Validation of an Ice Storage Model and its Integration into a Solar-Ice System

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Abstract

Ice storages allow the storing of solar heat in a compact volume for the later use as source for a heat pump that provides heat for a building. In the paper a novel ice storage with 2 m^3 water volume is described which contains heat exchanger plates for extracting the latent heat. Most of the components of the storage are made of stainless steel ensuring a long service life time. We present a detailed numerical model for heat exchanger plates that was implemented into the system simulation software Polysun. The model allows now for the first time to simulate ice storages with heat exchanger plates in Polysun. The accuracy of the modelling approach is evaluated based on lab measurements. The new ice storage model was implemented into a system simulation template in Polysun which was designed according to a field installation. The field installation includes three of the novel ice storages and will be used for the validation of the system template. The system template can be used as a design tool for solar-ice systems.

Keywords: Novel ice storage, heat exchanger plates, ice storage model, solar-ice system, validation

1. Introduction

Ice storages have been used for many decades in the cooling industry and for air-conditioning of buildings (Ashrae, 2015). If designed for this kind of application, ice storages are optimized for the provision of high cooling power in industrial processes and for the dispersal of cooling loads for air-conditioning over the day in order to reduce chiller needs at peak times of electricity cost. Different requirements are necessary when ice storage systems are used to provide space heating and domestic hot water in buildings in combination with a heat pump. Especially in this case, it is of high importance that the storage has low investment costs, is easy to install, and needs minimal maintenance.

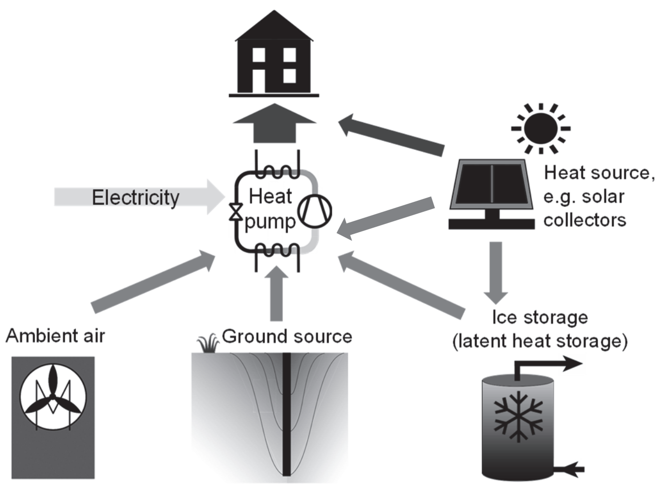

Fig. 1: Principle use of an ice storage as heat source for a heat pump in a solar-ice system. The solar heat stored in the ice storage is used alternatively to ambient air or ground source.

In combination with an ice storage, solar collectors are an alternative heat source that can replace the use of ambient air or of ground source (see Fig. 1). When the sun shines, solar collectors can provide enough heat directly to the building or to the heat pump evaporator. However, at cloudy or night time periods, another heat source is necessary. In this situation, the ice storage act as a temporal heat source, which is regenerated with the solar collectors at a very high efficiency. The heat pump can extract the sensible and latent heat via heat exchangers that are immersed into

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the ice storage water. Through the heat exchangers a heat transfer fluid is pumped which brings the heat to the heat pump. When the surface temperature of the heat exchanger drops below 0 °C, ice is formed on the heat exchanger and latent heat of the storage water is extracted. By freezing the storage water a high amount of heat can be extracted: per kilogram of water 333 kJ (0.093 kWh) are released during this process. Compared to that, using the sensible heat of water at temperatures above 0 °C, 4.19 kJ/(kg K) or 0.001 kWh/(kg K) can be extracted. From these numbers it can be derived that by freezing 1 kg of water the same amount of heat is released as by cooling 1 kg of water from approximately 80 °C to 0 °C.

1.1 Characteristics of ice storages in heating systems

In general, the following characteristics of ice storages are of interest for solar thermal and heat pump heating systems (Carbonell et al., 2017a):

- The use of the enthalpy of phase change of water leads to a high volumetric storage capacity, i.e. relatively small-sized ice storages can store a large amount of heat. Ice storages usually gain heat in winter from the surroundings.
- If the ice storage is installed outside the building (especially if buried in the ground) a thermal insulation of the walls of the ice storage may not be necessary. Eliminating the thermal insulation allows to achieve a heat gain in winter from the surrounding ground enabling to reduce the ice storage volume significantly.
- The impact on-site is lower compared to other heat sources for heat pumps like boreholes or air heat exchangers (no potential restrictions or risks like for boreholes and no visual or acoustic impacts like for air-source heat exchangers).
- The regeneration of the ice storage with solar heat at a low temperature level leads to additional solar gains in times during which the solar heat cannot be used directly for space heating or domestic hot water preparation.
- Low temperature heat sources like waste heat of e.g. exhaust air or waste water can deliver heat for melting the ice.
- If the ice formed in winter is stored until summer or if the building has both heating and cooling demands, the storage can be used as a heat sink for free cooling.
- The system design allows flexibility, i.e. lack of roof area can be compensated by larger ice storage volume and vice versa.

1.2 Heat exchanger types for ice storages

Several heat exchanger concepts for extracting the latent heat from ice storages can be used (Carbonell et al., 2017a). Each concept has to ensure that the ice layer on the specific heat exchanger reaches a maximum thickness that is appropriate for the concept and does not result in too low source temperatures for the heat pump. In principle, two strategies exist for the design of heat exchangers for ice storages:

(a) Large heat exchanger area homogeneously distributed throughout the whole storage volume. Depending on the extraction power of the heat pump and on the specific characteristics of the heat exchanger, a maximum ice layer thickness ranging from several centimeters to a few decimeters is usually allowed. This maximum ice thickness determines the distribution of the heat exchanger in the storage volume. The following heat exchanger types are commonly used:

- Coils or capillary mats typically made of plastic that are mounted on a supporting structure. These systems are known as "Ice-on-coil” type with suppliers such as e.g. Viessmann/Isocal, Fafco, Consolar, Calmac and Clina.
- Flat heat exchanger plates mounted on a supporting structure. Materials can be plastic or stainless steel with supplier such as e.g. Energie Solaire, MEFA and BITHERM.
- Spheres made of plastic filled with water (ice balls). The ice storage is filled with the spheres and brine is pumped through the gaps between the spheres, with a supplier such as Cristopia.

(b) Small heat exchanger in or outside the storage with prevention of ice formation on the heat exchanger or active removing of ice from the heat exchanger surface:

- Ice slurry machines that can be mounted outside the storage. On a compact heat exchanger either water is sub-cooled and freezes after being released into the ice storage or ice is directly formed on the heat exchanger, continually scraped away by a mechanic device, and washed into the storage (Abrahamsson, 1981). Suppliers such as e.g. Mycom Mayekawa and Shinryo Corporation.
- Falling water film: the storage water is sprayed over a heat exchanger mounted above an open storage. The storage water freezes on the heat exchanger which is periodically de-iced thermally by a hot gas (Mehling and Cabeza, 2008). This system is known as an ice harvesting system.
- Flat immersed heat exchanger plates made of stainless steel. The plates are mounted vertically at the bottom of the storage and have a low height compared to the water level. The plates are periodically de-iced thermally by low grade heat (Philippen et al., 2012).

From the above mentioned systems only the homogeneously distributed concepts are established in the solar and heat pump heating market. A comparison of the performance of commonly used heat exchangers for ice storages based on lab tests is given in Carbonell et al. (2017a).

1.3 Aim of developing a new ice storage and a design tool for system sizing

Most of the market available ice storage tanks have been designed for cooling applications and do not meet the specific needs of solar-ice heating systems. The number of manufacturers of ice storages is small and only a few designs of ice storages are available. Some of the ice storages available for solar-ice applications have to be installed outside the building due to their design and sizes (e.g. Viessmann/Isocal, DE) or are very small (few hundreds of liters) and thus only usable for single family houses (e.g. Consolar, DE). Further, market available ice storages have a guaranteed life time of only 10 years while heating systems should last at least 20 to 25 years, especially the storage tanks.

One goal of the presented work was to develop an ice storage in the range of 2 m^3, where mainly stainless steel components are used in order to ensure a long service life time of 25 years. The developed heat exchanger of the 2 m^3 storage consists of several heat exchanger plates and is meant for being used also in larger ice storages, meaning, its area can be scaled up for larger storage volumes.

In the design of solar-ice systems, hereafter named “ICESOL“, the frequently encountered trade-off between system efficiency and cost is partially caused by the installed heat exchanger area inside the ice storage. While a higher efficiency can be achieved by increasing the area, the number of installed heat exchanger is also a major cost driver in the system installation (Carbonell et al., 2017b).

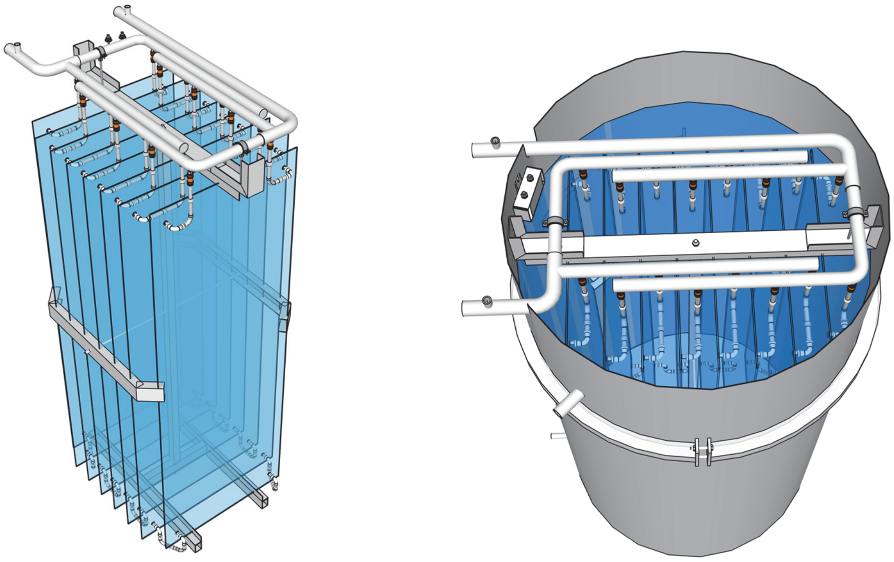
Due to the dependence from heating demand, climate and the variability of the components, solar-ice systems are not easy to design and to size. There is a need of dynamic system simulations to get reliable results in the planning phase. For this reason, it was decided to implement a model of the new ice storage with its heat exchanger plates into the simulation software Polysun. The ice storage model that had been implemented in Polysun in a previous program version takes only ice-on-coil heat exchangers into account and cannot be used for plate heat exchangers.

In addition to the goal of developing an ice storage, further goals of the project presented were i) to do a transcription of a mathematical model of an ice storage written in Fortran language from a TRNSYS type developed in Carbonell et al. (2017a) into JAVA language and its simplification and implementation into the software Polysun and ii) to validate the new model with measurement data from laboratory tests. Further, a whole solar-ice heating system was implemented in Polysun containing the new ice storage model. The system as well will be validated with measurement data from a field installation of a multi-family building were three units of the new ice storage were installed. Due to delays in installing the field installation, the measurement data is still missing and the validation of the system could not be finished.

2. Design of the new modular ice storage and set-up of lab measurements

A cylindrical ice storage was developed (Fig. 2) that can easily be installed in clusters to get larger total ice storage volumes if needed. The main components of the storage, like the cylindrical vessel, heat exchangers, pipes, fixtures and fittings are made of stainless steel which ensures long service life time and prevent diffusing of oxygen into the brine cycle. Tab. 1 gives an overview on most important parameters of the storage.

Four pairs of heat exchanger plates are mounted and hydraulically connected in parallel. Each pair consists of two plates that are connected in series. The heat exchanger plates have a distance between each other of 12 cm. Hence, the maximum ice thickness on the heat exchanger surfaces is 6 cm. The heat exchanger is made of stainless steel with a “cushion” geometry (Fig. 3). Each cushion has a size of 60 mm x 60 mm. The square bumps of the front sheet are set off half a pass towards the square bumps of the back sheet in a way to allow full irrigation. Both sheets are spot welded together and combined at the edges by welding. There is already 6 years of experience with the use of this heat exchanger in ice storage tanks which has given confidence in their reliability for this new application.



(a) (b)

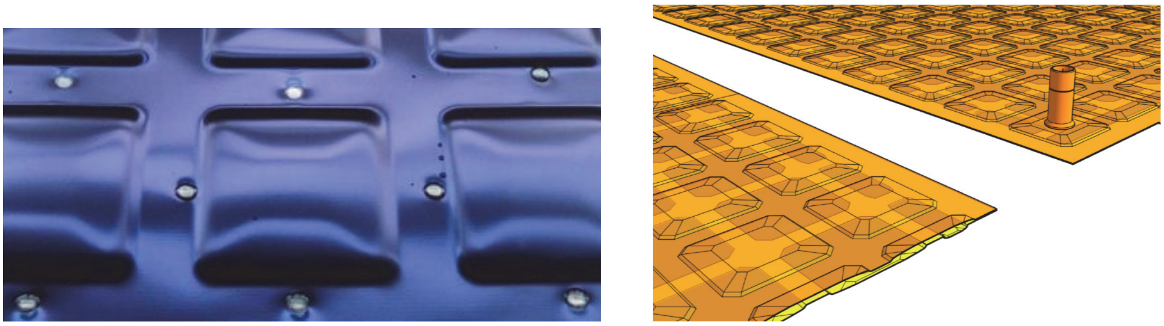
Fig. 2: Drawing of (a) the ICESOL heat exchanger with eight heat exchanger plates made of stainless steel (transparency in the drawing as artefact) and (b) the ICESOL ice storage with the heat exchanger immersed into the storage water.

To gather data for the model validation and for testing the mechanical stability of the storage, laboratory tests were conducted with a storage like specified in Tab. 1 following the test cycles described in Carbonell et al. (2017a). The test cycles include sensible heating of the ice storage up to 40 °C, sensible cooling, fully icing with decreasing brine temperature down to -10 °C, cycling (melting & freezing) at high ice fractions, and melting. Mass flow rates of 1’000 l/h and 2’000 l/h were used for the tests.

Tab. 1: Main specifications of the ice storage as tested in the lab.

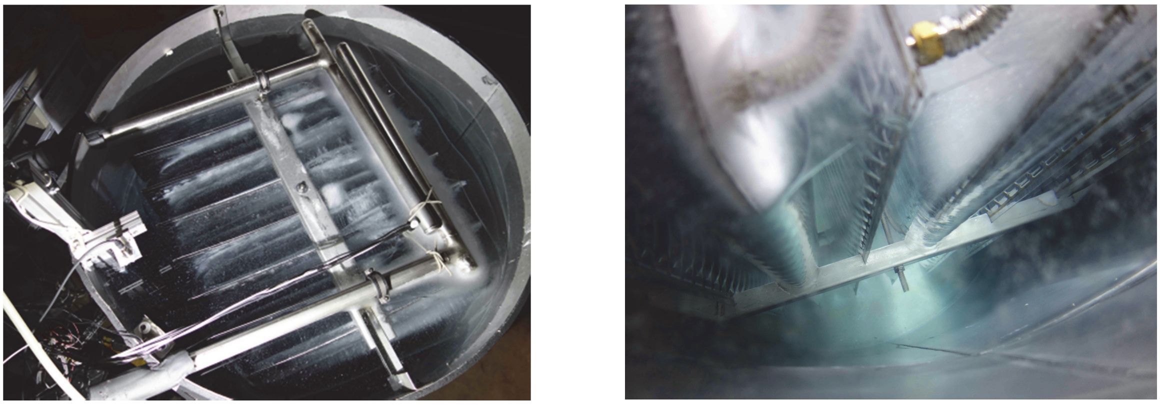
Diameter of storage	mm	1200
Height of storage	mm	1950
Water content	m^3	1.97
Number of parallel pairs of hx-plates	#	4
Distance between plates	mm	120
Active surface of heat exchangers	m^2	21.7
Latent heat (max.)	kWh	129
Maximum icing fraction	of mass	70 %

During the icing test phase a very high ice fraction was achieved and the ice layers reached the wall of the storage (Fig. 4). At this state of fully icing, the cycling phase of melting and icing started. As a result, mechanical tensions in the ice were dissipated and the ice cracked causing a slight movement of the ice. However, no deformation or damage could be detected neither at the built-in components nor at the wall of the cylindrical storage after melting all ice. As a result, the laboratory tests have shown also for harsh conditions that the ice storage is sufficient stable against the mechanical stress the ice is causing.



(a) (b)

Fig. 3: (a) Surface of the solar absorber of manufacturer Energie Solaire SA which – without dark coating – can be used as a heat exchanger in ice storage tanks; (b) section of the heat exchanger and 3D view.



(a) (b)

Fig. 4: Ice storage with iced heat exchangers during measurements in the lab (tank cover removed). (a) The heat exchanger inside the cylindrical ice storage and (b) View into the ice storage with water between storage wall and iced heat exchangers.

3. Mathematical model of heat exchanger plates

The mathematical model of the ice storage itself is based on discrete control volumes with the corresponding heat transfer equations. The implemented version is a simplified version of the model described in Carbonell et al. (2017a) which is restricted to heat exchanger plates. In comparison to the original model, the number of control volumes used in the storage is fixed to 1. The general structure of the model is shown in Fig. 5.

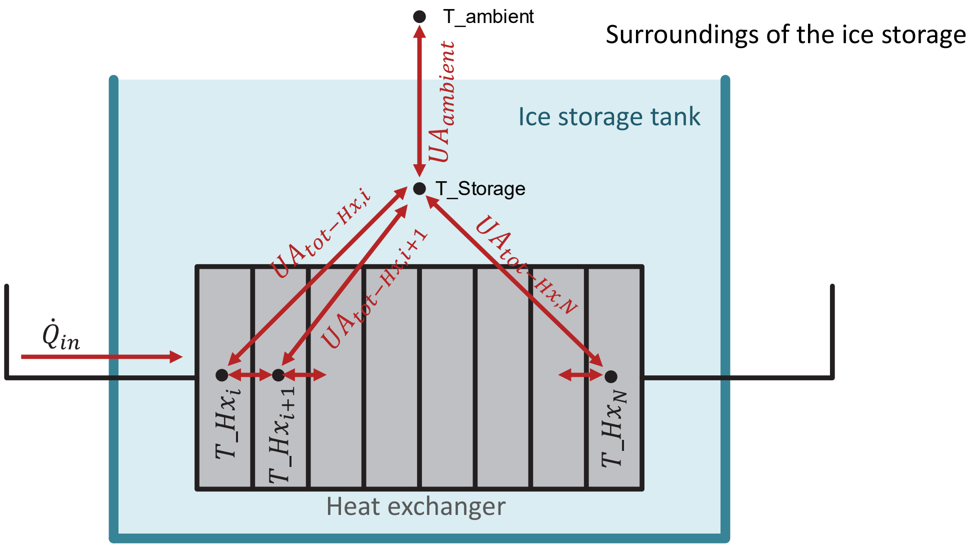


Fig. 5: Temperature nodes and UA-values of the ice storage model.

In the modelling approach used for the heat exchanger plates, apart from the chosen control volume geometry, the heat transfer coefficients (U) are the most important factors. In the following section, the governing equations for the heat transfer coefficients multiplied by the relevant surface area (UA-values) are presented. The energy transfer due to fluid flow in between the control volumes is computed according to Polysun's standard fluid flow interface.

The core elements of the model are the heat transfer values (UA_i) between the brine inside the heat exchangers and the water inside the storage. The UA-values limit the maximum power that can be extracted from or injected into the storage and thus, have a large influence on the simulation results. Sensible heating, sensible cooling, as well as icing are treated individually as they all inflict different physical dynamics in the fluid on small scales that effect the overall heat balance. In all states, the UA-values are derived from general heat transfer correlations.

In the following section the control volume number index i is omitted for simplicity reasons and all UA-values represent the values associated to one control volume. The heat exchanger has a fixed number of 12 control volumes which was found to be a good compromise between the accuracy on the heat exchanger model and the simulation time needed by the model.

The overall UA-value per control volume ($\mathrm{UA_{tot}}$) is a combination of the heat transfer area product coefficients between heat exchanger fluid and heat exchanger wall UA_{in}, through the wall UA_{wall}, through the ice UA_{ice} and from the wall or the ice layer to the storage water UA_{out}

$$\mathrm{UA_{tot}} = \left(\frac{1}{UA_{in}} + \frac{1}{UA_{wall}} + \frac{1}{UA_{ice}} + \frac{1}{UA_{out}}\right)^{-1} \tag{1}$$

3.1 Heat Exchanger Plates

The heat transfer area product coefficient between the heat exchanger fluid and the wall (UA_{in}) of the heat exchanger plates is calculated as follows.

If the Reynolds number $Re < 70$.

$$Nu_{laminar} = 1.68\, Re^{0.4} \left(Pr * \frac{d_h}{b}\right)^{0.4} \tag{2}$$

If $Re > 150$

$$Nu_{turbulent} = 0.2\, Re^{0.67} Pr^{0.4} \tag{3}$$

If $70 < Re < 150$, a linear interpolation between $Nu_{laminar}$ and $Nu_{turbulent}$ is used.

The diameter d_h of the flow cross section in the calculation of the Reynolds number is reduced by a factor of two in the case of corrugated heat exchangers. Based on the Nusselt numbers, the UA value can be computed as:

$$UA_{in} = 2A \cdot Nu \cdot \lambda_{fluid}/d_h \tag{4}$$

The factor of two indicates that the heat exchanger plate has both front sides in contact with the water.

Accordingly, UA_{wall} is calculated as:

$$UA_{wall} = 2A \cdot \lambda_{wall}/x_{wall} \tag{5}$$

3.2 Sensible heating and cooling without ice

In the case of no ice on the heat exchanger $UA_{ice} = \infty$ and the equation of $\mathrm{UA_{tot}}$ reduces to

$$\mathrm{UA_{tot}} = \left(\frac{1}{UA_{in}} + \frac{1}{UA_{wall}} + \frac{1}{UA_{out}}\right)^{-1} \tag{6}$$

In this case UA_{out} is calculated based on the Rayleigh number Ra.

$$Ra = 9.81\beta\rho^2(\mathrm{T_{storage}} - T_{wall})l_c^3 c_p \mu \lambda_{tank,fluid} \tag{7}$$

$$Nu = 0.55 \cdot Ra^{0.33} \tag{8}$$

$$UA_{out} = 2A \cdot Nu \cdot \lambda_{tank,fluid}/l_c \tag{9}$$

3.3 Icing

The model assumes that icing starts to build on the heat exchanger as soon as $T_{storage}$ reaches 0 °C and the brine temperature is below 0 °C (no supercooling is taken into account). No simultaneous energy transfer due to latent and sensible heating is modeled. When ice is present in the storage, the model distinguishes between a state where ice grows on the outer surface of the ice layer and a second state where a layer of liquid water is present between the outer surface of the heat exchanger and the ice layer due to partially melting the ice layer at previous time steps. At the maximum one layer of liquid is assumed between the heat exchanger surface and the ice layer. In case this liquid layer is present due to a partial melting phase, during the next icing, this inner water layer is iced first and only the thickness of the inner ice layer $x_{ice,inner}$ is considered for the calculation of the UA-value until it reaches the priory melted thickness. The following applies:

$$\mathrm{UA_{tot}} = \left(\frac{1}{UA_{in}} + \frac{1}{UA_{wall}} + \frac{1}{UA_{ice}}\right)^{-1} \tag{10}$$

where

$$UA_{ice} = 2A \cdot \lambda_{ice}/x_{ice,inner} \tag{11}$$

If there is only a single layer of ice and ice grows at the outer surface, UA_{ice} is calculated using the full thickness of the ice:

$$UA_{ice} = 2A \cdot \lambda_{ice}/x_{ice} \tag{12}$$

The thickness of the ice layer x_{ice} or $x_{ice,inner}$ are updated after each time step by the total energy transferred through the section of the heat exchanger $Q_{hx,i}$.

$$\Delta x_{ice,i} = \frac{Q_{hx,i}}{\Delta H \rho_{ice}} \cdot \frac{1}{2A} \tag{13}$$

3.4 Melting

During melting, $\mathrm{UA_{tot}}$ is calculated as

$$\mathrm{UA_{tot}} = \left(\frac{1}{UA_{in}} + \frac{1}{UA_{wall}} + \frac{1}{UA_{out}}\right)^{-1} \tag{14}$$

Melting is modelled with two different phases. At first, when the thickness of the melted layer x_{melt} is smaller than 0.01 m, the UA_{out} is assumed to be dominated by conduction

$$UA_{out} = 2A \cdot \lambda_{water}/x_{melt} \tag{15}$$

For larger depths of the melted layer ($x_{melt} > 0.02\ m$) convection is assumed to become relevant:

$$Ra = 9.81\beta\rho^2(\mathrm{T_{storage}} - T_{wall})l_c^3 c_p \mu \lambda_{tank,fluid} \tag{16}$$

$$Nu = 0.3 \cdot Ra^{0.208} \tag{17}$$

$$UA_{out} = 2A \cdot Nu \cdot \lambda_{tank,fluid}/l_c \tag{18}$$

In the transition a linear interpolation is used.

4. Model validation

The model implemented was validated using data from the test cycles mentioned in chapter 2. An example of the icing phase that is crucial for system performance is shown in Fig. 6. The results of the original model implemented in TRNSYS in Carbonell et al. (2017a) are also given. In the bottom right figure, it can be seen, that the UA-value of the Polysun model approximates the measured UA-value equally well than the TRNSYS model when the ice fraction is above 10 %. For lower ice fractions, the UA-value of the Polysun model surpasses the TRNSYS model up to a factor of 2. The source of this behavior was identified to be the different fluid properties used for the brine in Polysun and TRNSYS. Since in the tested configuration the brine was in the transition phase between turbulent and laminar flow, slightly different values in fluid properties lead to large deviations in UA_{in}. The calculations of both models are lying outside the uncertainty of the measurement quite often. However, especially for the aggregated values like energy and ice fraction the simulations are matching the measurement results well.

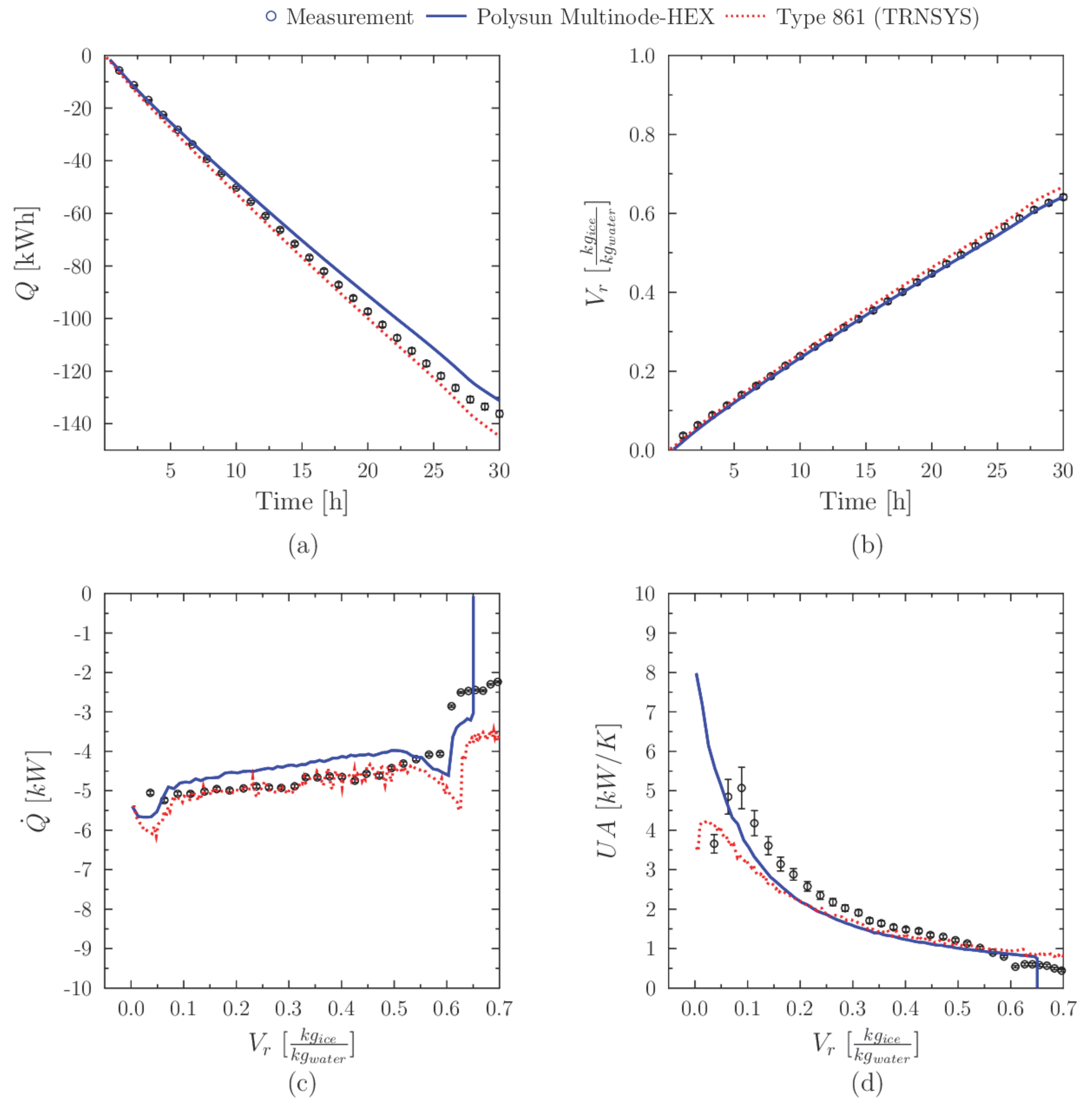


Fig. 6: Icing of 8 heat exchanger plates in the ice storage. Comparison of the new Polysun ice storage model with lab measurements and with a TRNSYS model. With extracted energy (Q), ice fraction (V_r), extracting power ($\dot{Q}$), and UA-value. At V_r = 0.65 the Polysun model assumes maximum icing fraction (due to the special conditions within the ice storage tank) and the heat extraction drops to Zero.

The power $\dot{Q}$ (lower left figure) is slightly underestimated by the Polysun implementation leading to a slower increase of the cumulative extracted energy Q (top left figure). This behavior is a result of the Polysun storage model simplification where only one control volume is used. During icing, this control volume has a constant temperature of 0 °C leading to a smaller temperature difference compared to the original TRNSYS model where each control volume of the heat exchangers is linked to a control volume of the storage. As a consequence, during icing, storage temperatures slightly higher than 0 °C are possible for the TRNSYS model due to the higher spatial resolution. Although the Polysun model shows a slower increase of the cumulative extracted energy over time, the increase of ice fraction is faster. This is due to different definitions of ice fraction used in the model implementation of the two simulation frameworks. While in the TRNSYS implementation the ice fraction represents the mass fraction, in the

Polysun model it represents the volume fraction.

Sensible heating of the ice storage from approx. room temperature to 40 °C is shown in Fig. 7. Although lying often not exactly inside the range of uncertainty of the measurement data, the new Polysun model shows a very good correlation with the measurement for the relevant values Q, $\dot{Q}$, and the outlet temperature of the heat exchanger ($T_{out,hx}$). This is the case also where sudden changes in the load power occur due to the regulation of the heater. Some larger deviations can be seen for the UA value (hours 5 to 9) but no relevant deviations for the other values can be seen as implication.

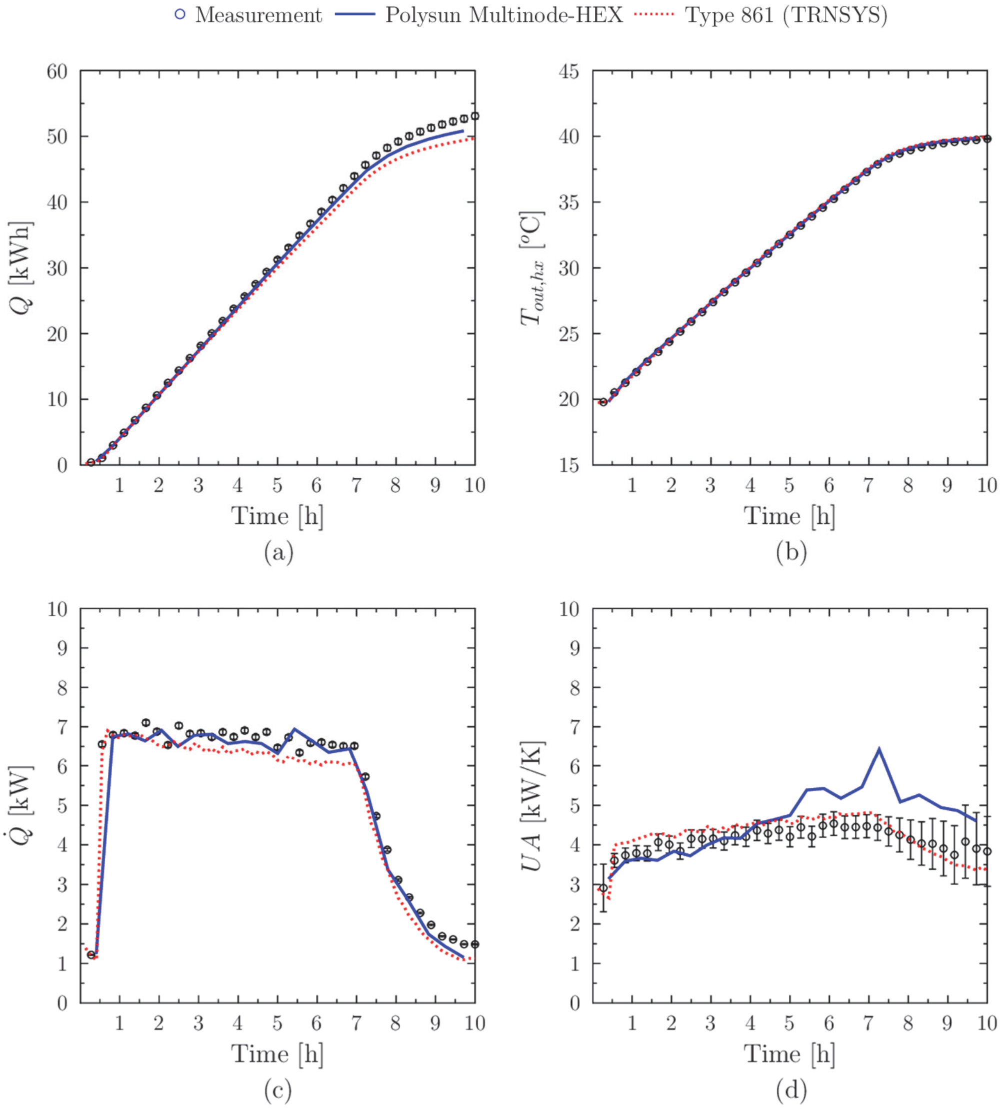


Fig. 7: Sensible heating with 8 heat exchanger plates in the ice storage up to 40 °C. Comparison of the new Polysun ice storage model with lab measurements and a TRNSYS model. With extracted energy (Q), outlet temperature of the heat exchanger ($T_{out,hx}$), extracting power ($\dot{Q}$), and UA-Value.

5. Field Installation and System Integration into Polysun

In winter 2017/2018 a solar-ice system with the developed ice storage was installed in a multifamily building that was refurbished and extended in 2017 to 1’800 m^2 of heated floor area (Figure 8). The building is located in the south-west of Switzerland near Geneva on a height of 360 m above sea level. The heating system is monitored and the monitoring data will be used to validate a newly integrated solar-ice heating system in Polysun.

The main components of the solar-ice system in the building are: a heat pump with a nominal thermal power of 30 kW (B0/W35), a field of unglazed solar collectors of 110 m^2, and three of the developed ice storages with a water volume of 2 m^3 each. The ice storages are regenerated with solar heat and also with the exhaust air of the ventilation system. As an air-to-air heat recovery system for the ventilation could not be realized due to the local conditions, the warm exhaust air is used to load the ice storage which is done with an air-to-water heat exchanger. This steady heat input into the ice storages allows to use a reduced ice storage volume in this heating system.

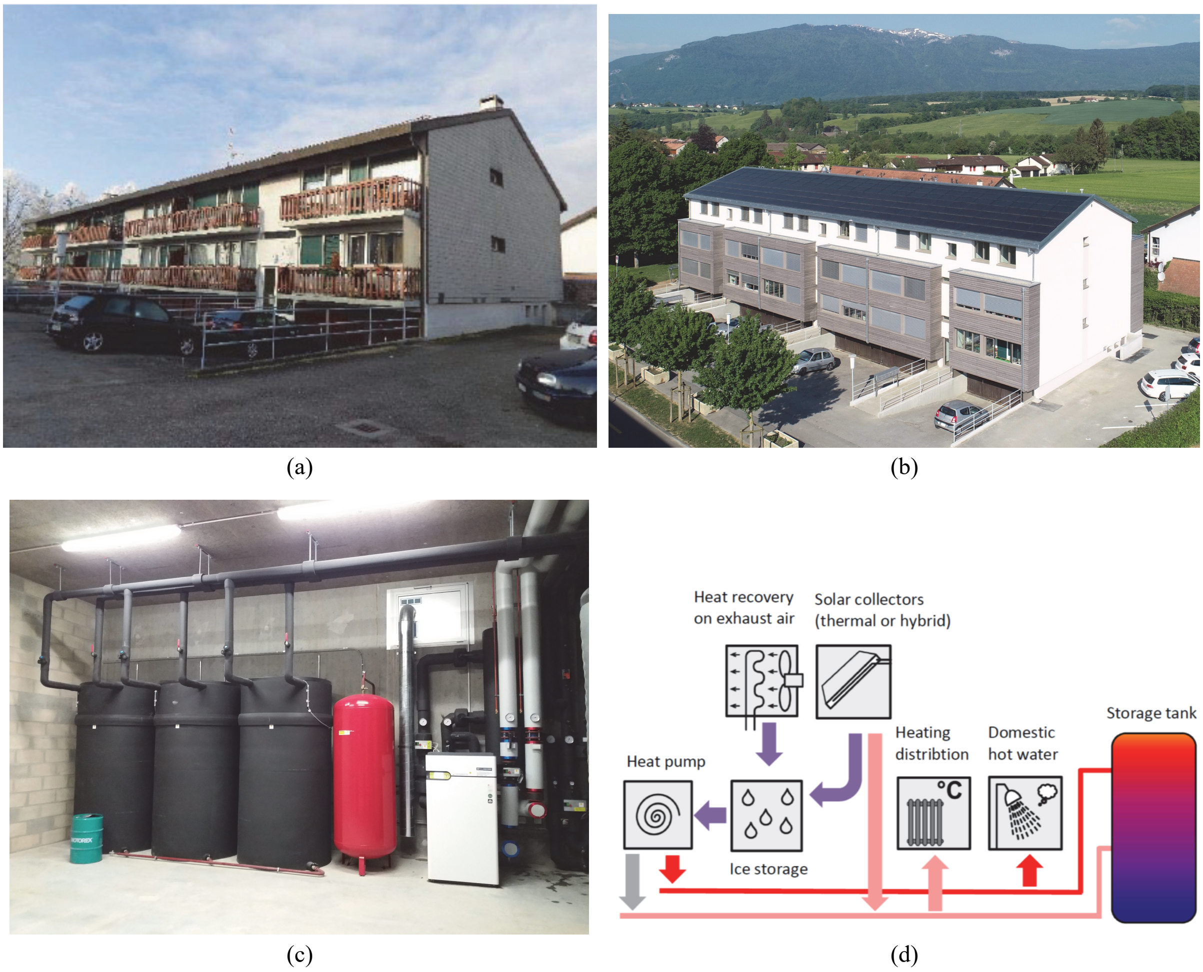


Fig. 8: Field installation including the developed ice storage, installed in a multi-family building. Building (a) before and (b) after the refurbishment and extension to 1'800 m² heated floor area. (c) Cellar with three ice storages of 2 m³ volume each and (d) scheme of the energy flows in the heating system.

The ICESOL system including the new ice storage model was implemented according to the specifications of the field installation into Polysun. The system will serve as template for the ICESOL systems of ESSA and will be validated with the monitoring data from the field installation. The template will be available in new Polysun versions and will allow to size heating systems containing an ice storage with flat heat exchanger plates.

The validation of the system template has still to be done as the finalization of the field installation was delayed and no measurement data from the heating system could be gathered during the last winter. After winter 2018/2019 the measured energy flows between the different main components (collector field, ice storage, heat pump, storages, and building) and their changes in temperature will be used for a validation of the system template.

6. ICESOL solar-ice heating systems

The ICESOL system installed at La Cigale in Geneva (largest MINERGIE-P refurbishment project in Switzerland www.renov-lacigale.ch) has shown that large ICESOL systems (500 kW heating power) are a valuable alternative to heat pump systems with boreholes, especially when borehole drilling is prohibited or technically not possible. The estimated geothermal potential in Switzerland is limited. In large areas ground source heat pumps are not allowed because of groundwater protection. Additionally, in urban environment drilling boreholes is not always technically feasible. Ice storages together with solar thermal as sources for heat pumps are relatively new and not explicitly considered in official predictions for energy supply. It is difficult to estimate the potential of the ICESOL heating system, since it is quiet young on the market. However, the market potential of his technology is high. The company

Energie Solaire SA, as example, is involved in several large projects that are planned in Switzerland in the next few years with a heating power of up to 1.5 MW per system, with large ice storage tanks of up to 300 m^3.

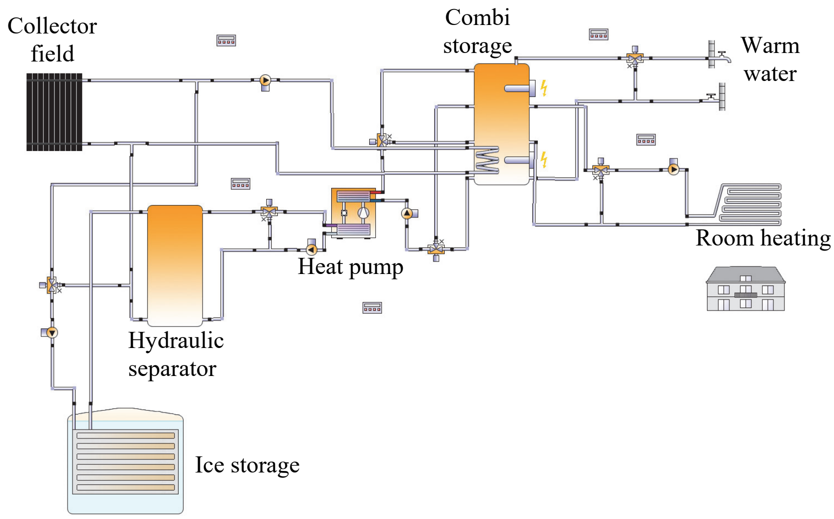


Fig. 9: Template of the solar-ice system with the new ice storage model which was implemented into the Polysun simulation software.

Main advantages of solar-ice-systems are as follows:

- High seasonal performance factors (SPF) are achievable.
- The system is competitive in comparison to geothermal heat pump systems.
- Unlike air-source heat pumps, ICESOL is silent and does not produce noise disturbances.
- Apart from using low temperature solar thermal heat, ICESOL can use low temperature waste heat recovery to de-ice the ice storage.
- Heat-exchangers in ice storages can easily be replaced in case of a default, which is not the case for boreholes.
- Solar collectors, the heat source for ICESOL heat pump systems, can quiet easily be integrated in the building envelope (roof, façade, etc.).
- Since the ice storages are relatively small they can be installed in the building or be part of the building, without using a lot of space.

7. Conclusion

A new ice storage with 2 m^3 water volume (129 kWh latent heat) was designed including heat exchanger plates made of stainless steel. With lab tests it could be shown that the ice storage and its built-in components are mechanically stable against icing and melting of the storage water. The ice storage was energetically characterized with measurements. The heat exchanger in the ice storage consists of four parallel pairs of heat exchanger plates. To get larger ice storage volume, a cluster of several ice storages can be used and connected in parallel. To obtain very large ice storages, the heat exchanger can be implemented in any kind of storage vessel and can be scaled by increasing the number of heat exchanger pairs.

The advanced ice storage model that was developed for Polysun and validated with measurement data extends the capabilities of Polysun to represent different kinds of ice storages. While the already existing model relies on an empirical fitting function fixed to the specific kind of coil heat exchanger geometry, the new model was designed to simulate an ice storage with any number of flat plate heat exchangers. The heat exchanger material and geometry as well as the distance between heat exchangers in the ice storage can be parametrized. In the following, the model can be used to test and simulate new ice storage configurations ad hoc without the need of providing experimental data. In addition, in comparison to the already existing ice storage model in Polysun, the new model accounts for measureable differences in the heat transfer properties between icing and melting making it more precise in reproducing both behaviors.

A new template for a solar-ice system including the new ice storage model was implemented into Polysun. The template will be validated with measurement data from a field installation in a multifamily building. As the installation of the monitoring equipment was delayed, no measurement data could be obtained until publishing of this paper and the validation of the system template is still pending. We expect to finalize the system validation by summer 2019.

8. References

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