The optimum analysis on air-conditioning system with partial cool thermal storage by PCM

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Abstract

The paper does some research work on limitations of design of PCM cool thermal storage in air-conditioning system, and provides some concepts related to the idea, on which the paper explains the capacity of this kind of air-conditioning system to reduce power highest need . Finally, the analysis method is described concretely by an example project in the campus of USTC.

Keywords: air-conditioning system, PCM cool thermal storage

1. Background

At present, cool thermal storage by ice has been accepted widely in the world for decreasing highest power requirement of air-conditioning system on day, and people have accumulated much experience on it. During operation, it's not difficult to find that refrigerators have to work under conditions below 0 when the system deposit the cool to water tanks. In this temperature range, refrigerators don't work efficiently. In design, the ice-making process have to be guaranteed fully, so the operation of refrigerator on day time can only be under a partial load condition. This , on the other hands, provided another cost because of inefficient operation of refrigerator on day-time period. For those retrofitted projects, the air-conditioning systems are non-cool-thermal-storage ones. In view of financial cost, the best way to add cool thermal storage function into the system is to have its main components left as soon as possible. Among them, the biggest component is refrigerator. SO it is the better for a kind of material which can become solid at temperature higher than 0 (PCM) to be used. The PCM has been studied widely in the world, and some demonstrative projects have been completed in some new buildings.

When PCM applies to air-conditioning system as a cool thermal storage material, the same refrigerators should provide cool for water tanks in night and for the chilled water in system on day. During design, these two kinds of cool needs have to be considered at the same time, and the selection of devices must meet the maximum cool need of the two, and some analytical work has to be done on the financial balance between the operation cost and the investment of cool storage system provided that the cool requirement be met. In some extremes, the saving of power cost cannot compensate for that of addition of cool thermal storage system. In other words, the payback years is too long. The following provides a method to estimate when and how the design of cool thermal storage system by PCM for air condition system can be cost-effective provided that the cool requirement be met?

The PCM system is shown in Fig.1. The refrigerator in the system serves day and night. In night, it deposits the cool into the PCM container. On day time, the cool is provided from the PCM container and refrigerator at the same time.So the size of refrigerator is reduced in comparison with the normal one(system(2) in Fig.1).Correspondingly, the investment and the highest power need of refrigerator also are reduced. The context following describe a method to analysis the financial balance and to estimate whether it can reduce the power need to the required level.

2. The cost of system

A. Investment of system

$$M_i = M_{i0} + M_{i1} + M_{i2} + M_{i3} + \delta M_i$$

where,

M_i —— total investment of system;

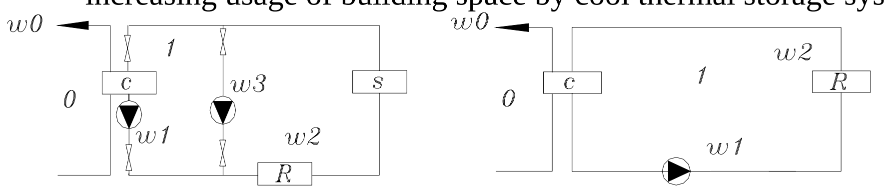
M_{i0}——the investment for devices and ducts of air system;

M_{i1} ——the investment for devices and pipelines of chilled water system;

M_{i2} —— the investment for refrigerators and their accessories;

M_{i3} —— the investment for devices and pipes of cool thermal storage system;

δM_i ——the payment for increasing line dimension of power supply and for increasing usage of building space by cool thermal storage system.



(1)With partial cool thermal storage system (2)No cool thermal storage system

c- fan coils, s-cool deposit device, R-refrigerator

Fig.1 Two projects discussed in paper

B. Annual payment for operation and maintenance of system

$$M_r = M_{r0} + M_{r1} + M_{r2} + M_{r3} + \delta M_r$$

where, M_r —— total cost of system for operation and maintenance a year;

M_{r0} —— the cost for devices and ducts of air system;

M_{r1} —— the cost for devices and pipelines of chilled water system;

M_{r2} —— the cost for refrigerators and their accessories;

M_{r3}—— the cost for devices and pipes of cool thermal storage system;

δM_r —— the cost for increasing line dimension of power supply and for increasing usage of building space by cool thermal storage system.

C. Total payment of system in n years

$M=M_i + M_r * k_c$

$$k_c = \frac{1-(1+i_e)^{-n}}{i_e}$$

$i_e = \frac{i_1+1}{i_2+1} - 1$, effective annual interest rate; i_1 annual interest rate; i_2 the rate of power price inflation.

3. Payback years and technical estimation model

A. Description of payback years

a). Air-conditioning system with cool thermal storage

$$M_r = \sum_0^d m_r$$

The daily cost for operation

$$m_r = \int_{\Delta t1} (w_0 + w_1 + w_2) \cdot P_1 \cdot d\tau + \int_{\Delta t2} (w_2 + w_3) \cdot P_2 d\tau_r$$

where

m_r =daily operation cost w_0 w_1 =power of fan-and-coils and circulating pumps

w_2 = power for refrigerators and their accessories

w_3 = pumps' power of cool charge system,*kw*

P_1 P_2 = electricity prices of day and night respectively

$\Delta t_1 \Delta t_2$ =periods for operation of air-conditioning and cool charge

d =days for operation of air-conditioning system

b). The air-conditioning system with no cool thermal storage system (expressed by superscription 0)

Annual operation cost $M_r^0 = \sum_0^d m_r^0$

Daily operation cost $m_r^0 = \int_{\Delta t1} (w_0^0 + w_1^0 + w_2^0) \cdot P_1 \cdot d\tau$

c). The comparison between these two kinds of projects

By comparison with normal one, air-conditioning system with cool thermal storage will increase investment (ΔM_i)and decease annual cost(ΔM_r). So in *n* years, the net present value of benefit from saving operation cost minus investment increment is

$$\Delta M = \Delta M_r \cdot k_c - \Delta M_i$$

When $\Delta M = 0$the payback years of investment is n

$$n = -\frac{\ln(1 - \frac{\Delta M_i}{\Delta M_r} i_e)}{\ln(1+i_e)} \quad (1)$$

where

$$\Delta M_i = M_i - M_i^{\ 0}$$

In the paper, we assume that $M_{i0}^0 = M_{i0}, M_{i1}^0 = M_{i1}, \delta M_i^0 = \delta M_i$, so

$$\Delta M_i = (M_{i2} + M_{i3}) - (M_{i2}^0)$$

$$\Delta M_r = M_r^{\ 0} - M_r$$

The assumption of $w_0^0 = w_0, w_1^0 = w_1$ leads to

$$\Delta M_r = \sum_1^d \left[\int_{\Delta t_1} (w_2^0 - w_2) \cdot p_1 \cdot d\tau \right] - \sum_1^d \left[\int_{\Delta t_2} (w_2 + w_3 \cdot) p_2 \cdot d\tau \right] \qquad (2)$$

B. Simplification of equation (2)

a). Definition of k_w

For a building, there are two alternatives available to air-conditioning system. One is the normal one, which is of no cool thermal storage; the other is that with cool thermal storage. The two alternatives will cost differently, and will require different highest value of power at the time of biggest cool requirement. To meet the same amount of cool, the ratio of the highest power provided for the air-conditioning system with cool thermal storage to that for the normal one is defined in the paper, which is called as coefficient of power supply(k_w). To simplify the analysis process, we use k_w to represent the ratio of the refrigerators' rated power plus fan-coils' rated power w_2 to w_2^0 in the normal one. That is

$$k_w = \frac{w_2}{w_2^0}$$

b) The annual equivalent annual time τ_e and k_t

If E is the actual annual power consumption, E_0 is the annual power consumption when the refrigerator(s) run at the rated power throughout the year(T), then $\tau_e = \frac{E}{E_0} \cdot T$ is called equivalent annual time for E_0. Here, we assume that the day(Δt)is divided into two parts of which Δt_1 is used for cool release for air-conditioning need, and Δt_2 is for cool deposit period . $\Delta t = \Delta t_1 + \Delta t_2$. So, a factor k_t is defined as follows:

$$k_t = \frac{\Delta t_1}{\Delta t_2}$$

c) Annual simplified operation cost calculation

$$\Delta M_r = \sum \Delta m_r$$

$$= \tau_e \cdot P_1 \cdot \left[\left(\frac{1}{k_w} - 1 - \frac{1}{k_t \cdot k_P} \right) \cdot w_2 - \frac{1}{k_t \cdot k_P} \cdot w_3 \right]$$

where $k_t = \Delta t_1 / \Delta t_2, k_P = P_1 / P_2$

d). $k_{w\max}$

When $\Delta m_r = 0$ there's maxim k_w that is

$$k_{w\max} = \frac{k_t \cdot k_P \cdot}{(1 - \frac{w_3}{w_2}) + k_t \cdot k_P} \qquad (3a)$$

Normally, $\frac{w_3}{w_2} < 1\%$, so $k_{w\max} = \frac{k_t \cdot k_P}{k_t \cdot k_P + 1}$ (3b)

e) $k_{w\min}$

In design day, supposed that the total cool need be Q_t(kwh), and that refrigerators run all day(24 hrs), the minimum load imposed on refrigerators is Q_t/24(kw), which is the minimum value that can drive the system with cool thermal storage system to satisfy the cool need of building. The k_w obtained in this case is the smallest one (k_{wmin}).

f) k_w

In practice, k_w *must be within (*k_{wmin}, k_{wmax}*)*. In other words, the requirement for decreasing power highest value of air-conditioning system by adding cool thermal storage system with PCM is within a fixed range. When k_w being out of this range, the design is improper either economically or technologically.

4. Procedure to apply the idea

As related above, the aim to add cool thermal storage to an air-conditioning system is to decrease the highest power requirement of refrigerators. For that with PCM as cool thermal storage material, the decreasing degree falls within k_{wmin} k_{wmax}, but not 01. When the required k_w is in this range, it can be realized by system in practice. So the procedure to see whether the system is operational is:

A. Calculate k_{wmin} and k_{wma};

B. Calculate k_w , to see whether $k_{wmin} < k_w < k_{wma}$;

C. If $k_{wmin} < k_w < k_{wma}$, calculate the payback years according to equation (1).

5. An example project

In following, an example project in my campus is provided to demonstrate the idea related above. USTC is setting up a building for foreign experts who visit or work in USTC. This project's air-conditioning system is planned to be added with cool thermal storage system. For the purpose of research work on properties of PCM, USTC made an contract with an air-conditioning company to provide a set of customized devices and materials for this cool thermal storage system, including other normal components and devices. This project is being completed by the end of the year.

If USTC requires this system could decrease 40% of highest power need of normal air-conditioning system, by use of the idea above, the paper makes an judgment if this requirement can be realized .

A. To define required k_w

k_w=10.4=60%

B. To define k_{wmin} k_{wmax},

According to [2], $\Delta t_1 = 14hrs$, $\Delta t_2 = 10hrs$, k_p=4, so k_{wmax}=0.848;

Because of Q_t=3470 *kwh*, the device selection can base on 3470/24=144.8 *kw*. In the extreme, two refrigerators,SJC-15 and SJC-30, are temporarily selected, with total rated power 45 tons. So, k_{wmin}=0.3.

C. Because of k_{wmin} <k_w <k_{wmax}, USTC's reqirement can be realized by system.

D. Payback years(*n*) in the case

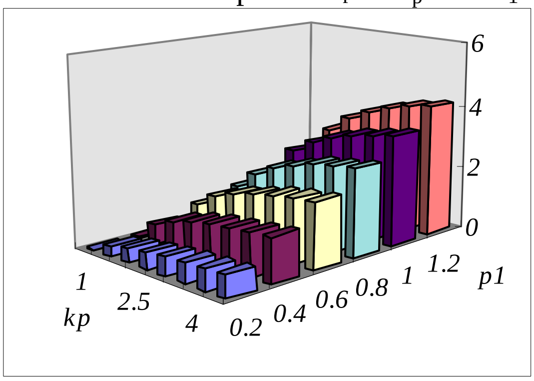
The selection above is only for k_{wmin} calculation. For the real system, it may not meet with highest cool need. So, it is necessary to select refrigerators once more. According to k_w=60%, select two sets of SJC-30H which are cooled by air, and corresponding k_w is changed to 56%.

The devices and accessories for PCM value at 1,200 /ton, 5000/ m^2 of construct area for addition usage, 3000/*kw* for power line capacity expansion , P_1=0.8(electricity price at busiest time), annual interest rate of bank 11%(At present, this has been decreased), annual inflating rate of power price 5%. The cool storage devices are placed in basement. So

ΔM_i=3.8+20.6191.04=252.4 10^3, ΔM_r=2.6$10^3$, i_e=0.0057

$\therefore n$ =10 years.

The relationship of ΔM_r vs k_p and $P_1 n$ vs k_p and P_1 is shown in Fig.2 and Fig.3 .



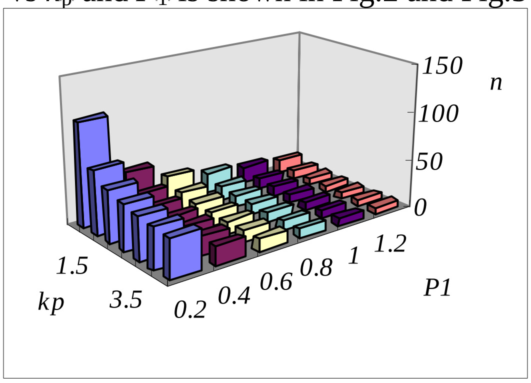


Fig.2 ΔM_r vs (k_p and P_1) Fig. 3 n vs (k_p and P_1)

6. Conclusion

The economic policy and operation schedule lead to a certain highest power need required by the air-conditioning system when it's added with cool thermal storage system. The requirement is less than that of the normal air-conditioning system. When using PCM in cool thermal storage system, the same sets of refrigerators work day and night. So there are a highest and a lowest power values between which the system can operate properly. In practice, when the PCM being applied to your cool thermal storage system, the owner cannot make a requirement of reducing the highest power value needed by system below the lowest limitation; and the designer could not design a system which power consumption can get over the highest limitation. During operation, the saving of operation cost increases with k_p and P_1; the payback term decreases with k_p and P_1.

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