

Cold Thermal Energy Storage (CTES) Study In A Hospital Building

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ABSTRAK

Artikel ini melakukan studi *cold thermal energy storage* di gedung rumah sakit. Terdapat 6 model CTES yang diterapkan di gedung yang terdiri dari *full storage*, *levelling storage*, *partial storage 30%*, *partial storage 50%*, *partial storage 70%*, dan *partial storage 90%*. Perhitungan penggunaan energi, penggunaan listrik, dan juga performansi chiller telah dilakukan untuk mencari model CTES yang optimal. Dari hasil perhitungan, *Levelling storage* merupakan strategi yang terbaik dalam penerapan CTES pada sistem pendingin baru dengan penghematan tahunan mencapai 10.5%. Ditambah, profil konsumsi energi pada mode ini termasuk rendah dibandingkan dengan sistem pendingin biasa tanpa CTES. Kapasitas chiller pada mode *partial storage 30%* mirip dengan kapasitas *chiller* pada sistem pendingin biasa, oleh karena itu startegy ini sangat cocok untuk penggantian existing sistem pendingin dengan penghematan tahunan mencapai 13%.

ABSTRACT

This paper studies cold thermal energy storage in a hospital building. There are six CTES strategies to implement in the building includes full storage, levelling storage, partial storage 30%, partial storage 50%, partial storage 70%, and partial storage 90%. The energy consumption, electricity cost and chiller performances are evaluated to find the optimum mode. The results showed that levelling storage found the best mode for new cooling system investment with annual savings up to 10.5%. In addition the energy consumption is considered lower than normal cooling system. The chiller capacity of partial storage 30% is closed to normal cooling, thus this strategy is the best for replacement system with the annual savings up to 13%.

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INTRODUCTION

Heating, Ventilation, and Air Conditioning (HVAC) is a significant system to maintain a friendly environment in commercial buildings. It is reported that the HVAC system consumed the most energy usage in the building which accounts for more than 60%(Balai Besar Teknologi

Konversi Energi, 2020). This is inline with the report from Government of Canada that the level of greenhouse gas emissions in building applications caused by HVAC have increased up to 88 Mt (Government of Canada, 2022).

Energy demand in the commercial building can be optimized by using cold thermal energy storage (Findik & Ermiş, 2020; Nie et al., 2020). Energy storage plays an important role in the energy management system that provide a balance supply and demand over time period. Many applications of CTES applied in the building application provide a significant profit in the reduction of electricity cost and also lower investment cost(Erdemir & Altuntop, 2018).

(Erdemir et al., 2021) investigated economic study of iced thermal energy storage with various storage strategies in a supermarket in Ankara, Turkey. Since this supermarket applied on two type of electricity price during off and peak hours, the variance of full storage resulted in the greatest profit. In addition, the load levelling and partial storage showed better in terms of profit amount at the end of 10 years and shorter a payback period. (Kamal et al., 2019) performed a strategic control using six scenarios using thermal energy storage (TES) to shift the peak electricity demand in the large commercial office. TES scenarios reduced the annual operational cost by up to 78% during peak electricity period. Previous reports(Biyanto et al., 2015; Guelpa & Verda, 2019) showed that TES provided a significant profit during the peak electricity period. Such buildings must be a large commercial building implementing peak and off peak hours operation. Hospital building required air conditioning system for 24 hours and among the high energy consumption building (Balai Besar Teknologi Konversi Energi, 2020). The electricity cost applied in hospital building excludes peak and off peak hours, instead of only one electricity cost is applied(PLN, 2023). Therefore implementing CTES scenario in hospital building is interesting to observe energy consumption and potential benefit on electricity cost reduction and energy efficiency.

In this research, cold thermal energy storage (CTES) is studied in a hospital building with storage variations in full storage, levelling storage, 30% partial storage, 50% partial storage, 70% partial storage, 90% partial storage. In addition, the energy consumption and the electricity cost operation of the buildings are provided based on various scenarios to provide insights on the feasibility of CTES implementation in hospital building.

RESEARCH METHOD

Hospital Building Cooling Load

Figure 1 shows cooling load profile in a hospital building. This cooling data of this commercial building were obtained from (Balai Besar Teknologi Konversi Energi, 2020) by auditing the energy consumption of commercial buildings in Indonesia. This cooling load represents the need of air conditioning supply to the hospital over time. As seen in Figure 1, the peak load was from 08.00 to 13.00. This is inline to the peak operation of the hospital for servicing the patients. It is observed that the air conditioning operation in hospital was 24 hours. According to the classification of commercial building from state of electricity company (PLN Indonesia)(PLN, 2023), Hospital is categorized as public service which is not applying in peak load cost. This is different with shopping builings as they have two electric cost which are peak and off peak cost (Biyanto et al., 2015; PLN, 2023). Therefore implementing cold thermal energy storage (CTES) in hospital buildings is interesting as only one electric price for 24 hours operations.

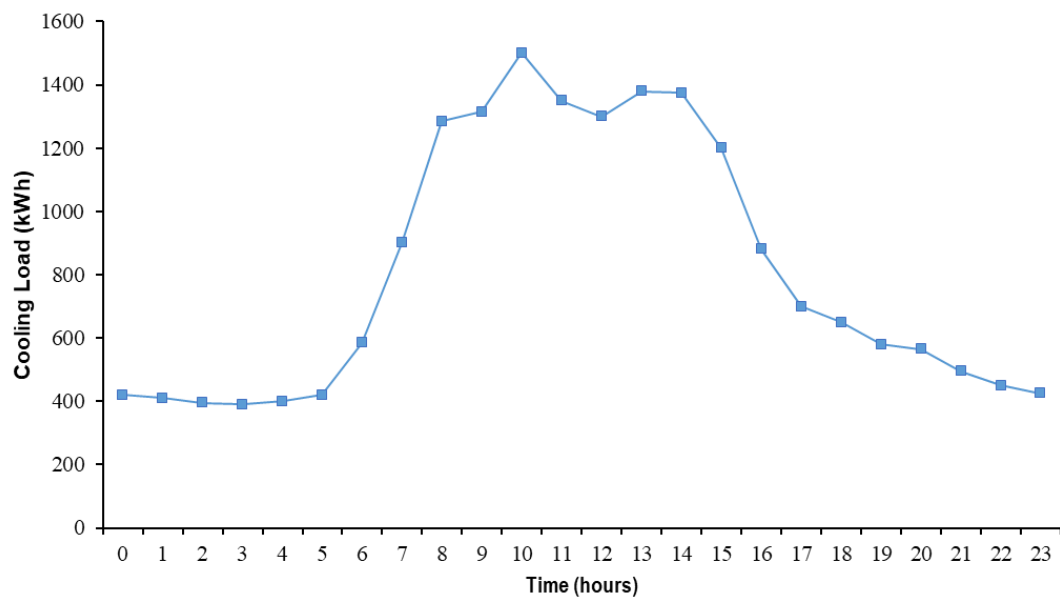


Figure 1. Cooling Load Profile of Hospital Buildings

Cold Thermal Energy Storage Scheme

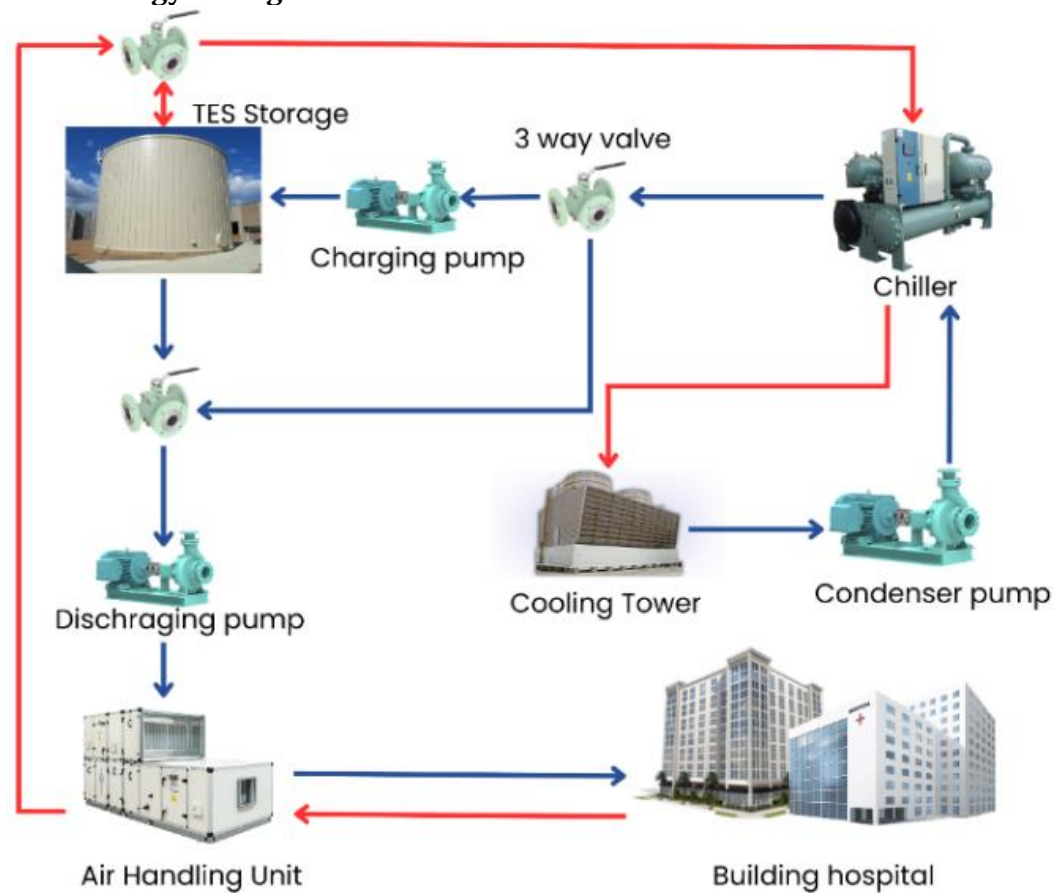


Figure 2. Cold Thermal Energy Storage (CTES)

Figure 2 shows the working principle of a cold thermal energy storage (CTES) system applied in hospital building. This schemes can operate both in CTES mode and non-CTES mode (conventional system) by operating three- way valves. The main difference of CTES mode is the addition of CTES storage. The chilled water from the chiller is supplied to the TES storage based on each scenario at a temperature between 6°C and 7°C. And the hot water returned from the air handling unit (AHU) is around 16°C to 17°C. The normal cooling system was operating the discharging water pump to supply the chilled water to air handling unit (AHU). All the CTES scemes used charging pump to save the chilled water to the CTES storage.

CTES Storage Scenarios

In this study six various storage schemes are investigated in hospital building. These schemes were desgained to find the optimum chiller operation in building with and without CTES. There are full storage, levelling storage, partial storage 30%, partial storage 50%, and partial storage 90%. Full storage scheme stored chilled water in the CTES tank at night period. Full storage strategy run chiller at night where chiller operates at higher coefficient of performance (COP). This may provide the lower electricity operation cost than non-CTES mode. Although the chiller capacity is bigger and the initial investment cost is rising, the significant reduction of operating cost can be expected from this scheme. In contrast to levelling storage, the chiller capacity is much lower than normal cooling system. However, the working operation of the chiller is 24 hours. Therefore the maintenance cost could be more expensive than full storage scenario. Partial storage provided the interesting scenario where the stored chilled water is aimed to shift a certain amount of the cooling load to off-peak hours. These scenarios provide more insight for users depending on the available space for the CTES storage.

RESULT AND DISCUSSION

Chiller capacity for each CTES scenarios

Table 1 shows the chiller capacity profil at various storage schenarios compared to normal cooling system without CTES. Full storagae strategy operated chiller from 00.00 to 06.00 and off operation for the rest of time. The chiller was intended to operate at night period where the ambient temperature was low. Hence the COP of chiller was expected to higher. It is noted that the higher COP of chiller can lower its energy consumption thus obtain a cheaper electricity cost (Shaibani et al., 2019). Full storage strategy also provided the benefit on shorter chiller operation which might reduce its maintenance cost. However, the size of chiller using this strategy is doubled the size of chiller at non CTES mode. Therefore it is increasing the initial investment cost. Table 2 shows the size of chiller and CTES storage for each CTES scenarios. Interestingly, levelling storage scenario used a half of the chiller capacity than that of normal cooling system. The smaller chiller operation was due to the supplying chilled water was operated for 24 hours. Thus, the CTES storage tank also smallest than other CTES scenarios. The major benefit on this scenario is the cheapest initial investment cost of chiller and CTES storage. However, the maintenance cost of the chiller might be increased as longer chiller operation. User may set the chiller in parallel operation to maintain the operation still contune while any trouble from the chiller.

Partial storage 30% has a chiller capacity close to normal cooling system. This is preferable for replacing the existing chiller in the hospital building with the addition of CTES storage tank 184 m³. Partial storage 30% indicating that only 30% of total cooling load are saved in the CTES storage. The lower amount of chilled water in the tank, the lower heat loss between the chilled water temperature and ambient temperature. In addition, as reported from (Biyanto et al., 2015) the maximum heat loss on the storage tank is up to 10%. Nevertetheless, the charging cycle of partial storage 30% can be done during night period where the ambient temperature is lower. The higher storage capacity of partial storage 50%, 70% and 90% resulted in the higher chiller capacity and CTES storage tank.

Table 1. Chiller capacity profile

Hours	Normal Cooling (kW)	Full Storage (kW)	Levelling Storage (kW)	Partial Storage 30% (kW)	Partial Storage 50% (kW)	Partial Storage 70% (kW)	Partial Storage 90% (kW)
0	268	1769	568	724	1022	1321	1619
1	262	1769	568	724	1022	1321	1619
2	252	1769	568	720	1022	1321	1619
3	249	1769	568	724	1022	1321	1619
4	256	1769	568	724	1022	1321	1619
5	268	1769	568	724	1022	1321	1619
6	374	1763	568	724	1022	1317	1619
7	575	0	568	403	288	173	58
8	821	0	568	575	411	246	82
9	840	0	568	588	420	252	84
10	959	0	568	671	479	288	96
11	863	0	568	604	431	259	86
12	831	0	568	581	415	249	83
13	882	0	568	617	441	265	88
14	879	0	568	615	439	264	88
15	767	0	568	537	383	230	77
16	562	0	568	394	281	169	56
17	447	0	568	313	224	134	45
18	415	0	568	291	208	125	42
19	371	0	568	259	185	111	37
20	361	0	568	253	181	108	36
21	316	0	568	221	158	95	32
22	288	0	568	201	144	86	29
23	272	0	568	190	136	81	27

Table 2. Nominal chiller capacity and CTES tank

Scenario	Chiller Capacity (kW)	Storage tank volume (m ³)
Direct cooling system	1065	-
Full storage	1966	1028
Levelling storage	573	184
Partial storage 30%	804	308
Partial storage 50%	1136	519
Partial storage 70%	1468	727
Partial storage 90%	1799	934

Energy consumption profile of each variation

Coolpack software (Coolpack, 2023) was utilized to calculate the work of chiller's compressor. The input data are listed in Table 3. The coefficient of performance (COP) chiller at hourly basis was shown in Figure 3. As shown in Figure 2, the instruments of CTES scenario are chiller, utilization pumps, cooling tower, and CTES tank. The mass flow rate of the pump and cooling tower was calculated by $q = mc_p \Delta T$, considering $\Delta T = 10^\circ\text{C}$. The isentropic pump's efficiency is 70% (Shaibani et al., 2019). Condenser temperature was the ambient temperature plus 10°C . It is noted that the ambient temperature was obtained from the daily temperature taken from (Badan Meteorologi Klimatologi dan Geofisika, 2023).

Table 3. Data to calculate the energy consumption using Coolpack Software

Data	Value
Cooler	: R134a
Cooler Capacity	: Cooling load
Cold water storage operating temperature (T_e)	: 7°C
Compressor isentropic efficiency (η_{is})	: 0,7235
Heat loss factor (f_Q)	: 10%
Condenser temperature (T_c)	: Ambient temperature + 10°C

Figure 3 shows the COP of chiller at hourly basis. The COP of chiller was at the highest level at night period from 00.00 to 06.00. These period is the best for running chiller operation and may reduce the electricity cost. The COP of chiller was decreased at the lowest level from 11.00 to 13.00 along with the rising in the ambient temperature. It is observed that the COP of chiller was increased from 15.00 to 23.00. This was because the ambient temperature is dropping during the evening period. It is worth noting that at the higher ambient temperature, the consuming work of compressor was increased and resulted in the higher energy consumption (Shaibani et al., 2019).

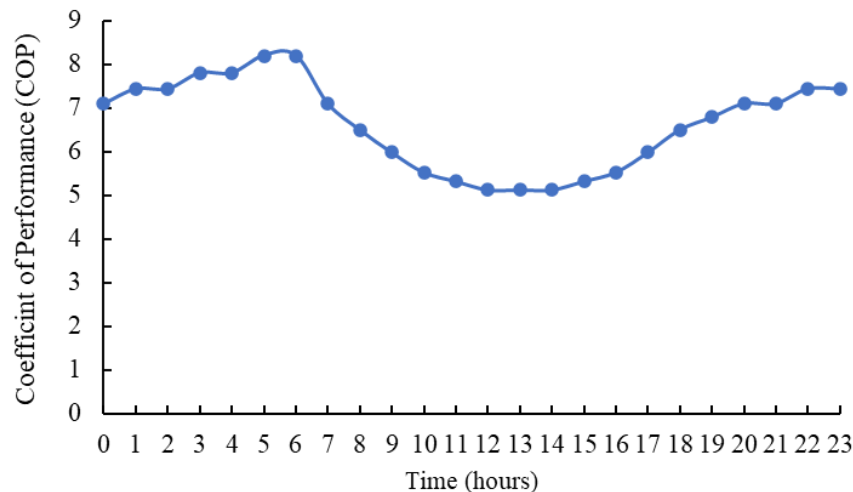
**Figure 3. Coefficient of Performance at hourly basis**

Figure 4 shows the energy consumption profile of each scenarios. It is observed that full storage scheme is the highest energy consumption than all the CTES modes. Interestingly, Full storage, partial storage 70%, and Partial storage 90% were consumed relatively higher in energy usage from 00-06.00. from 06.00 to 23.00, the energy consumption was significantly lower than normal cooling without CTES. Levelling storage consumed almost a half of energy consumption of normal cooling during 24-hours operation. The energy usage profile does not flat as the chiller utilization because of the COP of chiller was relied on the ambient temperature profile. When considering the economically way, levelling storage mode is the best with the smaller chiller capacity and CTES storage. Although full storage consumed greatest energy in the morning, at that time, the chiller works at the optimum condition, thus it might reduce the maintenance cost of chiller. In addition, the cost affiliated on full storage mode considering the discharging pump operation. This pump was on after the chiller finished to store cold water in the storage. Nevertheless, the electricity consumption of pump is much less than chiller, therefore, full storage strategy may provide the benefit on shorter chiller operation.

The CTES variations of partial storage can be potential choices for users considering the availability of CTES storage space. Although the higher portion (%) of storing the cold water led

to the higher in the energy consumption, chiller capacity and CTES tank, the energy consumption was much less from 06.00 to 23.00. This provide much benefit during the electricity management, since the HVAC is the highest energy consumption during afternoon with highly dense people circulation in the hospital at which it can be minimized the electricity cost by replacing with CTES storrage and utilization pumps.

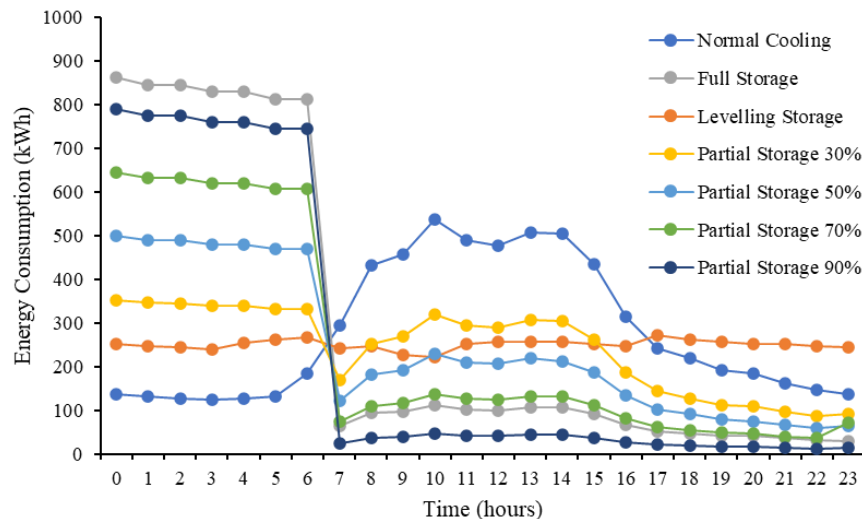


Figure 4. Energy consumption profile with and without CTES

Electricity cost profile for each variation

The daily cost of electricity tariffs was calculated based on the recent government tariffs (Rp. 1699.53/kWh) by analyzing the every day energy consumption prices of various CTES variations. It is noted that the hospital building is categorized as public service sector (P1/TR) which has voltage range from 6600 VA to 200 kVA (PLN, 2023). No peak load charge was applied to the hospital building, hence only one tariff is applied for calculating the electricity cost for 24 hours operation. Table 4 presents daily, and yearly savings in electrical energy consumption of CTES system and normal cooling system without CTES. The calculation of annual savings is a significant and exciting part to discuss in this hospital case study because it provides economic knowledge and evaluation between each variation of CTES. Annual electricity savings was calculated from the daily electricity cost and multiple by 365 days and each CTES variation was compared relative to normal cooling system as follow:

$$\begin{aligned} \text{Annual savings} &= (\text{daily normal cooling} * 365) \\ &- (\text{daily CTES scenarios} * 365) \end{aligned} \quad (1)$$

It is found that CTES mode is significantly profitable compared to a cooling system without CTES storage except for full storage scenario. It can be seen from Table 4 that full storage mode costed a slight higher in daily electrical cost than that of normal cooling. Although the energy consumption profile during afternoon is much less, this was because the chiller utilization at night consumed a little higher in electricity during charging period. Levelling storage showed cheaper electricity cost by as much as 10.5% than that of normal cooling system. This tendency was the same around 13% cheaper than normal cooling for the cases with partial storage strategies. Interestingly, partial storage 30% is the best for replacement of the existing chiller plant with the addition of medium sized CTES storage tank. This was because the size of chiller is smaller than normal cooling and it showed a higher percentage of electricity savings. As compared to the reports from (Biyanto et al., 2015; Erdemir & Altuntop, 2018; Erdemir et al., 2021), the electricity savings is much lower than that of CTES implementasion in a shopping mall. This was because a commercial buldings like shopping mall was charged by different electricity cost depending on the

peak and off peak period and the multiple coefficients can be up to a factor of 2. Meanwhile, a hospital building is different and it is classified in the sector of public services. Indeed, this building is highly dense people circulation like a shopping mall, but the electricity tariffs is applied only one tariffs without considering peak and off peak period. Nevertheless, the implementations of CTES in building is technically and economically feasible which provide more benefits in energy efficiency and cost reduction.

Table 4. Energy costs under various CTES strategies and its annual savings

Scenario	Chiller Capacity (KWh)	Price of daily electrical energy consumption (Rp)	Annual electrical energy consumption savings (Rp)
Normal cooling	1065	11.363.308	-
Full storage	1966	11.968.875	(221.032.171)
Levelling storage	573	10.181.507	431.357.245
Partial storage 30%	804	9.859.312	548.958.400
Partial storage 50%	1136	9.835.373	557.696.351
Partial storage 70%	1468	9.936.184	520.900.388
Partial storage 90%	1799	9.896.148	535.513.242

CONCLUSION

The CTES study in a hospital building was investigated and the important conclusions are follow:

- Full storage strategy has the greatest chiller capacity than that of all the CTES mode. In addition, the energy consumption of this mode is much lower during discharging period from 06.00 to 23.00. Although this mode does not profitable compared to normal cooling system, this strategy can be a good choice for electricity management where the chiller can be off operation during afternoon.
- Levelling storage is the best option for users when implementing CTES in a hospital building. Not only the size of chiller is smallest, but also the electricity savings can be up to 10.5% with the smallest CTES storage. This mode may share the cheapest initial investment cost but it is recommended to consider the maintenance cost since the chiller operation is done for 24 hours.
- Partial storage 30% is the best option for replacement the existing cooling system in the hospital. Not only the chiller capacity is close to normal cooling system, this strategy required a medium sized CTES storage tank which can be placed in a smaller space. In addition this strategy provide the higher electricity savings by up to 13%.
- Partial storage 50%, 70% and 90% are considering when users have the available space for storing the cold water. Those strategies provide the maximum electricity cost by 13% and a high annual savings relative to normal cooling system.

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