Semi-virtual dynamic tests of hybrid systems coupling solar thermal and PV panels with Heat Pumps

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SEMI-VIRTUAL DYNAMIC TESTS OF HYBRID SYSTEMS COUPLING SOLAR THERMAL AND PV PANELS WITH HEAT PUMPS

Summary

Despite the huge primary energy consumption associated with heating and cooling (H&C) demand in EU building stock, the share of installed renewable H&C solutions is still marginal (i.e. 5%). In order to speed up a transition towards the widespread application of renewable H&C in buildings, innovative solutions must be designed to compete against traditional solutions. SunHorizon project aims to unlock the potential for a user-friendly and cost-effective solution based on an optimized design and combination of commercial innovative solar technologies (thermal or/and PV) and Heat Pumps (HP). This paper aims to present how are performing experimentally two hybrid concepts, out of four in the whole project, that are coupling solar thermal and PV panels with heat pumps to satisfy thermal and electricity energy demand of residential buildings in Riga (Latvia) and Piera (Spain). Following hardware-in-the-loop approach, specific short test sequences are developed first for each of the two Technology Packages (TP) that allow for extrapolation of the measurements to annual seasonal performance figures including electricity self-consumption in addition to renewable heating and cooling indicators.

key-words: performance test, hardware-in-the-loop, solar thermal, PV, PVT, heat pump, electricity self-consumption.

1. Introduction

Buildings are responsible for 41% of EU energy consumption and H&C equals 55% of the total EU energy demand (ODYSSEE, 2018). This demand is mostly met by fossil fuels, with natural gas having the main share, while renewable energy sources (RES) remain marginal (5%). However, according to the EC's H&C Strategy, the H&C sector still accounts for 59% of total EU gas consumption, and almost half of EU's buildings have boilers with an efficiency rate below 60% (IEA, 2018). Nevertheless, RES are becoming increasingly common and socially accepted. Therefore, to speed up a transition towards RES-based H&C in buildings, innovative solutions must be designed to compete against traditional solutions with equivalent or lower investment costs and payback times, while guaranteeing similar or better levels of comfort. Both residential and tertiary new buildings types are expected to become highly-efficient. Currently, solar panels and HP are the most common and socially accepted RES Based H&C solutions. Bringing together existing and mature HP and solar technologies guarantees a simple energy system nevertheless efforts are still required to optimize their coupling, as they are used to be designed and operated often separately. Solar and HP can form an integrated solution with several key advantages: high RES share and energy efficiency, low electricity and primary-energy demand, low CO_2 emission. HP are well suited to low-temperature needs as for well-insulated residential and tertiary buildings. In parallel solar thermal and PV reduces also the thermal and electricity demand in non-renovated envelopes. SunHorizon project aims to demonstrate innovative and reliable HP solutions (thermal compression, adsorption, reversible) which, properly coupled and managed with advanced solar panels (thermal, PVT, PV), provide H&C to residential and tertiary building with lower emissions, energy bills and fossil fuel dependency. Four different TPs are being developed and demonstrated all across EU climates (i.e. Germany, Spain, Belgium and Latvia) and building typologies (small and large-scale residential and tertiary buildings).

In this work, the wide SunHorizon scope above is restricted on two approaches, TP2 and TP4, which generate solar heat and electricity to save non-renewable energy consumption in residential context. TP2 is focused on areas with predominating heating demand and will be installed and run in-situ in Riga (Latvia) from August 2021. TP4 can meet both heating and cooling demands rather in Mediterranean areas and will be operated in–situ in Piera (Spain). The Sunhorizon objective is here to validate the technologies integration into TP2 and TP4 concept through the semi-virtual testing approach, essentially control aspects, with respect to the relevant

operating conditions to be met afterwards on the real demo sites. The main new challenge of the test sequence elaboration compared to previous work is to address the electricity balance between PV production and both system and building consumptions in the one hand, and the challenging transition between heating and cooling seasons while keeping the sequences as short as possible.

2. Concepts, test method and setup

The preliminary TRNSYS simulation work (Chèze et al., 2020) led to the design and sizing of TP2 and TP4 concepts and it's been used to develop the related dynamic system test conditions.

The TP2 concept relies on 58m² Dualsun solar PVT panels, Boostheat 20kW thermal compression gas fired heat pump GUE=2.0 at A7/W35, 0.2/1.3 m3 cold/hot tanks and smart electric heater from PV electricity excess by Ratiotherm. The TP2 system was integrated in simulation in Riga (LV) demonstration context: residential house 34.5MWh space heating annual demand (SH), 2.9 MWh domestic hot water (DHW), electricity consumption 4.4 MWh. The estimation of annual green house gas emissions savings ($f_{sav,GHG}$) through TP2 is 51% compared to existing gas boiler.

The TP4 concept is developed from BDR Thermea products, separate 4 m² solar thermal flat plate and 10 m² PV panels with harmonized roof integration, air source reversible 6kW COP=3.4 at A2/W35 heat pump, 200/150L buffer/DHW tank, and global controller managing heating/cooling and PV electricity balance at system and building level. The system is integrated in simulation in Piera (SP) demonstration context: residential house 5.4 MWh SH and 1.2 MWh cooling SC demand, 1.2 MWh DHW, 2.3 MWh electricity consumption. The estimation of $f_{sav,GHG}$ is 53% for TP4 in Piera compared to existing oil boiler and 4m² solar DHW heating system, also considering extra comfort gain through new cooling supply.

The semi-virtual test is a global system test approach considering the real-time strong interactions between the building, the local energy systems and controllers, the environment and the users. In his PhD thesis work, (Sayegh, 2020) developed a new approach and automated tool called TYPSS to define a climate sequence short enough to determine with the full dynamic models the real-time tested system performances that are then extrapolated to the full year. This approach came after previous works following similar philosophy around the elaboration of short sequence test for dynamic thermal system test as in (Albaric et al., 2010), (Chèze et al., 2018) or (Menegon et al., 2020).

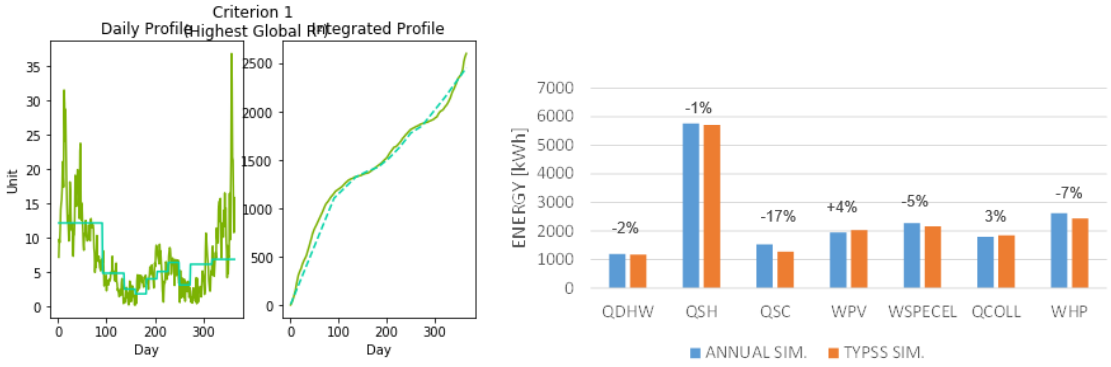

Fig.1: annual/test sequence comparison of HP electricity profile (left) and all integrated criteria (right)

In the SunHorizon work, the TYPSS tool was used together with the TP2 and TP4 TRNSYS simulations to elaborate short test sequences that are relevant with respect to the two different demonstration sites and environments. Fig.1 illustrates the various criteria involved in the TYPSS methodology to design a short sequence representative of one-year operation, looking at annual profile evolutions and integrated criteria. On the left, electricity consumption criterion 1, we can see that the summer increase in electricity consumption from the grid is well catch by the selected sequence: it reveals the actual balance between PV electricity generation and overall building consumption increase through cooling operation of the HP, from the self-consumption strategy developed in TP4 controller. With regard to the short 10-days sequence challenge, on the right figure representing the comparison between annual and sequence of energy cumulated criteria, we notice that the deviation of every criteria doesn't excess 7% except for the cooling load. It was decided an acceptable trade-off considering the short sequence duration requirement and higher priority given to the

overall electricity consumption of the system.

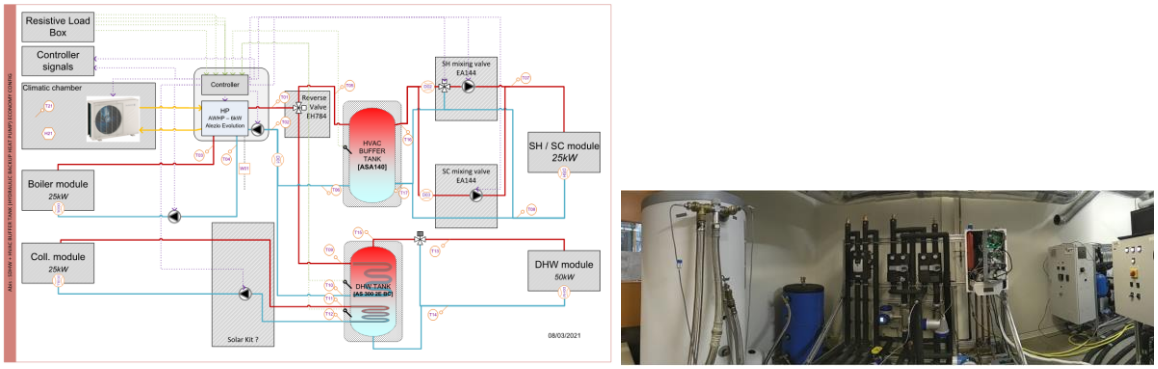

Fig.2 : TP4 concept and outlook of real system integrated in semi-virtual test bench

An illustration of the architecture of TP4 is presented in Fig.2, together with a picture of the indoor system parts integrated in dynamic thermal sytem test bench laboratory.

3. Conclusions

This work managed to develop relevant short 10-days test sequences for each system and demonstration environment, as customized building type, climate and users behaviors (DHW and specific electricity consumption). The test sequences allowed the extrapolation of the measurements during the 10-days tests to annual performance figures. The execution of both TP2 and TP4 tests revealed some tricky issues around the configuration of the controllers to achieve expected behavior, in particular for the TP2 system which is combining the components and controllers from two manufacturers, Ratiotherm and Boostheat. This testing experience allows issuing recommendations for the future reliable installations on-site in August 2021. In addition to the experience in fast-customized test sequence development and testing of TP2 and TP4 concept, the deviations of the measured performance figures compared to the simulated ones are discussed in this work.

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