Comparative Dynamic Performance Tests of Two Real Technology Packages for Buildings Heating System Retrofit

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Abstract

This work is performed within the framework of the THERMOSS EU project. The main objective of the project is to foster the deployment of advanced heating and cooling technologies with high replication potential, enabling 20-30% primary energy consumption reduction through thermal solar combination, model predictive control and storage strategy. The efficient match between supply and demand of energy is ensured by real-time management of thermal energy at building level and at district level for District Heating and Cooling (DHC) connected buildings. Before installing the systems in real THERMOSS demonstration sites by the end of 2018, the whole system test of two heating technologies (hybrid solar heat pump and interface unit to heat network) from the industrial partner has validated some recent features while assessing the performance of these technologies with dynamic reproducible boundary conditions (small residential buildings, Western European climate). The results assessed the primary energy savings in the range 9.7-36% and revealed its high sensitivity to control parameter settings related to the use of indoor temperature sensor. The realistic dynamic test also emphasized the major influence on the standby heat losses of thermal inertia of the system components combined with flow temperature control. For both technologies, the realistic radiator thermostatic valve emulation enabled to keep the deviation of the space heat load below 1.8% compared to the reference individual gas boiler.

Keywords: solar thermal, hybrid air source heat pump, heat network interface, building retrofit, experimental dynamic performance test, primary energy indicators, control validation, radiator thermostatic valve

1. Introduction

This work was performed in the framework of H2020 Thermoss project (Fuligni and Centeno 2016). It aims at the demonstration of efficient heating technologies recently arrived or arriving on the market that reduce primary energy consumption for heating or cooling of building, thanks to renovation of the heating/cooling system. A few technologies have been proposed for demonstration in real demo sites with real users and the performance of two others are to be demonstrated through test results in realistic operating conditions. This work focused on two technology packages for Space Heating (SH) and Domestic Hot Water (DHW) supply, at small residential building scale, abbreviated in this article as:

- SHP: Solar and air source split Heat Pump combisystem with gas backup and thermal storage.
- HIU: Heat Interface Unit in replacement of individual heating systems in apartments block by centralized highly efficient heat generators and distributed compact units in the dwellings.

In Thermoss perspective, the heating system test objective is to get experimental, reproducible evaluation of the overall system behaviour in realistic operating conditions, including real control. The subgroup of solar combisystems (here referring to heating systems providing both DHW and space heating by mean of solar thermal collector and with flexible heat backup like fuel boiler or electrical heater) test was investigated in the past by several research teams. In Albaric et al., 2010 the authors analysed two approaches to evaluate the system behaviour/performance either as extrapolated system behaviour from previous component tests or as direct whole system test. The findings were that the extrapolation approach based on components tests is limited in accuracy by the missing knowledge of the full components details and inter-connections, in particular regarding the control implementation. For this reason the comparison of performances of hybrid system packages including confidential

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developments of their manufacturers (blackbox systems) appears more straightforward with a 'whole system test' approach in specific reproducible test conditions. This latter approach was used for Thermoss work and its principles, main characteristics, new development (as the radiator thermostatic valve emulation) and comparison of primary energy figures are presented in the second section of this article. The description of the tested systems, installations on the test bench, test results and discussions are presented successively in the following sections.

2. Methodology of dynamic system test

2.1 Overview

A comparison of specific methodologies based on 'whole system test' are given in Haller et al. 2013. In particular, the authors categorized the findings based on the heating load as fixed heating load file or as dynamic models of the heating load. Among the studies relying on fixed load file, the recent work of Menegon et al., 2017, investigated the characterization of HeatingVentilationAirConditionning (HVAC) systems and the methodology to generate a customized test sequence for a given HVAC system. While it allows direct comparison of systems performance test results since the method ensures the systems are providing the same heat loads, it doesn't account for specific dynamic behaviors of the radiator and buildings that are influenced by the characteristic behavior of the real system control during the test. As a consequence, there's a discrepancy between the results from such test compared to those obtained in fully real operating conditions.

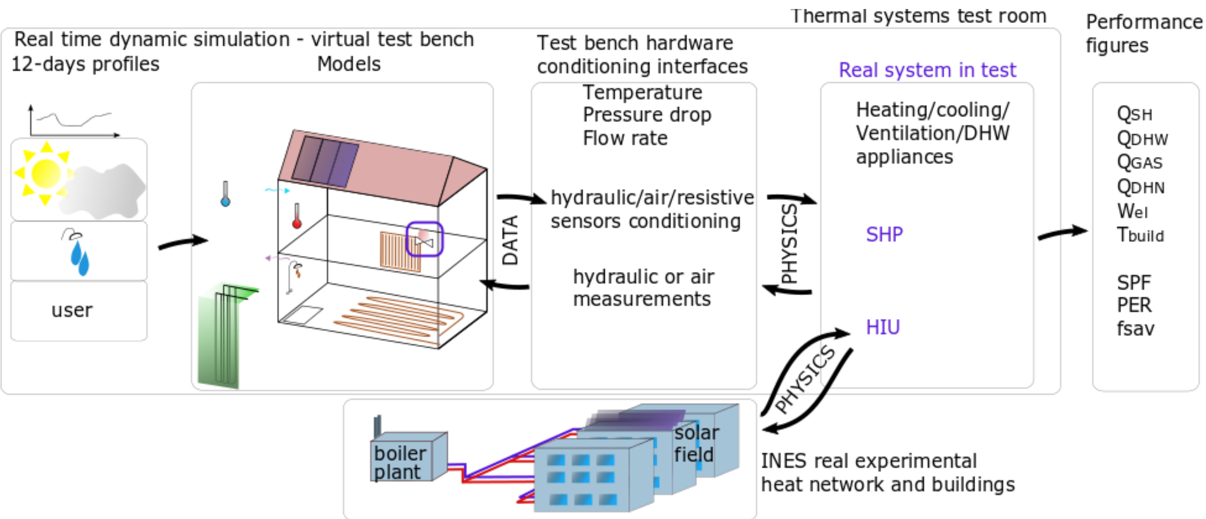

Fig. 1: Principle of semi-virtual dynamic performance test of HVAC systems at CEA INES ; illustrated by SHP and HIU test cases with performance figures defined in §2.3

A dynamic whole system test methodology using real time dynamic models of the heating load, called SCSPT test (Short Cycle System Performance Test), was originally developed for solar gas boilers combisystems (Albaric, M. et al., 2008) by CEA INES team. It consists in real-time hardware in the loop dynamic system test (including all thermal and control parts) for thermal systems during 12 days. It relies on TRNSYS 17 dynamic simulation system to cover the typical working conditions during 12 months of operation, as illustrated in Fig. 1. The test conditions are representative of annual variations of the Zurich climate (CH). The heat demand of the Single Family House simulated building is 60kWh/m²/year (SFH60) to maintain constant 20°C indoor temperature at the same location. The SFH60 building consists in a two storeys building of 140m² total floor heated area and 350m^3 volume. Further details about the building are contained in International Energy Agency Solar Heating and Cooling (IEA SHC) Task 32 work (Heimrath and Haller, 2007). During the 12-days test the total global horizontal radiation is 33.9kWh/m², the average outdoor temperature is 8.4°C and the total water draw-off reaches 2436L, about 200L/day with maximum flowrate of 8L/min and minimum of 3L/min. The simulated climate and draw-off profiles are applied in real time (no virtual time acceleration), with 1 minute time step operation, to the real tested appliance in the test room. Fig. 2 shows an outlook of the 12-days test conditions variations. The INES experimental Heat Network shown in Fig. 1 comprises a 280kW condensing gas boiler, 300m² of thermal solar panels, a hot tank storage of 40m^3 and a two-tubes distribution network (see Fig. 3). It supplies heat to several consumers, including real buildings and the aforementioned semi-virtual test-bench. In the HIU work described in section 4 we used the SFH60 building referred as 'Emulated Building' in Fig. 3.

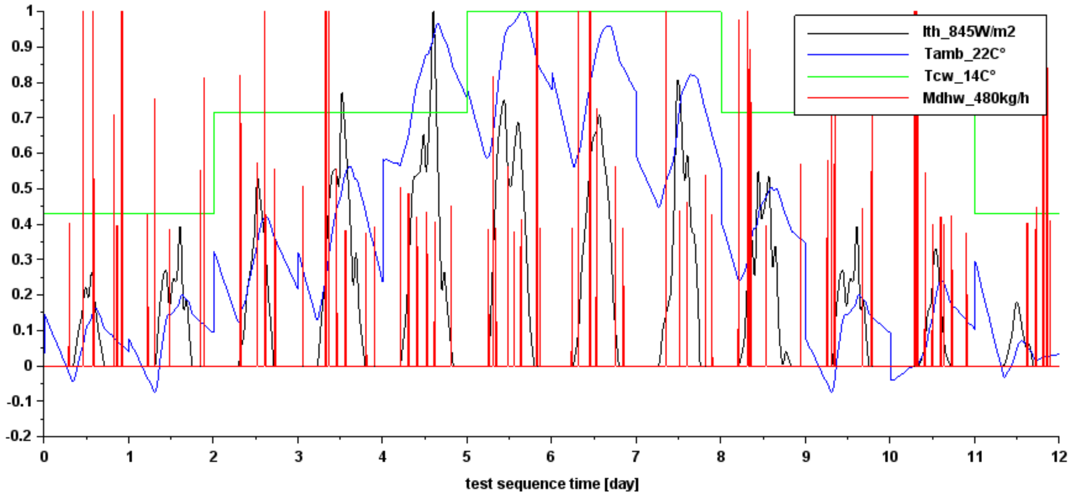

Fig. 2: Normalized total horizontal radiation, outdoor and cold water temperature and water draws flow rates along the 12-days test sequence

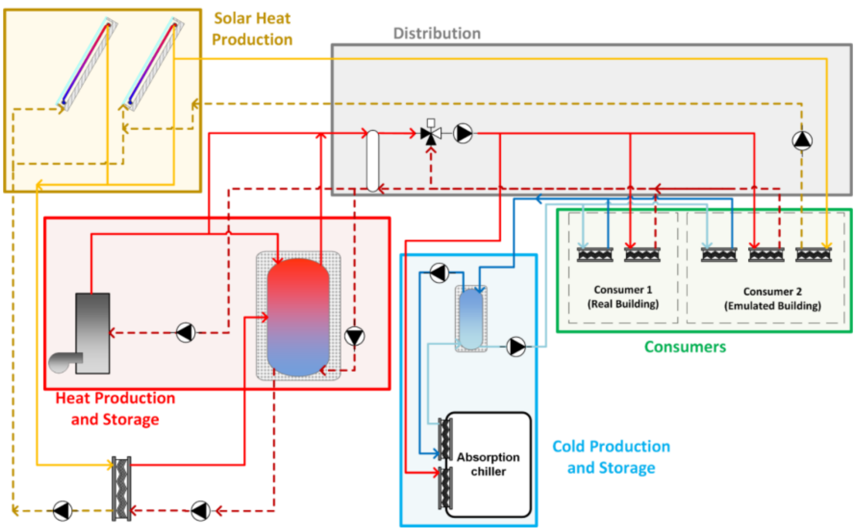

Fig. 3: Principles of micro District Heat Network (DHN) at CEA-INES

The dynamic whole system test methodology was recently improved by the testing institutes SPF, SERC, CEA INES as part of the MacSheep EU project (Chèze et al. 2014) regarding the control of space heating and DHW loads (with climate conditions selection for solarcombi systems relying on water heat pump) and the duration of the test sequence (reduced to 6 days). In this approach the fixed space heating load is achieved by combination of radiator dynamic model and a 1-minute-profile of authorized maximum load during the 6 days of simulation.

In the THERMOSS project, we used this approach to provide new results with the specific 6-days test sequence for the Solar Heat Pump (SHP) in section 3. We also performed the test following the SCSPT 12-days test procedure in order to compare the new SHP test results with those of the hybrid systems previously tested at CEA INES under different project and circumstances using the same test conditions.

2.2 Radiator thermostatic valve emulation

Within the THERMOSS framework, the SCSPT test method was upgraded with robust real dynamic pressure drop emulation of a thermostatic valve in the virtual radiator circuit. The aim is to evaluate the heat load behavior with a fully realistic emulation of the radiator thermostatic valve compared to previous developments within the MacSheep project to ensure a fixed heat load (Chèze et al., 2015) and (Haberl et al., 2015). So far most of the tested heating systems' controllers are using an indoor temperature sensor (an emulated one for the test bench experiments) to optimize flow temperature in the heating circuit. The emulated temperature sensor accounts for passive solar gains, electric devices and human occupancy gains. However, the emulated sensor is not able to operate for the case of thermostatic valve (THV) on radiators and without automatic heating curve adjustments, which is a very frequent type of installation. This happens even with the more recent appliances that can modulate the flow rate via variable speed pumps. When the emulated sensor is not able to operate, the supply flow temperature from the heating appliance is purely based on the outdoor temperature and occupancy schedules. Therefore, how to evaluate the performance of such a system? How to compare the performance test results between systems with/without indoor sensor information? In this study, we proposed to emulate a THV in order to observe realistic dynamic variable flows and pressure drop at the system boundaries. THV dynamic was approximated as ProportionalIntegral-controlled motorized valve instead of Proportional-controlled thermostatic actuators to ensure that the flow rate is actually reduced down to its minimal value, until the setpoint temperature is reached. This behavior is similar to the one of existing electronic thermostat embedded in the radiator valve head. The practical implementation is 100% on test bench side and consists of:

- Real controllable motorized valve in test bench;
- 20.5°C virtual indoor set point for PI control in TRNSYS dynamic simulation, similar dynamic as a radiator thermostatic valve, 0.5K is a common dead-band accuracy for room thermostat;
- 5% minimal opening level of the valve on the test bench (similar effect to these of safety differential pressure valve in heating circuit).

The influence of this emulated THV on the space heating flow rate was visible during SHP test n°3 as illustrated in Fig. 4. A constant nominal flow rate about 800kg/h in space heating loop is observed with the default settings of the space heating pump for the emulated building. In Fig. 4, when the emulated indoor temperature rises above 20.5°C, we see as expected that the valve progressively reduces the flow rate only for small periods in emulated 'cold season' (0 to 6000 min. or 14000 to 17000 min.) and for a long duration in 'hot season'(11500 to 14000 min.). The space heating pump is halted by the SHP controller when the daily average outdoor temperature rises above 16°C.

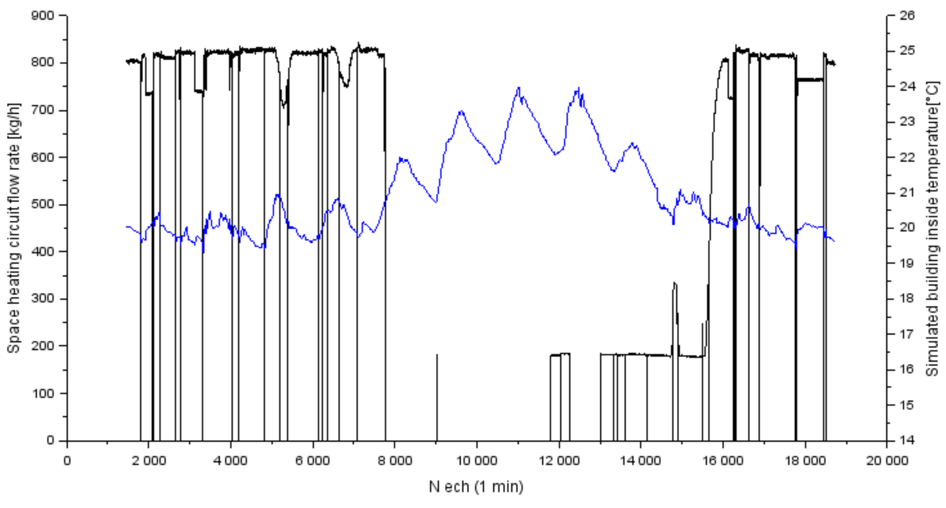

Fig. 4: Actual realistic space heating flow rate variations for a 12-days test with THV and indoor temperature emulation

2.3 Reference systems and indicators

Thermoss Project methodology relies on the primary energy savings approach for the comparison of the performance of several type of heating technology packages, as described in Deliverable 3.1 (Chèze et al., 2017). The methodology is based on the calculation of the fuel (gas and/or electricity) consumed by the testing systems compared to that of the R1 reference heating system, a condensing gas boiler with 85% average annual efficiency for space heating and DHW (including a 200L tank), single family house context. This reference has also been used in Task 26 (Streicher and Heimrath, 2003) and Task 32 (Heimrath and Haller, 2007). The indicators used in the test are:

- I_{hor}, total irradiation on horizontal plane over the period
- T_{amb}, mean ambient outdoor temperature over the period
- T_{build}, mean building indoor temperature over the period
- $\int P_{SH}.dt = Q_{SH}$, heat delivered to the building by the heating circuit over the period
- $\int P_{DHW}.dt = Q_{DHW}$, heat delivered to the user as DHW over the period
- $\int P_{COL}.dt = Q_{COL}$, heat from the emulated solar collector delivered to the real system under test over the period
- $\int P_{el}.dt = E_{el}$, $\int P_{elHP}.dt = E_{elHP}$ total absorbed electricity resp. by the whole system and by Heat Pump only when present over the period
- $\int P_{aux}.dt = Q_{aux}$, heat produced by the HP
- $\int P_{gas}.dt = Q_{gas}$, fuel energy consumption as lower heat content
- $Q_{PE} = 1 * Q_{gas} + 2.5 * E_{el}$, total primary energy consumed by the tested system over the period. By convention in the calculation for each system test performed in this work, the conversion factors from natural gas consumption to primary energy and from electricity consumption to primary energy are taken as 1 and 2.5 respectively. It is not specific to any country and there's still no agreement on common figures usable across Europe.
- N_{HP}, N_{BUR}, respective number of starts of HP and burner when present over the period
- $PF_{SYS} = \frac{Q_{SH}+Q_{DHW}}{Eel}$, performance factor of the whole system over the period, ratio of useful heat over total electricity consumption for heat pump systems (nb: when the period is one year, it is commonly named Seasonal Performance Factor (SPF))
- $PER_{SYS} = \frac{Q_{SH}+Q_{DHW}}{Q_{PE}}$, primary energy ratio of the whole system over the period
- $fsav_{PE,SYS} = 1 - \frac{Q_{gas}+2.5*E_{el}}{Q_{gas,ref}+2.5*E_{el,ref}}$, the primary energy savings over the period compared to the reference case, introduced in THERMOSS Deliverable 3.1.

The main performance values for the R1 reference case (residential context) are reported in Tab. 1.

Tab. 1: Reference system performance figures R1

Reference R1	Qsh	Qdhw	Eel	Qloss	Qgas	Q_{PE}	PER
kWh	279	100	22	21	471	526	0.72

In a heat network context, a reference heating system R2 is introduced that considers a network with a condensing gas boiler, a piping system and a pump to connect to a user with a heating system and a DHW tank. A density of 8MWh/m/yr (usually range between 1.5 and 15GWh/m/yr), a supply and return temperature of 60°C and 40°C and an average diameter of the piping of 100mm is considered for the network. That density led to an equivalent piping of 1.5m which was used to calculate yearly heat losses and pump consumption. Heat losses for a DHW tank of 50l were also calculated. Finally, the condensing gas boiler efficiency (101.9%) was obtained from traditional manufacturers' datasheet and based on the average network temperature. Tab. 2 summarizes the R2 system performance figures.

Tab. 2: R2 Reference system performance figures

Reference R2	Qsh	Qdhw	Eel	Qloss	Qgas	QPE	PER
kWh	279	100	24.4	20.1	391.7	454.6	0.83

3. SHP testing

3.1 Tested systems description

The Solar Heat Pump System (SHP) is based on existing components. It is a new hybrid combination for Compact pre-fabricated Bosch products Cerapur solar tank with gas boiler and Supraeco air source heat pump as main heat generators. An architecture with relay interaction between gas boiler and heat pump controllers exists but with less compact/pre-mounted integration of solar installation with either the gas boiler or the air source heat pump. In this context the control principle is that the solar combisystem controller manages the heat delivery to the user; it requests heat from the gas burner when the buffer tank temperature doesn't reach the setpoint temperature calculated from the current user demand (either SH or DHW demand). The heat pump is operating in space heating mode only of the top of the buffer tank following the same outdoor heating curve as the solar combisystem without indoor temperature sensor correction.

The SHP test comprises:

- Solar combisystem Cerapur JUPA SHU10 GC9000,
- HDS 400L buffer tank,
- emulated 8m² standard flat plate solar collectors (performance coefficients according to EN 12975-2 : $\eta 0$= 0.8, a1 = 3.5 W/m².K, a2 = 0.015 W/m².K²; south oriented, 45° tilted),
- 25kW gas boiler backup is integrated and combined with SUPRAECO A SAS 4-2 ASE heat pump (R410a, 4.5kW heating capacity, COP=3.5 for space heating at A2/W35) with outdoor split unit (in INES climatic test chamber).

Fig. 5 shows the installed SHP system on the dynamic thermal test bench of CEA INES facilities. It comprises four compact blocks of hardware appliances (flagged by the blue arrows on the top) connected to each other by two pairs of customized installation pipes and a proprietary communication bus. The complex hydraulic connections between the buffer storage tank and the gas boiler unit (manager of heat distribution to the heating demand circuits) relies only on pre-fabricated pipes with failure-proof designs to avoid installation errors.

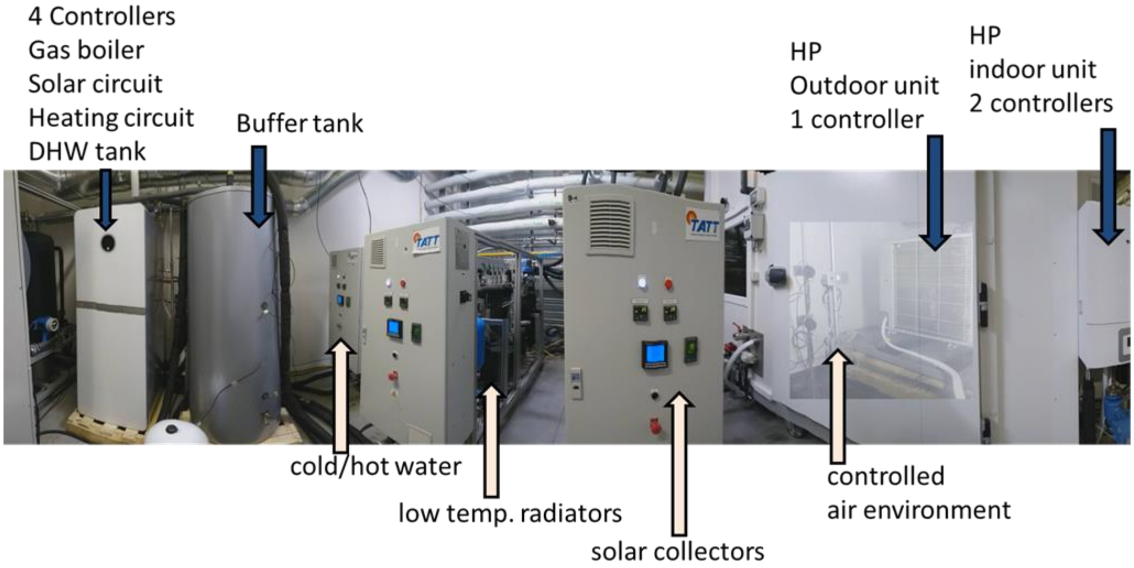

Fig. 5: Picture of the real SHP system under dynamic test process

The SHP system internal and external connections are summarized on Fig. 6. The names of the main energy flows of the tested system are introduced for further reference.

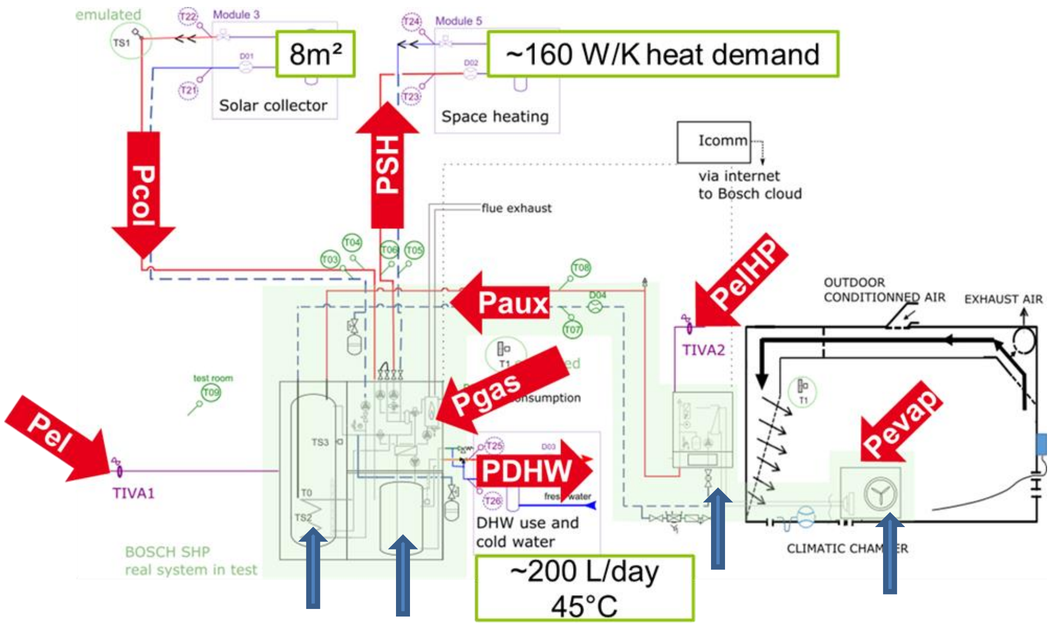

Fig. 6: Connections diagram of SHP installed on dynamic test bench

3.2 Test results

Three incremental performance tests were performed while changing the parameters of the SHP control system and/or the test procedure parameters as summarized in Tab. 3. The overall measurements from the three scenarios are reported in Tab. 4, performance figures in Tab. 5 while Tab. 6 provides an insight of daily measurements and performance.

Tab. 3: SHP test plan

SHP test n°	SHP configuration	Test procedure
1	Adjusted outdoor temp. heating curve, no indoor temperature sensor nor room thermostat	12-days, no THV
2	Adjusted outdoor temp. heating curve, ON/OFF heating controlled by indoor temperature sensor	6-days MacSheep test procedure with specific THV load control
3	Adjusted outdoor temp. heating curve with influence of indoor temperature sensor room thermostat	12-days, THV

The optimal settings of the SHP installation (fine control of the heat demand and heating curve looking at the building's indoor sensor) combined with the emulated of thermostatic valve on the radiators (described in Section 2.2) during the SHP test n°3 led to 36% of realistic primary energy savings compared to R1 reference gas condensing boiler under the same testing conditions. The solar thermal and heat pump technology from industrial partner outperformed the 20-30% primary energy savings goal of Thermoss for the three tests as shown by the figures from Tab. 5. The primary energy ratio (PER) is 1.11, including the electricity consumed by the whole system with a primary energy factor of 2.5. The average Seasonal Performance Factor of the heat pump during the whole test sequence is 2.98 and the solar fraction of the total heat demand is 22% with 8m² of flat plate solar collector.

Tab. 4: Overall three SHP tests measurements

SHP tests	Ihor	Tamb	Tbuild	QSH	QDHW	Qcol	EelHP	Eel	Qaux	Qgas	QPE
n°	kWh/m²	C°	C°	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
1	34	8.4	21.7	343	96	98	113	121	296	105	419
2	17	7.0	20.3	142	48	44	19	23	36	150	209
3	34	8.4	20.9	277	96	83	86	91	256	103	337

Tab. 5: Overall three SHP tests performance

SHP tests n°	COPHP	NHP	NBUR	PERsys	fsavpesys	SF
1	2.63	69	37	1.06	0.20	0.22
2	1.87	22	129	0.91	0.21	0.23
3	2.98	74	78	1.11	0.36	0.22

Looking at Tab. 4 test n°1 space heating load 343kWh, we notice a large overshoot above the R1 reference 279 kWh while the heat load from test n°2 (284kWh, with factor 2 to scale-up from 6-days to 12-days period) and test n°3 deviated by less than 1.8%. It shows the efficiency of the THV emulation to observe realistic system behavior and performance while keeping the heating load close to the R1 reference. The 16% increased savings between tests n°2 and 3 emphasizes the savings sensitivity to fine tuning of the space heating control parameters: to maximize the real operation efficiency of the HP (COPHP) and to reduce the gas boiler use (NBUR). As the real HP operating conditions during tests n°1,2,3 differ from those used in Standards testing, the measured COP differs.

Despite the 36% savings from test n°3 are significant, it deviates from the 46% savings estimations for SHP in R1 context in D3.1. This could be due mainly to the thermal inertia of the components (thermal capacity from boiler burner, HeatPump (HP) heat exchangers, pipes, water vessels etc…) and actual controllers that are actually influencing the standby heat losses of any real thermal systems, losses that are not accounted for the monthly sizing method relying only on measured efficiencies in steady state (even considering part load efficiencies of the heat generators).

Tab. 6 : SHP test n°3, daily results summary

day n°	Ihor kWh/m²	Tamb C°	Tbuild C°	QSH kWh	QDHW kWh	Qcol kWh	EelHP kWh	Eel kWh	Qaux kWh	Qgas kWh	QPE kWh	NHP	NBUR	PER sys
1	1.0	1.6	19.9	52	13	1	18	19	56	17	65	11	8	1.00
2	1.8	1.9	19.9	51	6	2	12	12	34	26	57	15	26	0.99
3	2.2	6.3	20.0	30	7	11	8	9	26	5	27	8	4	1.35
4	4.2	8.2	20.1	20	8	12	5	5	15	8	21	4	7	1.31
5	5.4	17.5	21.0	5	5	16	1	1	3	3	7	4	3	1.35
6	5.1	18.8	22.1	0	10	9	0	0	0	2	3	0	3	3.15
7	4.3	18.0	22.8	0	7	12	0	0	0	3	4	0	4	1.85
8	3.7	14.4	22.9	0	5	9	0	1	0	2	3	0	3	1.70
9	3.1	8.7	21.9	0	9	6	0	1	0	4	5	0	4	1.72
10	1.8	1.9	20.6	24	8	2	9	9	24	8	33	9	6	0.98
11	1.0	2.1	20.1	42	10	3	14	14	40	15	52	13	6	1.00
12	0.6	1.4	19.9	54	8	0	18	19	58	10	59	10	4	1.05
Tot	**34**	**8.4**	**20.9**	**277**	**96**	**83**	**86**	**91**	**256**	**103**	**337**	**74**	**78**	**1.11**

4. HIU testing

4.1 Tested systems description

The Heat Interface Unit (HIU) tested is the Greenstar HIU-E-PLUS model from Bosch. Recalling from Bosch website, the HIU is “the perfect solution for district heating and applications with a centralised plant room, providing both domestic hot water and heating” (Worcester-bosch.co.uk). HIU-E-PLUS model exhibits a nominal DHW output power of 39kW for a temperature rise of 40°C and a SH output range from 1.5 to 15kW. It is an indirect-indirect HIU with the separation of the DHW performed on the primary side. The specificity of this HIU is to be able to handle very low flow rate on the primary side with accuracy (suitable for renovated envelope building) and thus reducing the primary return temperature. The latter allows decreasing the heat losses on the building primary heat network while increasing the efficiency of the heat generator in case of a condensing gas boiler for example.

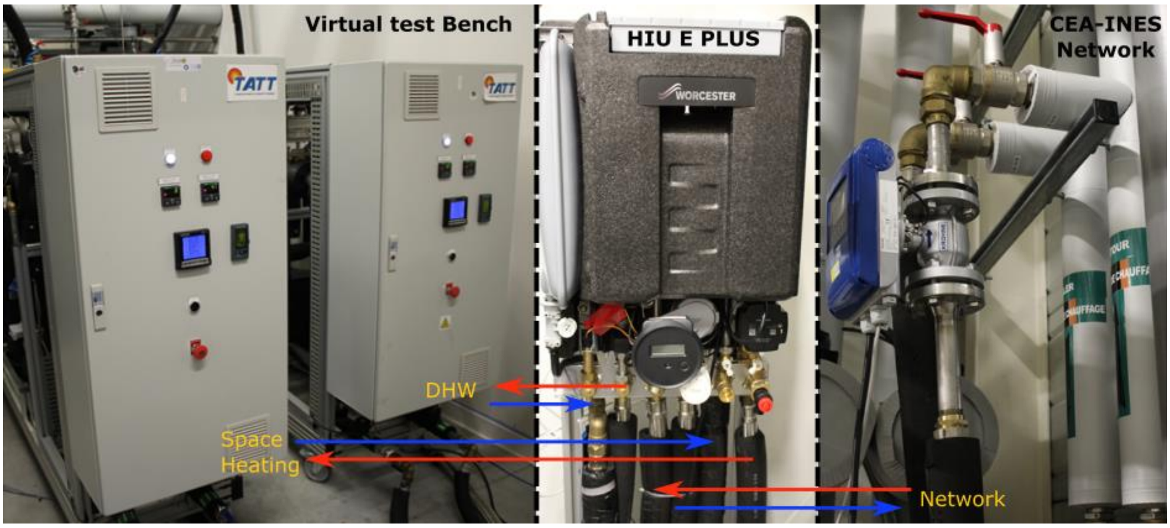

Fig. 7: CEA-INES test setup picture for the HIU testing

The Heat Interface Unit (HIU) tested is connected on one end to the micro District-Heating Network of CEA-INES and to the same semi-virtual test bench as for the SHP testing on the other end. Fig. 7 and Fig. 8 respectively present a picture and the schematic of the tests performed in the frame of the Thermoss project at CEA-INES. In Fig. 8, the HIU on the left, the network on the right and the Space Heating (SH) and Domestic Hot Water (DHW) modules from the semi-virtual test bench are highlighted. The different energy flows are also shown.

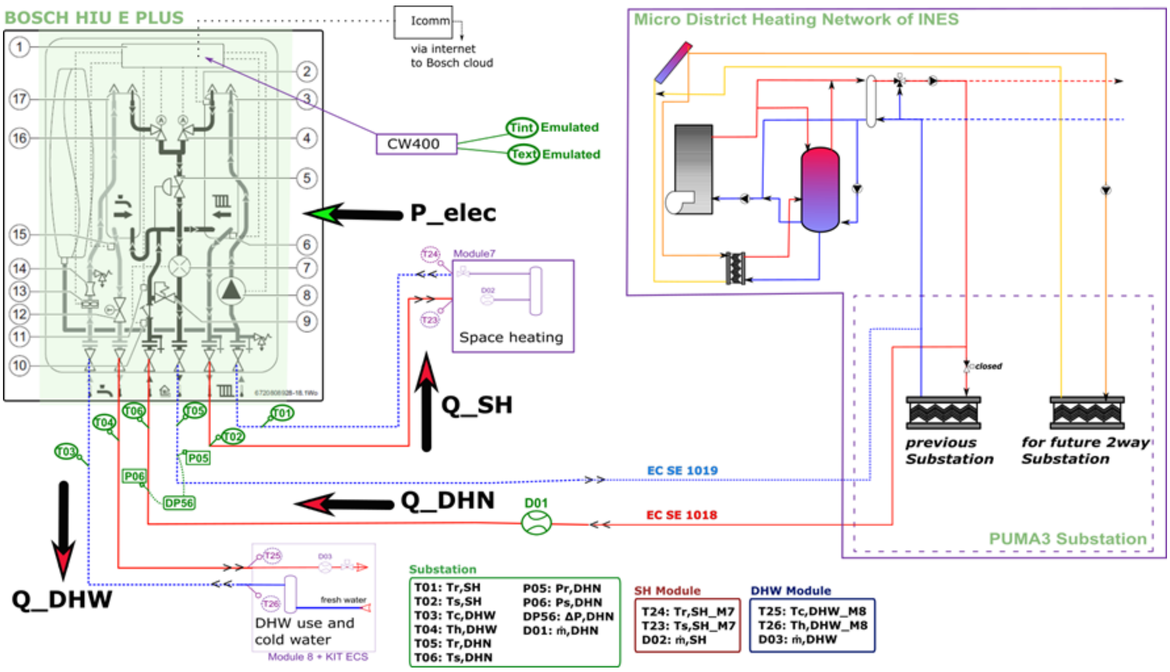

Fig. 8: CEA-INES test setup schematic for the HIU testing

4.2 Tests results

- ***Tests Description and Reference Cases Presentation***

Tab. 7 presents the 3 tests that were performed with varying control strategies and network temperatures.

Tab. 7: HIU test plan

HIU Test n°	Type	Control Strategy	Network Supply Temperature
1	12-days, THV	Outside Temperature	60
2	12-days, THV	Outside + Inside Temperatures	60
3	12-days, THV	Outside + Inside Temperatures	50

Compared to the other technologies tested usually on the semi-virtual test bench, the HIU does not convert heat from any chemical fuel or electrical source; it is merely a hydraulic and thermal interface. Thus, in addition to the residential context reference case R1, a specific reference case referred as R2 was established to compare the impact of a situation with and without HIU, as described in section 2.3.

- ***Tests Results Summary***

Besides giving the opportunity to meter and control the heat consumption of each dwelling, the HIU also allows for reduction of the return temperature, with consequent disposal of the DHW tank usually found at consumers (as in reference case R2). The former leads to lower network pump power consumption (due to the larger dT obtained), lower piping heat losses (due to the lower average temperature of the network) and higher gas boiler efficiency (due to fumes condensation), while it eliminates the heat losses inherent to the DHW tank.

Tab. 8 summarizes the results obtained for the 3 different HIU tests. First, it is observed that for Test 1, the controlled strategy using a heating curve based only on the external temperature leads to a higher building internal temperature than the set point. The latter was also observed with the closing of the THV valve at 95% for a long time during the test underlining the fact that the building was not needing that much heat. The closing of this valve also results in higher pump consumption for the HIU. This over-production of heat for space heating is not observed for the other control strategy based on internal temperature. For the 3 tests, the DHW needs are slightly lower than the theoretical needs (100kWh) because of the small delay between the thermo-hydraulic modules and the theoretical demand.

Tab. 8: Summary of HIU performance tests measurements

Tests	Tamb	Tbuild	QSH	QDHW	EelHIU	EelDHN	Qgas	QPE	Treturn	$fsav_{PE,R1}$	$fsav_{PE,R2}$
n°	°C	°C	kWh	kWh	kWh	kWh	kWh	kWh	°C	-	-
1	8.4	21.6	304.5	91.5	2.3	2.4	398.5	410.5	33.6	21.9	9.7
2	8.4	20.8	280.2	92.2	1.9	2.3	374.0	384.7	37.0	26.9	15.4
3	8.4	20.8	281.9	91.9	2.0	2.3	371.3	382.3	36.9	27.3	15.9

In comparison with reference case R1, the main differences of the three different tests are i) the lower DistrictHeatNetwork (DHN) return temperature that reduces the DHN heat loss but most importantly leads to an increase of the DHN production unit efficiency and ii) the lower auxiliary electricity use of the heating component because of higher pump efficiency.

In comparison with reference case R2, the main differences of the three different tests are i) again a much lower auxiliary electricity consumption of the HIU pump with regards to the reference pump and ii) a much higher DHN boiler efficiency with regards to the R1 reference case boiler. The efficiency of the latter is much smaller (85% estimated seasonal efficiency of gas condensing boiler in individual dwellings from in-situ measurements campaigns (D3.1) vs about 104% coming from datasheets relying on steady state measurements in lab) because it exhibits much more frequent ON/OFF cycles and thus higher standby heat losses than the DHN boiler that is assumed in the HIU performance calculations to run continuously (because of other consumer needs). At this stage it's the documented optimistic choice that is made in the analysis. As a consequence, the experimental savings of HIU in R1 context are theoretical maximum since the seasonal efficiency of DHN boilers is likely lower than the value assumed. The DHN boiler efficiency assumption has to be investigated further in the future with real in-situ seasonal measurements of DHN condensing gas boilers.

- ***Detailed Results for Test 3***

Fig. 9 and Fig. 10 presents respectively the dynamic measurements of powers and temperatures during 12 days (real time) test. The main conclusions to draw from these graphs are:

- The good tracking of the internal temperature set point;
- The DHW priority can be observed as peaks in network power with no space heating power. The latter

leads to return temperature reduction peaks;

- The increase of return temperature during summer days due to the low demand.

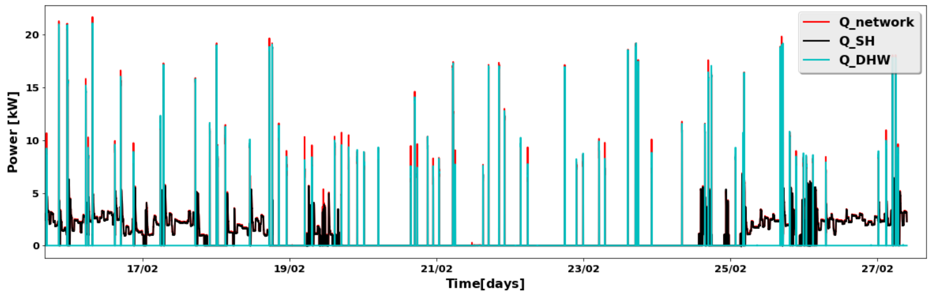

Fig. 9: Heat Power for the DHN, the space heating (SH) and the domestic hot water (DHW) loops for Test 3

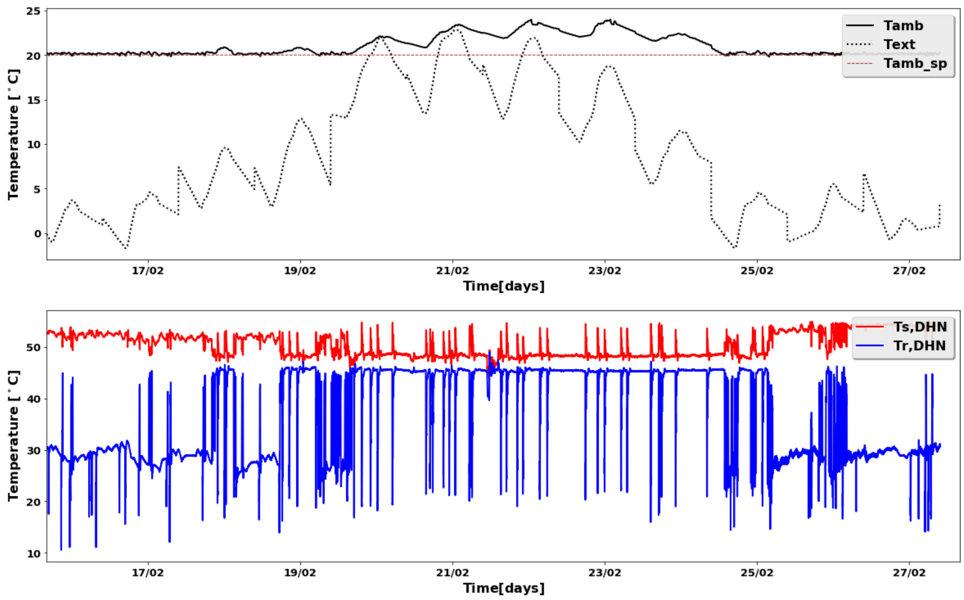

Fig. 10: Ambient and external temperature and network temperatures for Test 3

Tab. 9 summarizes the integrated results on a daily basis. As expected, the integrated results over the 12 days period are the same as the last line of Tab. 8. The Primary Energy Ratio is very high for the HIU. The latter is expected since this equipment is transferring heat in a very efficient manner.

Tab. 9: Daily summary of HIU performance tests

Day	Tamb	Tbuild	QSH	QDHW	EelHIU	EelDHN	Qgas	QPE	PERsys
N°	°C	°C	kWh	kWh	kWh	kWh	kWh	kWh	-
1	1.6	20.2	54.7	12.7	0.3	0.4	66.2	68.0	0.99
2	2.0	20.2	50.3	5.9	0.3	0.3	55.1	56.7	0.99
3	6.3	20.3	30.5	6.1	0.2	0.2	36.5	37.7	0.97
4	8.2	20.3	19.5	7.6	0.2	0.2	27.2	28.1	0.97
5	17.6	21.1	3.8	4.5	0.1	0.0	8.5	8.8	0.94
6	18.8	22.2	0.0	9.9	0.1	0.1	10.1	10.4	0.95
7	18.0	22.8	0.0	6.5	0.1	0.0	6.9	7.2	0.91
8	14.4	22.9	0.0	4.6	0.1	0.0	5.1	5.3	0.87
9	8.7	21.9	0.0	8.8	0.1	0.1	9.3	9.6	0.92
10	1.9	20.2	17.1	7.5	0.1	0.1	24.6	25.4	0.97
11	2.1	20.1	47.5	10.1	0.3	0.3	56.5	58.0	0.99
12	1.4	20.1	58.5	7.7	0.3	0.4	65.3	67.1	0.99
Total	8.4	21.0	281.9	91.9	2.0	2.3	371.3	382.3	0.97

5. Conclusions

Two heating technologies have been tested during 12 days in realistic operating conditions that are covering typical annual 12 months variations. For the SHP technology, the savings assessments from measurements are in the range 20-36% in R1 individual gas boiler context. The maximum theoretical primary energy savings of the HIU derived from the experimental results are in the ranges 22-27% in R1 individual gas boiler context and 10-

16% in R2 reference DHN context since it relies on DHN boiler efficiency evaluated in steady state. In both technology cases it revealed the high sensitivity of the performance to the control parameter settings related to indoor temperature sensor use. The realistic dynamic test also emphasized the major influence of thermal inertia of the system components combined with flow temperature control on the standby heat losses. Therefore the 20-30% primary energy savings goal of Thermoss is achieved by both SHP and HIU technologies. For both technologies, the realistic radiator THV emulation enabled to keep the deviation of the space heat load below 1.8% compared to the reference individual gas boiler. The detailed HIU test results also enabled the validation of components simulation models currently used in THERMOSS to develop a solar bi-directional substation connected to a district heat network.

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