

HEATING AND COOLING WITH OFF-SEASON THERMAL STORAGE

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ABSTRACT

The concept and basic principle of heating in winter and cooling in summer with the anti-season thermal storage have been proposed, and provides a basis for effective application of solar energy and temperature difference in different seasons. According to geography, weather, solar energy collection and thermal storage, the new method to design the building heating and cooling system is established, which provides a basic technical guidelines for solo solar energy around-year air conditioning system with this new technique. The new technique can be applied in the regions of 25°-45° north and south latitude and will reduce total energy consumption worldwide by 18%.

Keywords:

heating, cooling, off-season, thermal storage

1. INTRODUCTION

Through the analysis of meteorological data, we can find that although there is a tendency towards abnormal climate and global warming, the local climate feature is obvious and steady

from statistical data. The total quantity of solar radiant heat is steady, which is the steady heating resources for heat collection; the average temperature of the coldest month in winter doesn't fluctuate wildly, which is the steady cooling resources for cooling storage in winter; the annual average temperature also doesn't fluctuate wildly, which demonstrates that the abnormal climate has periodical symmetrical features between cool and heat; the periodical climate change caused by the earth moving around the sun contains a vast reservoir of cooling and heating resources. The anti-season thermal storage technology is the effective method to solve the problem of building heating and cooling by using natural cooling and heating resources as more as possible.

The earth's surface solar energy has three prominent features: (1) The annual average radiation intensity is low (110-260w/m²), and the efficiency of transferring into high-grade energy (high-temperature thermal energy and electric energy) is low (10-20%), but the efficiency of transferring into low-temperature (60-80°C) thermal energy is high (40-60%). Thus, it is one of the high-efficiency methods to supply building heating directly. (2) The annual total radiation quantity is steady, but

the transient radiation intensity is not steady because of the climate influence. So it is necessary for heating supply with the thermal storage. (3) The meteorological statistics show that the total radiation intensity in summer is twice to three times of that in winter, the distribution of radiation intensity is opposite to heating demand in different seasons. Thus, the distribution of radiation intensity opposite to heating demand in different seasons and unstable transient radiation can be solved with the anti-season thermal storage, which is the best technique to realize the sole solar energy heating. As to the area where the average temperature is less than 5°C in the coldest month and more than 25°C in the hottest month, the building cooling is supplied by stored cooling in winter. The around-year air conditioning system with anti-season thermal storage make use of the earth's surface solar energy and temperature differences energy, it is the core technology of sole solar energy building.

2. PRINCIPLE AND CALCULATION METHOD (Fig.1)

The around-year air conditioning system with anti-season thermal storage is using solar collector to collect heat from solar energy and store them in heat cellar in non-heating season, which will be used for building heating in winter. When the solar energy stored in non-heating season just can supplement the heating supply collected in winter, which is less than requirement due to the low radiation intensity, the smallest area solar collector and reasonable thermal storage volume to realize the sole solar heating in winter will be used. Anti-season cooling storage is to collect and store cooling energy in winter with the cool cellar and then to supply it for building cooling in summer. The just cooling energy stored in winter to satisfy the need of building cooling in summer can be

used in order to obtain the least volume of cool cellar. According to the collector area, the heat cellar volume and the cooling cellar volume determined by above-mentioned principle, the initial construction cost can be estimated. Combined with the reduced operating cost, the investment recovery period can be calculated, which can be used to determine its economic reasonability. According to the meteorological data in many years and in different regions, and with the construction thermal engineering design criterion, the calculation results following will demonstrate that in the regions of 25°-45° north latitude in China, the around-year air conditioning system with anti-season thermal storage can economically and reasonably replace all the heating boiler and chiller.

2.1 Brief Introduction of Related Meteorological Data and Concept (Fig.2)

The mean daily illumination in standards meteorological year is $E_s(d)=E_s(d+365)$; the mean daily temperature, $t_e(d)=t_e(d+365)$, is the period function of d (date). Different locations constitute quasi-function family and they are the foundation of calculating solar radiation energy, heating and cooling time and outside air temperature.

Yearly solar radiation illumination:
 $\bar{E}_s=1/365 \cdot \sum E_s(d)$, (Meteorological statistical unit :[W/m²])

Mean solar radiation illumination in heating period in winter: $\bar{E}'_{sw}=1/Z(d) \cdot \sum E_{sw}(d)$,

$Z(d)$ is the number of the days when $t_e(d)$ is lower than 5°C.

Mean solar radiation illumination in cooling period in
 Summer: $\bar{E}'_{ss}=1/Z'(d) \cdot \sum E_{ss}(d)$,

$Z'(d)$ is the number of the days when $t_e(d)$ is higher than 25°C .

2.2 Calculation of Solar Radiation Energy

The annual heat production quantity of 1m^2 solar collector in earth's surface:

$$Q_s = 365 k_i \cdot \bar{E}_s \cdot \eta \quad [\text{kJ}/\text{m}^2]$$

The heat production quantity of 1m^2 solar collector in earth's surface in the heating period in winter:

$$Q_{sw} = Z(d) \cdot k_i \cdot \bar{E}'_{sw} \cdot \eta_w \quad [\text{kJ}/\text{m}^2]$$

The annual electrical production quantity of 1m^2 solar cell: $P_s = 365 k_i \cdot \bar{E}_s \cdot \eta_p \quad [\text{kJ}/\text{m}^2]$

The electrical production quantity of 1m^2 solar cell in

cooling period in summer:

$$P_{ss} = Z'(d) \cdot k_i \cdot \bar{E}'_{ss} \cdot \eta_p \quad [\text{kJ}/\text{m}^2]$$

here,

η is the annual mean efficiency of solar collector, $\eta \approx 50\%$;

η_s is the efficiency of solar collector in summer, $\eta_s \approx 55\%$;

η_w is the efficiency of solar collector in winter, $\eta_w \approx 40\%$;

η_p is the efficiency of solar cell, $\eta_p \approx 15\%$;

k_i is dimension conversion coefficient.

Note: If the collector only absorbing the direct solar energy is used, $E_s(d)$ should be chosen as the direct radiation component of solar energy; and if the solar collector and solar cell are not placed horizontally, $E_s(d)$ should be taken as its component according to its inclination angel.

2.3 Calculation of Building Energy Consumed

The heating load of per building area in the heating period:

$$Q_H = 0.024 K_{sw} \cdot S_o / S_B \cdot (T_{18} - \bar{t}_e) \cdot Z(d) \quad [\text{kJ}/\text{m}^2]$$

The cooling load of per building area in the cooling period:

$$Q_C = 0.024 K_{ss} \cdot S_o / S_B \cdot (\bar{t}'_e - T_{26}) \cdot Z'(d) \quad [\text{kJ}/\text{m}^2]$$

here,

K_{sw} is the overall heat transfer coefficient of building envelope in the heating period of winter,

K_{ss} is the overall heat transfer coefficient of building envelope in the cooling period of summer;

S_o is the total surface area of building envelope;

S_B is the floor area of the building;

$\bar{t}'_e$ is the outdoor mean air temperature during the cooling period, $\bar{t}'_e = \sum t_e(d) / Z'(d)$;

$\bar{t}_e$ is the outdoor mean air temperature during the heating period, $\bar{t}_e = \sum t_e(d) / Z(d)$;

T_{18} is the indoor design temperature in the heating period;

T_{26} is the indoor design temperature in the cooling period.

2.4 Calculation of Thermal Storage Efficiency of Cooling and Heating Cellar

Suppose: the thermal storage quantity of solar collector in the non-heating period is Q_K ; the annual thermal storage loss is ΔQ_K ; the annual thermal storage efficiency is $\eta_K = 1 - \Delta Q_K / Q_K$; the thermal storage ratio is $\lambda = Q_K / Q_H$; $T_H \geq 60^\circ\text{C}$ is annual average temperature of heat cellar; C_p is average volume specific heat capacity of heat cellar; T_O is local annual average temperature $T_O = \sum t_e(d) / 365$ (can be seen as shallow underground temperature without geothermal resources); S_H is the shape coefficient of heat cellar, and V_K is the volume of heat cellar, and K_H is the total heat transfer coefficient of heat cellar, the thermal storage time is 365 days.

The annual thermal storage loss is:

$$\Delta Q_K = S_H \cdot V_K \cdot K_H \cdot (T_H - T_O) \cdot 365 \text{ ki} ;$$

the thermal storage quantity in the non-heating period is: $Q_K = V_K \cdot C_p (T_H - T_{18}) / \eta_K$

From above equations we can get the annual thermal storage efficiency:

$$1/\eta_K = 1 + S_H \cdot K_H / C_p \cdot (T_H - T_O) / (T_H - T_{18}) \cdot 365 \text{ ki} \quad (1)$$

Suppose: the annual cooling storage efficiency is η'_K , the cooling storage quantity is Q_C / η'_K , $T_C (\leq 5^\circ\text{C})$ is local cooling storage temperature, that is the average temperature in the coldest month, S_C is the shape coefficient of cool cellar, and V_C is the volume of cool cellar, K_C is the total heat transfer coefficient of cool cellar, the cooling storage time is 210 days, C_p is average volume specific heat capacity of cool cellar.

The annual cooling storage loss is:

$$\Delta Q_C = S_C \cdot V_C \cdot K_C \cdot (T_O - T_C) \cdot 210 \text{ ki}$$

The cooling storage quantity in winter is:

$$Q_C / \eta'_K = V_C \cdot C_p (T_{26} - T_C)$$

The annual cooling storage efficiency is:

$$\begin{aligned} \eta'_K &= 1 - \Delta Q_C / (Q_C / \eta'_K) \\ &= 1 - S_C \cdot K_C / C_p \cdot (T_O - T_C) / (T_{26} - T_C) \cdot 210 \text{ ki} \quad (2) \end{aligned}$$

Note: when ice storage is the way to storage cooling, C_p includes volume melting heat of ice.

From equation (1) and (2), we can learn that the smaller the K_H , S_H and the higher the C_p , the bigger the η_K . η_K should be kept larger than 70% when the thermal insulation of heat cellar is designed.

2.5 Energy Balance Equation of Anti-season Thermal Storage

Define the thermal storage ratio: $\lambda = Q_K / Q_H$;

S_K is the efficient area of solar collector needed for per building area.

When the solar energy stored in non-heating period can just satisfy the heating requirement in the heating period in winter, and the solar energy collected directly in heating period of winter is utilized firstly, the energy balance equation can be established.

The heating quantity supplemented in the heating period in winter is:

$$Q_H - S_K \cdot Q_{sw} = \eta_K \cdot Q_K, \quad (3)$$

The stored solar energy in non-heating period:

$$S_K \cdot (Q_s - Q_{sw}) = Q_K, \quad (4)$$

Equation (3) and (4) are the basic equation set of anti-season thermal storage.

From above equations we can get:

The thermal storage ratio:

$$1/\lambda = Q_{sw} / (Q_s - Q_{sw}) + \eta_K \quad (5)$$

The collector area:

$$S_K = (1 - \lambda \cdot \eta_K) \cdot Q_H / Q_{sw} \quad [\text{M}^2/\text{m}^2] \quad (6)$$

The circulation thermal storage volume:

$$V_K = \lambda \cdot \eta_K \cdot Q_H / C_p (T_H - T_{18}) \quad [\text{m}^3/\text{m}^2] \quad (7)$$

Under the ideal adiabatic condition, $\eta_K = 100\%$, above equations are changed as:

$$\lambda = 1 - Q_{sw} / Q_s,$$

$$S_K = (1 - \lambda) \cdot Q_H / Q_{sw}$$

$$V_K = \lambda \cdot Q_H / C_p (T_H - T_{18})$$

λ is only related to local meteorological data, so is called meteorological thermal storage ratio.

2.6 Calculation of Cool Cellar Colume

The cooling storage quantity in winter is:

$$Q_C / \eta'_K = V_C \cdot C_p (T_{26} - T_C).$$

The cooling storage volume of 1m² building area is:

$$V_C = Q_C / \eta'_K / C'p (T_{26} - T_C) \quad [\text{m}^3/\text{m}^2] \quad (8)$$

According to standard meteorological year data and equations (1)-(8), the thermal storage ratio, collector area, circulation thermal storage volume and cooling storage volume can be calculated. If the maximum difference between 50 or 100 years' meteorological data and standard meteorological year data are taken into account, a new design criterion to ensure 50 or 100 years' requirement can be obtained.

2.7 Capacity Estimation of Solar Cell

The capacity of solar cell should be calculated considering the heating circulation in winter, the thermal storage circulation and local radiation intensity in winter. Because the average radiation intensity in summer is twice to three times of that in winter, the solar cell is chosen to simultaneously drive thermal storage circulation and cold wind circulation in summer. As to multi-story building which is lower than 30m, the effective area of solar cell which is used to drive the water circulation can be estimated as $S_p = 10\% S_K$.

2.8 Estimation of Initial Construction Cost

The initial construction cost is:

$$\Delta C_K = C_1 \cdot S_K + C_2 \cdot V_K + C_3 \cdot S_p \quad [\text{yuan}/\text{m}^2]$$

The estimation coefficient for the solar collection system (including pipeline, pumps, circulation energy reserved cupboards), $C_1 = 1500 \text{ yuan}/\text{m}^2$.

The estimation coefficient for heating and cooling system (including the underground construction, thermal insulation, heat exchange, waterproof of heat cellar and cold cellar), $C_2 = 300 \text{ yuan}/\text{m}^3$.

The estimation coefficient for the direct current power system of solar cell, $C_3 = 3000 \text{ yuan}/\text{m}^2$.

2.9 Recovery Period of Energy-Saving

The recovery period of energy-saving, N , can be calculated as:

$$\Delta C_K = (P_1 \cdot Q_H + P_2 \cdot Q_C) \cdot \sum_{1}^N (1 + \alpha)^N$$

Here, α is annual growth rate of energy price ($\alpha = 6\%$, forecasted by the trend of 50 years' energy price); P_1 is heating supply price; P_2 is the price of electrical power.

3. CALCULATION RESULTS AND ANALYSIS OF 25 TYPICAL CLIMATE PROVINCIAL CITIES

25 capital cities chosen here represent the typical climates of 25°-45° north latitude in China, covering frigid zone, cold zone, hot summer and cold winter zone, which account for 90% of population, territory area, gross amount of economy and energy cost.

According meteorological data of to these 25 cities and construction thermal engineering design criterion, the major technique parameters of around-year air-conditioning system with anti-season thermal storage under all kinds of climate conditions are calculated (Table1).

In the cities where the solar radiation intensity is strong and there is no cooling requirement, such as Lasa, Lanzhou, and Yinchuan, the initial cost is lower and about 400-500 yuan/m². Although the solar radiation intensity is not strong in Chengdu city, the climate is warm, thus, the initial construction cost is low and about 300 yuan/m². The initial construction cost of around -year air conditioning system with anti-season thermal storage in the areas with a high heating and cooling load is great, and the

energy-saving efficiency is obvious. So the invest recovery periods by energy-saving tend to be consistent.

Calculation assumptions: solar collector and solar cell are all install horizontally, the water is chosen as the intermedium for heating storage and cooling storage. The water temperature of heat cellar is 60°C ($T_H=60^{\circ}\text{C}$) and the thermal storage efficiency of 365 days is 70% ($\eta_K=70\%$). The water temperature of cool cellar is 5°C ($T_C=5^{\circ}\text{C}$). The cooling storage efficiency of 210 days is 90% ($\eta'_K=90\%$). Solar collector efficiency is 50%, solar cell efficiency is 15%, and building energy consumption should satisfy with JGJ26-95 and JGJ134-2001 standard.

In the Table1, the initial cost of existing heating and cooling system (60 yuan/ m^2) are not included. Heat price is 0.35 yuan/Mcal, cooling price 0.5 yuan / $\text{kW} \cdot \text{h}$. Taking energy price growth (6% rising each year) into account, the initial construction cost of around-year air-conditioning system with anti-season thermal storage is equivalent of energy costs of heating and cooling in 12-15 years, i.e., the recovery period of investing by energy-saving is 12-15 years.

From Table1, it can be seen that in the areas of 25° - 45° north latitude in China, the around-year air-conditioning system with anti-season thermal storage can replace all the boiler for building heating and chiller for building cooling, and to make indoor environment meet the requirements of building standards. The recovery period of investing by energy-saving is 12-15 years, and it is lower than that of heat and power plant supply system, which is 15-20 years.

4. CONCLUSIONS

In the areas of 25° - 45° north latitude in China, the around-year air-conditioning system with anti-season thermal storage can replace the boiler for building heating and chiller for building cooling, and to make the indoor environment meet the requirements of building standards. The calculation results shows that the earth's surface solar energy and temperature difference energy brought by the periodical change of climate can meet the requirements of building heating in winter and cooling in summer. The basic principle and technical scheme of around-year air-conditioning system with anti-season thermal storage are proposed, which provide a new method of utilizing solar energy and temperature differences energy.

5. SIGNIFICANCE OF APPLYING AROUND-YEAR AIR-CONDITIONING SYSTEM WITH ANTI-SEASON THERMAL STORAGE

It can reduce by 18% of global energy cost and reduce the discharge amount of CO_2 drastically. It will change the human's life style for the heating and cooling. Just like the boiler and chiller to have changed the human's life style in the industry civilization era, the around-year air conditioning system with anti-season thermal storage can lead human's life style for heating and cooling into green complete solar energy era.

I wish to get financial aid from the World Nature Foundation and cooperate with the related organizations in the countries located at 25° - 45° north latitude to study the application programs of around-year air-conditioning system with anti-season thermal storage and build the pilot demonstration projects.

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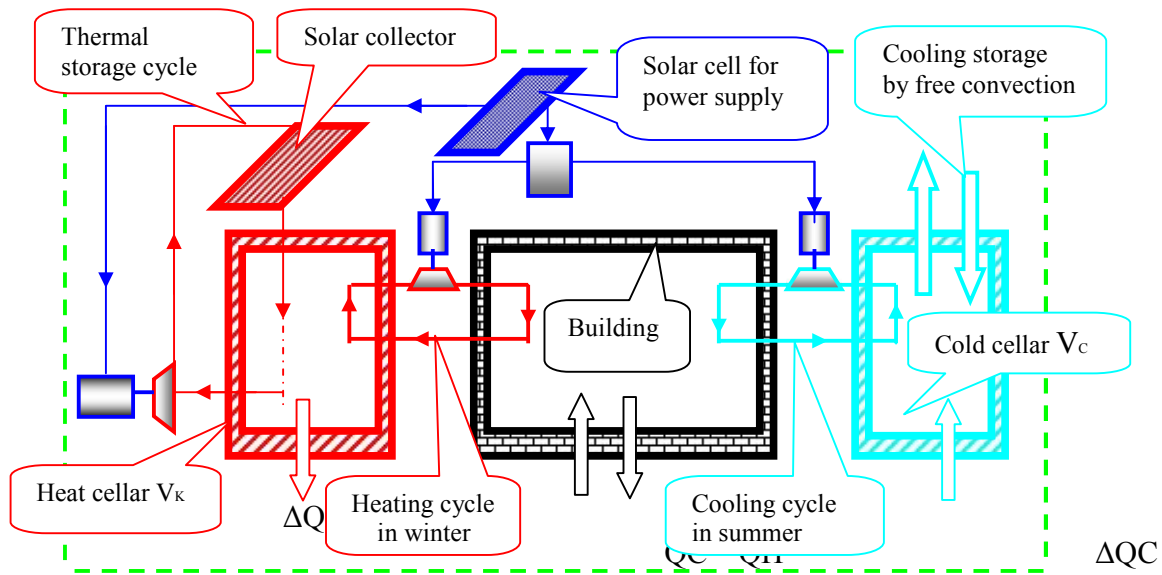


Fig.1. Schematic of the around-year air conditioning system with anti-season thermal storage

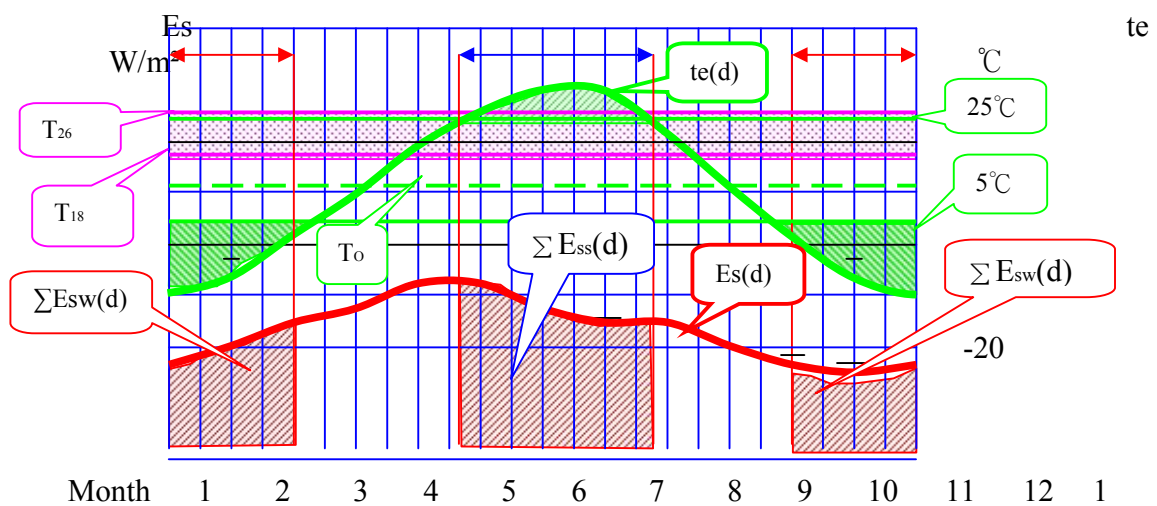


Fig.2 Meteorological Data

TABLE 1:

Climate zone		Frigid zone	Cold zone		Hot summer and cold winter zone	
		I C , I D , VII B, VI A	II A , II B	II B, VI C	III A , III B	III C
city		Harbin, Changchun, Shenyang, Hohhot, Xining, Urumqi	Shijiazhuang, Beijing, Tianjin, Xi'an, Zhengzhou, Jinan, Taiyuan	Lhasa, Yinchuan, Lanzhou	Hefei, Shanghai, Nanjing, Hangzhou, Nanchang, Wuhan, Changsha, Chongqing	Chengdu
equivalent heat storage volume of water	m ³ /m ²	1~1.5	0.7~1	0.7~1	0.2~0.5	0.25
Equivalent cold storage volume of water	m ³ /m ²	0	0.7~1.5	0	2~2.5	0.55
Horizontal plate solar collector area	m ² /m ²	0.15~0.25	0.1~0.15	0.1~0.15	0.05~0.1	0.04
Area of solar panels	m ² /m ²	0.015~0.025	0.01~0.015	0.01~0.05	0.005~0.01	0.004
The initial cost of anti-season thermal storage	yuan/m ²	600~700	400~500	400~500	200~300	120
Total invest for heating and cooling storage	yuan/m ²	600~700	800~900	400~500	800~1000	300
recovery period of investing	year	15~15.18	15	12~14	14-15	13.5