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Free-Cooling in Seasonal Cold Accumulator

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***Abstract*—One of the ways to reduce the consumption of traditional energy sources is the use of seasonal cold accumulator that takes advantage of the geographical location in the country and allows, during the winter season, ie, November, December, January, February, March accumulate cold because of lower ambient temperature in these months. This leads to saving a significant amount of electricity and reduce operating refrigerant, which is dangerous for the environment. This paper presents a method for determining the size of cold storage with charging devices as chiller and dry-cooler. The approximate costs of device operation including the time of framework of these components has been obtain.Design seasonal cold accumulator allows to conclude that this solution has a number of economic and ecological advantages. Due to the seasonal tank design the saves on chiller, which under normal circumstances would have been selected for the highest hourly energy demand, which means that the device should be several times larger than the device that was used in the project. By selecting a small chiller the environment from hazardous refrigerants is protected, which are chlorofluorocarbons, specifically in the case of refrigerant called R- 410A.**

***Index Terms*— cold accumulator, free cooling, ventilation, ice water, seasonal storage.**

I. Introduction

The issue of cold accumulation, relating to air conditioning systems, comprises both, preparation and storage as well. The installation of cold accumulation makes easy way to reduce the cost of cold production energy by using dual-rate electricity charges. In addition, the cold accumulation systems allow to use devices with lower power demand and improve the reliability of the cooling system. Cooling energy can be stored in the form of sensible and latent. In the case of a sensible energy storage (SES) we deal with an increase of material temperature used as a accumulator of heat or cold, but in the case of latent heat storage (LHS) phase change material are used (usually between the solid and liquid). The air-conditioning system uses two main types of cold storage systems. These include: tank with ice water and cooling energy storage in materials PCM (phase change material) [1].

II. Use cold water as a refrigerant

Water is well suited for storage both heat and cold, due to high specific heat (4.19 kJ/kgK). In practice, its mixture are common as a substances that reduce the freezing point. It is mostly ethylene glycol and propylene glycol as well. Cooling capacity of ice water tanks depend on the amount of storedwater and the temperature difference (Δt) between supply and return water. The temperature difference has a strong influence on the size of the accumulation reservoir. The values of the temperature difference of supply and return water flow through the accumulator are placed on level 7-9K. In the case of an increase of this difference to the value of 11-13K the volume of the reservoir will be reduced as close as to 50%. The minimum value of Δt at which the storage system is a cost-effective is assumed as 5K. Chilled water accumulators can be made ground, partially buried or underground. They can also be integrated into the structure of the building. Ground storage tanks are often made of steel, underground as concrete bunkers[2]. Because of the simplicity of operation, reliability, efficiency and low investing cost the cold accumulation system are more and more common. Water has a melting heat of 335 kJ/kg, the high specific heat of 4.2 kJ/kgK, high density 1000 kg/m3, the material is safe and has a melting point at a level suitable for use in conventional air conditioning systems.

The melting point is very stable and is 0 °C at sea level. Under certain conditions, a slight supercooling of water close to 1 to 3 K is observed. After reaching the maximum supercooling point of water and freezing, it returns rapidly to 0°C[3].

The density of water is slightly reduced at temperatures below 4 °C while the volume increased by 9% during freezing. This feature is used as an indicator of the formation of ice crystals in cold production systems in the form of frozen ice crystals. If frozen ice floats on the surface of the water volume remains constant until all of the water freeze or melt.

Below the freezing point of water ice slightly increases its density, but it does not matter accumulation cooling system because the majority of systems work close to of the phase changes of water.Scheme of capsules ice formation during charging and discharging process is shown in Figure 1.For ice capsules charging temperature decreases during freezing of water due to growth of the ice layer through which heat is conducted. Water has become a dominant factor in the energy storage in air conditioning systems. However, someprocesses

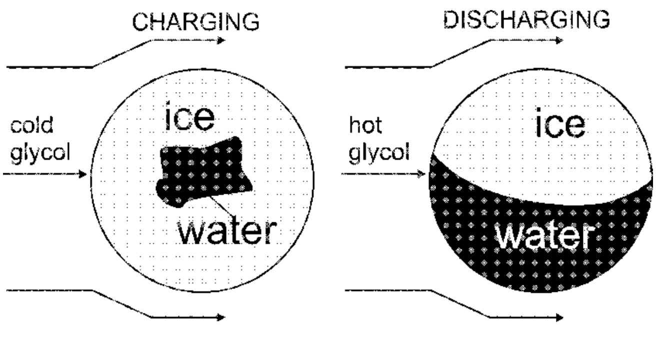

Figure 1 Schema of ice creation in capsule during charging and discharging LHS process.

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require medium temperature in the range that exceeds the capabilities of water systems. Therefore directed towards other substances that despite of freezing temperature above 0°C can produce refrigerant at satisfy temperature during the discharge process.

III. DAILY AND SEASONAL COLD ACCUMULATION

The main task of the daily accumulation of cold is heat storage using a chiller, which charges the accumulator during night hours when the price of electricity is lower, which translates into lower operating costs - Figure 2.

This process helps to save money not only on energy consumption but also on the costs related to purchasing a chiller that is selected on the maximum power of cold demand for unfavorable hour in whole year. The result - that most of the time during the summer season device unit seems to be oversized. But when the chiller is selected for average hour and cooling demand it will act as a complement to the maximum rise of possibility to choose a smaller and cheaper one. Seasonal cold accumulation is accumulation of cold in the container field or another. The cold production using the chiller or device for cooling water via the natural cooling capacity of air as dry-cooler. The tank must have a low U coefficient to minimize losses of cold to the ambient air - Figure 3.This process is extremely beneficial because of the medium is lead to desired temperature at ambient one at low electricity demand and, in addition, this process takes place at night, when energy is cheaper. Dry-cooler can provide, depending on the weather about 60% of the total cooling demand in a year. The rest 40% is provided by the chiller.

IV. CALCULATION OF COLD STORAGE VOLUME

The Inn type building was taken to calculation of monthly demand for cold. Building is situated in moderate climate with the higher temperature 30^{o}C. Usable surface of building is 254 m^2 with half of the windows on south-west exposition. Calculation included external heat gain from the sun only enter to inside the building through the windows and walls. Monthly cold demand is presented in Table I.

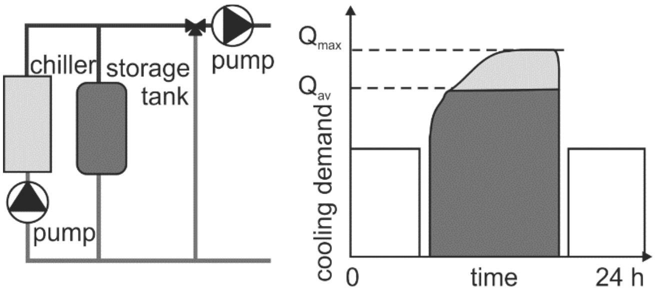

Figure 2Schema of daily cold accumulation.

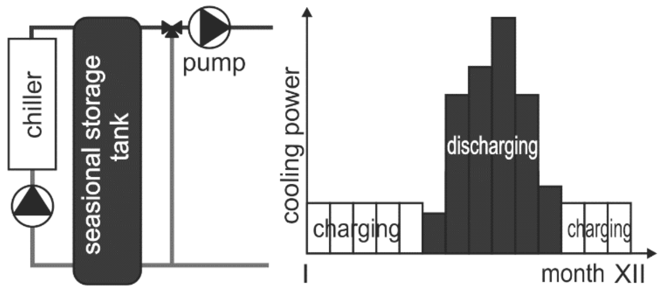

Figure 3Schema of seasonal cold accumulation.

Table I. Cold demand for analyzed building.

Month	Cold demand, Q_{cnd}, kWh/m-th	Hours t_M, h	Time of building cooling t_C, h
1	0,00	744	0
2	0,00	696	0
3	0,00	744	0
4	25,89	720	3
5	355,94	744	30
6	1191,35	720	97
7	973,37	744	85
8	1321,64	744	111
9	333,90	720	30
10	0,00	744	0
11	0,00	720	0
12	0,00	744	0
Σ	**4202,10**	**8784**	**356**

The energy demand for cooling was calculated based on the method of preparation of energy performance certificates [4]. Seasonal accumulation of cooling will take place in the field reinforced concrete tank. The accumulation tank is filled with water. Refrigeration system operating time is set to 11 h/day from 8 to 19 in the summer period. The total cooling demand in time for the summer cooling was obtain as 0.8 kWh/(m^{2}year). Discharging of cold accumulator takes place in the months of April, May, June, July, August, September, between the hours of 8 to 19 (the highest cooling demand). Storage tank charging will occur during the months of October, November, December, January, February, March, 8 hours a day (from 23 to 7 am). Overall cold demand of building in cooling season is placed on level 4 804kWh/a.To serve the seasonal demand for cooling, ground cooling tank is loaded over 183 days, eight hours per day, which gives 1464 hours of charging during the year what gives 4804/1464 = 2,87kW - power, which should be provided within hours of charging. The water was selected as accumulation material (phase change temperature = 293K). As the coolant (secondary refrigerant) a glycol-water mixture was selected. The calculations of cold loses from the tank to the environment has been taken into the account determined based on EN ISO 13790 [5].The calculations are summarized in TableII. The table show that the cool accumulator releases the most energy in the summer months, ie. June, July, August.
Time of dry-cooler operation in winter period to charge storage tank (month 1-3 and 11-12) was obtain on 363 hours.

Table II Characteristic parameters for cold accumulator

Month	Discharge time t_C, h	Dry-cooler charge Q_{dc}, kWh/m	Cooling demand ΣQ_k, kWh/m	Chiller energy Q_{agr}, kWh/m	Chiller time t_{agr}, h/m
1	0	1020	-1258	192	43
2	0	470	-658	192	43
3	0	295	-415	192	43
4	3	55	-63	192	43
5	30		543		
6	97		1368		
7	85		1122		
8	111		1410		
9	30		361		
10	0		-25		
11	0	830	-1068	192	43
12	0	980	-1316	192	43
Sum	356	3 650	4 804	1 152	258

To determine the number of hours in cooling season during which the outdoor temperature is lower than the return glycol temperature into the tank the data from meteorological stations in Rzeszow was used.The energy provided by a dry-cooler in the each months, when the outdoor temperature is lower than the temperature in the cooled room (simplified) and energy provided by the chiller was counted according to the following scheme presented below.

- Dry-cooler

Dry-cooler calculation was processed assuming the power of device N_{dc} = 5kW. To sum up months of work of dry-cooler the total power of the device in the winter season is obtained by eq. 1.

$$Q_{dc} = \sum_{12}^{1} t_{mp,i} \cdot N_{dc,i} \quad [kWh] \tag{1}$$

Then, cold produced by dry-cooler per overall year was calculated on Q_{cd} = 3650 kWh.

- Chiller

Total cold production by chiller in all period is equal to cold demand in year minus cold provided from free-cooling systems with dry-cooler. Than, $Q_{agr} = 1152$ kWh. Working time of the chiller operation during a year $T_{agr}$is:

$$T_{agr} = \frac{Q_{agr}}{N_{u,agr} \cdot n} \tag{2}$$

The number of month taken in accumulation process n = 6 and power of chiller $N_{u,agr} = 4{,}5\ kW$. Then, $T_{agr} = 42{,}9\ h$. Comparison between cold production by chiller and dry-cooler was shown in fig. 4. Most productive months for dry-cooler operation are November, December and January. While the chiller is running 5 or 4 days in each month to complete the charging of cold accumulator, which could provide a dry-cooler because of too high ambient temperatures and monthly downtime for service and maintenance.The total cost of exploitation of these devices is placed on level E = 95 USD/a, what is insignificant value.The cost of energy $E_c$for the chiller only assuming the COP = 3,5 and the unit cost ofelectricity n_{el} = 16 cents per kWh is (eq.3):

$$E_c = \frac{\Sigma Q_k}{COP} \cdot n_{el} \quad = \frac{4804}{3{,}5} \cdot 0{,}16 = 219{,}6\ \mathrm{USD/a} \tag{3}$$

Saving energy between the chiller system without cold accumulator, but with dry-cooler is 60 USD per year which allows for savings of 27%.

Sizing seasonal cold accumulator after taking into account the heat loss through the tank permeation barriers:

$$V = \frac{3600 \cdot \sum Q_k}{C_m \cdot \rho_m \cdot \Delta T} m^3 \tag{6}$$

Assuming $\Delta T = 7\ ^oC$, $\rho_m = 0{,}67 \cdot 999{,}7 + 0{,}33 \cdot 1018 = 1005{,}7\ kg/m^3$ (33% mixture water and ethylene glycol), $C_m = 3{,}84\ \frac{kJ}{kgK}$.The volume is $V = 640\ m^3$ of cold water in sensible heat storage system (SHS). It is a lot of water in seasonal tank, huge dimensions and many construction problems. To reduce a volume of cold storage tank the latent heat storage (LHS) can be used. Average value of energy density of that systems DLHS = 89 kWh/m^3, thus volume of storage tank could be V = 4804/89 = 54 m^3. It allows to significant decreasing of tank volume, almost 12 times.

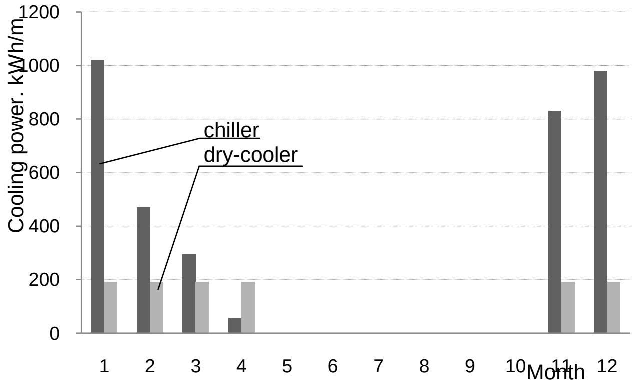

Figure 4 Cold production provided by chiller and dry-cooler

V. Conclusions

Design seasonal cold accumulator allows to conclude that this solution has a number of economic and ecological advantages. Due to the seasonal tank design the saves on chiller, which under normal circumstances would have been selected for the highest hourly energy demand, which means that the device should be several times larger than the device that was used in the project. By selecting a small chiller the environment from hazardous refrigerants is protected, which are chlorofluorocarbons, specifically in the case of refrigerant called R- 410A. Another huge advantage of the project is to provide the majority of the demand for cooling by dry-cooler, thanks to its simple design makes use of Polish temperate climate where winter occurs. It allows to charge cold accumulator without additional costs for electricity. With its rechargeable accumulator with a dry- cooler and chiller a lot of savings during operation period of the system is achieved at the level of 30 %. It is without a doubt a very good result.

The disadvantage is that the size of the cold accumulator, and thus the cost of excavation and tank with a low coefficient of heat transfer. All of above make this investment expensive with the 15 years of operation of the system return. This fact force to seek other cold storage solutions or substance which are able to give higher specific heat ratio. This can be done for example by the use of phase change materials(PCM), with a heat capacity is in the range 18,0 kJ/kgK, which in comparison with the glycol-water mixture used in the project, 3,84 kJ/kgK makes possible to reduce accumulation container more than 4.5 times or up to 12 times in LHS system with ice as PCMmaterial. That container can be moved inside the building which result in lower costs for excavation works and the cost of the tank itself.

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