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Table of contents

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Summary

In the frame of the DeCarbCH project within WP3, the potential of integrating thermochemical networks (TCNs) into district heating networks (DHN) has been studied and evaluated using numerical simulations. Thermochemical networks differ from classical DHNs by transporting a thermochemical fluid (TCF) that converts low-temperature environmental heat into usable heat, similar to 5th generation DHNs. The work presented in this report builds upon the foundation laid within the TCology project. Specifically, in TCology, the models of the thermochemical reactor (TCR) for charging, i.e., regenerating the TCF, and discharging, i.e., diluting the TCF to produce usable heat, the media model of the sodium hydroxide aqueous solution, and three case studies were developed, implemented, and analysed to compare the performance of TCNs with traditional hydronic DHN. Space heating, domestic hot water, and industrial drying were integrated into the framework, and a set of generation, distribution and energy storage performance indicators were established and used for comparison.

In DecarbCH, the work is extended to understand the potential for implementing a hybrid TCN coupled to a traditional DHN to increase its renewable fraction. To this end, a case study based on the Losone (Ticino, CH) DHN is implemented. A centralised charging and discharging TC plant is coupled to a hydronic distribution network to meet the heating demand of the residential users connected to the network. A solar collector field produces the heat to regenerate the TCF and the excess heat of this process is taken to regenerate a borehole field. The borehole field acts as a low-temperature heat source in the discharging reactor to produce heat provided to the DHN. TCF storage tanks couple the charging and discharging loops. The results indicate that it is possible to meet the heating demand with a 100% renewable fraction.

Further, this report synthesizes the results from the TCology project and the Losone case study to identify limitations and constraints that hinder the performance of TCNs, and to provide recommendations and guidelines to better exploit the potential of TCN and TC energy storages towards the decarbonization of the heating sector. The performance of the TCNs is closely dependant on the temperature levels of the application, the heat sources and sinks and the TCF concentrations. As a result, TCN are strictly suitable for low-temperature applications compatible with the available temperature lift from the TCF. While it is possible to achieve higher temperature lifts using double stage reactors, the temperature differences across the reactors diminish and with it, the exploitation of the chemical potential, leading to very high TCF mass flows. Nevertheless, TCNs promise higher exergy efficiencies and higher energy storage densities than traditional DHNs. The sweet spot for the application of TCNs instead of classical DHNs yet has still to be found and proven.

1 Introduction

In Switzerland, there is currently a strong expansion of district heating networks (DHN) happening along with the effort to increasingly displace fossil fuels and thus push the decarbonization of space heating. To do so, alternative fuels, heat generation processes and energy storages are needed. The introduction of short-term thermal energy storage (TES) allows for substitution or redimensioning of the commonly installed fossil peak boilers. For substitution of the fossil base load a common approach taken by many of the district heating operators is to switch to wood. 677 networks out of 1077 networks, i.e. 62.8% in Switzerland use wood chips as their primary fuel [1]. In terms of heat being produced, fossil fuels contribute to 27.5%, wood to 26.1% and the use of waste heat from the incineration plants to 36.2% [2].

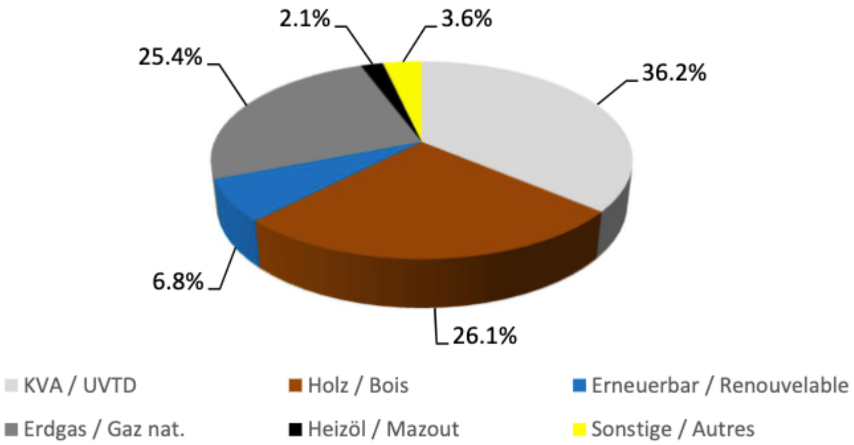

Figure 1: District heat generation in Switzerland in 2021, differentiated by different energy carriers [].

While the proper exploitation of waste heat from incineration plants (ideally in cogeneration plants) is crucial the use of wood for the provision of low-temperature heat should be avoided as the thermodynamic potential of using the fuel this way is wasted (it should be used for high-temperature applications instead) and its scalability is limited due to the limited sustainable potential of waste wood within Switzerland. As a consequence, other energy generation and storage options are needed to guarantee the heat supply to the networks.

Large-scale, seasonal thermal energy storages (STES) are an important element in the energy and heat transition and towards the goal of decarbonizing the district heat. With STES, short but also longer-term fluctuations in energy supply and demand can be balanced, further allowing for the integration of waste heat and renewable energy, e.g. by exploiting solar energy excess in summer to make it available in winter. Until now, in Switzerland, STES has received little attention in the district heating sector and no large-scale STES operating at utilization level has been implemented yet. Recently, the awareness for the potential benefits of STES is raising such that research needs to provide answers to the potential implementers of how to ideally dimension, integrate and operate STES and what technology to use.

Most commonly used STES technology are large-scale sensible energy storages such as aquifer energy storage (ATES), pit energy storage (PTES) or borehole thermal energy storages (BTES) [3]. An alternative approach to sensible heat storage is to use thermochemical processes. This way, a reversible chemical reaction is taking place to generate a chemical potential that can be stored and again be used for heat generation [4], [5]. While thermochemical storage for low temperature applications has been substantially researched [6], the extension of the concept to thermochemical networks (TCN) is less explored. An early exploration of the topic was done in the EU Horizon2020 project H-DisNet (**https://cordis.europa.eu/project/id/695780**) [7]. In the SFOE funded TCology project (SI/502368) this concept has further been investigated along with a closed sorption process using sodium hydroxide as described in [8] and dedicated numerical simulation models have been implemented to allow for an evaluation of its performance. A first simplified study out of this project was presented in [9] and the extended work in [10]. The research provides a performance comparison between a 4th generation hydronic district heating network operated with a ground-source heat pump with thermochemical networks.

1.1 Characteristics of DHNs and TCNs

When comparing TCNs to DHNs, it's crucial to understand the key differences in their characteristics. Classical DHNs transport energy by transporting hot water that is being cooled down upon discharge. TCNs transport a thermochemical fluid, e.g. salt solutions carrying a chemical potential, enabling the conversion of low-temperature environmental heat into usable heat. Consequently, the transported thermochemical fluid drives a chemical heat pump process that upgrades environmental heat to the temperature level needed by the application. This makes TCNs similar to 5th generation, ultra-low temperature DHNs that need e.g. electrical heat pumps to upgrade the heat from the network to utilization level.

TCNs feature a charging and a discharging part that can take place in one and the same place or be separated from each other. While charging, i.e. the regeneration of thermochemical fluid with renewable heat can be centralized, the discharge is decentralized, at the location where the heat demand occurs (see Figure 2). In this regard again, TCNs share a close similarity with 5th generation DHNs with active local discharge and are in contrast with the more commonly implemented 1st-4th generation DHNs, featuring a centralized heat generation.

The transport of a chemical rather than a thermal potential brings the advantage that no continuous thermal losses occur during distribution and storage. Consequently, the chemical potential can be stored seasonally, even at small scales. This allows TCNs to operate on the stored chemical potential during winter when renewable electricity is scarce, enabling effective seasonal load shifting. Ultimately, thermochemical storage shows the potential for higher volumetric energy storage densities compared to sensible water storages.

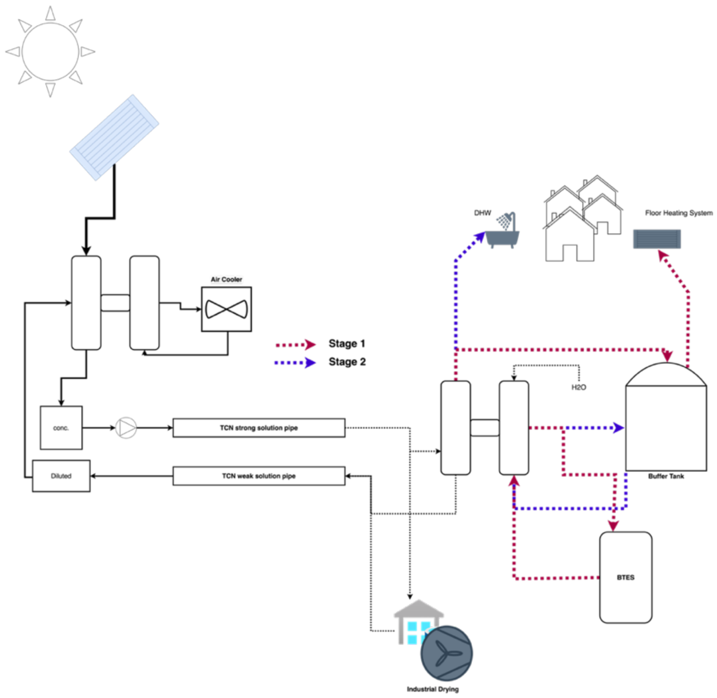

Figure 2: Example of a TCN with centralized solar regeneration (charging) and storage and a decentralized heat generation (discharge) at the building level, featuring a two-stage operation for supply of space heating (stage 1) and domestic hot water (stage 2), taken from [10].

In the TCology project, the foundations for the analysis of TCNs were layed by developing the numerical simulation models. Within DeCarbCH, the models have been adapted and applied to a specific district heating case in Losone, Ticino, Switzerland. The same case study was also considered in other research Tasks within WP3 of DecarbCH, such as a study on the implication of temperature reduction strategies and controls on the energy efficiency, peak power requirements and energy flexibility [11].

2 Deliverable content

The deliverable D3.3.2 covers the investigation of a TCN for the Losone district heating network case with the specific aim of studying the potential of TCN to integrate renewable energy, allowing for district heat supply with up to 100% renewable fraction. To this end, the study considers the residential heating demand connected in the DHN of Losone (omitting the non-residential / industrial heat demand) for reasons of a limited temperature lift available from the closed sorption process [12]. Specifically, the case study presented here, considers a hydronic network with a centralized sorption-based heat generation and storage, including a solar regeneration plant.

Furthermore, the potential applications and contexts where TCN have a competitive advantage over traditional DHN are discussed. To this end, the results of the Losone case study presented in this report, together with the findings of the project TCology are synthetized. Ultimately, design recommendations and considerations are provided, aiming to guide future research and applications for enhancing the potential of TCNs and overcoming their limitations.

2.1 Losone case study

This case study is proposed to assess the potential of integrating TCN into the existing DHN for increasing the renewable fraction of the network. Therefore, this case represents a hybrid solution between a TCN and a classical DHN. It features a centralized, sorption heat generation, storage and regeneration but relies on the hydronic distribution grid. The thermochemical process provides the potential for integration of renewable or waste heat and its seasonal storage at elevated storage density and with lower losses when compared to a sensible storage. The discharge by means of the thermochemical process allows for heat generation in winter with minimal electricity demand, which is crucial as renewable electricity in winter-time is scarce.

2.1.1 Network description and input parameters

Figure 3 shows the schematic of the network implemented. The centralized thermochemical (TC) plant consists in a solar assisted charging reactor, and a ground-source, double stage discharging reactor for generating the heat. The charging and discharging loops are coupled by concentrated and diluted thermochemical fluid (TCF) storage tanks. The distribution network represents the cumulative pipe length of the Losone DHN, serving the aggregated heating demand of the residential buildings connected to the Losone DHN. This case study is implemented in Modelica, using the interface Dymola v.2023 [13], and the models developed in [10].

Charging loop

A continuous regeneration process is implemented using a solar collector plant coupled to a regeneration reactor that dissipates the excess heat to the environment. Thereby, a 100% renewable fraction is achieved to regenerate the TCF. The typical meteorological year (TMY) weather file for Monti, Locarno was implemented in the simulation, i.e., calculated from data measured ~ 2km away from Losone [14]. As described in [10], the ASHRAE93 flat place solar collector model [15] from the Modelica Buildings Library is implemented, and the solar collector plant is built by scaling multiple 9m^2 solar collector units in-parallel, being south oriented, with a tilt angle of 45°, a nominal mass flow rate of 0.04kg/s, and internal tubes connected in series. The solar collector is operated when at least 10W/m^2 can be achieved with an inlet temperature equal to the saturation temperature of the diluted TCF, and when there is enough diluted TCF in the storage tank to be regenerated. Regarding the TC reactor, its regeneration operation is driven by the amount of heat produced by the solar collector and controlling the mass flow rate of the diluted TCF that can be regenerated to a concentration of 45 wt.%. In the reactor's condenser, the water, evaporated from the TCF using the solar collector's heat, is condensed rejecting the heat to environment, i.e., using the ground heat exchanger. The condensation temperature is fixed to 29°C thereby, resulting in a saturation pressure of 40mbar.

Discharging loop

Ambient heat is extracted from a ground heat exchanger with a fixed temperature of 15°C. This temperature is assumed considering that the heat rejected by the charging loop can be used to recharge the borehole. In the Stage 1 reactor, a fixed evaporation temperature is set to 11°C, and therefore, with a 45 wt.% concentrated sodium hydroxide aqueous solution, the temperature in the water loop of the reactor's absorber can be lifted to ~ 40°C. In the Stage 2 reactor, running in-series with Stage 1, the evaporation temperature is fixed to 36°C, allowing heat to be generated at ~ 64°C. The saturation pressure at which each stage operates is defined by its evaporation temperature, i.e., Stage 1 at 13.2mbar and Stage 2 at 57mbar. Given the heating demand, each reactor is controlled by the required mass flow rate of concentrated sodium hydroxide aqueous solution. In the Stage 1, this is the evaporation heat required by the Stage 2 reactor. In the Stage 2, this is the heating demand of the end users plus the thermal losses of the hydronic distribution network. The reader is directed to [10] for a detail description of the TC reactor and sodium hydroxide fluid models implemented.

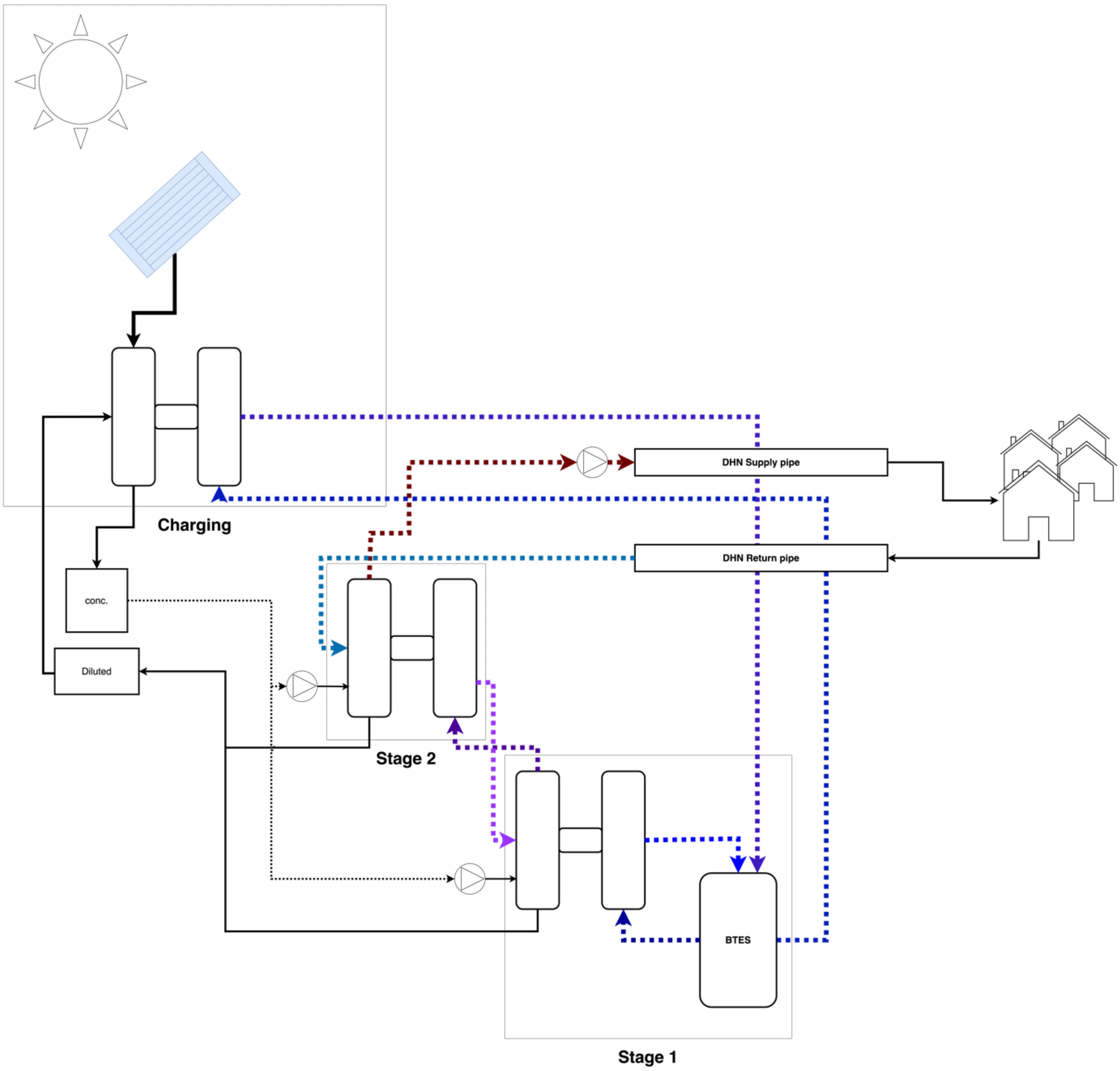

Figure 3. Case Study i). Schematic of the hybrid TCN – DHN implemented.

Heating demand and hydronic distribution network

72 buildings, i.e., industries, schools, residential buildings, and commercial buildings are connected to the Losone district heating network, accounting for a total heating demand of ~ 10GWh/y. Heat is produced using two biomass boilers, supported by an oil boiler, and supplied with a temperature of ~ 90°C during winter and ~ 80°C in Summer. Combining the topology of the Losone DHN , monitored data, and the Swiss Federal Register of Buildings and Dwellings (RBD) [16], 58 buildings classified as residential are extracted. As a result, in this project, it is considered a heating demand of 4.75GWh/y and 1.7MW peak power (see Figure 4).

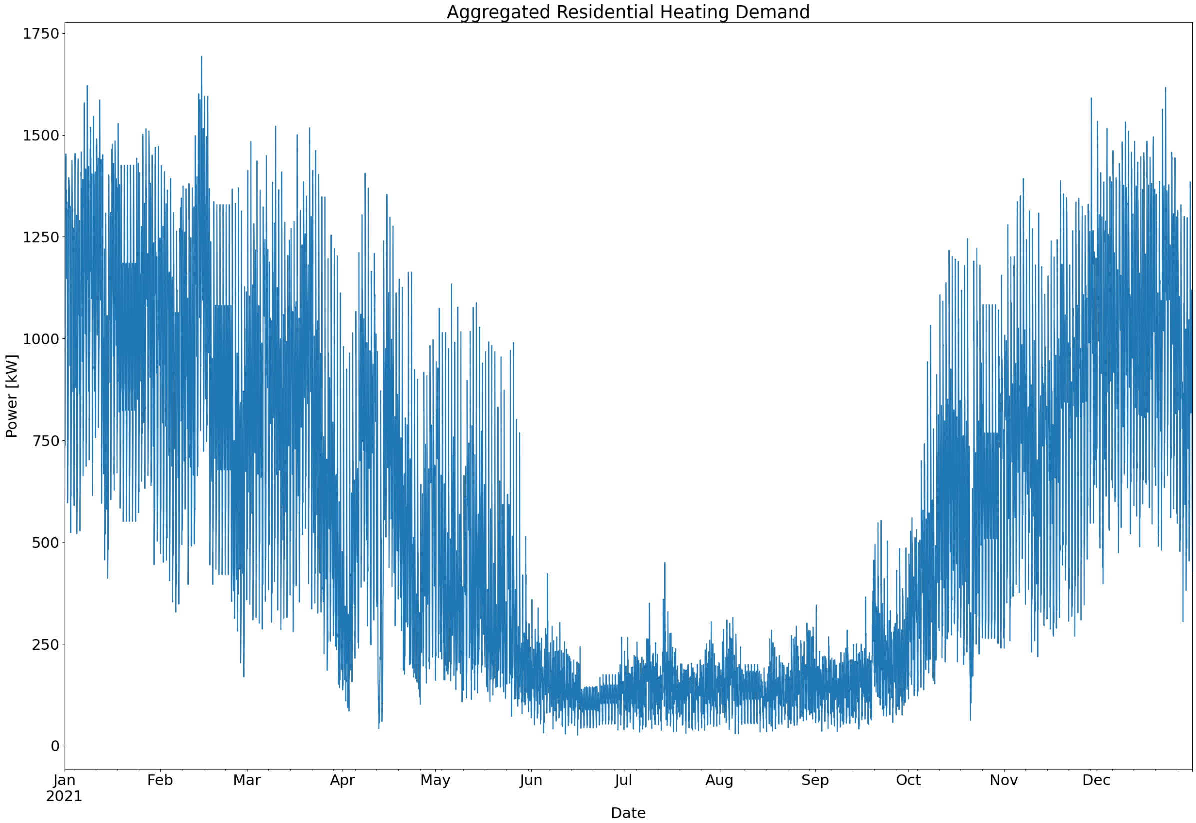

Figure 4. Residential heating demand

The heat is supplied using a main supply and return line that connects the TCN with the residential users. The mass flow rate is calculated using the heating demand profile and the temperature difference measured in the DHN. While in the real scenario the supply temperature produced by the biomass boilers is over 80°C, by considering only the residential heating demand, it is assumed that it can be lowered to ~ 65°C. The pipe length and diameter are calculated so that the thermal and hydraulic losses are equivalent to the ones perceived by the Losone DHN. From monitored data it is estimated 15% thermal losses, and the hydraulic losses are defined as per recommendation in [17], to get a pressure drop of around 150-250 Pa/m in the network (supply and return together). In this case, the distribution length is assumed to be equal to 4360m i.e., the length of the main distribution line of Losone DHN, with a pipe diameter equal to DN80, and a mean mass flow rate of 6.27kg/s, resulting in ~10% thermal losses and a pressure drop of 176.96Pa/m.

2.1.2 Results

A yearly simulation is performed to capture all the relevant parameters for assessing the performance of the hybrid TCN-DHN. Figure 5 shows the supply and return temperature profiles at the generation and consumers points. The thermochemical reactor (TCR) produces heat at 64.1°C and given the network topology, operation parameters and inherent thermal losses, it reaches the end-users with a mean temperature of ~ 63°C. During December and January, when the maximum heating demand occurs, the return temperature entering the TCR reaches a minimum of ~ 30°C. During summer, when the heating demand is driven by the DHW demand, the return temperature has a mean value of ~ 53°C.

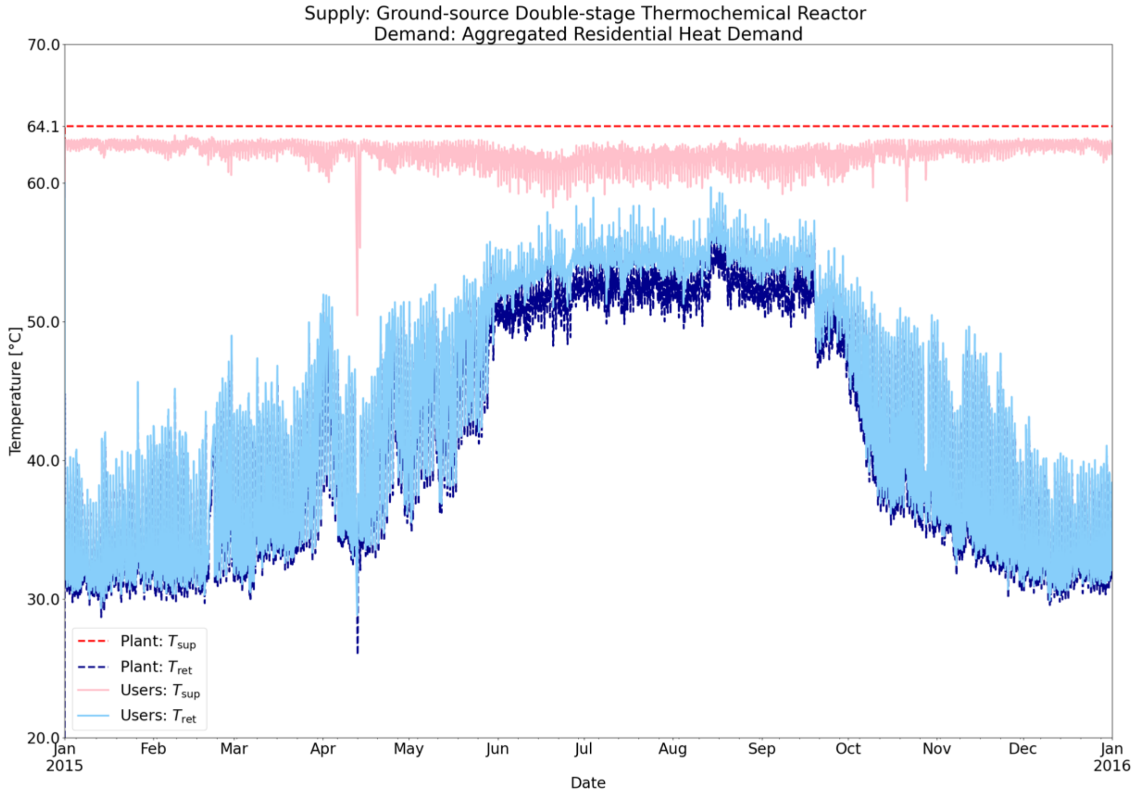

Figure 5. Supply and return temperature: Generation and end-users

Figure 6 presents the mass flow rate of concentrated TCF required by each stage of the discharging process. Significant differences can be observed between the operation of each stage due to varying operational parameters. On average, Stage 1 requires 4.5 times more TCF than Stage 2. This can be attributed to the temperature difference in the absorber of each reactor, the resulting concentration difference, and the extent to which the chemical potential is exploited in each reactor.

In Stage 1, the temperature difference in the absorber is determined by the saturation temperature of the concentrated solution (Stage 1 supply temperature) and the evaporation temperature of the Stage 2 reactor (Stage 2 return temperature), which is 4K. In Stage 2, the temperature difference is defined by the supply and return temperatures of the hydronic distribution network. This difference varies seasonally, with a maximum of ~41.3K in winter, a minimum of ~5.6K in summer, and an average value of ~21.6K. As shown in Figure 7, with these temperature differences, the concentrated TCF in Stage 1 is diluted by only 5 wt.%, whereas in Stage 2, a maximum concentration drop of 15 wt.% is achieved. With the temperature differences available in the Stage 2, higher concentration differences could be achieved. However, it is important to highlight a limitation in the concentration difference across the reactor. This is because the driving force for water vapor absorption decays with lower TCF concentrations. This leads to non-equilibrium conditions which are not accounted for in the mathematical model implemented in this project. Consequently, to account for this circumstance, the diluted concentration is artificially limited to 30 wt.% [10].

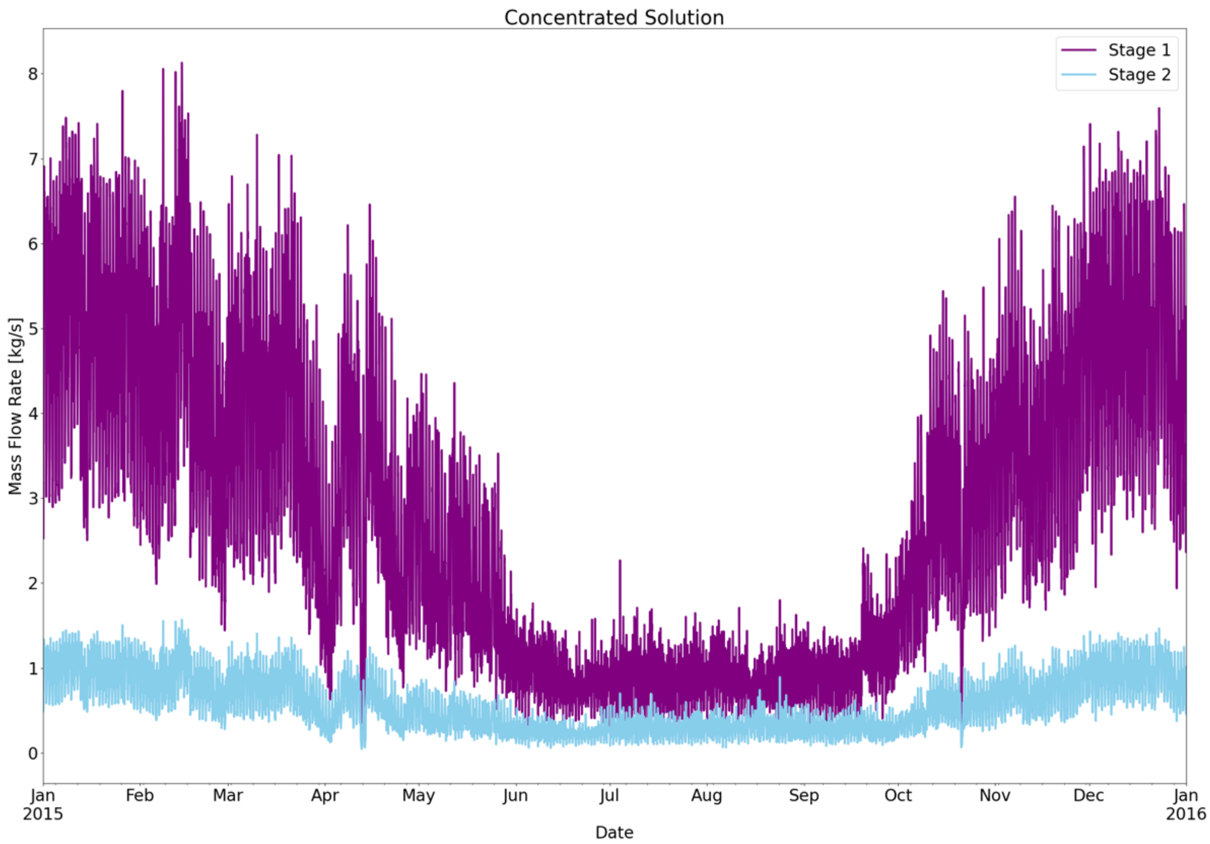

Figure 6. Concentrated TCF mass flow rate: Stage 1 and 2.

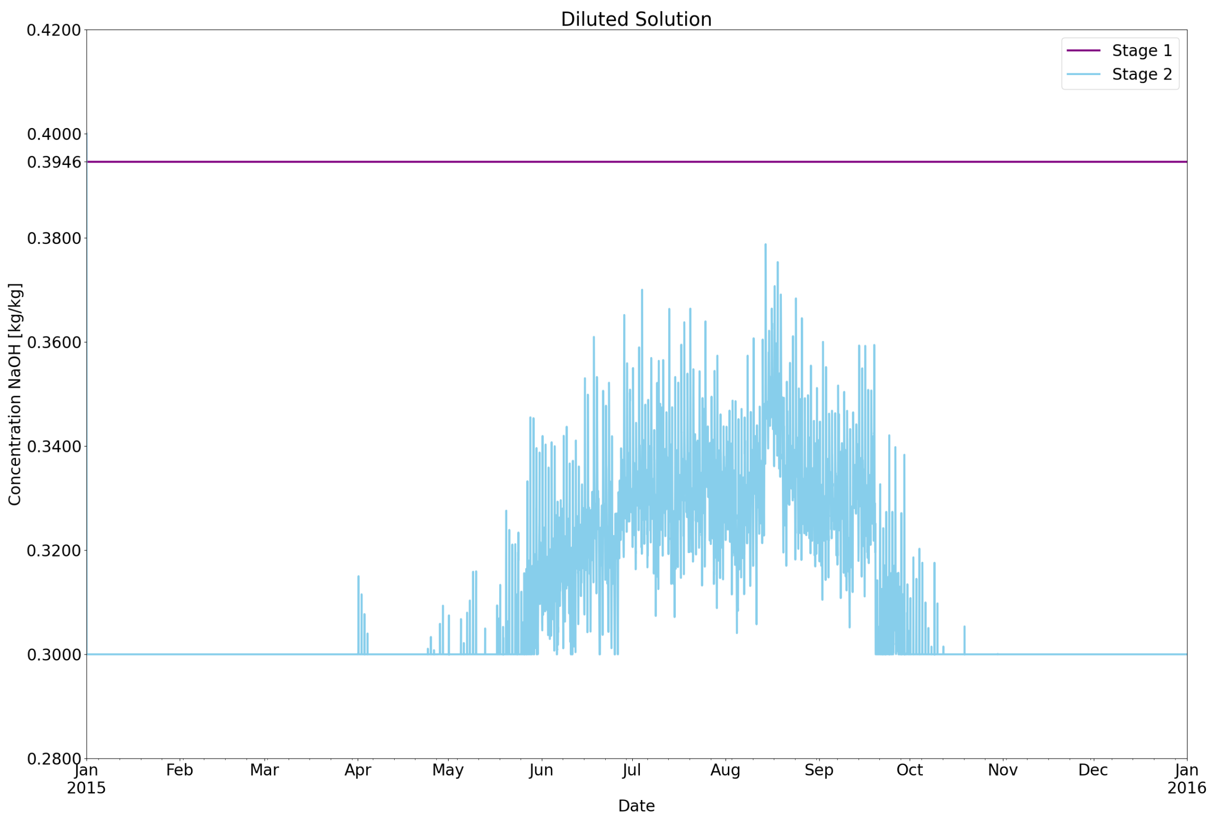

Figure 7. TCF diluted concentration: Stage 1 and 2

Regarding the charging operation, a 53'100m^2 solar plant is required to regenerate all the TCF diluted during the discharging process. This involves evaporating water from the mixed diluted TCF stored from Stages 1 and 2, to increase the concentration from a mean sodium hydroxide concentration of 37.5 w.t% to 45 w.t%. Figure 8 shows the power produced by the solar collectors. With the weather conditions of Losone, the characteristics of the collectors, and the operation of the charging reactor, the charging plant can be operated during the whole year, with reduced power during fall and winter, and a maximum operation during spring and summer. Specifically, in December is registered the minimum average peak power with 7.87MW, and in August the maximum mean peak power with 18.01MW.

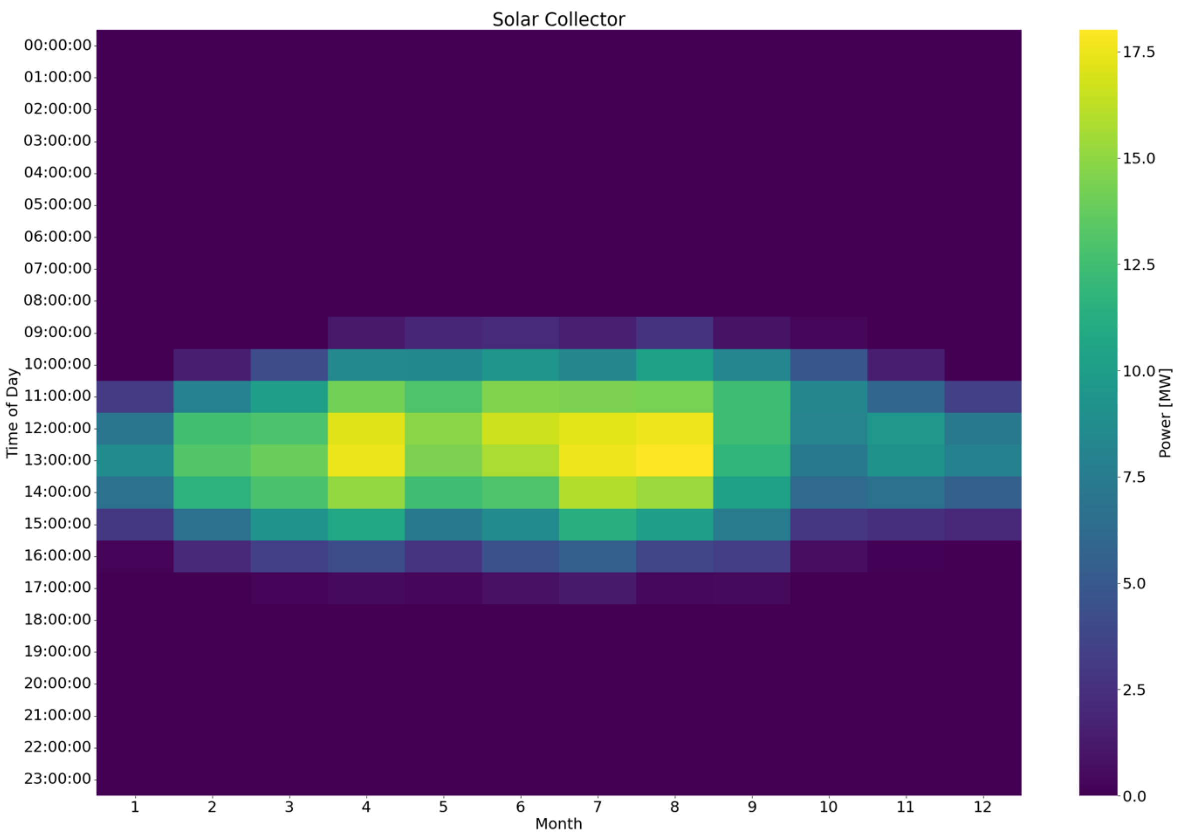

Figure 8. Solar Collector Plant: Heat map of the heat produced during the year.

The solar collectors produce the heat with a mean supply temperature of 62.22°C and perceiving a mean return temperature of 41.35°C, resulting in a mean temperature difference of 20.87K. Figure 9 presents daily profiles of the solar collector’s supply and return temperature, and diluted TCF mass flow rate being regenerated for two sampled days i.e., with maximum and minimum performance. In both scenarios, the solar collectors start lifting the temperature of the water when they produce enough power. In December this happens at approximately 11:00 and in August at 8:00. The reactor starts its charging operation only when the supply temperature is greater than the saturation temperature of the concentrated TCF, i.e., approximately 55°C for a concentration of 45 w.t%, saturation pressure of 40mbar, and condensation temperature of 29°C. As a result, the reactor only operates for a fraction of time the solar collector is providing heat, i.e., with a daily minimum and maximum of 3% and 70% respectively, and a cumulated yearly value of 50%.

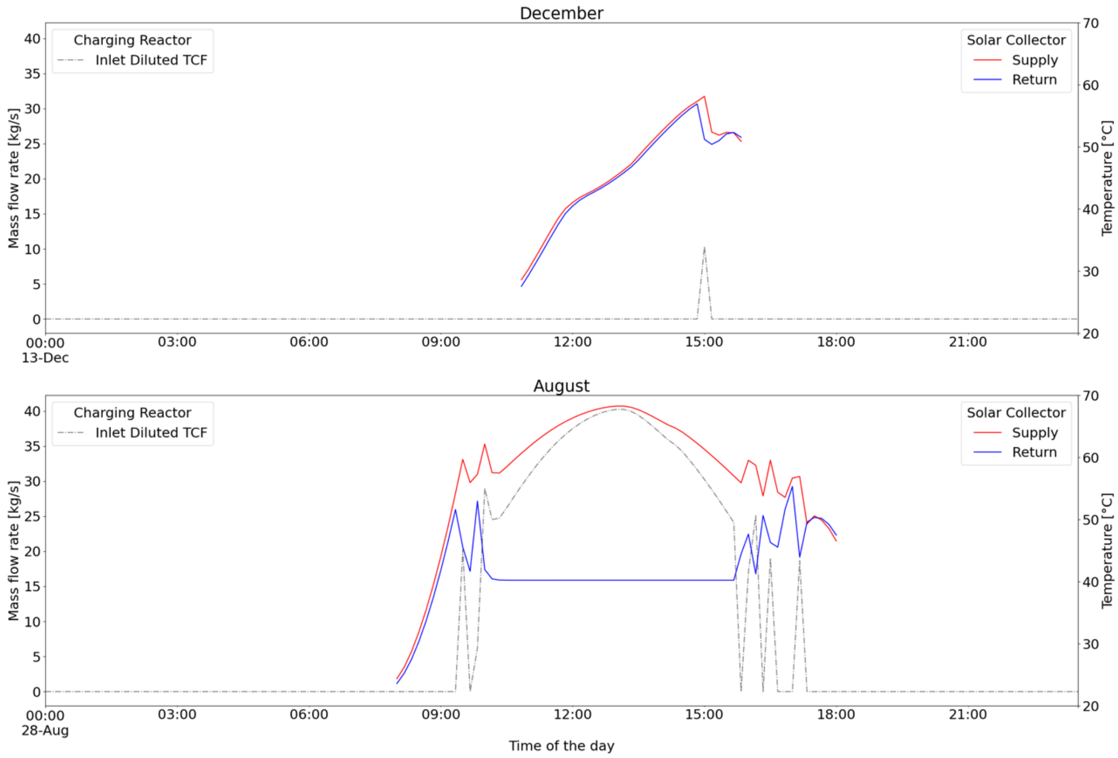

Figure 9. Minimum (February) and maximum (April) regeneration plant operation.

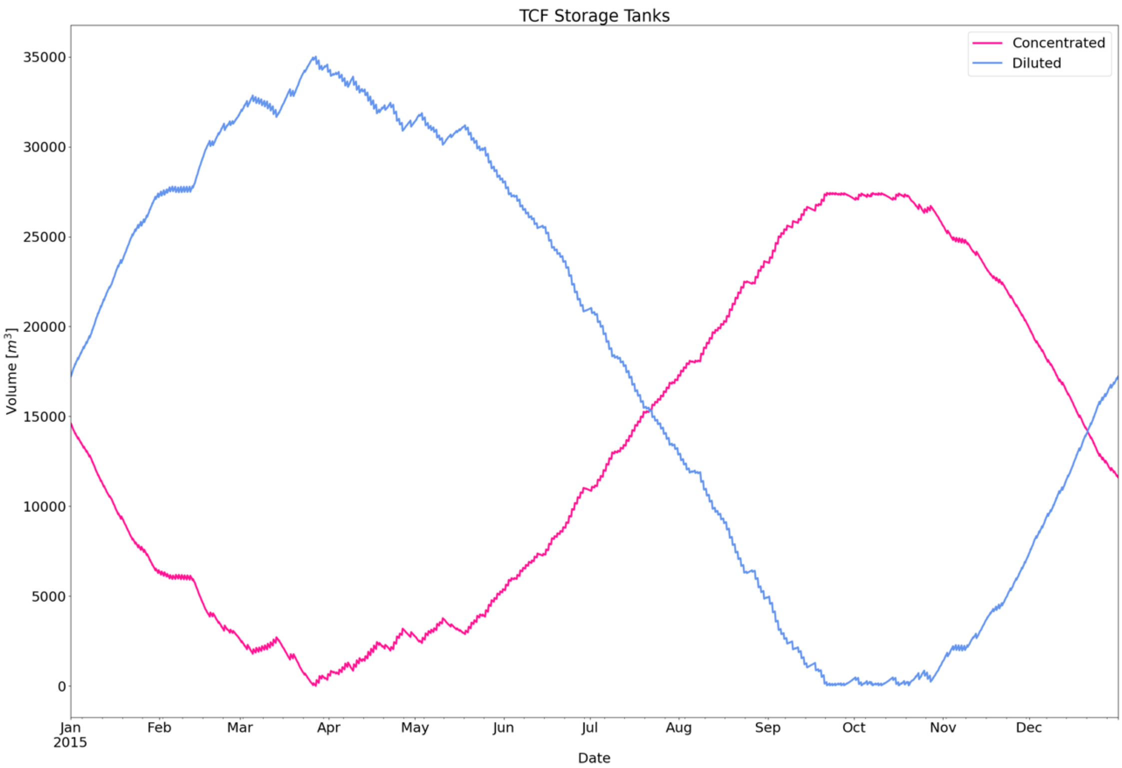

Figure 10. TCF storage tanks

Finally, given the heating demand, discharging and charging operation, Figure 10 shows the state of the TCF storage tanks. In this case, the volumes of the concentrated and diluted TCF tanks required to couple the DHN and TCN are ~28'500m^3 and ~34'400m^3, respectively. During the heating period, i.e., November to April, the concentrated tank is continuously discharged and thus the diluted tank is charged. While the solar collector plant has some capacity during this period to regenerate a portion of the TCF, the main part is regenerated between April and October, where the heating demand is low, and the solar collector plant has the larger capacity. It can be noticed that during the second half of September the diluted tank remains at the minimum level. This is because the solar plant is slightly over dimensioned. Reducing its size would result in a continuous TCF regeneration up to the end of October.

Considering the heat produced by the TCR and the volume of diluted TCF, in this case study, the thermochemical storage density is 154.68kWh/m^3, 2.65 times larger than a sensible water thermal energy storage charged with a temperature difference of 50K. As a result, integrating the TCR and TCF storage into the DHN allows for a seasonal shift of the heat produced by the solar collectors. Nevertheless, important limitations being discussed in Section 2.2 can be identified, arising from the boundary conditions of this very case study.

2.2 TCN potential, advantages and limitations

2.2.1 Losone case study

The results presented in Section 2.1.2 represent a hybrid solution comprising a hydronic distribution grid with a TCF storage and a TCR for heat generation. With this combination, two potential benefits of TCNs are not exploited, i.e. the absence of continuous heat losses and the low pumping cost for circulation. The latter results from the fact that lower amounts of TCF need to be circulated when compared to hydronic networks. The most important limitation for an efficient operation of a TCN is determined by the network / supply temperature required by the buildings. Replacing one-to-one the heat generation in a high-temperature DHN with a TCR has shown to have important limitations that hinder its application and appropriate exploitation of its potential. The case study presented in 2.1 shows it is possible with the hybrid TCN to achieve a 100% renewable fraction to supply the residential heat demand at 65°C. However, the boundary conditions to charge and discharge the TCF are not optimal, resulting in large systems, e.g., solar collector field. A TCR can be seen as a chemical heat pump that lifts low-temperature heat to heating application levels. The following conditions are critical to improve the operation of the TCN and the charging and discharging process of the TCF.

During the discharging phase, water is evaporated using a low temperature heat source. The resulting water vapor is then condensed into the concentrated thermochemical fluid (TCF), initiating an exothermic reaction that produces usable heat at a higher temperature. The higher the temperature of the low temperature heat source, the higher the pressure at which the water is evaporated. The higher the pressure and concentration of the TCF, the greater the available temperature lift. The higher the temperature difference in the absorber, the higher the concentration difference, i.e., the higher exploitation of the chemical potential.

Under the boundary conditions of the Losone case study, using ground heat at 15°C to evaporate water at 11°C, and a concentrated TCF at 45 w.t%, i.e., maximum concentration to avoid crystallization at a minimum temperature of 5°C, the maximum supply temperature is approximately 35 °C. At this level, the space heating needs of retrofitted and new buildings with floor heating systems can be met. Yet, the Losone District Heating Network (DHN) is a high-temperature network, so a second temperature lift is required. As a result, two TCRs were connected in series using the first reactor as the low temperature heat source for the second reactor to achieve ~65°C. This is because a minimum evaporation temperature of 31°C is required in the second reactor. This translates into a temperature difference of ~4 K in the absorber of the first reactor and thus a limited concentration difference, i.e., poor exploitation of the TCF's chemical potential, which results in large amounts of TCF required.

During the charging phase, the condensation temperature sets the saturation pressure at which the reactor regenerates the TCF. The lower the condensation temperature, the lower the saturation pressure, and thus lower desorption temperatures required. The high temperature source e.g., from solar collectors or industrial waste heat, needs to provide heat at temperatures slightly higher than then desorption temperature. Under the boundary conditions of the Losone case study, the solar collectors can only provide heat at the required temperatures for 50% of their operation, considering a condensation temperature of 29°C. Reducing this temperature would increase the amount of time the reactor can recharge the TCF and thus, reduce the size of the solar collector field.

Based on the analysis performed for the Losone case the conclusion can be drawn that under the boundary conditions of a 3rd generation DHN a TCN would not be economically feasible and competitive with a classical DHN. For this reason, for the comparison of a TCN with a DHN needs to be done for more suitable boundary conditions, i.e. for lower supply temperatures. To this end, the analysis for a synthetic network case is presented in Section 2.2.2 along with a performance comparison of TCN with DHN.

2.2.2 Low temperature district heat supply - Hydronic DHN vs. TCN

In the TCology project a direct comparison of a TCN with a hydronic network operated by a ground source heat pump was done for a synthetic network case revealing the key features of TCNs, being the high COP and exergy efficiency due to the low electricity demand in winter for discharge and the decentralized heat generation as well as the increased energy storage density [10]. Contrary to the Losone case study, here, the heating demand is assumed to be for retrofitted/new residential buildings with low temperature floor heating systems. This means that the first stage reactor can directly supply the space heating demand, while the second stage reactor is only required to lift the temperature of the DHW.

Briefly, a buffer tank is used to regulate the daily heating demand, and it is charged by the first stage to ~31°C. The heat stored in the tank is used directly by the space heating system and by the evaporator of the second stage of the TCR to provide DHW. In this way, the thermochemical potential is exploited better, resulting in lower TCF needs. This case study is compared to a hydronic DHN. Further, two TCN scenarios were evaluated. Scenario A, where the diluted concentration of the reactor's Stage 2 operation is limited to 30 wt. %, while the concentration of the Stage 1 is 39 wt.%, thereby, an additional mixing occurs in the distribution network and storage tank; Scenario B, where the diluted concentration is limited in both Stages to 39 wt.% to prevent mixing within the distribution network. The comparison for selected KPIs is shown in Table 1 and the following observations can be made:

- Energy efficiency is comparable between DHN and TCN. Thermal losses occurring in the TCN in the daily buffer tank integrated to operate the reactor in SH and in DHW mode, together with the heat required to saturate the concentrated TCF results in an energy efficiency of 0.78 (Scenario A) and 0.72 (Scenario B). An increase of the energy efficiency would be possible to realize if a two-stage TCR was used instead of single-stage reactor together with a buffer tank.
- Regarding the exergy efficiency and the electric COP, the large differences are mainly because of the chemical heat pump of a TCN substituting the electric heat pump of a DHN and the electricity required to circulate the TCF in the TCN is small compared to the electricity required to circulate the water in the DHN assuming the same diameter for the piping.
- Additionally, the TCN has a better exergy efficiency because in the TCN the heat is supplied at lower temperatures than the DHN (70 °C), closer to the demand requirements, i.e., for the SH with a heating setpoint of 22°C, heat is supplied at ~30 °C.
- Finally, regarding the volumetric energy storage density, TCN generally shows higher values than DHN. The storage density for the DHN is indicated for a temperature difference of 50 K instead of the effective temperature difference in the network of around 30 K. This increase in temperature difference leading to the significant increase in storage density would at the same time further decrease the exergy efficiency of the DHN, which is not displayed here. For the TCNs the difference between the Scenario A and B comes from the reduction of the exploitation of chemical potential in Scenario B.

Table 1: KPIs comparison between TCN and DHN, with a larger concentration difference (Scenario A) and a lower concentration difference but avoided dilution within the network (Scenario B), taken from [10].

	Hydronic DHN	TCN (Scenario A)	TCN (Scenario B)
Energy efficiency	0.87	0.78	0.72
Exergy efficiency	0.12	0.63	0.56
Electric COP	2.11	60	34.86
Storage density @ΔT=30K [kWh/m^3]	38.5	109.81	79.26
Storage density ratio @ΔT=30K	-	2.85	2.05
Storage density @ΔT=50K [kWh/m^3]	58.33	109.81	79.26
Storage density ratio @ΔT=50K	-	1.88	1.35

3 Conclusion

TCNs are explored in two different contexts within the project DeCarbCH (Losone case) and TCology (synthetic case), to meet the heating requirements for the residential sector. In the first one, a hybrid solution that integrates a TCN into an existing DHN is implemented. Thereby, the TCN is exploited to partially shift the heat produced during summer using solar collectors to the winter for space heating, while the traditional hydronic DHN is used to transport the heat between the TCR and the end users. In the second case, a pure TCN is implemented, transporting the chemical potential between the regeneration plant and a decentralized TCR for discharge to meet the terminal heat demand.

Important conclusions can be deduced to guide future research and applications towards overcoming important limitations and fully exploiting the potential of TCN as a solution to decarbonize the heating sector:

- TCN is applicable in its pure form to substitute a hydronic DHN. To this end, TCF is transported in the network to drive a chemical heat pump process at the terminal station where heat is demanded. This requires the availability of a local low-temperature heat source such as ground heat exchangers. Hybrid TCN solutions can be implemented but parts of the potential benefits of TCNs, i.e. the lossless distribution is given away. For this reason, feasible hybrid configurations feature a TCN connecting a central regeneration plant and several semi-decentralized generation plants. The latter feed-in the heat to a local DHN that supplies a number of buildings/developments over very short distances. This way, sensible heat losses are marginal.

- Achieving a 100% renewable fraction using TCN is possible by storing and exploiting the chemical potential of TCF. However, the performance of the TC process is highly sensitive to operating parameters, especially temperature levels.

- TCNs are more suitable for integration into low-temperature applications where the temperature lift can be achieved using only one TCR, i.e., single-stage reactor.

- For meeting space heating and DHW application a single-stage operation is possible with the use of a sensible buffer tank, allowing to use the tank as a heat source to achieve DHW temperature levels. The sensible buffer brings continuous heat losses lowering the thermal efficiency of the system. Alternatively, a two-stage operation can be implemented to avoid or reduce the need of the buffer tank. Important is to restrict the use of the 2nd stage only to the production of DHW such that the over-all mass flow of TCF and a sufficient exploitation of the chemical potential can be guaranteed. The use of a single stage TCR plus buffer tank vs. a two-stage operation has further implications on the economic feasibility of the installation.

- It is important to optimize the systems / heating application such that the return temperatures from the application to the TCR are low. This enables to achieve a significant concentration difference, enhancing the exploitation of chemical potential and thereby reducing the TCF mass flow and storage volumes.

- Generally, temperature boundary conditions need to be carefully optimized as they strongly influence the system performance of TCNs. This also includes the optimization of the low-temperature source and sink for the operation of the TCR.

  - During the discharging phase, higher heat source temperatures lead to higher evaporation temperatures, resulting in higher saturation pressure and absorption temperatures, ultimately achieving higher supply temperature.

  - During the charging phase, lower condensation temperatures result in lower saturation pressure and desorption temperatures, allowing the regeneration of TCF using lower temperature heat sources.

- The current studies carried out in the frame of both, the TCology and the DecarbCH project reveal the main characteristics of TCN and allow for understanding the limitations and the potentials for further improvements. Thus, more research is needed for the evaluation of TCNs for a low-temperature district heating area with the implementation of more accurate models to represent the low-temperature heat source and sink such as borehole fields. This allows for validation of the statically assumed boundary conditions and for further optimization of the operational boundary conditions for the TCNs.

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