Upgrade of ice storage system in congress centre

Urška Mlakar [a], Uroš Stritih [a]

[a] Faculty of Mechanical Engineering, University of Ljubljana, Ljubljana, Slovenia, urska.mlakar@fs.uni-lj.si

Abstract. Storage of various forms of energy is a relevant topic in last decades. The ability to store energy that is produced at a time when we have a surplus of a particular source and use it at a time when energy needs are greater is crucial. We can store energy as electricity or as thermal energy (heat and cold). In this paper, we will take a closer look at latent cold storage with ice bank technology. Ice bank technology exploits latent heat in the liquid-solid phase change of water. Of all the cold storage technologies available, ice storage is the most popular in recent decades due to its high latent heat, especially when available space is limited. Cold in ice banks is produced at night, when electricity is cheaper, and is used to cover cooling needs especially at peak hours during the day.
In Slovenia, the technology of ice banks has already been applied several times. Among other buildings, this technology is also used in buildings such as the Opera and Ballet, the Crystal Palace, and the Congress centre Cankarjev dom. This Congress centre has a system with nine ice banks with a total nominal capacity of 405 kWh per ice bank, for its cooling needs. The transition to ice bank technology has allowed them to cut by 41 % the power of their refrigeration units, while saving money is achieved since ice is produced at night time with lower prices. The article presents the three phases of the system: Energy for cooling of a system without ice banks, a system with ice banks and saved energy with this technology and an analysis of the upgrade of this system with PV modules. The simulations were done with the Trnsys program. Indicative savings with the application of ice banks and additional upgrades with PV modules are presented. The payback periods are also analysed.

Keywords. energy storage, ice storage, case study, economic analysis, upgrade analysis.
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1. Introduction

According to the storage mechanism, thermal energy storage (TES) is divided into three types: sensible, latent, and thermo-chemical storage. Among them, energy storage occurs in sensible storage with a change in temperature and latent storage with a change in aggregate state (1).

Cold storage technology is an effective way of shifting maximum electrical loads as part of an energy management strategy in buildings. Such systems can help electrical devices to reduce peak loads and increase loads during off-peak periods, which could improve the utilization of base load generation equipment and thus reduce dependence on peak units with higher operating costs (2).

The use of spherical capsules for PCM encapsulation in air conditioners has been studied by various researchers. Fang et al. (3) experimentally studied the characteristics of the operation of refrigeration air conditioning systems with spherical capsule filling. Spherical capsules with an outer diameter of 100 mm and a wall thickness of 1 mm were filled with water. Experimental results have shown that refrigerated air conditioners with spherical capsules have better performance and can operate during charging and discharging; and have a COP system variation of 4.1 to 2.1 during the latent heat storage period.

The term ice storage is used as a general name for heat storage, which uses the enthalpy of water as part of its storage capacity to change its physical state from liquid to solid. By freezing water, a high amount of heat can be removed: 333 kJ (0.093 kWh) are released per kilogram of water during this process (4).

We know different ice storage technologies (5); Ice Harvesting, Ice on coil, encapsulated ice (6) and others. Key benefits of ice bank technologies (7):

- Reduced final power requirements (kW) for pumps and fans - Designs that use cooler liquids and larger temperature changes reduce the need for air and water flow, so component sizes, including the size of the electric motor, may be smaller. The first savings in equipment and work can be significant.

- Reduced electrical distribution - smaller components such as refrigeration units, fans and pump motors reduce connected power and thus save on electricity distribution costs from the building's main transformer to the starting panels. Reduced connection power can also reduce the size of emergency generation equipment that may be required.

- Space savings in the building - smaller supply and return channels require less floor space. Smaller air ducts reduce the height of the ceiling, allowing for shorter floor-to-ceiling dimensions. The result is lower construction costs and more usable/rental floor space.

- Operation at 100 % capacity - Refrigeration units will always operate at or near 100 % capacity while filling the storage system, and usually have a higher capacity factor compared to a conventional chilled water system. This shortens the time when the refrigeration units operate in low load conditions as well as on / off at refrigeration loads. When refrigeration units operate at near full capacity most of the time, they require less maintenance. Any fluctuations in the cooling load will be covered by an ice storage tank.

- Adaptation to cooling peaks - Process operations often have short but high cooling peaks. Refrigeration units are not designed to adapt quickly to these peaks. The ice storage tank can respond quickly and efficiently to variations in load fluctuations and can follow rapid cooling peaks.

- Adapting to changes in the schedule of energy use - Periods of use of electric peaks vary greatly. The demand period can be 8-10 hours or a series of shorter sections 2-3 hours. Ice storage is very efficient at any service demand schedule and can be easily changed if periods change in the future.

An example of a successful application of the use of ice bank technologies is the University of Arizona campus presented by Tarcola (8). The ice storage system is powered by a Combined Heat and Power [CHP] system located at the Arizona Health Sciences Centre (AHSC) plant, that supplies electricity to three ice chillers. These chillers make ice at 3,2 MW and 0.783 kilowatts per ton. They freeze water in the 156 storage tanks that are discharged on demand. They are so satisfied with the operation of the system that they decided to upgrade the system with an additional 49 ice storage tanks and a 4.4 MW refrigeration unit.

Examples of the use of ice bank technologies in Slovenia are the Crystal Palace (9), Ljubljana Castle (10) and Cankarjev dom which example is presented below.

2. Research methods

2.1 System presentation

Cankarjev dom has decided to modernize and improve its air conditioning systems, as the appropriate comfort in the premises where various events, performances, conferences and other events take place is very important for the satisfaction of guests.

Until the replacement, two water-cooled liquid coolers were intended for cooling in Cankarjev dom, each with a cooling capacity of 1021 kW, which prepared cooled water with a temperature range of 11/6 ° C. When they were replaced, they were replaced by two new ones with a lower cooling capacity of 595 kW. To one of the refrigerant units was added a system of latent cold storage - an ice bank. The system has nine 340-liter latent storage tanks with a total rated capacity of 405 kWh (1 ice bank) (11). **Fig. *1*** shows the system of nine ice banks in Cankarjev dom.

Their system allows them different modes of operation. Night operation - filling the latent cold storage tank; daily operation - preferably mechanical cooling with a liquid cooler and additional emptying of the cold storage tank, and daily operation - preferably cooling by emptying the cold storage tank and supplementary mechanical cooling with another liquid cooler.

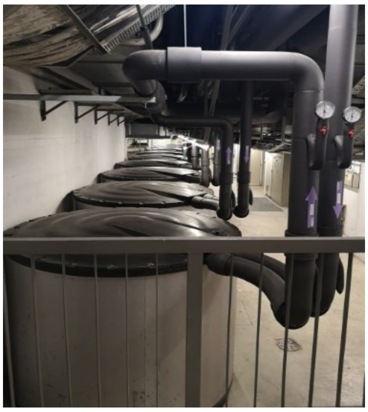

Fig. 1: System of nine ice banks in Cankarjev dom

2.2 Building

The building of the Cankarjev dom congress centre is interesting to consider because part of this building is underground. The building has eleven floors, of which seven are above ground and four below ground. Under the ground are Kosovel's, Linhart's, Štih's, Gallus's hall (ground floor) and ten conference halls. Above the ground is only part of the Gallus Hall (balconies), the Duše Počkaj Hall and the Lili Novy Glass Hall. Below the second lobby are a few more floors that provide storage and preparation of the program in the technical field, e.g., storage of acoustic shell and other props, shelters, technical rooms, etc. The total area of Cankarjev dom is 36,000 m^2. On the south side, the envelope of the building is lined with marble slabs, while in the western part we have mostly brick and in the higher floors concrete, and at the same time about 80 % of the western part is glazed. **Fig. *2*** shows a view of the envelope of

Cankarjev dom from the Southwest. The northern part of the building envelope is partly covered with marble slabs, and partly has copper foil on the envelope as an outer layer. In the eastern part of the envelope, we have marble slabs, but also a lot of glass surfaces.

Fig. 2: Cankarjev dom from the Southwest

The interior of the building is covered in the simulation model with 40 zones, which have no further division with the interior walls. The building is divided into so many zones that we were able to define it as relevantly as possible. Through all these zones, we were also able to define the parameters that affect the internal heat gains, which are especially important in the zones where the congress halls are located. The building has a lot of glass surfaces, through which we get quite a few external heat gains from the sun, and at the same time we have heat losses in the winter. We also defined ventilation in the building, which is tied to a system with latent cold storage. In most zones the temperature is set to 20 ° C.

2.3 Photovoltaic module

To be able to use the real values of the photovoltaic panel surfaces in the simulations, we first inspected all the roof surfaces of Cankarjev dom on site. The most suitable areas were found to be in the southern and south-eastern part of the building, as illustrated in **Fig.** *3*.

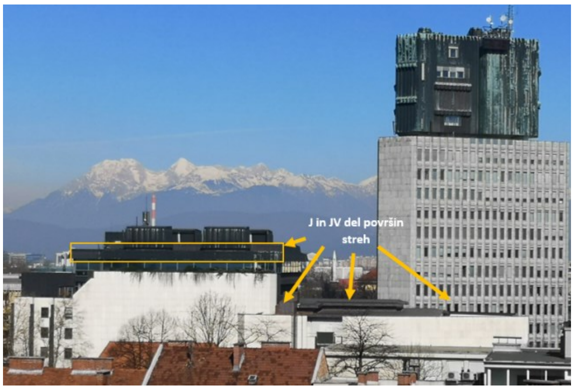

Fig. 3: Roof surfaces of Cankarjev dom taken into account for the installation of PV panels

In the simulations, we used a value of 430 m^2 and the inclination of the panels at an angle of 45 °.

2.4 Numerical simulations

The scheme of the system without latent cold storage consists of the following sets; weather data, building, soil temperature and display and storage of results. The Cankarjev dom module is crucial, as it contains all the information about the building, its construction, heat gains, cooling with a refrigeration unit, etc. The weather data module contains a file with weather data for Ljubljana and, in combination with the radiation module, contributes the necessary data to take into account solar radiation on the building. The ground temperature module allows this temperature to be considered as a boundary condition for parts of the building envelope elements that are in contact with the ground (we have 4 basements under the ground). The Q_cooling module sums up the output data of the building, which illustrates the use of cooling energy for each zone in the building (we have 40 zones). The results display module allows us to monitor the results in the form of a graphical display. The results module generates an external txt file in which the hourly data of the calculations are stored. The lines and arrows between the individual modules show the connections between them. The output of an individual module is the input for another module. Cooling is switched on at 24 ° C.

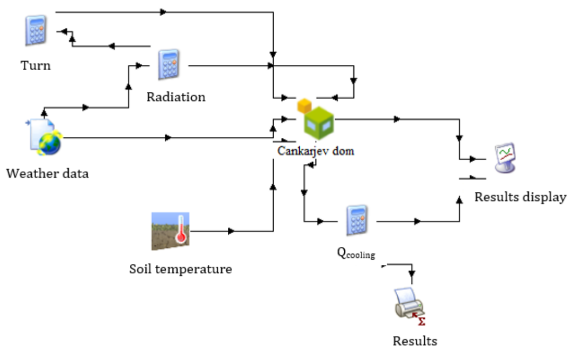

Fig. 4: Schematic of a system without latent cold storage in the Trnsys software environment

Due to the complexity of the system, we did not perform a dynamic calculation of ice bank charging in Trnsys, but a static calculation in Excel, which was as follows. The latent capacity of ice banks was calculated by the equation **1**:

$$Q_{\text{lat}} = m_{water} \cdot q_{fus} \qquad \textbf{(Eq. 1)}$$

A value of 333 kJ / kg was taken into account for the heat of fusion. The mass of water in one latent storage tank is 3677.9 kg. The monthly value of stored energy of ice banks was calculated according to the equation **2**:

$$Q_{\text{january}} = Q_{\text{lat}} \cdot n_{\text{bank}} \cdot n_{days} \qquad \textbf{(Eq. 2)}$$

Tab. 1 shows how we obtained the results of stored energy in 9 ice banks on an annual basis. We assumed the number of days in the month when the ice banks are fully filled and the number of days when they are half full charged (the use of cold did not completely empty the ice banks, for example, in the winter months days energy needs for cold are smaller compared to summer days, therefore withstands cold in ice banks for several days). In the months from June to August, ice banks are certainly filled every day, but it is not necessary that ice banks are completely emptied every day. The results are presented in the subchapter 3.2.

Tab. 1: Number of days in the month when the ice banks are fully charged and the number of days when they are half charged

Month	Number of days - full charge [days]	Number of days of half charge [days]
January	5	0
February	6	1
March	8	7
April	11	9
May	15	10
June	19	11
July	25	5
August	20	11
September	16	11
October	12	8
November	8	5
December	6	2
Sum	151	79

Using a separate model, we calculated how much electricity we produce with a 51.6 kW photovoltaic power plant, which is presented in more detail in the economic analysis section. ***Fig. 5*** shows the scheme in the Trnsys program, through which we calculated the energy production potential of photovoltaic panels.

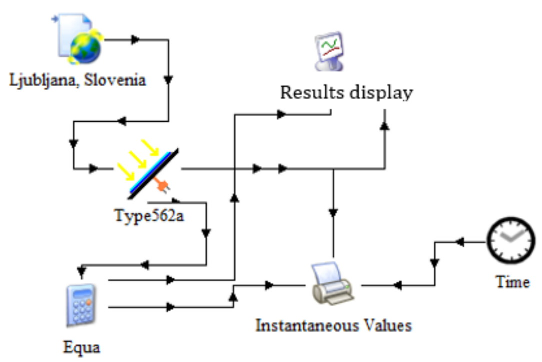

Fig. 5: Scheme for calculating the production potential of a PV power plant

3. Results

3.1 System without latent cold storage

In the case of a building without the use of latent cold storage, the simulation time was one year. For each simulation, we showed the energy consumption for cooling by months for a period of one year. The location of the simulations was Ljubljana, where the Cankarjev dom building also stands. In the simulations, the building is supposed to turn on cooling at 24 °C. Cooling is provided to ensure suitable conditions in rooms where the presence of people, devices (e.g., computers) and lighting generates internal heat gains. The premises of the building that are exposed to solar radiation also have external benefits due to the sun. Without cooling, all the above heat gains would lead to overheating of the premises.

In the case of a system that does not use latent cold storage, the total energy required for cooling or. it produces air conditioning with refrigeration units (leading and reserve refrigeration unit). **Tab. *2*** shows the monthly energy consumption for cooling of Cankarjev dom without latent cold storage tanks. Simulations were performed on an hourly basis (8760 hours = 1 year) and then the values were summed to give monthly values. When the temperature in the individual room to be cooled or air-conditioned exceeded 24 °C, the cooling was switched on and the program recorded the energy required for cooling on an hourly basis.

Tab. 2: Monthly values of energy use for cooling of Cankarjev dom without the use of latent cold storage tanks

Month	$E_{c\_without}$ [MWh]
January	18,89
February	20,97
March	36,02
April	59,38
May	98,12
June	138,76
July	180,68
August	167,52
September	112,67
October	72,70
November	35,44
December	21,45
Annually	962,60

Tab. *2* shows that the use of energy for cooling is highest in the summer months, as we have higher use due to external heat gains. Cooling energy is also needed in the winter to ensure the basic conditions of the indoor environment in the premises, especially in the halls, where people and lighting contribute to greater internal heat gains. Most of the halls are underground, so interior comfort is even more important.

3.2 System with latent cold storage

In the case of the system using latent cold storage, the simulation time was one year. For each simulation, we showed the stored energy by months for a period of one year. In the analysis of the system with latent storage tanks, we simulated and calculated the stored energy in latent cold storage tanks on an annual basis. **Tab. *3*** collects the monthly values of energy stored in latent cold storage tanks and the column with the energy required to cool a building in a system without latent cold storage tanks.

Due to the complexity of the system in Cankarjev dom, which uses 52 air conditioners for the purpose of air conditioning the building, we were not able to "dynamically" model this scheme in the Trnsys program. We decided to use all the data on the system and its operation, which we obtained during the acquaintance with the system, to make a "static" calculation or energy estimate, which is provided with the help of nine ice banks.

Tab. 3: Monthly values of estimated energy stored in latent cold storage tanks and required energy for cooling in a system without latent storage tanks

Month	$E_{c,\,bank}$ [MWh]	$E_{c\_without}$ [MWh]
January	15,31	18,89
February	19,90	20,97
March	35,21	36,02
April	47,46	59,38
May	61,24	98,12
June	75,02	138,76
July	84,20	180,68
August	78,08	167,52
September	65,83	112,67
October	48,99	72,70
November	32,15	35,44
December	21,43	21,45
Annually	583,29	962,60

According to equation **3** , proportion of cooling energy stored in latent cold storage tanks can be calculated.

$$E_{c,bank,\text{ann.},\%} = \frac{E_{c,\text{bank,ann.}} * 100}{E_{c,without,ann}} \qquad \textbf{(Eq. 3)}$$

The share of energy stored in latent cold storage tanks is 60.6 %. The rationale for using latent cold storage tanks is evident from the result, as this share of energy is produced at a time when electricity is cheaper.

Then we calculated how much more energy could be stored in latent cold storage tanks in case we would charge them every day from May to September, when the energy needs for cooling or air conditioning are maximum (in the remaining months we cover all the necessary energy). If we subtract the values of required energy and lack of energy, we get 733.33. The maximum stored energy was calculated as the product of the ice bank capacity, the number of ice banks and the number of days in each month. The result of the calculation of the largest share of stored energy in latent cold storage tanks for the case of the Cankarjev dom building is 76,2 %, calculated by equation **4** :

$$E_{\text{bank,ann,max,\%}} = \frac{E_{bank,may-sept} * 100}{E_{c,without,ann}} \qquad \textbf{(Eq. 4)}$$

3.3 Upgraded system with latent cold storage

Considering that Cankarjev dom still has a higher use of electricity most of the year at a time when electricity is more expensive, we thought it would make sense to include in the system the production of electricity from solar energy, which would allow additional reducing the required electricity from the grid.

In this part, a simulation of electricity production of a 51.6 kW photovoltaic power plant on monthly basis was performed. The area of the power plant was 430 m2. The results of the simulation of electricity production of the 51.6 kW photovoltaic power plant on monthly basis are summarized in **Tab. *4***.

Tab. 4: Electricity production of 51.6 kW PV power plant on monthly basis in MWh for Ljubljana

Month	E_{PV} [MWh]
January	1,23
February	1,86
March	3,40
April	4,42
May	5,80
June	6,08
July	6,68
August	5,67
September	3,78
October	2,34
November	1,12
December	0,75
Annually	43,1

From the extended energy audit of Cankarjev dom (12), which was carried out in 2016, we obtained data on the estimate of electricity consumption of the refrigeration unit, which amounts to 213 MWh per year.

By calculating the electricity production of a 51.6 kW photovoltaic power plant on monthly basis for Ljubljana and having data on the energy consumption of the refrigeration unit, we can calculate what share of energy consumption for the refrigeration unit can be covered by a photovoltaic power plant. The calculation is made according to equation **5**:

$$E_{\text{refrig. unit,\%}} = \frac{E_{\text{PV,ann}} * 100}{E_{\text{refrig. unit, ann}}} \qquad \textbf{(Eq. 5)}$$

20 % of energy needs for refrigeration unit can be covered by photovoltaic power plant.

3.4 Economic analysis

The first part of the analysis presents the calculation of the return-on-investment costs in the upgrade of the system with ice banks and the reconstruction of the old system. **Tab. *5*** shows some of the costs that make up the entire investment.

Tab. 5: Ice bank price data, documentation and total investment

Data	Cost [EUR]
The price of an ice bank - CALMAC 1098A	11000 -15000
Price of reconstruction documentation	9998,56
The cost of the entire investment in the reconstruction of the system	482.736,53

The price of the entire investment includes all elements of the system from 9 ice banks, 2 refrigeration units with a cooling capacity of 595 kW, installation prices, the price of distribution elements, insulation, etc. The representative of CALMAC in Slovenia is VALMOR, where we also received information on the price of the ice bank, which at the time of purchase also depends on the cost of transport from America.

The savings were calculated as the difference between the price of the high and low tariff multiplied by the energy stored in the ice banks throughout the year. We got savings of 22.835,72 EUR/year.

The savings are such because all the energy stored in latent storage tanks is produced at the time of the lower tariff. The price difference between high and low tariff is 50 %. With such savings, our investment pays off in 21 years. If we take a loan with a 2 % interest rate, the investment will be repaid in 28 years, and at a 3 % interest rate in 35 years. If we had invested in only 9 ice banks, our investment would have paid off in 6 years.

The following is a calculation of the return-on-investment costs in a photovoltaic power plant. All calculations were performed in Excel. **Tab. *6*** collects basic data on the photovoltaic power plant, such as different efficiencies and the mean density of solar radiation on the Earth's surface.

Tab. 6: Data on photovoltaic power plant

Data	Unit	Value
Average density of solar radiation on the Earth's surface	W/m^2	1000
Efficiency of PV panels	%	12
Relative efficiency	%	86
Efficiency of inverters	%	95

Tab. *7* contains data and calculations on the area, rated power of the photovoltaic power plant, annual electricity produced and operating time at nominal power.

Tab. 7: Data and calculations on the size and nominal power of the power plant

Data	Unit	Value
PV power plant surface	m^2	430,00
Nominal power of a PV power plant	kW	51,60
Annual electricity produced	kWh/a	47.469
Operating time with nominal power	h/a	1021,8

The repayment period is calculated by dividing the total investment costs by the annual savings. **Tab. *8*** contains basic economic data and calculations on the photovoltaic power plant.

Tab. 8: Basic economic data and calculations on PV power plant

Data	Unit	Value
Total investment costs	EUR	50.000
Amortisation period	let	15
Amortisation costs	EUR/a	3.333
Savings due to own electricity production	EUR/a	3.377
payback period	years	15

We calculated average monthly values of daily sums of incident solar energy and electricity production monthly. Calculations of average monthly values were made from data obtained from the website meteo.si (13) for the location Ljubljana. The data are made for a typical meteorological year, which consists of data from 2001 to 2015. The electricity produced for each month was obtained by multiplying the average monthly values of the daily sums of the incident solar energy and the number of days in the month.

Based on the data and calculations collected in **Tab. *6*-Tab. *8*** and the calculations of electricity produced monthly, calculations were made for two variations. In the first variation, own funds are used for the investment, and in the second, credit is taken to pay the price of the investment.

When using own funds for the investment, it is repaid within 15 years. If we take a loan, the investment will be repaid in 18 years (2 % interest rate) or in 20 years (3 % interest rate). In the case of obtaining an Eco Fund subsidy, the repayment periods may be even shorter.

4. Conclusions

Energy storage is one of the key areas in which more attention and projects will need to be focused to better address the challenges of energy efficiency and the integration of renewable energy sources into heat storage systems in the future. Storing cold in latent heat accumulators or. in this case, the technology of ice banks can help solve various problems such as: overloading the electrical network, reducing the rated power of refrigeration units, reducing operating costs, etc. The building of the Cankarjev dom congress centre was interesting to consider because part of this building is underground. The building has eleven floors, of which seven are above ground and four below ground. The premises are intended for different types of activities, which had to be considered when modelling the building zones. As part of the work, we performed the following steps and came to the following conclusions:

1) In TRNBuild, we assembled and defined the Cankarjev dom building, which covers 40 zones. The building was then included in the simulations of the operation of the cooling and air conditioning system, through which we were able to determine the energy required for air conditioning.

2) We designed the original cooling system in Cankarjev dom, before the ice banks were installed, in the Trnsys software environment. In this system, refrigeration units were used for cooling. We have calculated that they need 963 MWh of energy for air conditioning on an annual basis.

3) The original system was upgraded to a system with ice banks, which enables the production and storage of cooling energy at times of lower electricity prices to cover the need for cooling during peak cooling loads, when electricity is more expensive. We have shown that ice banks in Cankarjev dom cover 61 % of all energy needs for cooling. In the case of continuous recharging of ice banks (every night from May to September), ice banks could cover a maximum of 76 % of the annual energy required.

4) The system with ice banks was upgraded with photovoltaic modules to produce a share of electricity from renewable energy sources, and at the same time the refrigeration unit could be supplied with the produced electricity. The obtained results showed that a solar power plant could produce 20 % of electricity for a refrigeration unit. To increase the share of electricity produced from photovoltaics, we would increase the area of the solar power plant, as we still have some suitable space compared to the roof area of Cankarjev dom.

5) We found that for an investment in a 51.6 kW photovoltaic power plant, it would be repaid within 15 years if own funds were used. If we had taken out a loan with a 2 % interest rate for an investment in a photovoltaic power plant, the investment would have been repaid in 18 years, and at a 3 % interest rate in 20 years.

6) We found that given the savings that an investment in an ice bank system brings, we need 21 years to recoup the investment when we use our own funds. If we took out a loan with an interest rate of 2% for the investment, it would be repaid in 28 years, and at a 3% interest rate in 35 years. If we had invested in only 9 ice banks, our investment would have paid off in 6 years.

7) Given the amount of investment for the reconstruction of the system, it will pay off faster if we successfully apply for a tender for grants or subsidies. This would be an additional incentive to integrate energy storage technologies.

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The datasets generated during and/or analysed during the current study are available in the RUL repository (Repozitorij Univerze v Ljubljani), https://repozitorij.uni-lj.si/IzpisGradiva.php?id=129124&lang=slv .