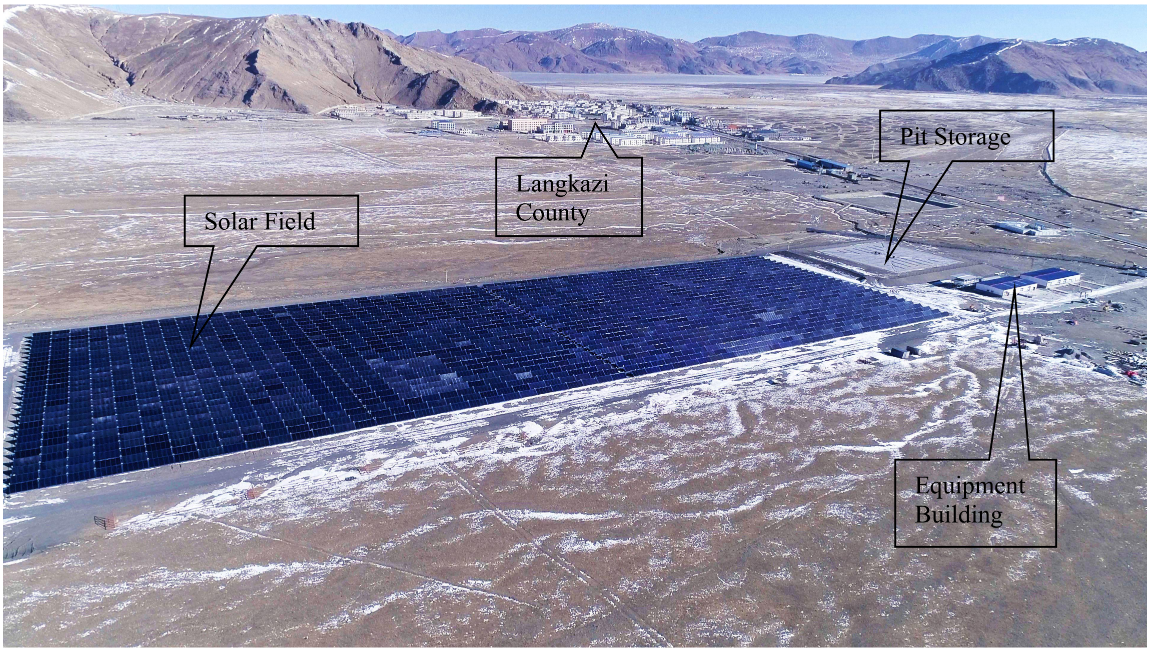

Fig.2: Langkazi project overview

2.2 Heat load

To calculate the load of heat consumers, heat load of buildings in winter should be estimated through calculating heat load index of unit area by taking two-floor typical buildings as reference building and based on meteorological condition in the region as well as national codes and standards such as ***CJJ34-2010 Design Code for City Heating Network***, ***DBJ 540001-2016 Design Standard for Energy Efficiency of Civil Buildings in Tibet*** **and** ***GB50189-2015 Design Standard for Energy Efficiency of Public Buildings.***

For public buildings, the heating demand is 54.9 W m^{-2}, with a heat consumption index of 36.8W m^{-2}. For residential buildings, the heating demand is 50.2 W m^{-2}, with a heat consumption index of 33.6 W m^{-2}.

Tab. 1: heat load and heat consumption index

	Public buildings meeting energy saving standards (W m^{-2})	Residential buildings meeting energy saving standards (W m^{-2})
Heat load	54.9	50.2
Heat consumption index	36.8	33.6

Based on general plan and actual situation of the county, the heating building area planned is 152,000 m^2, with a total heat load planned of 7.99 MW by statistical calculation, of which, heat loads of public buildings and residential buildings are 3.90 MW and 4.09 MW, respectively. For details, please see Table 2 and Table 3. Building heat consumption in winter is 5.35 MW, of which, 2.61 MW is for public buildings and 2.74 MW is for residential buildings.

Tab. 2: Calculation of heat load in Langkazi County

S/N	Name	Occupation area (m^2)	Building area (m^2)	Thermal index (W m^{-2})	Heating load (MW)
1	Public buildings	168,622	77,627.75	50.2	3.9
2	Residential buildings	207,703	74,552.59	54.9	4.09
Total			152,180.34		7.99

2.3 Solar collector

As the most crucial part of solar heating system, collector has a direct influence on the heat supply performance of solar heating system. Collectors used in China nowadays can be divided into two types in general: flat-plate collectors and evacuated tube collectors.

For this project, collector with metal runner such as flat-plate solar collector featuring pressure bearing operation, convenient replacement, excellent thermal performance, safe operation and low cost should be recommended. Besides, anti-freezing solution required for such collector in winter is less, as diameter of metal runner is relatively small and thus heat transfer working medium in it is less than that of full-glass evacuated tube collector.

2.4 System temperature

Average altitude of Langkazi County is around 4,600m, where barometric pressure is around 650.6 hPa in winter and boiling temperature of water is about 85°C. The temperature of heating network had better not be too high, in order to operate the system in a safe and efficient way. Temperature for water supply/return is determined as 65/35°C in final design, so as to secure an easy-to-use and safe-running heat supply system and convenient maintenance.

2.5 System design

The solar system is a closed loop filled with propylene glycol as heat-exchange fluid. The energy could be stored in a 15, 000 m^3 pit storage. The city district grid is a closed loop system filled with demineralized water. Since the storage is non-pressurized, two heat exchangers are designed to separate the pressurized solar system and city grid from the storage to ensure safe operation of the whole system.

The supply temperature in the city grid is 65°C with a return temperature of 35°C, while the Logarithm temperature difference of the two heat exchangers is 5^{o}C, which means that the temperature on the top of the storage is 70°C, while that at the bottom is 40°C. And the circulation temperature in the solar field is 45/75^{o}C.

Solar field circulation pumps are controlled by frequency converter. The solar field circulation controlling is based on readings from the irradiation sensors and the inlet/outlet temperature sensors at solar field to ensure stable and safe operation of the system.

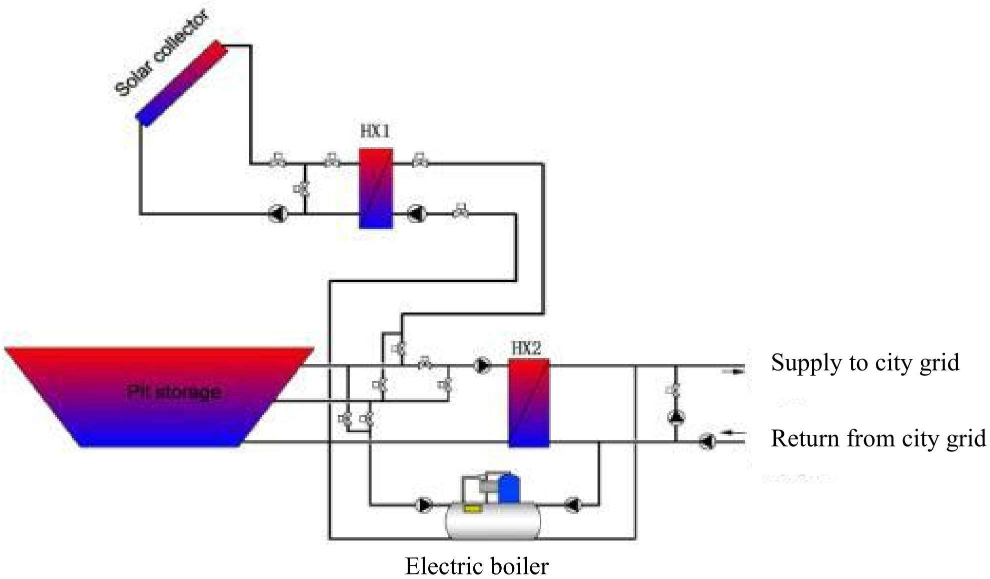

Fig. 3: System schematic of Langkazi project

3.System Performance

3.1 Collector performance

Collectors of large single aperture area (see Fig. 4) are used in Langkazi project, showing good performance. The collector parameters and efficiency curve plot (see Fig.5) are shown below.

Fig.4:Collector of large single aperture area

- *Outer dimensions:* *2,52 x 5,96 x 0,18 m*
- *Gross area:* *15,00 m²*
- *Aperture area:* *13,75 m²*
- *Weight, without liquid:* *340 kg*
- *Fluid content:* *14 liter*
- *Efficiency:*

$$\eta = \eta_0 - \frac{\alpha_1 \cdot (T_m - T_a)}{G} - \frac{\alpha_2 \cdot (T_m - T_a)^2}{G} \qquad \text{(eq. 1)}$$

where: T_a = *Ambient temperature [°C]*
T_m = *Mean fluid temperature [°C]*
G = *Irradiance [W m^{-2}]*

Efficiency factors:

η_0 = *0,850*
a_1 = *2,30 [W/(m^{2}K)]*
a_2 = *0,029 [W/(m^{2}K^2)]*

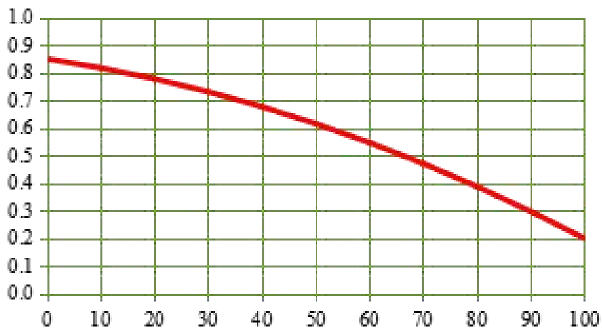

Fig.5: Efficiency curve (G = 800 W m^{-2})

The total solar field efficiency is compared with the theoretical efficiency of a single collector. The energy meter is located at the secondary loop of heat exchanger (HX1). It means that the heat loss of solar field pipes, influence of heat exchange Logarithm temperature difference and other possible heat loss are all taken into account.

A clear day was selected (Dec.21) to analyze the efficiency difference between the calculation and measurement, with a variable-speed pump to control the flow. Fig. 6 shows the measured and theoretical efficiency of the collector array.

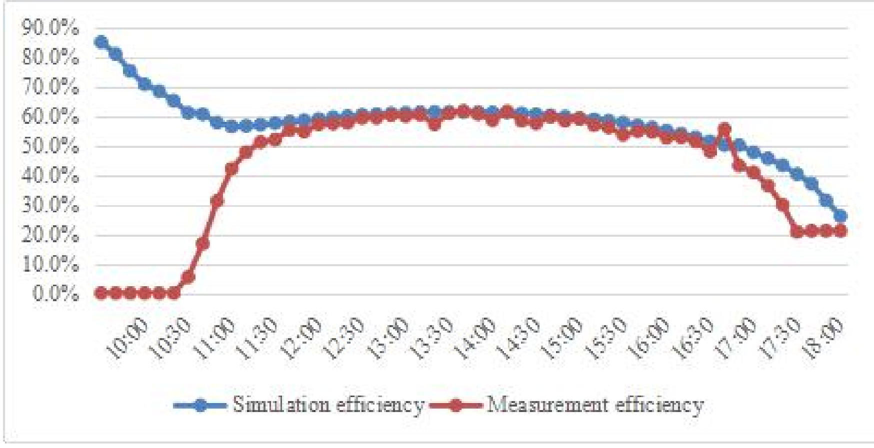

Fig.6: Comparison between calculated efficiency and measured efficiency

Since the collector loop, filled with propylene glycol, is exposed over night to the outdoor cold ambient, it must be heated up at the start of circulation. During this period, the propylene glycol-to-water heat exchanger is protected from freezing temperature by an actuating valve that directs the propylene glycol through a bypass loop which is isolated from the heat exchanger. The heat transfer fluid keeps recirculating until it either reaches 75°C when the heat will be directed to the city grid, or is 5°C higher than the temperature at the top of pit storage when the energy starts to be directed to the pit storage.

From Fig.6 we can find that the measured data start at 10:00 am, which seems very weird. The reason lies in the frost on the surface of collectors. Fig. 7 shows gradual changes of frost outside of collectors. The collector surface is almost totally covered by the frost even at 8:34 am, and it normally begins to melt at 9:00 am and almost disappears at 10:00 am.

Fig.7: Frost outside of collectors at different time points

At midday, the operating efficiency is quite high in that it can be kept at 60%. The highest efficiency measured is 61.8%, which was spotted at 13:50 pm.

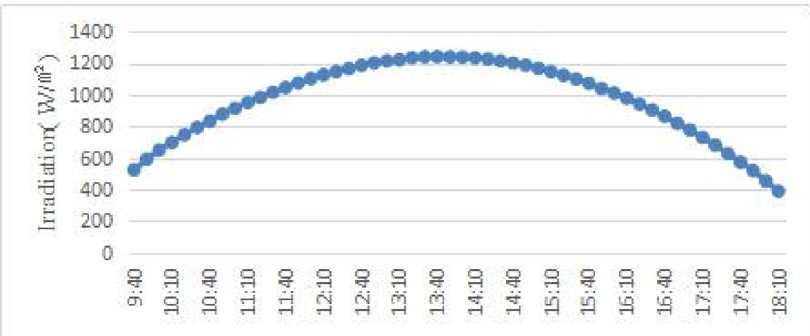

Fig.8: Typical solar irradiation in heating season in Langkazi

By comparing the theoretical calculated and measured values of the collectors' power, it is found that the difference between these two is small, as shown from Fig.9.

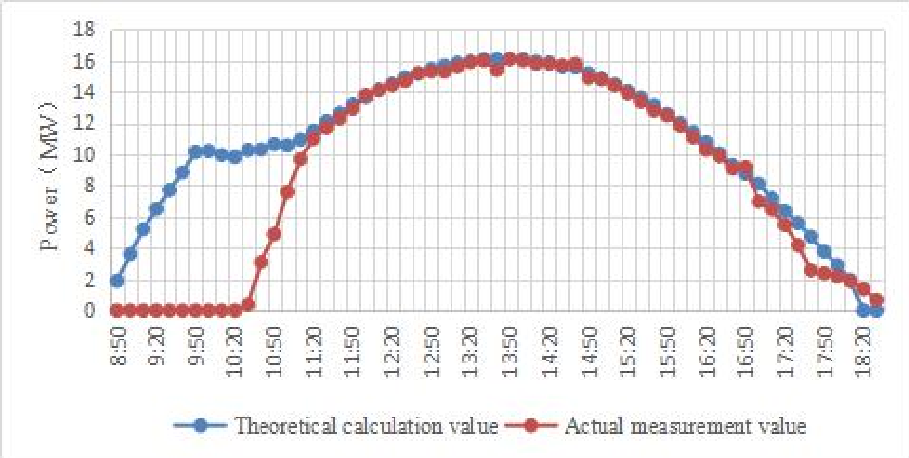

Fig.9 Hourly power comparison of theoretical calculated and actual measured values in a typical day

The reason is that the method of obtaining the calculated value is different from that of the measured value. The calculated value is determined based on the inlet and outlet temperatures of the solar collector, while the measured value is determined by measuring the power and irradiation, and then dividing the power by the irradiation to calculate the efficiency. Since the heat meter for measuring power is installed on the secondary side of the heat exchanger, it is inevitable that there will be pipeline heat loss and a delay in the measured value of the heat exchanger. This heat loss and delay are the root causes of difference between the calculated value and the measured value.

Tab. 3: Measured and calculated data for solar field (collector array)

Time	Irradiation ($W m^{-2}$)	Ambient (°C)	Inlet (°C)	Outlet (°C)	Calculated efficiency	Measured efficiency	Deviation
11:50	1074.5	-3.36	46.49	82	58.2%	55.4%	-4.83%
12:00	1102	-3.34	46.89	82.44	58.6%	54.8%	-6.48%
12:10	1125.9	-3.29	47.12	82.58	59.1%	57.4%	-2.98%
12:20	1146.2	-3.28	46.73	82.47	59.7%	57.6%	-3.62%
12:30	1164.6	-3.28	47	82.42	60.1%	57.8%	-3.72%
12:40	1186.1	-3.3	46.91	82.42	60.5%	59.5%	-1.69%
12:50	1201.5	-3.29	47.08	82.4	60.8%	59.5%	-2.13%
13:00	1214.2	-3.28	47.07	82.42	61.1%	60.4%	-1.07%
13:10	1220.9	-3.23	47.19	82.28	61.2%	60.1%	-1.88%
13:20	1233.9	-3.22	47.31	82.4	61.4%	60.6%	-1.38%
13:30	1239.2	-3.24	47.42	82.27	61.5%	57.3%	-6.81%
13:40	1240.7	-3.2	47.24	82.57	61.5%	61.0%	-0.90%
13:50	1238.9	-3.24	47.12	82.65	61.5%	61.8%	0.52%
14:00	1237.7	-3.21	47.37	82.41	61.5%	60.7%	-1.19%
14:10	1233.1	-3.21	47.31	82.6	61.4%	58.7%	-4.28%
14:20	1226	-3.2	47.32	82.35	61.3%	61.7%	0.68%
14:30	1213.8	-3.15	47.74	82.06	61.0%	58.5%	-4.13%
14:40	1200.3	-3.1	47.98	81.99	60.8%	57.6%	-5.12%
14:50	1186.6	-3.06	48.21	82.4	60.3%	59.9%	-0.76%
15:00	1166.5	-3.1	48.08	82.42	59.9%	58.5%	-2.31%
15:10	1145.6	-3.08	48.19	82.45	59.4%	59.2%	-0.39%
15:20	1123.4	-3.1	48.08	82.28	59.0%	57.1%	-3.24%
15:30	1099.1	-3.1	47.81	82.14	58.5%	56.2%	-3.93%
15:40	1072.3	-3.13	47.82	82.04	57.9%	53.8%	-7.11%
15:50	1039.5	-3.19	47.89	82.2	56.9%	55.0%	-3.35%
16:00	1010.8	-3.11	47.96	82.13	56.2%	54.7%	-2.53%
16:10	977.9	-3.16	47.89	82.04	55.2%	52.8%	-4.36%
16:20	940.3	-3.14	47.74	82.01	54.1%	53.0%	-2.11%
16:30	903.6	-3.15	47.66	81.92	52.9%	51.5%	-2.59%

The average deviation is 2.89%, which is almost the same as the design heat loss of pipeline (3.0%). It is well above expectation considering the influence of heat exchange, Logarithm temperature difference and other possible heat loss. It means the collector is better than expected under high solar irradiation conditions.

Tab. 4: Highest measured data for collector array

Time	Irradiation ($W m^{-2}$)	Ambient (°C)	Inlet (°C)	Outlet (°C)	Calculated efficiency	Measured efficiency	Deviation
13:50	1238.9	-3.24	47.12	82.65	61.5%	61.8%	0.52%
14:20	1226	-3.2	47.32	82.35	61.3%	61.7%	0.68%

The measured value is even higher than the calculated value, and at the same time, the measured efficiency is at the highest value, even though the solar irradiation is not at the peak. The reason lies in the long distance of the fluid flowing to the energy meter, which should last for some minutes.

3.2 System performance

The total system performance is also recorded by the energy meter installed behind the heat exchanger (HX2).

Tab. 5: Typical days in heating season in Langkazi

Date	Weather	Irradiation (MWh)	Output (MWh)	Efficiency
19-Dec	Sunny (snow melting)	178.6	76.6	42%
20-Dec	Overcast to sunny	134.4	58.8	43.75%
21-Dec	Sunny	181.9	87.6	48.16%
22-Dec	Sunny	182.8	93.2	50.98%
23-Dec	Sunny	180.4	90.2	50.00%
24-Dec	Sunny	180.2	88.8	49.28%
25-Dec	Sunny	180	92.2	51.22%
26-Dec	Sunny	177.8	92.5	52.02%
27-Dec	Sunny	172.9	88.4	51.13%
28-Dec	Cloudy to overcast	114.7	43.3	37.75%
29-Dec	Sunny	178.6	85.8	48.04%

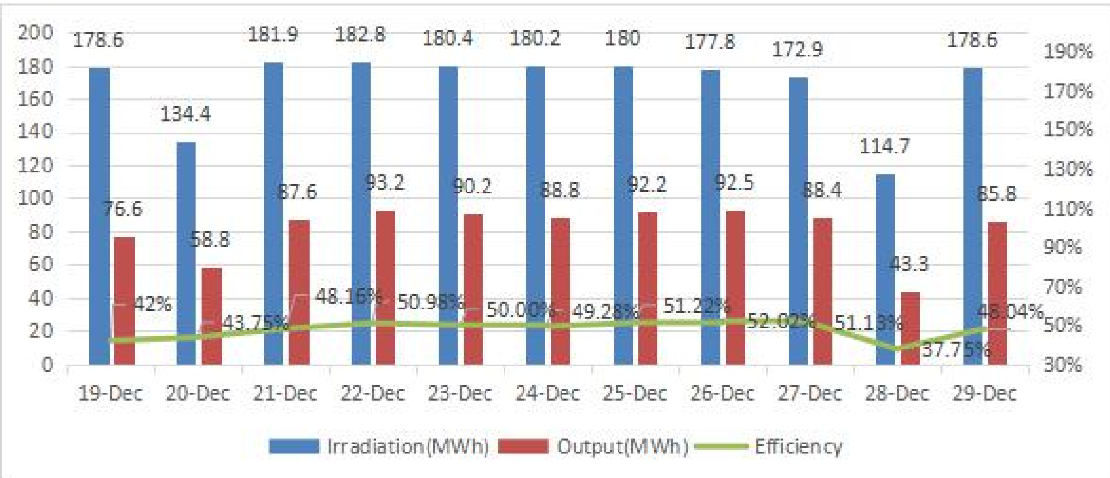

Fig.10: Comparison between irradiation and output

The irradiation can be kept at about 180 MWh, while the output is around 90 MWh in sunny days. It means the efficiency is about 50%, which is higher than expected.

The stronger the irradiation is, the higher the efficiency goes, which suggests good performance of the collectors.

3.3 Storage performance

Tibet is among the regions claiming the highest annual solar irradiation in the world, we can see from Table 5 that even in winter Tibet still has more sunny days than cloudy days. Therefore, the collector-area/pit-storage-volume ratio is quite different from those PTES systems in northern Europe, at 1.62 m^2/m^3 as against Marstal at 0.44 m^2/m^3 for example.

Even with such a high collector-area/pit-storage-volume ratio, the pit storage system still delivers very good thermal stratification. Fig. 11 shows that the dynamic energy output from Dec 19th 2018 to Dec 28th 2018. This suggests that the stratification design and thermal insulation performance of the pit are very impressive.

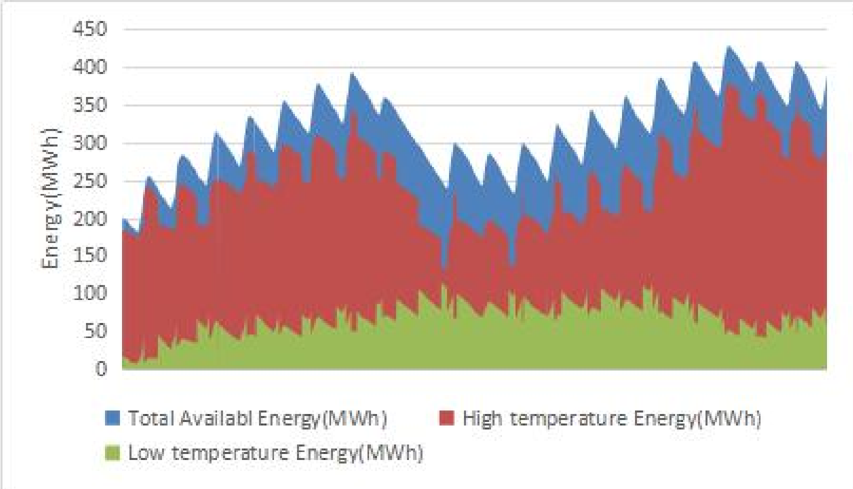

Fig.11: Storage pit stratification effect

The Figure above shows that the pit can use 78% of high-temperature heat. This is only a short period of observations in the first year of the project's formal operation. In the future, we will also observe the heat charging and discharging cycles in different periods of time - e.g., in one year, one Quarter or one month - to figure out proportions of available high-temperature heat.

3.4 District heating grid

For the Langkazi project, the district heating grid was designed to work at 65/35°C throughout the main supply /return pipes of more than 15 kilometers long (single way distance). The main pipes were buried 2 meters under the ground to avoid freezing and reduce energy lost. The supply/return temperature adopted in the Langkazi project is higher than that of some advanced PTES system in Europe, since in Langkazi residents still use traditional radiators. To keep those radiators working properly, the running temperature of the solar system shall be adjusted to gear to the working temperature of those radiators.

Fig. 12 shows the energy distribution of Langkazi project from Dec. 19th to Dec. 29th, a period in deep winter. Measured data show that over 81% of the energy produced by solar field is distributed directly to the end users via district heating loop, while 19 % to the pit storage. On two cloudy days, i.e., Dec. 19th and 28th, the pit storage discharged and released 30.8 MWh of energy to end users, along with 102.1 MWh of energy supplied by the solar field.

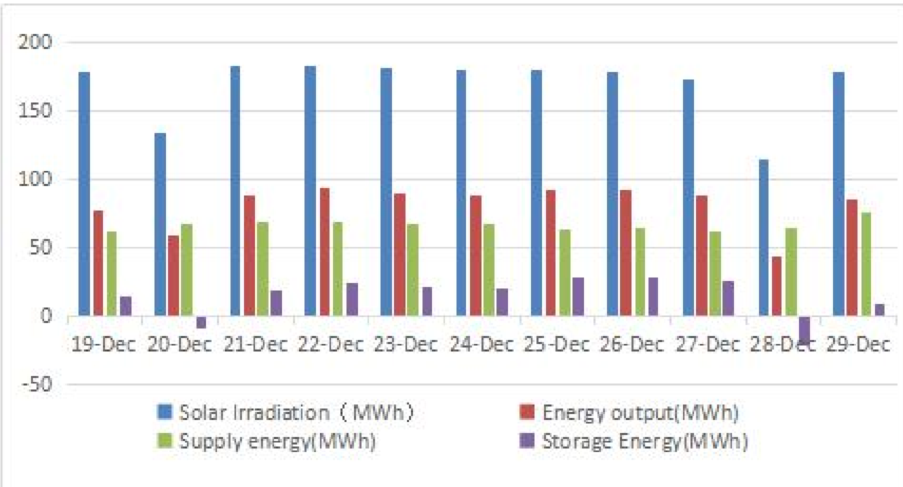

Fig.12: Energy distribution of Langkazi project

4.Conclusions

This paper summarizes the design concept and specific parameters of the large-scale solar district heating project in Langkazi, Shannan, Tibet, and focuses on the performance of the main components of the system.

It is ascertained through statistical analysis that the concept of large-scale solar central heating is completely feasible in high-altitude cold areas. In addition, due to the characteristics of non-polluting, low operating costs and long life, the solar central heating system has broad prospects in Tibet.

5.References

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