

# Existing school energy consumption diagnosis and low carbon transformation strategy of Tianjin Yaohua High school

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**ABSTRACT:** As an important part of public buildings, the school's energy consumption and carbon emissions have received widespread attention. Relying on the existing building energy conservation situation and the energy consumption of Tianjin Yaohua High school, this paper puts forward the existing problems and energy saving space of high school. Based on the goal of low-carbon transformation, the roof and other utilizable conditions were analyzed, the transformation scheme of low-carbon energy system was brought forward, which realizes clean heating, electric energy replacement and domestic hot water supply with PVT coupling with heat pump. According to calculation, it can realize 70% replacement of school electricity, 100% clean heating and 100% consumption of renewable energy. Based on economic analysis, it has strong feasibility, which provides a reference for the subsequent low-carbon transformation of existing high school.

## 1. GENERAL INTRODUCTIONS

School buildings account for 13% of the total energy consumption of public buildings in the United States, 10% in the United Kingdom, and 4% in Spain Mata (2020) [1]. Yasemin (2020) put forward the Intelligent buildings could generate crowd-sourced databases of building energy data, investigates the impact of the five school massing typologies on energy efficiency [2]. Nazanin (2019) put forward the educational buildings are in charge of about 15% of the total energy consumption of the non-residential building sector [3]. Daniel Daly (2022) found that 64 % of schools in Australian had a solar PV array installed, and schools with PV used on average 16% less energy than schools without [4]. Mohamed M.Ouf (2017) benchmark historical energy consumption over a ten-year period of 30 school buildings in Manitoba, Canada [5].

In China, there are 529,300 schools at all levels in 2021. Among them, 154,300 ordinary primary schools at the stage of compulsory education, with a floor area of 87128 9,800m<sup>2</sup>, 52,900 junior middle schools (2020) [6]. Ni Wenhui (2020) analyzed the energy consumption of 279 school buildings in Wuxi [7]. Xie (2020) analyzed the energy consumption characteristics of 19 school buildings in Qingdao [8]. Li (2021) analyzed the energy

consumption of 54 school buildings in Liaoning Province [9]. Standard for energy quota of public institutions was build up by Tianjin Administration for Market Regulation (2020) [10].

In this paper, Yaohua high school in Tianjin was investigated on the spot to obtain the basic information of buildings, to study its overall energy consumption level, characteristics and energy efficiency, the low-carbon energy system transformation was proposed.

## 2. SCHOOL PROFILE

### 2.1. Overview of school buildings

The first school building of Yaohua high School was built in 1929, and the new teaching building was built in 2003. The school covering an area of 80 mu, consisting of 11 buildings, 67710 m<sup>2</sup>, the heating area is 50000 m<sup>2</sup>. It has more than 400 teachers and 3000 students. In 2018 and 2019, energy-saving renovation was carried out for teaching buildings, dormitory buildings and gymnasiums, more than 300 sets of lamps and lanterns were replaced, and 11 multi-connected air-conditioning systems were added, see figure 1.

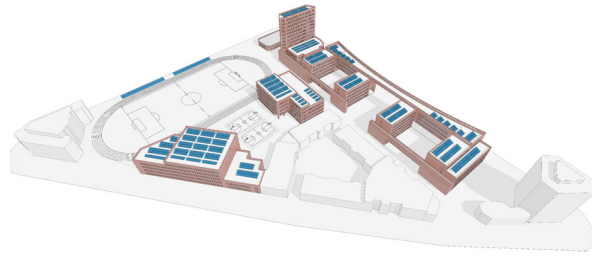
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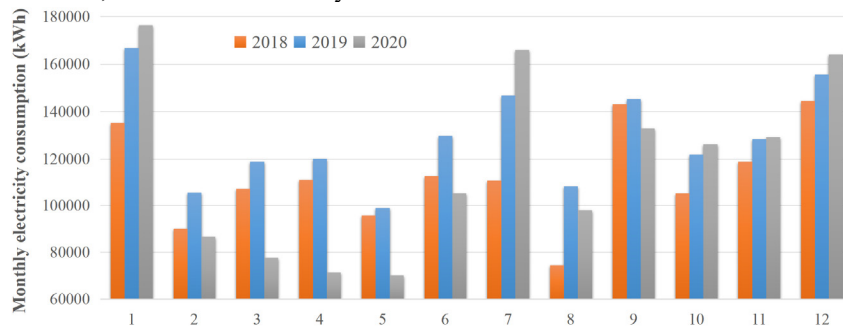


**Figure 1.** Yaohua high School

**2.2. Current situation of school energy system**

Yaohua high school is municipal heating, decentralized cooling with air conditioners and fans. The price of electricity is 0.52 yuan/kWh, the annual electricity cost

is about 630,000 yuan, and the heating cost is 2.3 million yuan. The total energy consumption in 2018 is 1,347,600 kWh; 2019 is 1,545,900 kWh. The last three years monthly electricity consumption see figure 2.



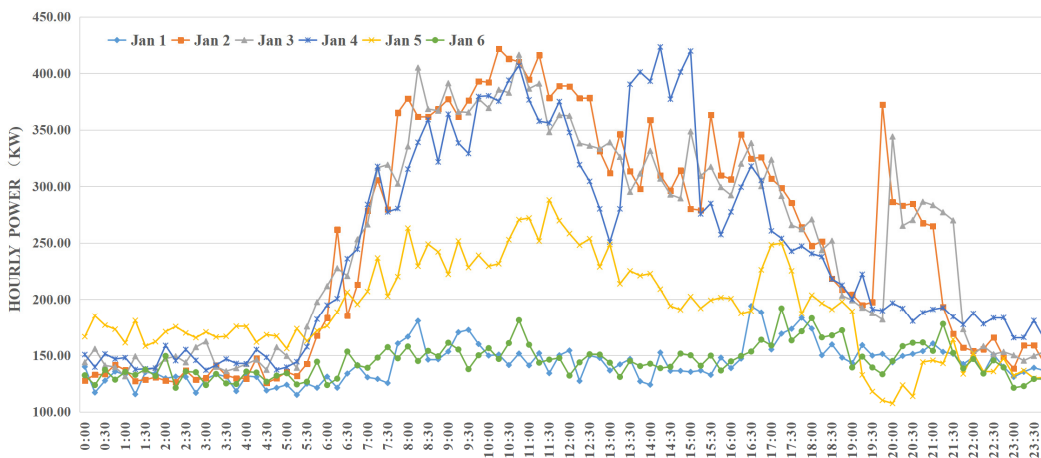
**Figure 2.** Electricity consumption in 2018-2020

As shown in figure 2, the peak value of power consumption in winter is higher, and the average monthly power consumption is basically the same as that in summer, or even higher. Taking 2019 as an example, the power consumption in December increased the heating season compared with April, and the power consumption increased 33570 kWh. In the whole heating season, the power consumption increased by nearly 90000 kWh. It shows that air conditioning is also turned on in winter, which means the municipal heating does not meet the thermal comfort requirements.

**3. DIAGNOSTIC ANALYSIS OF SCHOOL ENERGY CONSUMPTION**

**3.1. Analysis of typical daily power consumption in heating season**

The period from 1.1-1.6, 2020 is selected for correlation analysis, see figure 3, involving holidays and working days. However, there is an obvious basic load, about 100kWh, the load fluctuation at night (0: 00-5: 00), which indicates that some electrical equipment is not turned off.



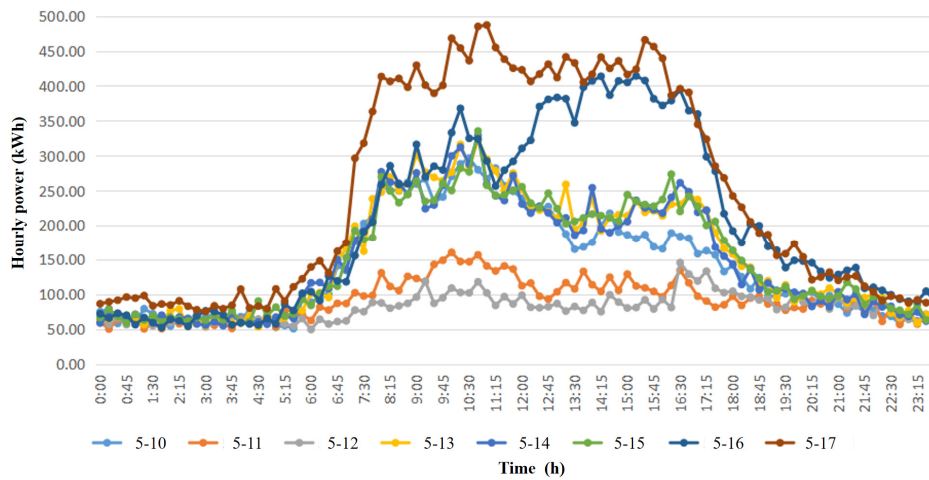
**Figure 3.** Hourly Power Consumption of 1.1 to 1.6, 2020

Through the data analysis, the hourly power of holidays (Saturday and Sunday) is maintained at about 150kW; On weekdays, the power during class is basically maintained at 300-400 kW. By selecting typical days and Saturday days, it can be found that there are

obvious differences.

### 3.2. Analysis of typical daily power consumption in transition season

The electricity hourly load in transition season typical days of 5.10-5.17, see figure 4.



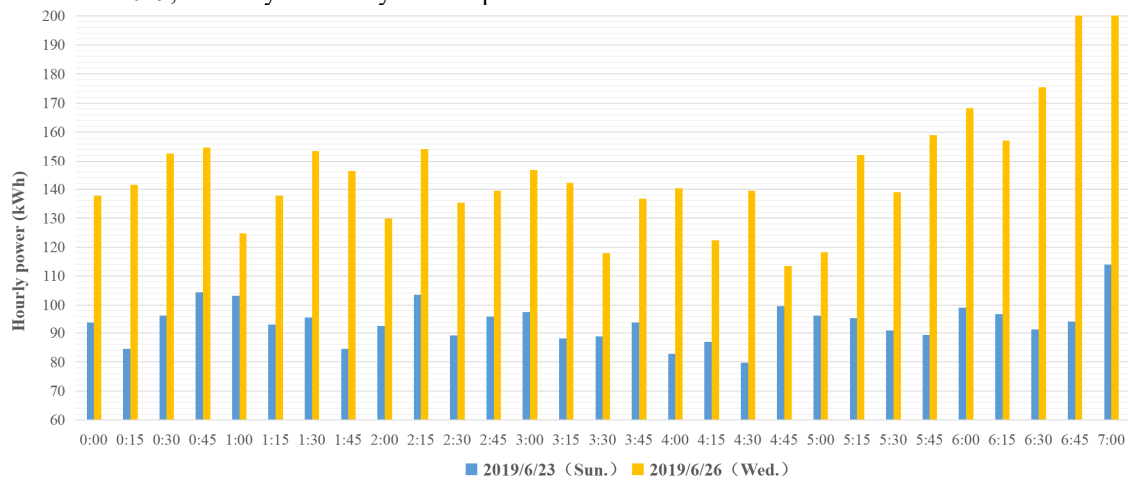
**Figure 4.** Hourly Power Variation Curve from May 10- 17, 2019

During the days, the highest temperature is 32°C, and the air conditioning is turned on, resulting in a sharp increase in hourly power. The hourly power is also above 50 kW at night, which means that the standby energy consumption is high and there is a great potential for energy saving.

on Saturday is about 1000kWh, while from Monday to Friday, it is 2000-2500kWh. Power consumption and room temperature showed a relatively complete consistency. Due to the existence of basic load, the night data of June 23 (Sunday) and June 26 (Wednesday) in 2019 are selected for analysis. As shown in figure 5, the night load difference is obvious, indicating that some of the electrical equipment opened on June 26, involve the air conditioner is not turned off, and the hourly load is about 50 kW.

### 3.3. Analysis of typical daily power consumption in cooling season

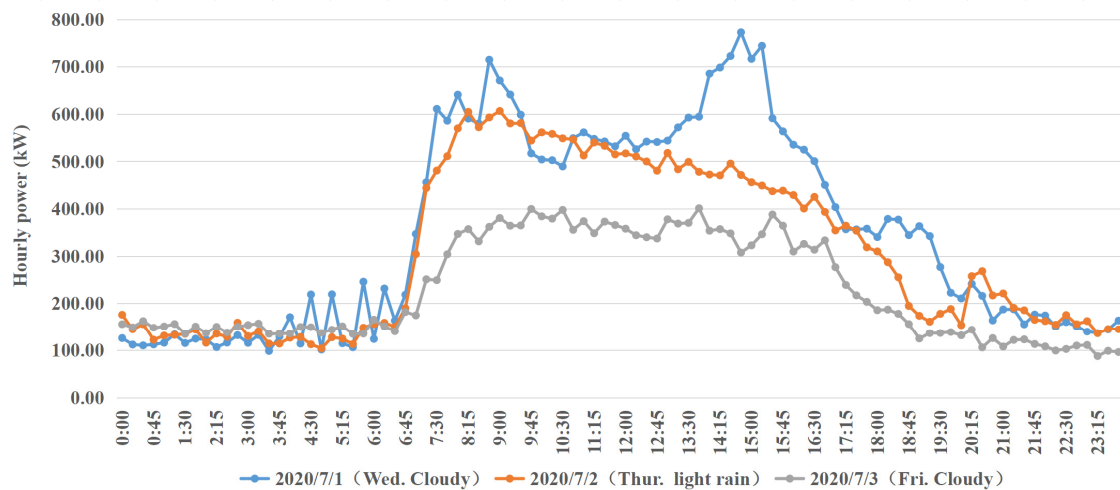
In the summer of 2019, the daily electricity consumption



**Figure 5.** Hourly Power Variation Curve at Night 6.23, 6.26

From June 23 to June 30, 2019, the average daily power consumption of typical working days in the air conditioning season is 6000 kWh, while that of Saturday and Sunday can be reduced to 3000 kWh. As the school is on holiday in the hottest period in summer, the data of several days in early July 2020 are selected for analysis.

As shown in figure 6, when the outdoor temperature is high, the hourly load increases significantly after the air conditioner is turned on, and the peak is nearly 700 kW. According to the school's curriculum time, the main energy consumption of the school is concentrated from 7:30 to 17:30.



**Figure 6.** Hourly Power Variation Curve in 7.1-7.3, 2020

### 3.4. Energy consumption benchmark

At present, Tianjin Public Building Energy Consumption Standard DB/T 29-249-2017 and Standard for energy quota of public institutions DB12/T 943-2020 both give the energy consumption index of middle schools, the constraint value of non-heating energy consumption index for complete middle schools is  $24\text{kWh}/(\text{m}^2 \cdot \text{a})$ , the recommended value is  $20\text{kWh}/(\text{m}^2 \cdot \text{a})$ , and the guiding value is  $18\text{kWh}/(\text{m}^2 \cdot \text{a})$ . On the basis of annual building power consumption and gas consumption, the non-heating energy consumption index of the school is  $26.25\text{kWh}/(\text{m}^2 \cdot \text{a})$ , which is higher than the constraint value of  $24\text{kWh}/(\text{m}^2 \cdot \text{a})$ , exceeding the standard by 9.4%.

Since the energy consumption of canteen and data room is not measured separately, it is not deducted. At the same time, because some school buildings have not been equipped with air conditioning and fresh air system, the indoor comfort at this stage still needs to be improved, and there is more energy consumption need to rise.

### 3.5. Diagnostic analysis of energy efficiency

(1) There is a 100kW basic load in the school, After deducting the standby power required by the data room and refrigerator for 24 hours, the other 50 kWh needs to be reduced.

(2) At present, the dormitory building use solar domestic hot water, but the hot water system is relatively rich, which can be considered to couple with heat pump to assist heating, to realize the comprehensive utilization of solar energy, obtain better economic and environmental benefits.

(3) The Municipal heating in winter can not achieve the expected effect, and the air conditioning still needs to be turned on, which increase about 10,000-150,000 kWh, it is double payment and insufficient comfort. At the same time, due to the existence of winter vacation, except for dormitories, most of the school buildings are used in the daytime considering the solar radiation, the heat load would be low. So the heating has a larger

energy-saving space. Meanwhile, the municipal heating fee is  $40/\text{m}^2$ , not a heat metering charge, so if Yaohua high school switches to heat pump heating, the annual heating cost can be reduced, the clean heating is valuable.

(4) In combination with the current national policy on roof photovoltaic, considering the site conditions and load characteristics of the school, it is considered to install PV on some roofs.

## 4. LOW-CARBON TRANSFORMATION OF SCHOOL

### 4.1. Building energy-saving renovation

The first to fourth school buildings and auditoriums are built around 1930, and other buildings are also built around 2000, the building energy efficiency is low. In recent years, it has carried out passive energy-saving renovation of some buildings, such as replacing energy-saving doors and windows. According to the simulation analysis of similar projects, the external shading, replacement of doors and windows, and external insulation of external walls should be given priority to meet the requirements of the National General Code for Building Energy Conservation and Renewable Energy, reduce the energy demand of buildings, with an energy saving rate is about 15% -20%.

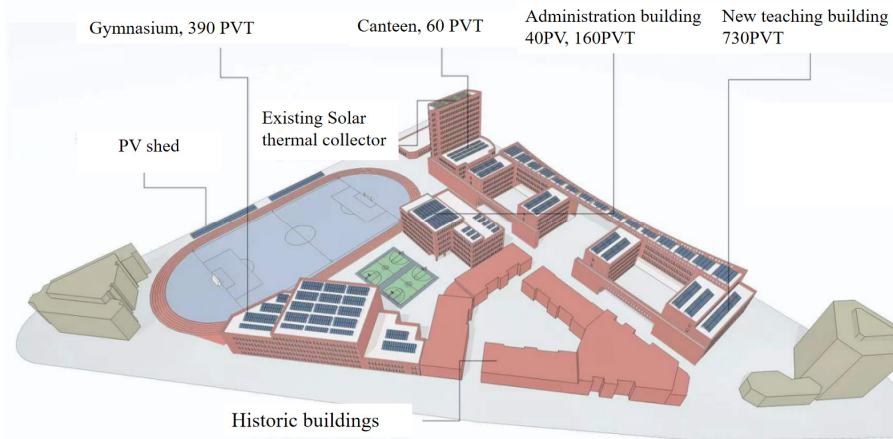
### 4.2. Replacement of high-efficiency and energy-saving equipment

At present, many energy-using equipment in the school have low energy efficiency, such as some T5 fluorescent lamps, split air conditioners, fans, which are replaced by Grade 1 energy efficiency products. As reducing the energy consumption, as reduce noise, improve refrigeration capacity and improve indoor thermal environment. According to statistics, only lamps are replaced by energy-saving lamps, which can save about 40 kWh/d and 10000 kWh per year.

### 4.3. Distributed PV

According to the solar radiation simulation analysis, excluding the shielding part, the roof of Yaohua high school can install PV 3500 m<sup>2</sup>, 536.8kWp. Considering improving the comprehensive utilization efficiency of solar energy, some roofs can install PVT components, which can not only improve the power generation

efficiency, but also meet the hot water demand of dormitories, canteens and swimming pools, as shown in figure 7. The PV system can generate about 783,000 kWh annually, and self-sufficiency electric 56%. Based on the 3.8 yuan/Wp, the PV static payback period is about 7 years. Considering the 25-years life, the income can be about 400000 yuan.



**Figure 7.** PV and PVT Installation on the Roof

### 4.4. Clean heating transformation

Yaohua high school is centralized heating, for to reduce the cost of heating and improve the indoor environment comfortable, the mode of PVT, multi-source heat pump, energy storage is adopted, this system can produce the electric whole the year, and produce the heating water for the washing and restaurant. Considering the influence of the winter and summer vacations, The time-weighted average load rate method based on the concept of temperature-frequency is adopted to calculate the heating and cooling loads of the school, as shown in Formula 1 and 2.

$$Q_c/Q_h = (q_c/q_h) \times \beta \times T \quad (1)$$

Among them,  $Q_c$ , cooling capacity, kWh;  $Q_h$ , heating capacity, kWh;  $q_c$ , cooling load index, W;  $q_h$ , heating load index, W;  $\beta$  time weighted average load rate;  $T$ , total heating/cooling hours.

$$\beta = \sum_i^n T_i \times \alpha_i / T \quad (2)$$

Among them,  $T_i$ , the running hours of the cooling and heating systems corresponding to each outdoor temperature sub-interval;  $\alpha_i$ , the load rate of cooling and heating systems corresponding to different outdoor temperature ranges.

The heating index is calculated as 50W/m<sup>2</sup>, and the heat load is 2500kW, the daily domestic hot water demand is 40t, the PVT modular is installed on the roof. The initial investment is about 4 million yuan, the annual operating cost is about 700,000 yuan, and about 1.0 million yuan of heating cost can be saved annually, the payback period is 4 years.

It can achieve 100% clean energy heating, and reduce more than 30% heating costs. The solar energy system can meet about 52.3% of the hot water demand, and the annual supply of PVT energy is 220MWh, reduce carbon dioxide emissions by about 38667 kg, the monthly heating supply.

## 5. CONCLUSION

Based on the investigation of the existing primary and secondary school buildings in Tianjin, the following conclusions are drawn: (1) Most of the existing junior and senior high school campuses in Tianjin were built before 2010, the level of building energy efficiency is low, the passive energy-saving renovation has obvious energy-saving benefits, and the expected energy-saving rate is more than 20%; (2) The school mostly uses municipal heating and split air conditioning for cooling, and there is no fresh air system, so the heating cost is high, and the energy consumption of heating and cooling is high; (3) The indoor thermal environment is not comfortable, the wind and light environment need to be improved; (4) The utilization rate of renewable energy in the school is low, and there are few projects such as distributed photovoltaic and clean heating.

Based on the energy efficiency diagnosis and analysis of Yaohua high school, this paper proposes energy-saving renovation of existing buildings, replacement of energy-efficient equipment (including more protective lighting, replacement of split air conditioning), addition of photovoltaic, and low-carbon renovation strategy based on solar + air source heat pump + energy storage for clean heating and domestic hot water, which can achieve 100% clean heating. According to the preliminary calculation, the carbon emission of buildings can be reduced by more than 70%. If reinforce management and the PV installation of playgrounds is considered as a whole, the goal of zero energy consumption and zero carbon can be achieved, which has reference significance for the transformation of existing primary and secondary schools in Tianjin and other areas of China.

## ACKNOWLEDGMENTS

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