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BigIce

Assessment of solar-ice systems for multi-family and tertiary buildings.

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1 Project objectives

The overall goal of the project is to assess and quantify the potentials of solar-ice systems for large buildings with the possibility to include cooling demands. The specific objectives of the project are:

- Determinate the cost and energetic performance of solar-ice systems for the selected buildings.
- Quantify the potentials of the system when cooling demands are included.
- Analyse and quantify the effects of different hydraulics in the primary loop (solar collectors, ice storage and heat pump).
- Provide clear recommendations on sizing strategies and hydraulic connections.
- Develop a fast-algorithm based an a large amount of simulations with varying key parameters such as component sizes, hydraulics and building demands, including the relevant climates found in Switzerland.

2 Status and work carried out

The work plan is shown in Fig. 1 where the work done is represented as shares in red.

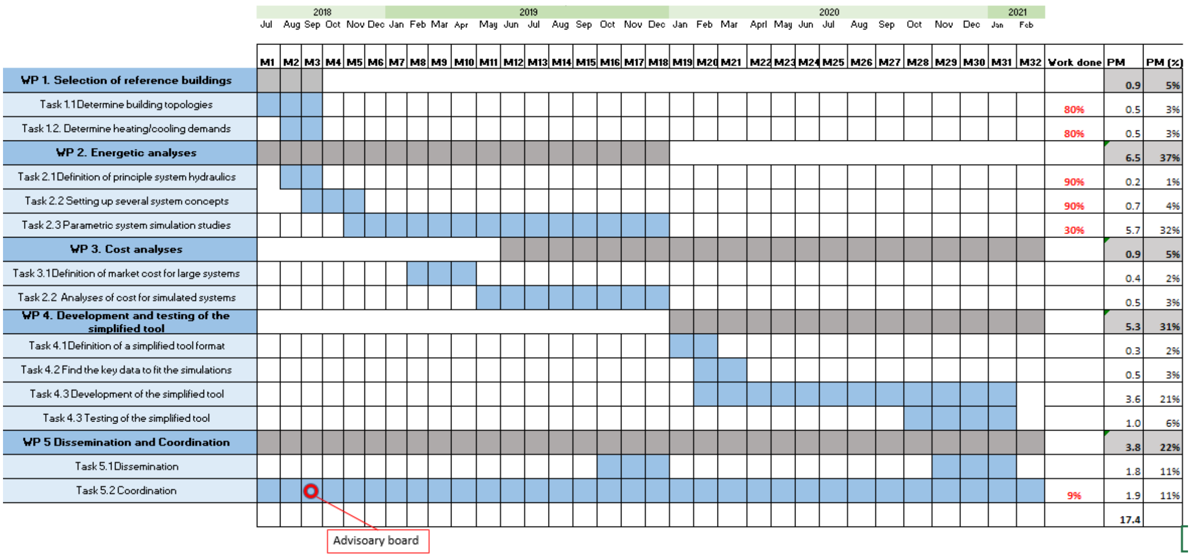

Figure 1: Work plan and current status.

In the following, a summary of the work done is provided.

2.1 Definition of space heating and domestic hot water demands

A multi-family house (MFH) is used as the reference building for the simulations. The reference building is described in Mojic et al. (2018). The reference building has an energy reference area (A_E) of 1205 m^2 that consists of traffic areas and three residential floors with a total of six apartments. The ratio of the thermal building envelope to the energy reference area is 1.3 and the window share in relation to A_E is 25.1 %. A depiction of the building can be seen in Fig. 2. The zones and internal loads correspond to the specifications of the data sheet SIA 2024 (Schneider, 2015). The building was modelled as a solid structure and the building envelope was designed in such a way that the heating requirement meets the swiss "Minergie" standard for sustainable buildings, with mechanical ventilation that has a heat recovery

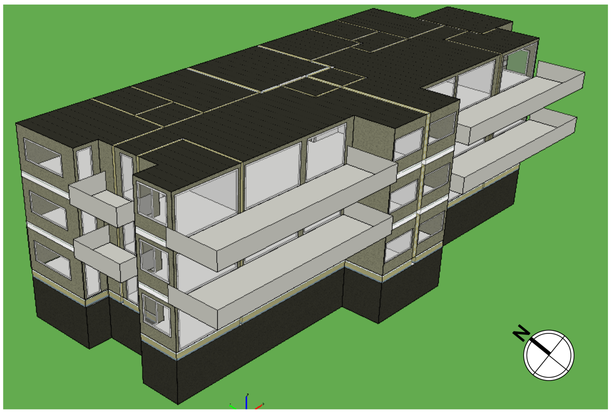

Figure 2: IDA ICE model view of the reference building.

efficiency of 80 %. The building has a standard heating demand of 29 kWh/(m^2 a) for the reference weather station Zurich SMA. The results obtained with a detailed building model from IDA-ICE where used to fit a simplified building model using the standard ISO 13790:2008 (D) (2008). The TRNSYS model used is a modified version of Leconte et al. (2014) as described in Carbonell et al. (2016).

A DHW profile has been created using the Load Profile Generator software (Plugradt, 2010). A single profile for each of the six apartments has been considered:

- Couple under 30 both at work.
- Family with two children (14-16), one at work, one at home .
- Family both at work, two children (9-12).
- Retired couple, no work.
- Shift worker couple.
- Family, two children (6-12), parents without leaving home for work.

These profiles include a delivery temperature of 35 °C. A scaling factor of the volume flow consumed has been applied to use 60 °C as delivery temperature, since it is a much common set temperature. All these single profiles have been included into one single DHW profile with an annual consumption of 16.9 MWh at a delivery temperature of 60 °C. The DHW demand is in the order of 16 kWh/m^2 of heated surface area. Circulation losses have also been included such that the return temperature of the circulation loop is 5 °C below the delivery temperature, i.e. 55 °C. The circulation mass flow rate has been defined such that the circulation losses are around 45 % of the DHW demand. In total, the DHW heat demand including circulation losses account for 23 kWh/m^2.

2.2 Analyses of hydraulic configurations

The solar-ice systems that are sold on the market or analyzed in the literature can be classified by the way the solar heat is used. Besides the common use of regenerating the ice storage, solar heat can be used directly to load the warm storage (direct heat mode) or to work in series with the heat pump providing heat to the evaporator (series mode). For both sinks, direct and indirect integration of the solar heat can be realized, which results in four principle system types shown in Fig. 3. Hyd-Ice is the simplest configuration where the solar energy can only go to the ice storage. Hyd-IceHp allows to bring the energy from the solar collectors to the heat pump directly in the so-called series operation. The third plot represents Hyd-IceTes where the energy from the collector field can be used for the provision of

SH or DHW (via the warm storage) or to the heat pump. The use of solar heat in the warm storage is know as solar direct heat operation mode. finally, Hyd-IceHpTes represents the most complete hydraulic configuration allowing all possibilities described above.

Viessman (Isocal) sells a system with non-selective unglazed collectors with designs according to Hyd-Ice and Hyd-IceHp. Consolar has a system for single family houses with hydraulics according to Hyd-IceTes. Energie Solaire SA offers systems with Hyd-IceTes and Hyd-IceHpTes hydraulics together with their selective unglazed collectors. Comparisons between these hydraulics are necessary to quantify the benefits of adding hydraulic possibilities.

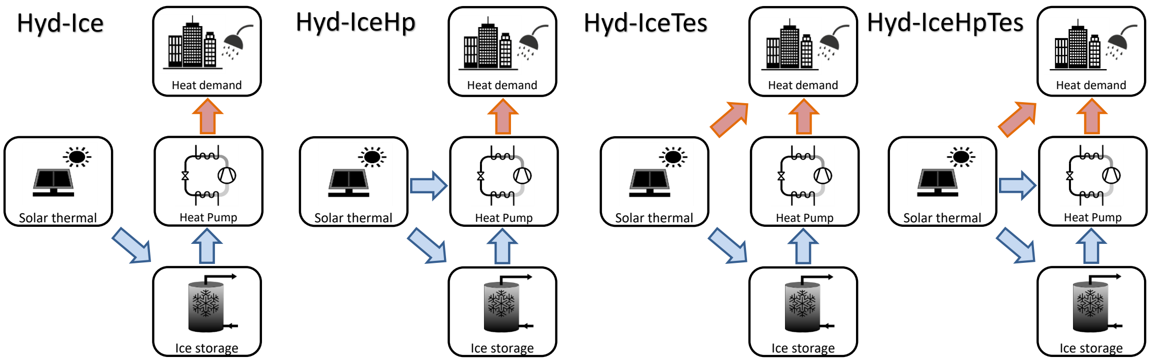

Figure 3: Principle concept of solar-ice systems. The arrows show the heat fluxes that are on different temperature levels, i.e. red and blue for high (>30 °C) and cold (<10 °C) respectively.

Dynamic yearly system simulations have been carried out for ice storage volumes of 0.3 to 0.6 m^3/MWh and collector areas of 1.5 m^2/MWh to 2.5 m^2/MWh. These ranges of size have been shown to be cost competitive while achieving system performances in the range of ground source heat pump systems (Carbonell et al., 2017). However, companies such as Viessman (Isocal) tend to size the ice storage as 1 m^3/MWh for single family homes and well above 2 m^3/MWh for multi-family buildings, using as heat source plastic collectors that are used more as air heat exchangers than as solar collectors. Others, such as ESSA, tend to size the ice storage with values around 0.2 m^3/MWh, making use of a high collector field in the range of 2.5 m^2/MWh.

All simulations from this section are carried out using the multi family building described in section 2.1, located in Zurich with approximately 31 MWh of total heating demand for SH and DHW. A normal year from SIA Klotten weather station has been used to represent Zurich. In the following section 2.3, comparisons between cold, warm and normal years from the SIA standard is provided (Zweifel, 2010). The range of results using different hydraulic configurations is shown in Fig. 4.

It is clear that the higher the possibilities allowed by the hydraulic integration, the better. Thus, Hyd-Ice achieves the worst performances with all SPF_{SHP+}<3.25 Adding direct solar heat to Hyd-Ice leads to Hyd-IceTes. In this case the performance improves achieving a range of SPF_{SHP+} between 2.6 to 3.4 Adding series operation to Hyd-Ice leads to Hyd-IceHp. In this case the performance increases more compared to the addition of solar direct heat, leading to SPF_{SHP+} in the range of 3.2 - 4.7. Adding solar direct heat to Hyd-IceHp leads to Hyd-IceHpTes, the most complete, where the SPF_{SHP+} increases to values between 3.5 to 5.2. From these simulations the average SPF_{SHP+} are 2.8 for Hyd-Ice, 4.1 for Hyd-IceTes, 3.0 for Hyd-IceHp, and 4.5 for Hyd-IceHpTes. This represents an average increase of 7 % to 9 % for adding solar direct heat and 44 % to 47 % for considering series operation to the heat pump without using the ice storage. In total from Hyd-Ice to Hyd-IceHpTes there is an average improvement of 58 %. Thus, an appropriate implementation of the hydraulic is of high importance.

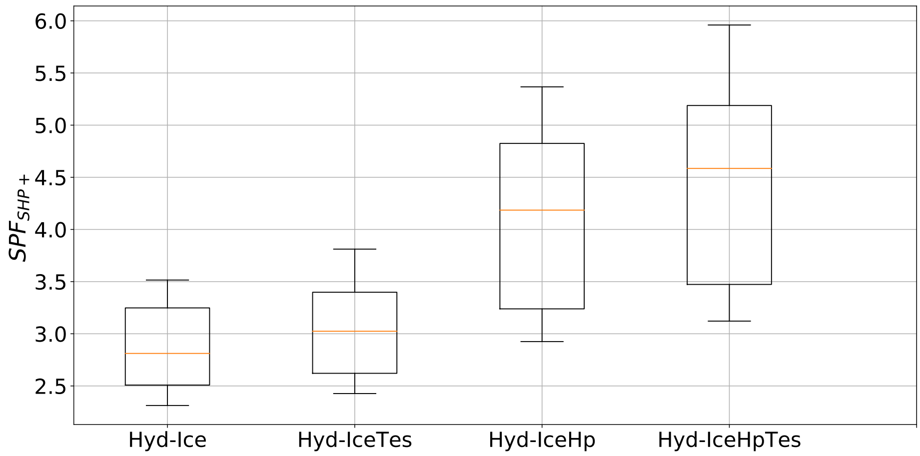

Figure 4: System performance range with the simulated range of 0.3 m^3/MWh to 0.5 m^3/MWh and 1.5 m^2/MWh to 2.5 m^2/MWh for the different hydraulic integration.

2.3 Analyses of weather data

In order to systematically assess the influence of the different weather data profiles from the same location and also to assess the behavior with different locations, the SIA weather data is used. The SIA weather data uses the standard SN EN SO 15927-4 to generate a collection of the so-called "Design Reference Years". This collection is based on measurement data from the years 1984 to 2003. It contains weather data of 40 different locations in Switzerland, each with an extreme warm, an extreme cold and a normal design reference year as described in Zweifel (2010).

2.3.1 Chosen year per location

A comparison of simulation results for three cities, Davos (DAV), Zurich (KLO, Kloten station) and Locarno (OTL) is shown in Fig. 5. Short names used for each city are those used in the SIA standard. Results are obtained using the sets of 1.5 m^2/MWh, 2 m^2/MWh and 2.5 m^2/MWh collector area and 0.3 m^3/MWh, 0.4 m^3/MWh, 0.5 m^3/MWh and 0.6 m^3/MWh ice storage volume, using the normal weather data for each location to calculate the total heating demand that is used for sizing the system. Therefore, the collector field and the ice storage volumes are different for each location, but kept constant when changing the weather data from normal to cold and warm. Davos is located in the Swiss Alps, which is characterized for very cold but sunny winters. This kind of climate is perfect for this type of system if snow is removed from the collector field. In the simulations, the presence of snow on the collectors has not been considered. Davos shows the best performance of these three locations, and - as will be shown afterwards - of all Swiss locations. Almost all simulations show system performances well above 4, reaching SPF_{SHP+} up to 9 for warm years. These results clearly outperform any other heat pump based system. For Zurich, the SPF_{SHP+} is considerably lower. In the cold year, it ranges from just below 2 to around 2.8, though for the warm year it reaches between 4 and 6.7. The city of Zurich is known to have less sun during winter, as there are many cloudy and foggy days. Finally, Locarno (OTL) - which is south of the alps - has again a very different climate, with much solar irradiation, but warm temperatures. Because of the high solar irradiation, the solar ice systems also performs better than in Zurich, ranging between above 3 for cold years, up to almost 9 for warm years.

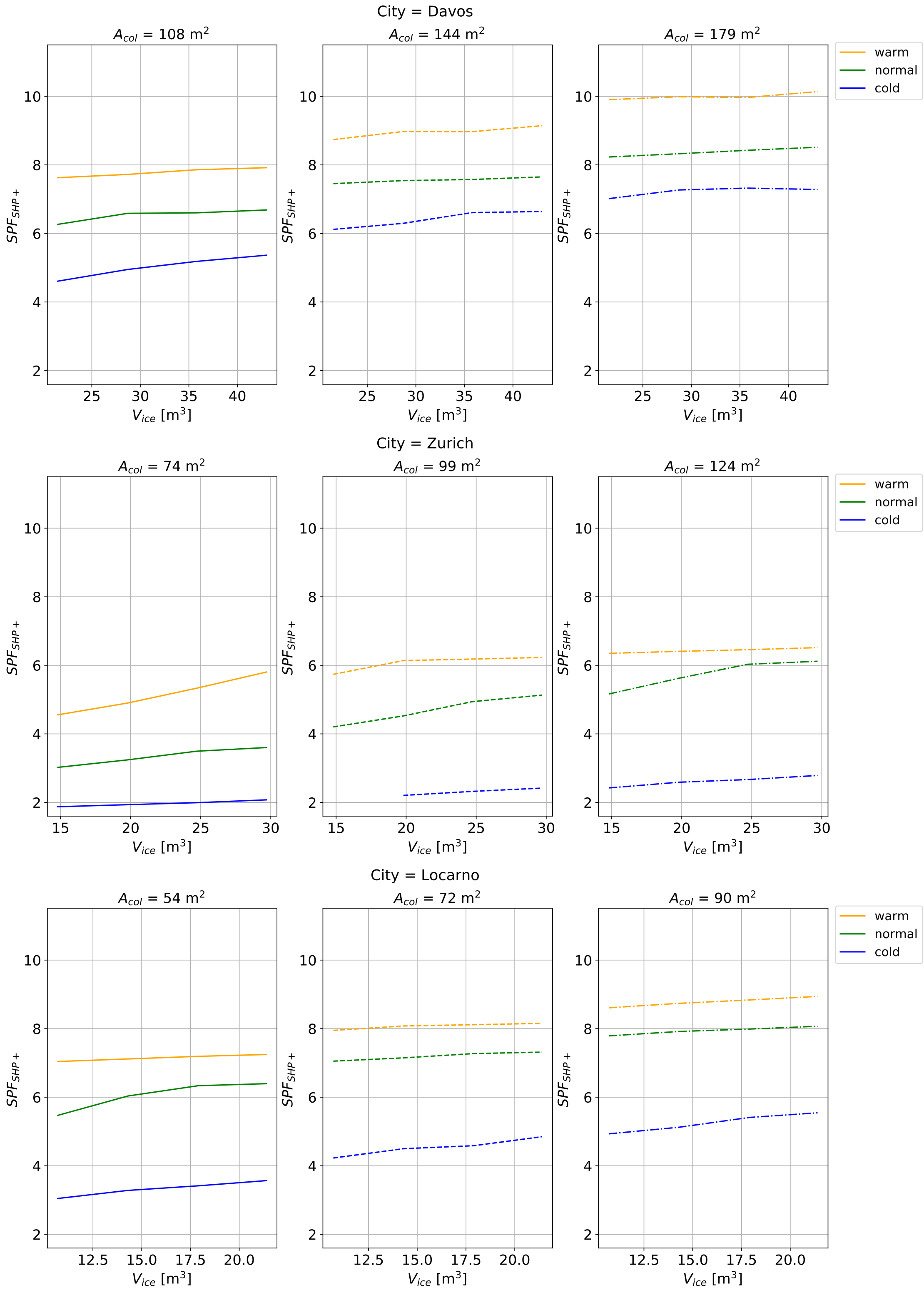

Figure 5: Influence of cold, normal and warm weather data sets on system performance for three locations.

2.3.2 Influence of locations

Several locations have been considered in order to cover most of the weather types in Switzerland. In total 8 locations have been considered: Basel (BAS), Bern (BER), Davos (DAV), Geneva (GEN), Zurich (KLO), Lucerne (LUZ), Locarno (OTL) and St. Gallen (STG). All these locations have been used considering the cold, warm and normal weather data sets. All results are shown in Fig. 6 for each location. The used range is 1.5 m^2/MWh to 2.5 m^2/MWh for the collector area and 0.3 m^3/MWh to 0.6 m^3/MWh for the ice storage volume using cold, warm and normal weather data sets. In this section, the ice storage volume and collector area values are scaled with the heat demands of each location and weather data sets (cold, normal and warm). This means that a particular set-up, e.g. 1.5 m^2/MWh and 0.4 m^3/MWh will lead to three different absolute values for collector area and ice storage volume for each location, i.e. the cold, normal and warm weather data sets. As discussed in the section above, the best results are obtained in Davos, followed by Locarno. The system performance is in the same order of magnitude for the rest of the locations.

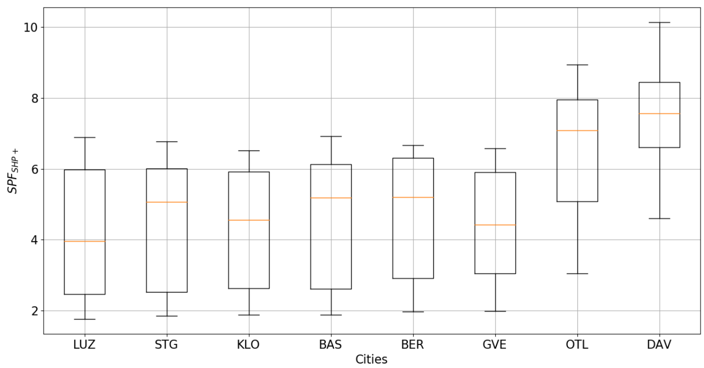

Figure 6: System performance as function of location for all the simulated range of 1.5 m^2/MWh to 2.5 m^2/MWh and 0.3 m^3/MWh to 0.6 m^3/MWh using cold, warm and normal weather data sets.

All results have been condensed into Fig. 7 using the total winter (December, January, February) irradiation reaching the collector field $H_{\text{T,winter}} \cdot A_{\text{col}}$ in the x-axis in MWh. Results correlate relatively well using the winter irradiation on the collector plane as independent variable.

3 National / International cooperation

The cooperation at national level has been started by means of the advisory board. A first meeting with the advisory board was held in Bern on the 17 th of September of 2018 with the following experts.

- Frank Doppenberd from BG Ingénieurs Conseils SA (BG)
- Romain Spaeth from Amstein & Walthert (A&W Geneva)
- Andreas Weber from Amstein & Walthert (A&W Zurich)
- Bernard Thissen from Energie Solaire (ESSA)

The main outcome of the meeting could be summarized as:

- There is an interest for cooling applications for multi-family buildings with also non-residential use.
- Cooling is also of interest for industry, but very case specific and difficult to find a “reference case”

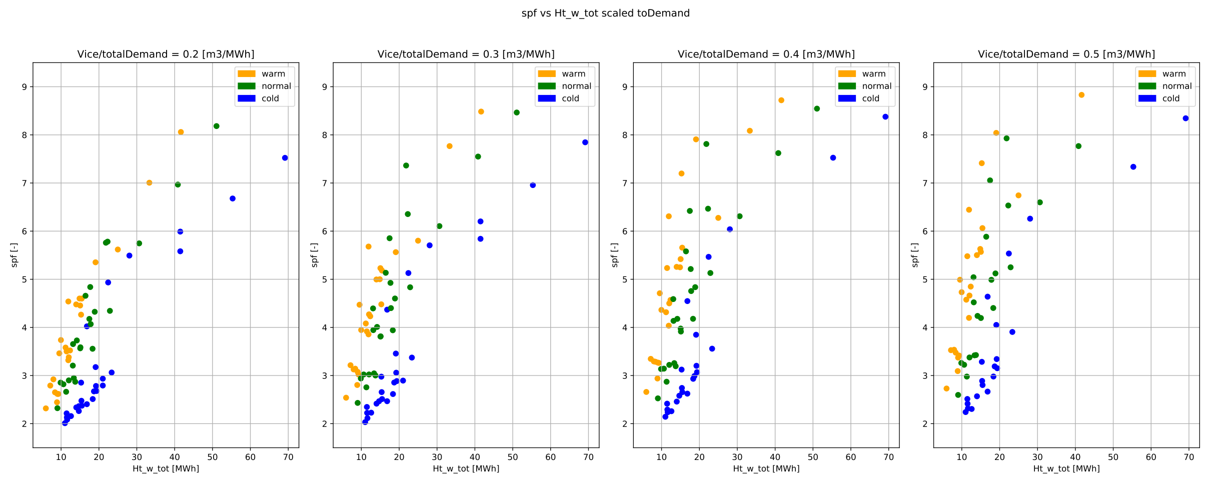

Figure 7: System performance as function of an scaled ice storage volume for different hydraulic configurations for the simulated range of 1.5 m^2/MWh to 2.5 m^2/MWh.

- A possible reference case with cooling could be a residential building with offices/supermarket.
- Although that most of the multi-family buildings in Switzerland are in the range of 6 apartments, planners from the Advisory board design heating systems for larger sizes. Moreover, there is a tendency for new multi-family buildings to be larger. Thus, the reference building might need to be adapted ti this new trend.
- A design tool is of interest, but it was recommended by the experts to include it into existing tools, i.e. the one from FWS Fachvereinigung Wärmepumpen Schweiz or Polysun.

3.1 Publications and presentation in conferences

A paper has been accepted for the REHVA 13th HVAC World Congress (CLIMA 2019), that will be held in Bucharest, Romania on the 26 - 29 May of 2019.

4 Evaluation 2018 and Outlook 2019

During 2018, studies on multi-family buildings have started. Some parametric studies including different Swiss locations and weather data files for each location have been realized in order to start to capture the influence of the weather data. As seen in Fig. 7, solar irradiation in winter has a predominant influence on the system performance. However, the main work on parametric studies will be conducted during 2019 as can be seen in the work plan from Fig 1. Moreover, a case where cooling demands are relevant will be defined and simulated to assess the potentials of solar-ice systems when cooling demands are included. Moreover, during 2019, the first numerical experiments on the potentials of using self learning algorithms for developing a simplified model based on a large number of detailed simulations will be conducted.

References

Carbonell, D., Philippen, D., Battaglia, M., and Haller, M. Y. (2017). Cost energetic analyses of ice storage heat exchangers in solar-ice systems. In *ISES Conference Proceedings. International*

Conference on Solar Heating and Cooling for Buildings and Industry (SHC 2017), Abu Dhabi, United Arab Emirates.

Carbonell, D., Philippen, D., and Haller, M. Y. (2016). Modeling of an ice storage buried in the ground for solar heating applications. Validations with one year of monitored data from a pilot plant. *Solar Energy*, 125:398–414.

ISO 13790:2008 (D) (2008). Energy performance of buildings – calculations of energy use for space heating. Standard, European Committee for Standardization, Brüssel, BE.

Leconte, A., Chèze, D., and Jobard, X. (2014). TYPE 5897 - ISO building model, model description. unpublished.

Mojic, I., Luzzatto, M., Lehmann, M., Benz, M., van Velsen, S., and Haller, M. Y. (2018). *ImmoGap -Einfluss der Kombination aus Nutzerverhalten und Gebäudetechnik auf den Performance Gap bei Mehrfamilienhäuser*. Institut für Solartechnik SPF for Swiss Federal Office of Energy (SFOE), Research Programme Buildings, CH-3003 Bern.

Plugradt, N. (2010). Load profile generator. Technical report, Version 1.3.5. TU Chemnitz, Prof. Technische thermodynamik, Germany.

Schneider, C. (2015). Standard-Nutzungsbedingungen für die Energie- und Gebäudetechnik. Technical Report Schweizerischer Ingenieur- und Architektenverein, Merkblatt 2024.

Zweifel, G. (2010). Klimadaten für Bauphysik, Energie- und Gebäudetechnik. Technical Report Schweizerischer Ingenieur- und Architektenverein, Merkblatt 2028.