# Concise cycle test methods to evaluate heating/cooling systems with multiple renewable sources

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The goal of the project TRI-HP is to develop systems based on electrically-driven natural refrigerant heat pumps coupled with photovoltaics to provide heating, cooling and electricity to multi-family buildings with an on-site renewable share of 80 %. The implementation of different energy sources for such a system often leads to a complex architecture of the overall system. The performance evaluation of such systems is not trivial and cannot be done via steady-state measurements of individual components. Instead, dynamic measurements using the hardware-in-the-loop approach are performed to test the performance of the newly developed systems. A method called concise cycle test (CCT) has been developed for this purpose. This method was adapted to the systems to be tested and applied in different versions. The CCT method is based on the selection of several representative periods of the year, and shows the behaviour of a complete system for heating and cooling under relevant conditions in these periods, enabling then to extrapolate the results for a whole year operation. Two different approaches were used to select the test sequence. For the measurement of a dual source/sink system, the annual weather data were divided into four clusters, from each of which representative days were selected. For the solar-ice-slurry system, a single, contiguous test cycle of typical days from throughout the year was selected. This allows both, to test the functionality of the ice-slurry storage and the advanced energy management strategies by performing experiments only on selected days. For the tests, the complete system including a heat pump and thermal and electrical storages are installed on a test rig. The test rig emulates a building, including the space heating and cooling distribution system, the domestic hot water draw offs, the solar collector field or ground heat exchanger depending on the system tested and the photovoltaic installation. The system tested must act completely autonomously to cover the demand for heating and cooling of the building and the draw-offs during a test cycle. In this work, the methodology has been applied to two different cases of complete systems adapted to different climates (Switzerland and Spain).

**Keywords.** hardware-in-the-loop, emulation, whole system test, test cycle, heat pump.
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## 1. Introduction

### *1.1 H2020-TRI-HP*

The overall goal of the TRI-HP project is the development and demonstration of flexible energy-efficient and affordable trigeneration systems. The systems are based on electrically driven natural refrigerant heat pumps coupled with renewable electricity generators (PV), using low temperature thermal and/or electrical storages to provide heating, cooling and electricity to multi-family residential buildings with a self-consumed renewable share of 80 %. The innovations proposed should reduce the CAPEX system cost by at least 10-15 % compared to current heat pump technologies with equivalent energetic performances. Two natural refrigerants with very low global warming potential, propane and carbon dioxide, are used as working fluids. Two system concepts were developed for two different combinations of heat sources for the heat pumps, i) dual ground/air source/sink and ii) solar with ice-slurry as intermediate storage. These two concepts combined with the two heat pump types developed ($CO_2$ and propane) lead to three complete systems ($CO_2$-ice, propane-ice and propane-dual) that are being tested in the laboratory.

### *1.2 Purpose and general procedure of the Concise Cycle Test*

The implementation of different energy sources for systems for space heating (SH), space cooling and domestic hot water (DHW) preparation often leads to a complex architecture of the overall system. The efficiency of the resulting system is highly dependent on dynamic operating conditions due to transient on/off cycles, component interactions, thermal storage, hydraulic designs, overall system control, and other factors. Performance evaluation of such systems is not trivial and cannot be done via steady-state measurements of individual components. For this reason, the Concise Cycle Test (CCT) [1,2,3] as a hardware-in-the-loop approach was developed at the institutes SPF and IREC.

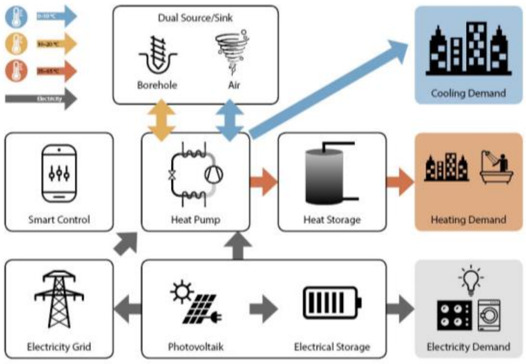

**Fig. 1 -** ***Dual source/sink system***: ground/air system concept for cooling-dominated climates

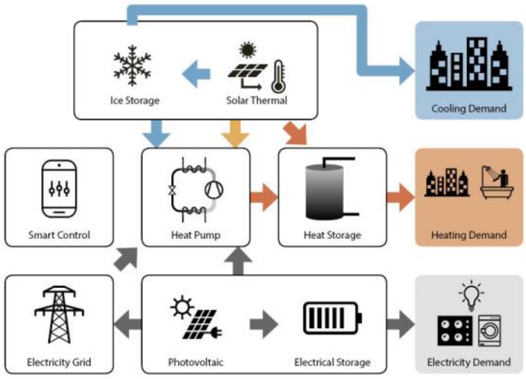

**Fig. 2 – Solar-ice slurry system ($CO_2$ and propane HP)**: solar-ice-slurry system concept for heating-dominated climates.

The CCT shall show the behaviour of a complete system for heating and cooling under real-life conditions at different days of the year. In TRI-HP, the functionality of an ice-slurry storage will be tested in the system test as well as an advanced energy management (AEM) control developed within the project. Therefore, the complete system will be installed on a test rig. The test rig emulates a building, including the SH and cooling distribution system, the DHW draw offs, the solar collector field and the photovoltaic (PV) installation. The system under test must act completely autonomously to cover the demand for heating and cooling during a test cycle. This test cycle is composed of a number of representative days of a real year, which vary from four to seven depending on the goal of the test, e.g. benefits of the advance energy management system or quantification of the yearly energetic efficiency. The selected days are put together to a consecutive test-cycle.

### *1.3 Procedure for online simulation and emulation*

Emulation can be based on load files or on real-time online simulations. In order to emulate a realistic response that is dependent on the behaviour of the tested system, real-time online simulations are used to calculate the behaviour of the components interacting with its environment. The emulated components are: solar thermal collectors, PV field, the building with the heating and cooling distribution systems and the ground source heat exchangers.

The procedure for simulation and emulation can be described as follows: at the end of each simulation/emulation time step, measured values are passed from the test bench control software to the system simulation software. Based on these values, the simulation software is simulating the response of the emulated device for the next time step and returns the result to the test bench control software, which controls the emulation of the emulated time step at the beginning of the next time step. Meanwhile, the simulation software pauses and waits for the next input of measured values from the test bench control software. The input data for the simulation is then based on measurements that were acquired before the emulated time step. The actual values may deviate from those values during the current time step. In order to minimize the error resulting from this deviation, the time steps of the simulation shall not be larger than 2 min. Components whose behaviour is independent of the rest of the system are implemented using predefined load profiles: a draw-off profile for the DHW consumption and a household electricity profile.

## 2. Tested systems and boundary conditions of climate and load

### *2.1 Overview*

As described above, the newly developed systems are aimed for different climatic conditions. Concept schemes of the systems are shown in Fig. 1 and Fig. 2. In the TRI-HP project, prototypes of the most important new developments of individual components of the system were built and measured individually. The prototypes were sized for laboratory-scale measurements. The main developments are related to the heat pumps including the innovative natural refrigerant based circuits with the new heat exchangers as well as the advance energy management of the complete system.

This chapter describes the assumed annual climate data and electrical and thermal demands of the final applications as well as the load adjustments done in order to to measure a functional overall system at laboratory scale.

## *2.2 Dual source/sink system*

The dual source heat pump is able to use both a ground source heat exchanger and the ambient air as heat source (or sink), and can provide both, heating and cooling depending on the season. The system is completed by thermal storages, photovoltaic panels and a battery for the electrical part (Fig. 3).

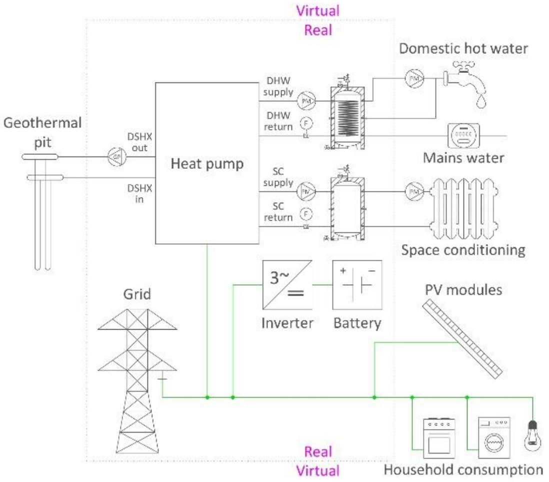

**Fig. 3 –** Sketch of the hydraulic and electrical components of the system test of the dual source/sink system.

A renovated building in the city of Tarragona, Spain was defined for this system. This climate zone represents a significant cooling load. Furthermore, the renovated version of the building corresponds to the current standards of the Spanish Building Code, which is in force for all new constructions. The weather for Tarragona was retrieved from the software Meteonorm, which produces a typical year file based on historical records from official weather stations covering the years 1991 to 2007. The yearly average temperature is 17.4 °C, while the yearly total horizontal irradiation sums up to 1665 kWh/m$^2$.

Apart from the weather, different profiles of occupancy have been implemented in the modelling environment. The internal gains from occupants, lighting and equipment are defined from the CTE (Spanish Building Code) [4]. Considering these assumptions, the peak heating load of the building amounts to 43.9 kW, while the peak cooling load amounts to 28.3 kW. The DHW tapping profile is generated with the tool DHWcalc [5] that enables to distribute the DHW load stochastically, keeping a certain pattern and a global energy demand corresponding to the number of families in the building. The electricity consumption from appliances (not considering HVAC) is also generated as a 10 minutes stochastic profile, with a peak load of 44.7 kW (99 % percentile at 29.5 kW).

## *2.3 Solar-ice-slurry system*

The solar-ice-slurry system uses solar thermal energy as a source for the heat pump as well as to partly cover the heating and DHW demands directly. When possible, the solar energy is stored in an ice slurry storage, which serves as a source for the heat pump when solar radiation is not available. Additionally, a PV plant delivers electricity for the heat pump and the household electricity and a battery is included to reach the goal of 80 % renewable onsite share.

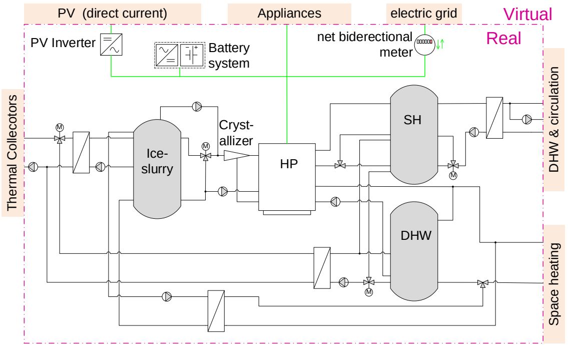

**Fig. 4 –** Sketch of the hydraulic and electrical components of the system test of the solar-ice-slurry system.

For selection of days, weather conditions of the city of Bern are chosen. Bern represents the dense populated Swiss midlands with rather cold winter and foggy periods. The SIA weather data is used, which is based on the standard SN EN ISO 15927-4 to generate a collection of 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 [6]. In order to be able to analyze the cooling potential in the system tests, SIA-warm weather data is used. The average ambient yearly temperature for warm weather data in Bern is 12.3 °C and the yearly total horizontal irradiation is 1230 kWh/m$^2$.

Other boundary conditions are the user profiles for household electricity, DHW consumption and internal gains in the building due to the presence of the people themselves and the equipment and lighting used. Individual profiles of each household were obtained from the load profile-generator [7] tool for a total of 6 apartments.

## *2.4 Scaling of laboratory systems*

The dual source heat pump prototype has a nominal thermal capacity of 10 kW, compared to 44 kW needed for the multi-family building of Tarragona, therefore the scaling factor is around 4.5. All boundary conditions have been scaled down with this factor, notably the building floor area and capacity, the DHW and household electrical demand profiles. The capacities of the thermal storages have also been reduced accordingly. In the case of the electrical systems, the electrical cabinets present in the lab are also limited to 7.5 kW, therefore the scaling factor is slightly higher in that case, and these systems are a bit undersized relatively to the rest of the systems.

The final sizes of the systems to be tested in the lab are summarized in Tab. 1.

The retrofitted multifamily building in Bern (MFB90) serving as the load case for the solar-ice-slurry system has about 50 kW heating capacity. The size of the building (building capacity, floor and roof area and as a result the heating demand), all additional demands (DHW, household electricity) as well as internal gains and sizes of the energy system (ice storage, thermal collector field area, PV area, battery) have been sized to one fifth of the initial size of the reference system. As roof space is limited, and solar-thermal collectors and PV are both used in the ice-slurry system, the PV field is distributed to the roof and the southward directed façade. In this case 60 % of the PV modules are on the roof and 40 % on the façade. The sizes of the system tested within the system test are summarized in Tab. 1.

**Tab. 1 -** Summary of the component sizes for both systems tested in the system test.

| | | dual source | ice-slurry |
|---|---|---|---|
| Heat Pump | [kW] | 10 | 10 |
| DHW storage tank | [l] | 500 | 1000 |
| SH storage tank | [l] | 300 | 600 |
| Battery capacity | [kWh] | 10 | 7 |
| PV plant | [kWp] | 7.5 | 8.2 |
| Solar thermal | [m$^2$] | - | 33.3 |
| Ice-storage tank | [m$^3$] | - | 2 |

The yearly simulations of both the scaled system and the original system were compared and resulted in the same yearly energetic efficiency. From the scaled simulation, the days for the system tests were selected. In order to test the system in the test rig the ice storage was scaled down to a size of 2 m$^3$ in order to represent its behaviour as seasonal storage in a seven day test. The ice storage will be emulated first and installed as a prototype within the test rig in the system test in a later stage.

# 3. Selection of periods

## *3.1 Overview*

This chapter presents two different methods for determining test sequences for system testing. The different methods are necessary because of the characteristics of the systems or the components used: The measurement of a system with intelligent controller, which makes a prediction for the next 24 hours based on the current boundary conditions, requires a continuous sequence with weather data with a fluctuation that corresponds to the annual course. The measurement of a system with seasonal storage, on the other hand, should optimally reproduce the course of a year in order to be able to map the interaction of heat sources and heat sinks.

## *3.2 Dual source/sink system*

The selection of the most representative days for the system's operation over the whole year are based on the developed method K-meansGA. This method uses the classification method K-means and optimization based on a genetic algorithm (GA). Meteorological and demand data are used for obtaining the results for Tarragona. First, the weather data is classified in a number k of clusters. For this, the k-means algorithm from the python library sklearn is used. The clusters are generated by the data distribution. Each data point is classified using the lowest quadratic distance to the nearest centroid. The centroids are the mathematical centres of the cluster and are not actual data points. In each iteration, the centroids position change until the distance between each data point and their centroid is minimum. The closest point to the centroid is the final result. Secondly, a genetic algorithm is used, based on natural selection applied to optimization problems. In each iteration, random "parent" solutions are selected, crossed and mutated, generating "descendent" solutions for the next iteration. In the end, the most fitted solution is found.

For the test of the advanced energy management (AEM) algorithm, the days selected must be consecutive rather than different days of the year put together, so as to observe the behaviour of the AEM systems over several consecutive days (e.g. storing PV energy on a sunny day for the next day with less production). Because of this, the algorithm selects all the possible combination of consecutive days of the year (e.g. series 1: day 1, 2, 3 and 4, series 2: day 2, 3, 4 and 5). Therefore, each data point is a series of 4 consecutive days. For the current application, the daily average temperature and the daily solar irradiation are used for the k-means. The algorithm does not take into account the chronological order of the days. Therefore, each cluster has points from various dates of the year. The intermediate results of the k-means are one series of four days for each cluster, each one representing different conditions of the year. This result is used for the genetic algorithm as seeds for the solutions. Also, cluster classification is used. The function to optimize by the GA is the minimum difference between the extrapolated load of the selected series of days (load of the selected days multiplied by the number of days in the cluster) and the total load of the cluster. The algorithm searches for series of days that minimize that difference and are near the centroids.

The genetic algorithm can optimize for different loads at the same time. For this project, three different load types were considered: space conditioning, DHW and electrical power consumption from the appliances. Space conditioning is the main load associated with the heat pump, divided into space heating during the cold season and space cooling during the warm season. In the following we analyse if adding the DHW and appliances consumption to the optimization to select the days could improve the results.

For DHW, stochastic data was used to obtain the extraction profiles along the year. Space heating and DHW can be added together as a total heating demand. However, the result may lead to a selection of days where one type of demand is dominating and the other is not correctly represented. To avoid this, SH and DHW are considered as two different variables to optimize.

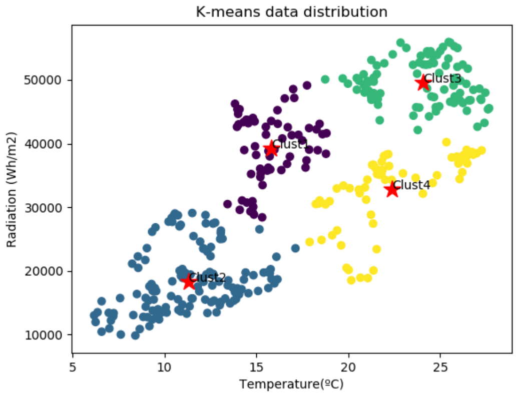

**Fig. 5 –** K-means clusterization of Tarragona. The solar radiation is the sum of the 4 days series and temperature the average. Each cluster is shown with a different colour. The red stars are the centroids of the clusters.

The stochastic distribution and the lack of seasonality of the DHW made it hard to select representative days throughout the year. Only one of the eight solutions changed when adding the DHW to the optimization. In that case, the results do not show enough improvement to justify the consideration of the DHW demand in the selection process. Therefore, the DHW demand will not be considered for optimization.

For the appliances, the electric consumption is based on a typical yearly profile. This annual profile does not present seasonality. When optimizing based on the appliances consumption, half of the results changed while the other half stayed the same as when considering only space conditioning. For the ones that changed, the results for space conditioning worsened. The improvement of the results for the appliances consumption is not enough to justify the worsening of the space conditioning load prediction.

Taking into account the test objectives, the use of only space conditioning as the input load data was considered the most appropriate option. The k-means algorithm considers the climatic data which affects the photovoltaic generation, while the GA algorithm selects the days which best extrapolate the load for the whole year.

Fig. 5 shows the clusterization of the climate data from Tarragona. Cluster 3 corresponds to the warmest days of the year, while cluster 4 are the coldest ones. Cluster 1 and 2 are in the middle, being the latter the one with less radiation. Cluster 1 and 4 have heating demand, while clusters 2 and 3 have cooling demand. The climate of Tarragona is cooling dominated.

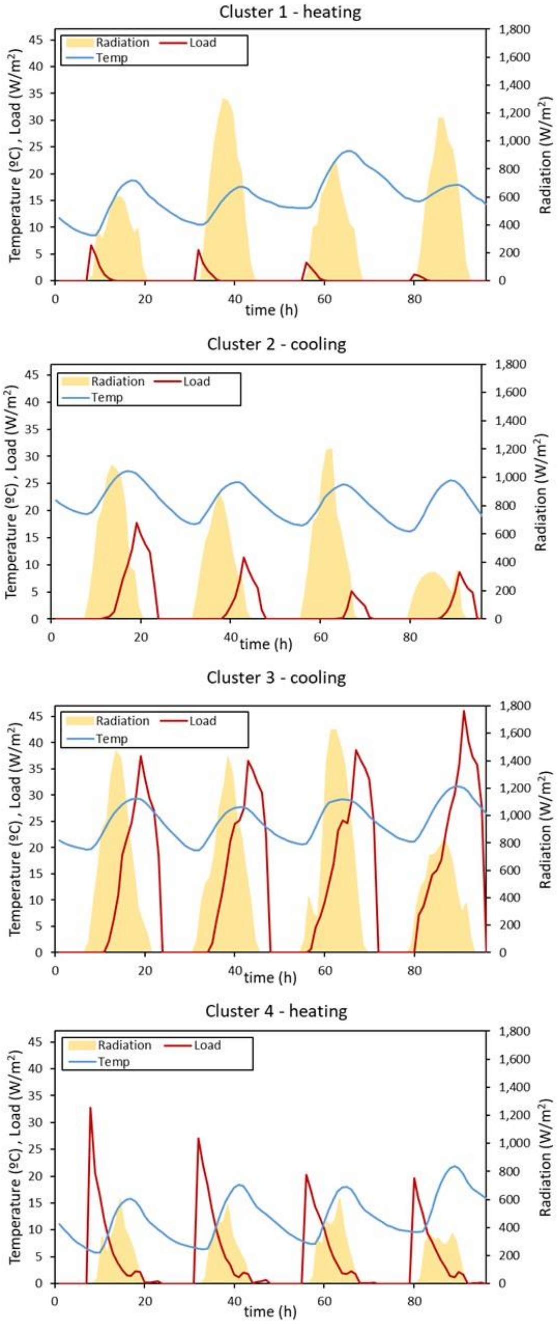

**Fig. 6 –** Hourly profiles of temperature, solar radiation and load for the selected series of days for Tarragona.

## *3.2 Solar-ice-slurry system*

The first goal of testing the solar-ice system in a system test is to proof the functionality of the complex system. Additionally, a real installation of an ice-slurry storage with supercooling water in the evaporator of the heat pump and generating ice-slurry by means of a crystallizer will be tested as well. To achieve this goals, a period of 7 days was selected representing a year in a way that the ice-slurry storage reaches its maximum ice fraction only in a small period of time. The CCT test will be performed with the propane heat pump during spring 2022 and with the CO2 heat pump during autumn 2022. Additionally, the simulation model should be validated with the results of this system test in order to evaluate the system performance with a reliable, validated model in a yearly simulation.

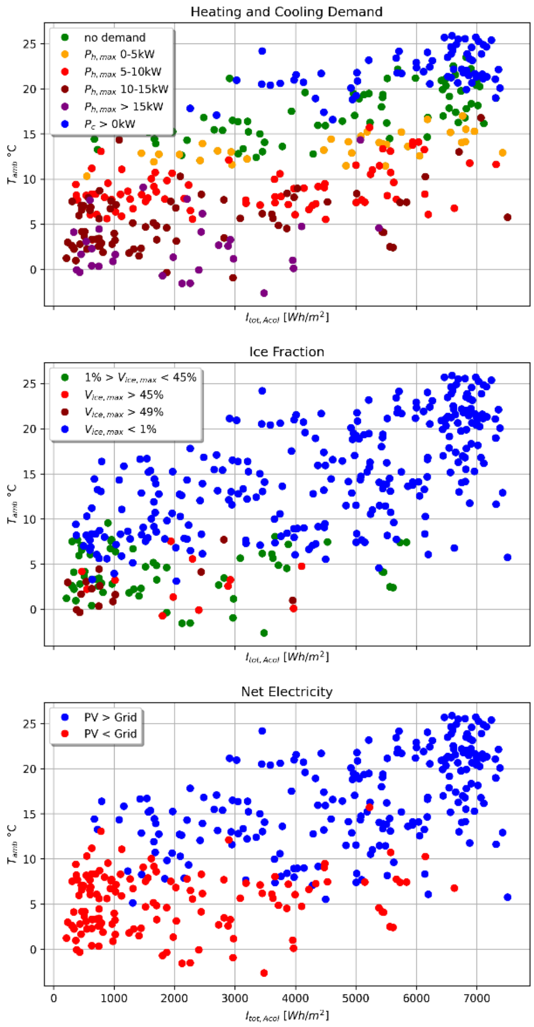

**Fig. 7 –** Ambient temperature vs total solar irradiation in the collector plane in Wh/m² for all days in a year. The colours represent the values of several variables (up) heating and cooling, demand, (mid) ice fraction and (bot) net electricity.

The first step for selecting the days for the system test is to get an overview about the distribution of different weather conditions and their influence in the heating system over the year. However, as a difference of the method presented in the above section 3.1, here we also need to consider the charge/discharge status of the ice storage, which cannot be pre-processed like the energy demands and weather data, but it needs to be simulated. Fig. 7 shows the distribution of the daily averaged ambient temperatures with the daily sum of solar irradiation into the collector field. The colour code indicates different situations in terms of the heating and cooling demands and the ice fraction of the ice storage. The days with low irradiation and low temperatures tend to have a high heating demand but very different status of the ice fraction. The ice fraction on days with high heating demand is deciding on system efficiency. A system with an SPF of 4 reaches the maximum ice fraction only on 3.5 % of the days.

In the yearly simulations, 60 % of the days have heating demand, 20 % have cooling demand and 20 % have neither. The seven days were chosen in a way that they represent this distribution as far as possible, reaching the fully iced ice storage only for a part of a day in order to be comparable with the yearly simulation. The ambient temperature and the total horizontal irradiation are shown in Fig. 8. The ambient temperature was smoothed at the transitions between the days to get a temperature profiles without unrealistic steps. For the system simulation of the seven days, the ice storage was scaled down further to a lab-size of 2 m³. These profiles of the seven days as well as a seven day profile for household electricity and DHW was then fed into the system simulation and results for the seven day period were calculated.

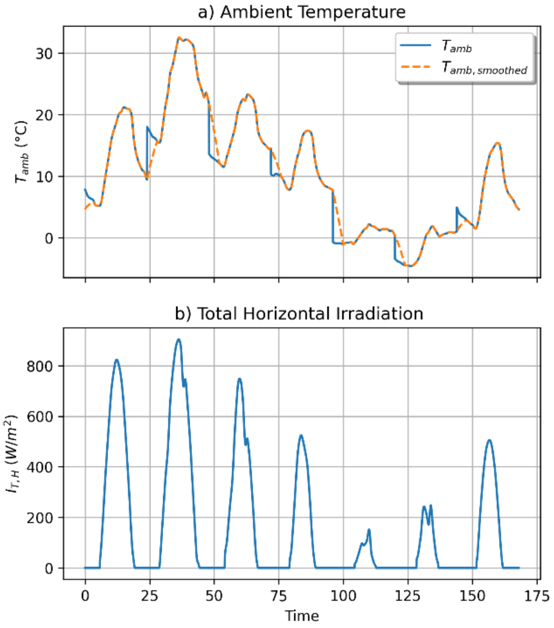

**Fig. 8 –** Ambient temperature and total solar irradiation in Wh/m2 for different conditions as a function of the time for the seven test days.

The system test with the propane heat pump using the seven days selected should serve for validation of the simulation model. The results of the system test will be compared with the simulation results of the seven selected days and the simulation model will be calibrated. Afterwards, a yearly simulation will be carried out with the calibrated model to calculate the energetic yearly system efficiency.

The building respects medium insulation standard of a retrofitted, old building and has a high thermal capacity. Such heating up in warm weather periods or cooling down in cold periods takes some days. To get realistic building temperatures corresponding to the actual ambient temperature for the system test, the temperature of the building is reinitialized every day at midnight with the temperature of the following day from the yearly simulation. In this way, the cooling and heating demand in the system test is not influenced by the short-term change of seasons.

**Tab. 2 –** Comparison of the KPI for yearly simulation and the simulation of the selected 7 days.

| | annual simulation | 7-day simulation |
|---|---|---|
| $R_{RE,loacal}$ | 81 % | 82 % |
| *SPF* | 4.1 | 4.3 |

The TRI-HP goal of reaching at least 80 % of onsite renewable share is fulfilled for the ice-slurry system in yearly simulations as well as in the simulation of the seven representative days selected (see Tab. 2). Additionally, the electricity produced by the onsite PV plant is about the amount of electricity used by the heating system (including pumps and inverter/battery losses) and the households in the yearly simulation.

# 4. Test procedure and evaluation of results

## 4.1 Dual source/sink system

The storage units installed on the consumer side, both thermal and electrical, lead to inertia in the overall system. To start the test in a more realistic state, an additional day of pre-conditioning will be carried out in the experiments: the day before the chosen series of 4 days will also be tested in real time in the experiments, in order to bring the tanks into a usual stratification state that corresponds to a normal operation. We will, however, discard this first day of pre-conditioning, and only consider the 4 actual days of the test for the analysis. Since the capacity of the installed storage units does not exceed the respective daily demand, no further conditioning measures are necessary.

It could happen that because of the control strategy or the test conditions, the states of the storage are different at the start and at the end of the 4 days test period. Therefore, the differences in charged/discharged energy will be calculated for all the storage elements (thermal mass of the building, storage water tanks, electrical battery) and taken into account in the energy balances.

As described, four different 4-day sequences including one additional conditioning day each are used. From the sequences, quantities such as the useful heat or cold as well as the electricity demand can be extrapolated. The sum of the four extrapolated data then results in the annual value, from which the defined KPI can be calculated.

## 4.2 Ice-slurry-system

After the installation and commissioning of the whole system, the controller must be parameterized. For this purpose, some preliminary tests are required to check the speed of the pumps, the heating curve of the controller and the domestic hot water mixing valves. Before the actual start of the test, all tanks included must be conditioned. This means that the DHW tank should be in the upper range between 50 °C and 60 °C and the heating buffer at about 40 °C. The ice slurry storage should have an ice content of about 50 %, and the battery should be discharged to just above the maximum depth of discharge. Once the test has started, no changes or interventions in the system or its controllers are allowed until it is completed. The tested system must operate autonomously to meet the building's heating, cooling and household electricity needs. After 7 days or 168 hours, the end of the test cycle is reached. However, the test is not stopped then, but continues seamlessly, starting again at day 1. The end of the test is not reached until the so-called Concise Cycle criterion is reached. This ensures that no energy is stored within the system, or that the state of the system is identical at the beginning and end of the test. The Concise Cycle criterion for the termination, or the successful completion of the test, consists of three key aspects: energy consumption and storages state of charge as explained in the following:

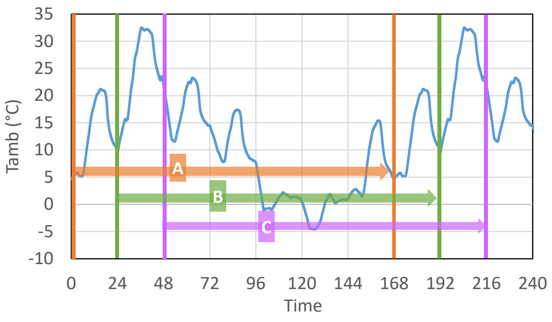

**Fig. 9 –** 7-day test sequence as a cycle, which is seamlessly aligned, respectively repeated. The test can be completed successfully if the evaluation of two consecutive phases is identical (A = B or B = C etc.).

**El. energy consumption:** At the end of the eighth test day, the consumption of electrical energy in the period 0 h to 168 h (cf. phase "A" in Fig. 9) can be compared with the consumption of electrical energy in the period 24 h to 192 h (phase "B"). These values have to be identical (±1 %), if not the test is continued to compare phase "B" with phase "C".

**Storage tank temperature:** The storage tank temperature is measured by means of contact sensors on the storage tank wall. This temperature measurement can be used to determine an average storage tank temperature and thus its state of charge.

This temperature must be identical at the beginning and end of the test cycle (±0.5 K). If the temperature does not match, this means that the conditioning of the storage tank was not correct and the energy content of the storage tank has changed during the test period. In this case, the test must continue for at least 24 h and at the end of the next day the initial and final temperature has to be compared again.

**Battery state of charge:** The state of charge of the battery must be identical at the beginning and at the end of the test cycle. This can be done either by the display of the battery itself, or by balancing the supplied and discharged electrical power.

The test cycle used for ice-slurry systems was created with the aim of combining all relevant operating conditions in one test cycle while providing a directly extrapolated result. The comparison of the 7-day simulations and the annual simulations from the selection of test sequences shows that this has been achieved. However, this is only true if, on the one hand, the test confirms the expected efficiency from the simulations carried out in advance and, on the other hand, the dimensioning of all components is suitable for the load of the test. In case of a deviation, the source temperature of the heat pump changes and thus also its efficiency. For this reason, the measured data will be used to calibrate the already existing simulation model of the tested system. If the simulation results from the 7-day simulation match the measured data we can assume a well set simulation and the parameter study can be extended with annual simulations for different locations.

## 5. Conclusions

The CCT method will allow a proof of concept of the two heating and cooling heat pump systems developed within the project TRI-HP at laboratory size: for warm regions in southern Europe, the dual source/sink system was developed with a propane-dual heat pump. This system makes use of ground source heat exchangers and air as heat sources for the heat pump. For colder regions in central Europe, the ice-slurry system was developed with a propane heat pump for retrofitted buildings with a rather low share of DHW demand on the total heat demand and with a $CO_2$ heat pump for with a share of DHW demand about 50 % of the total heat demand.

The methods for selecting the representative days are different for both systems. The proposed methodologies demonstrate an efficient selection of the test periods representative for the operation of the system over a whole typical year, and they allow an accurate assessment of the dynamic behaviour of the system and its energetic efficiency.

For testing the AEM, the weather data is divided into four different seasonal clusters. Representative days for each clusters are selected and used for the system tests in order to evaluate the behaviour of the advanced management control method and their cost-economic advantages compared to a rule-based control.

For selecting the representative days for the ice-slurry system, the weather data and heat demands alone are not sufficient as the system efficiency depends on whether the ice storage freezes completely or not and by how long. Therefore, system simulations were used to select the representative days comparing the KPIs obtained for one year simulations with the ones corresponding to the seven consecutive days selected. It will serve as a proof of concept for an ice-slurry storage prototype integrated into a heating system. With the results from the concise cycle test the simulation model will be checked and adjusted for getting reliable results for a simulation study for testing the viability of both systems for different climates in Europe.

## 6. Acknowledgement

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## 7. References

[1] Peter Vogelsanger. The Concise Cycle Test Method - a 12 Day System Test. A Report of IEA SHC. IEA-SHC Task 26 Solar Combisystems, Paris, France: 2002.

[2] Haller MY, Haberl R, Persson T, Bales C, Kovacs P, Chèze D, et al. Dynamic whole system testing of combined renewable heating systems – The current state of the art. Energy and Buildings 2013;66:667–77. https://doi.org/10.1016/j.enbuild.2013.07.052.

[3] T. Péan, J. Romani, E. Fuentes, J. Salom (2020). Treballs tècnics relatius al potencial de les bombes de calor aerotèrmiques d’alta eficiència energètica per a climatització i generació d’aigua calenta sanitària a Catalunya. Technical report for ICAEN.

[4] Ministerio de Fomento de España. Código Técnico de la Edificación CTE - Documento Básico HE - Ahorro de Energía. (2019)

[5] Jordan, U. and Vajen, K. DHWcalc: Program to generate domestic hot water profiles with statistical means for user defined conditions, ISES World Congress, Orlando, 2005.

[6] SIA. SIA Merkblatt 2028: Klimadaten für Bauphysik, Energie- und Gebäudetechnik 2010.

[7] Pflugradt N. Load Profile Generator Version 1.3.5. Chemnitz: Prof. Technische Thermodynamik, Germany; 2010.