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Experimental comparison of heat pump seasonal efficiency using EN 14825 and a dynamic load emulation approach

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Abstract

Heat pumps are central to the EU's climate neutrality goals, particularly for decarbonizing the building sector. Current standards, such as EN 14511-3 and EN 14825, assess performance under steady-state conditions, which do not reflect real-world dynamic operation or interactions with the building. This study presents a test campaign on an air-to-water heat pump, comparing conventional standard procedures with a load-based test (compensation method) that maintains the unit's native control strategy. Results show that the compensation method provides a more realistic representation of performance under varying loads, especially at low temperatures and below the unit's minimum capacity. Conventional standard tests tend to overestimate heating capacity and COP because they do not include ON-OFF cycling at very low part-loads, the occurrence of defrost cycles at lower outdoor temperatures and the presence of oil recovery under certain conditions. When these factors are incorporated into a seasonal performance assessment, the overall efficiency of the tested unit decreases up to 15%, leading to a one-class downgrade of its energy label. The findings highlight the value of dynamic, load-based testing for modern modulating heat pumps.

Keywords: compensation method; load-based testing; seasonal performance

1. Introduction

In the pursuit of the European Union's climate neutrality goals, the building sector plays a key role. In this framework, the full decarbonization of the building stock by 2050 is one of the main objectives [1,2].

EU policymakers have identified heat pumps as an essential technology to reach these goals and to support a competitive and sustainable European economy based on clean and innovative technologies. From a legislative point of view, heat pumps are well integrated into the EU's regulatory framework. They are central to several policy measures that aim to improve energy independence, reduce industrial emissions, and meet the EU's updated climate and energy targets for 2030. All these measures rely on heat pumps' energy efficiency as displayed through their Energy Label classifications.

Currently, the standards used for evaluating the nominal and seasonal performance of heat pumps, i.e. EN 14511-3:2022 e EN 14825:2022 [3,4], are based on tests carried out in stationary conditions. This means that tests are conducted with fixed operating parameters, such as compressor frequency, and in some cases, fan speed and expansion valve opening. These stationary conditions, however, do not reflect the actual operation

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of the heat pumps once installed, where the parameters vary continuously. Furthermore, in such tests, the machine control is bypassed, not reflecting the dynamic interaction that occurs in real operational situations.

An additional aspect to consider is that testing in accordance with these standards typically requires active involvement from the manufacturer. Specific provisions related to frequency settings, dedicated software, or the exchange of control boards often necessitate direct collaboration with the manufacturer/ technical support and input directly from the manufacturer.

In recent years, several institutions and laboratories have started to develop a new, more representative test methodology that allows taking into account the dynamic control of the machine. These methods are all load-based testing with active on-board (native) control.

At the European level, BAM has made a significant contribution by conducting two round-robin tests (RRT) with leading European testing laboratories and, in the second campaign, engaging CEN Technical Committee 113 Working Group 8, responsible for the EN 14511 revision. The two campaigns followed different approaches.

The first round-robin test was the initial attempt to apply the compensation method. At each test point, the building load applied to the machine—calculated according to EN 14825—was maintained constant throughout the test. The guidelines did not specify any provisions regarding the test bench. Although good repeatability and reproducibility were observed, the absence of prescribed test-bench inertia led to non-uniform on–off operation and other issues, particularly for laboratories with fast-response (direct) test stands[5].

The second round-robin test addressed this issue using a different approach. The building and the heat distribution system were simulated using a simple two-mass model (mass B: Building, mass H: heating system), where the load results from the interaction between the model and the operating machine. As a result, the load was no longer fixed but at each step varied according to the heat pump's capacity and the resulting heat fluxes calculated by the model [6].

Within this second RRT, the RELAB laboratory at Politecnico di Milano extended the test campaign to conduct the full series of tests according to current standards, with the aim of comparing the results.

This paper presents the findings obtained using both current standards and the compensation method, highlighting differences in applicability, machine behavior, and overall performance.

2. Methodology

For the purpose of the present work, two series of tests have been carried out: one according to the current standards, i.e. EN 14511:2022 – 3 + EN 14825:2022; and one according to the new test method where the load is emulated through a "two-mass model" developed by BAM in cooperation with RWTH Aachen University.

Both campaigns covered all testing points necessary for the seasonal evaluation for average climate.

At each test point, the main quantities of interest have been measured, calculated, and compared between the two approaches.

2.1. Current standards

The first test campaign was carried out according to the standards EN14511:2022-3 and EN 14825:2022.
The standard 14511:2022-3 defines the test methodology used to determine the main performance figures—heating/cooling capacity and COP/EER—at both standard rating conditions (nominal values) and at the conditions required for seasonal performance evaluation. The methodology can be summarized as follow:

- **Stationary operation**: All tests are performed at stationary conditions. After installing the unit according to the manufacturer's instructions, all inlet quantities - air inlet temperature (*dry and wet*), water inlet temperature, flow rate and voltage - are kept constant at the specific values defined by the standard rating conditions. This requirement applies to both fixed and variable flow rate units as well as during transient tests. The stationary operation is guaranteed by the respected permissible deviations.
- **Capacity setting:** Once boundary conditions are reached and stabilized, the unit is adjusted to achieve the target capacity. This is typically done by fixing the compressor frequency; in some cases, the fan speed or the expansion valve position is also set. This procedure generally requires direct involvement from the manufacturer.
- **Capacity assessment**: For units using water as the heat-transfer medium on the user side, the direct enthalpy method is used to determine the heating or cooling capacity according to the corresponding standard equation.

The standard EN 14825:2022, instead, provides the test conditions and the calculation method (based on bins of temperatures) for determining the seasonal performances. With the exception of defrost tests—which are considered transient—all tests are conducted under stationary conditions, with all input quantities maintained constant in accordance with the methodology defined in EN 14511:2022-3.

2.2. Compensation method

The compensation method applied in this test campaign is a load-based test method in which the building load is not fixed and is emulated according to a two-mass model run at the same test conditions of EN 14825:2022 for the seasonal performance assessment (outdoor air, volume flow rate, outlet water temperature).

The two-mass model, as the name suggest, consists of two thermal masses: mass H, representing the heating transfer system ((i.e. radiator / underfloor) and simulating the heat exchange between heating distribution systems and the building; and mass B, representing the building and simulating the heat exchange between the building envelope and the ambient, thereby influencing the indoor air temperature.

Mass B and H scale according to the design capacity of the heat pump, ensuring that the building load at the design outdoor temperature equals the unit's design heating capacity.

According to this method, at each time step the model calculates the return water temperature (i.e. heat pump inlet temperature) and indoor building temperature based on the measured supply water temperature (i.e. heat pump outlet temperature) and instantaneous heating capacity delivered by the heat pump under test. The test rig then dynamically adapts the compensation load in order to emulate, at the next time step, the calculated return temperature and indoor building temperature as closely as possible.

In the meanwhile, the heat pump responds in accordance with its control as it tries to maintain the required supply temperature. The evaporator inlet conditions (dry and wet air for air-to-water units or water/brine temperature for ground/water-to-water units) are kept constant at the values of the corresponding rating conditions.

Unlike the standard tests, no manufacturer intervention is required in the compensation method. Only ettings on the user level (e.g., setpoint supply temperature, heating curve) are adjusted. As a result, the heat pump is tested with its integrated control logic and not in a fixed-speed mode, allowing natural modulation behaviour and, when necessary, ON–OFF compressor cycling.

3. Results and Discussion

3.1. Case study

The two experimental test campaigns were conducted on a monoblock air-to-water heat pump, characterized by the following design parameters:

- **Nominal heating capacity (Pdesign)**: below 15 kW at a design outdoor temperature (Tdesign) of −10 °C, representative of average climatic conditions;
- **Bivalent temperature:** −7 °C (corresponding to the "A" operating condition);
- **Temperature application**: medium temperature application (radiators);
- **Control capacity**: variable (inverter driven);
- **Operation conditions**: fixed flow rate; variable outlet temperature.

All operating conditions from A to E, as defined in the EN 14825 standard for seasonal performance evaluation, were investigated using the two distinct methodologies: the EN 14825 procedure and a load-based approach based on a two-mass model.

The tests have been carried out by RELAB laboratory at Politecnico di Milano (POLIMI). The unit was directly connected to the test rig, without hydraulic separation to minimize additional thermal inertia and pressure losses.

Several adaptations were implemented to enable testing with the compensation method. The test rig control software was upgraded to integrate the two-mass model and to establish real-time communication between the rig and the heat pump under test, allowing dynamic emulation of the return temperature at the heat pump inlet. The hydraulic circuit was optimized through appropriate pipe sizing to maintain suitable water velocities and to reduce the response time of the test rig, while the PID controller was carefully tuned to accurately track the dynamically varying setpoint. In addition, a temperature offset was introduced to compensate for the distance between the 3-way valve—used to reproduce the target return temperature—and the corresponding return temperature sensor.

3.2. Analysis of test results

For each test condition, a comparative analysis of the two methodologies was performed, assessing their applicability (i.e. capability to reproduce the specified test conditions and remain within the permissible deviations), test duration, operational behaviour of the unit (steady-state or dynamic/transient), and resulting performance indicators.

Performance figures are expressed as percentage differences relative to the results obtained using the current standards, calculated according to Eq. (1):

$$\Delta X = \frac{X_{COMP} - X_{STD}}{X_{STD}} \times 100\ [\%] \qquad (1)$$

where X_{COMP} is the value obtained using the compensation method and X_{STD} is the value obtained under the standard test procedure.

A detailed analysis is presented for each test point: Condition A/F is examined in depth, while the results for the remaining test conditions are summarized in Table 5.

<u>Test A/F</u>

Figures 1 and 2 present the temperature profiles—including supply and return water temperatures at the heat pump, as well as dry-bulb (DB) and wet-bulb (WB) air temperatures—for condition A/F, obtained using the EN 14511-3 procedure and the compensation method, respectively. As observed, the test performed according to the current standard, with fixed compressor frequency and fixed inlet water temperature, exhibits steady-state operation: during the 60-minute stabilization period followed by 70 minutes of data acquisition, no degradation in delivered capacity or outlet water temperature was detected. In contrast, when a variable load and corresponding variable inlet/return temperature were applied, allowing the unit to operate under its internal control logic, the system behaviour became non-stationary, with defrost cycles occurring approximately every 1.6 hours.

Although the effective heating capacity remained comparable between the two methodologies—since in both cases the unit was required to meet the heat load equal to 88.46% of *P*design—the occurrence of defrost events resulted in a reduction of performance with the COP decreasing by approximately 8.5%.

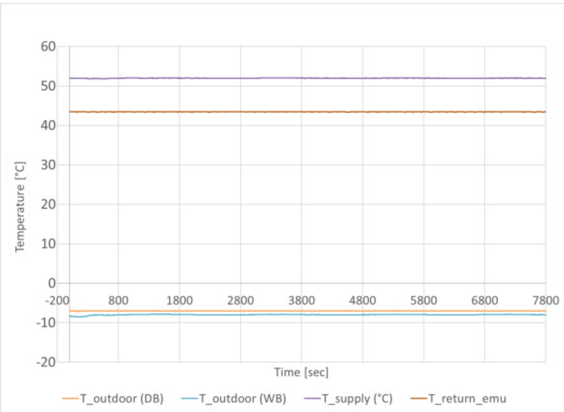

Figure 1: Test A according to EN14511-3: temperature patterns

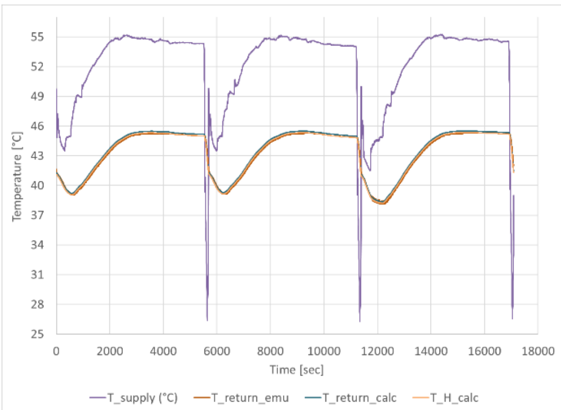

Figure 2: Test A according to Compensation Method: temperature patterns

At this specific test condition, an additional experiment was conducted to evaluate performance degradation associated with defrost events under the current standard (see Figure 3). Test A/F was extended beyond the standard 70-minute data acquisition period until the defrost event occurred.

In this additional test, the defrost cycle lasted 152 minutes—considerably longer than the 96 minutes observed with the compensation method—while the post-defrost recovery was noticeably faster, resulting in a COP reduction of only 3.3% compared to the standard EN 14511 procedure. These differences can be attributed to two main factors: (i) in the standard procedure, the return water temperature is maintained at a fixed setpoint, which allows faster recovery but does not reflect the lower return temperature typical of actual building loads; and (ii) with a fixed compressor frequency, the temperature ramp-up is faster, as it is not governed by the internal control logic that dynamically adjusts operating parameters to achieve the target outlet temperature

Regarding test duration, the compensation method guideline specified at the time of testing that if defrosting occurred, the test should be terminated after at least three complete defrost cycles, or after 6 hours if completing three cycles takes longer. Only complete defrost cycles are considered for data evaluation, or the full 6-hour interval if recording three cycles exceeds this period.

Defrost cycles recorded with the compensation method are highly repeatable in terms of operating behavior and calculated COP. Based on this observation, a single cycle would be sufficient to determine the COP which translates into a test time of 150 min (60 min preconditioning plus 94 min data collection for one complete cycle). This is very comparable to the 130 min (60 min preconditioning plus 70 min data collection) needed for the EN 14511-3 test. However, test time may vary for both approaches, the compensation method and the standard test, depending on the tested heat pump and its defrost characteristics. Therefore, the prescription for the test duration is still under discussion.

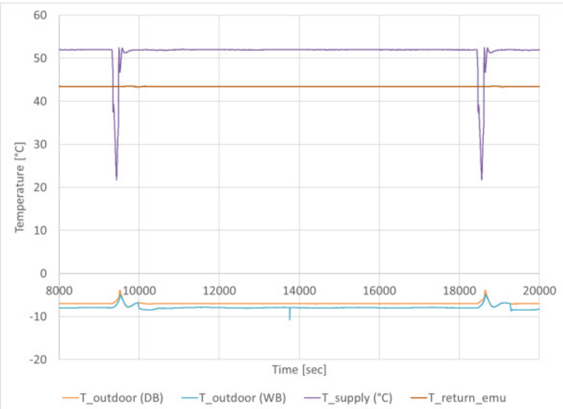

Figure 3 Test A according to EN 14511-3, extended until defrost occurrence: temperature patterns

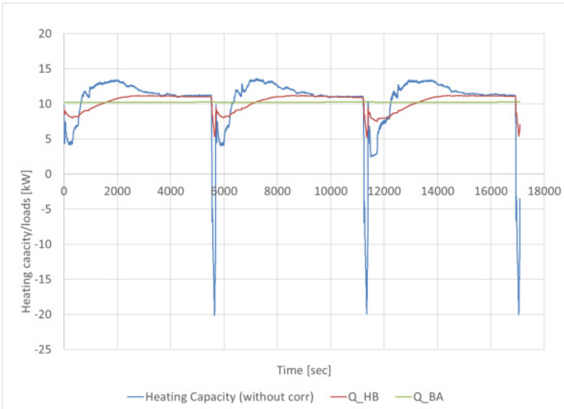

Figure 4 Dynamic Load Profile of the Heat Pump During Compensation Method Testing, heat pump capacity (blue), heat flow between Mass H and B (red), heat flow between Mass B and ambient (green)

Figure 4 presents instead the thermal load applied to the system during testing conducted with the compensation method. Q_BA - the heat exchanged between the building and the ambient - remains nearly constant, as mass *B* is defined with very high inertia; Q_HB - the heat exchanged between the distribution system and the building - varies depending on the heating capacity delivered by the heat pump. Under the EN 14511-3 standard, no external load is applied; the water inlet temperature is maintained constant, representing a building with infinite thermal mass.

Deviating from EN 14511-3, the test guideline for the compensation method defined permissible deviations for single measured values of the return temperature of +2/-5 K during defrost operation and ±0.5 K for all other operating conditions at the time the test was performed. Figure 5 illustrates the permissible deviations—both negative and positive—around the calculated return temperature (black line) and the emulated return temperature (red line) at each step. In this case, the more restrictive permissible deviation of ±0.5 K was applied. It can be observed that the emulated return temperature remains within the tolerance limits even during the defrost phase, despite the use of this stricter criterion.

Figure 6 provides a detailed view of Figure 5 and highlights the delay of the emulated temperature relative to the calculated one, which represents the time response of the test rig. . Based on the experience gained from these tests, a test-rig response delay of up to 30 seconds is considered acceptable to remain within the permissible deviation.

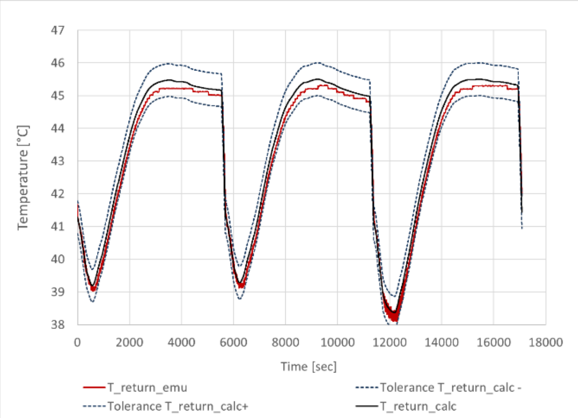

Figure 5: Calculated and emulated return temperatures with permissible deviation bands (±0.5 K) at each step.

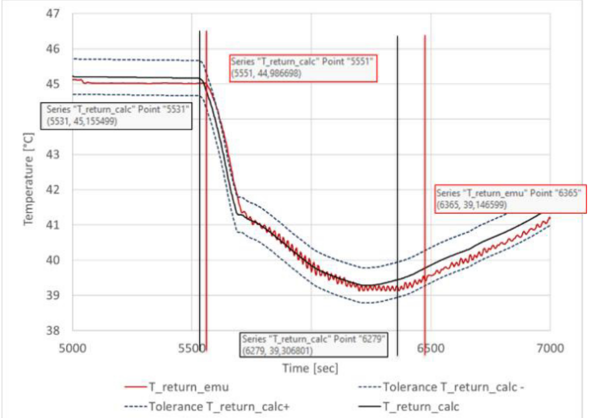

Figure 6: Detail of emulated temperature delay and test rig time response during defrost

Test E

Figures 7 and 8 present the temperature profiles - supply and return water temperatures at the heat pump, DB and WB air temperatures - at the design condition E, corresponding to an outdoor air temperature of -10 °C. These data were obtained using the EN 14511-3 procedure and the compensation method, respectively. As in the previous case, the test performed according to the current standard exhibits steady-state behavior, whereas the test conducted under the proposed methodology shows transient operation.

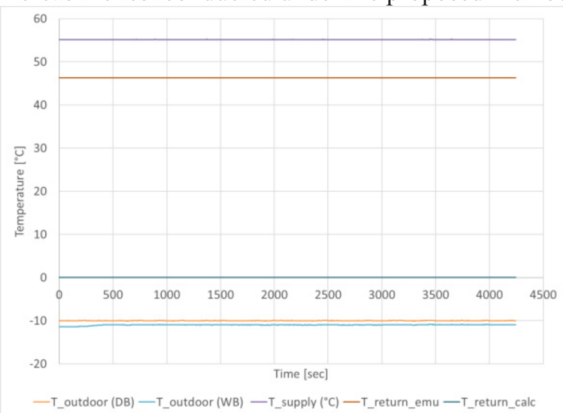

Figure 7: Test E according to EN 14511-3: temperature patterns

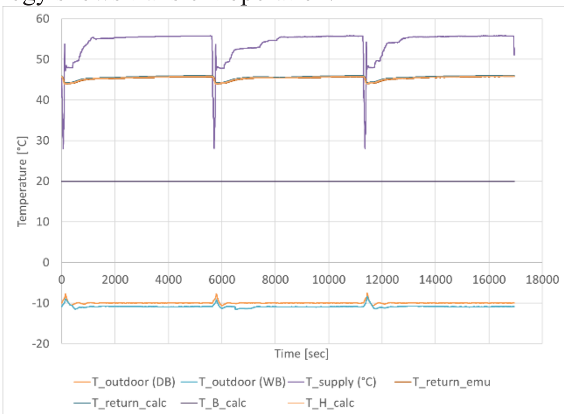

Figure 8: Test E according to Compensation Method: temperature patterns

Also, for condition E the unit shows very repeatable defrost cycles. Following the same rational as for condition A/F the data collection could be reduced to one defrost cycle resulting in a test duration of 160 min compared to 130 min for the standard test.

Regarding performance, a 3% reduction in COP was observed, while the heating capacity determined using the compensation method remained within 10% of the required load..

It is important to note that the calculated return water temperature (T_return_calc) accounts for the contribution of a virtual auxiliary (backup) heater, as this unit does not have a real backup heater. The virtual heater compensates for the temperature deficit needed to reach the target outlet temperature of 55 °C. As a result, compared with tests conducted according to EN 14511-3 and EN 14825, the return temperature is lower, and the supply water temperature (T_supply) may fall slightly below the nominal setpoint of 55 °C. This condition provides a slight advantage in terms of both COP and effective heating capacity..

Figures 9 and 10 confirm that, also in this case, the permissible deviations specified by the compensation method guideline were fully respected.

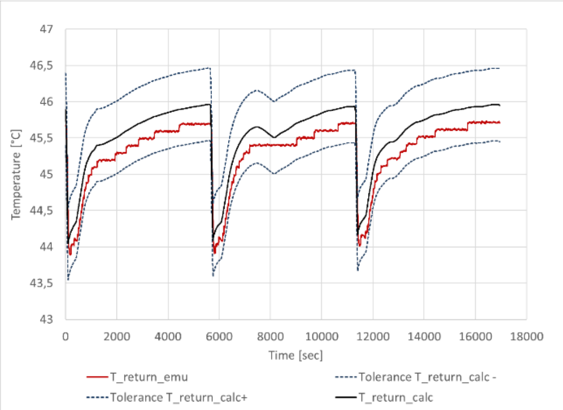

Figure 9: Calculated and emulated return temperatures with permissible deviation bands (±0.5 K) at each step.

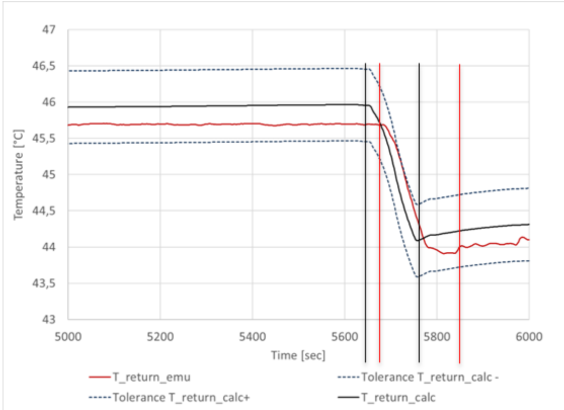

Figure 10: Detail of emulated temperature delay and test rig time response during defrost

Test B

Figures 11 and 12 present the temperature profiles—supply and return water at the heat pump, and DB and WB air temperatures—under test condition B (outdoor air temperature 2 °C) for both the EN 14511-3 procedure and the compensation method. As before, the standard test exhibits steady-state behavior, whereas the proposed methodology produces transient operation.

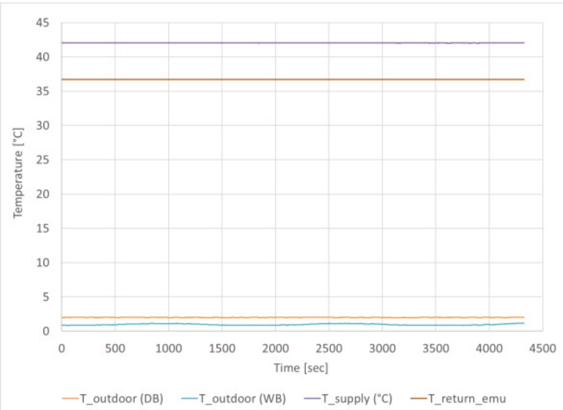

Figure 11: Test B according to EN14511-3: temperature patterns

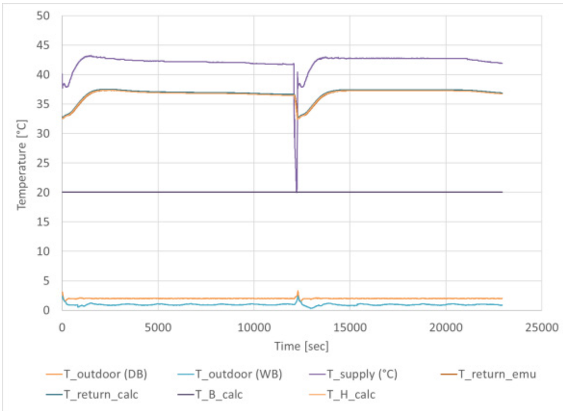

Figure 12: Test B according to Compensation Method: temperature patterns

Considering a single defrost cycle as outlined in previous sections the required test time increases from 130 min for the standard test to about 260 min for the load-based test. However, tests conducted according to EN 14511-3 can last up to 240 min (60 min preconditioning plus 180 min data collection), if the heating capacity decreases more than 2.5 % within a predefined interval.

The reduction in performance, expressed in terms of COP, was approximately 4.2%, while the heating capacity obtained using the compensation method remained within 10% of the required load, equivalent to roughly 1.4%.

Also in this case, the permissible deviations in emulated return temperature specified by the compensation method guideline were fully respected as shown in Figures 13 and 14.

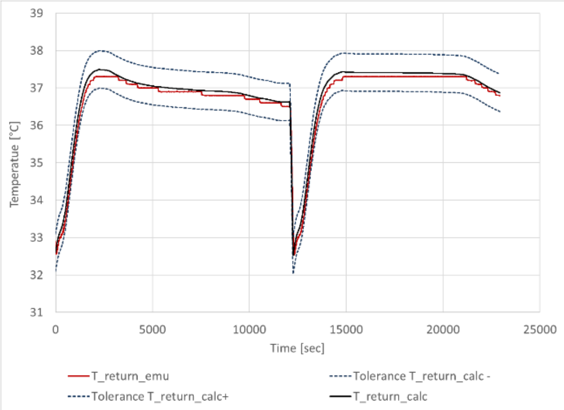

Figure 13: Calculated and emulated return temperatures with permissible deviation bands (±0.5 K) at each step.

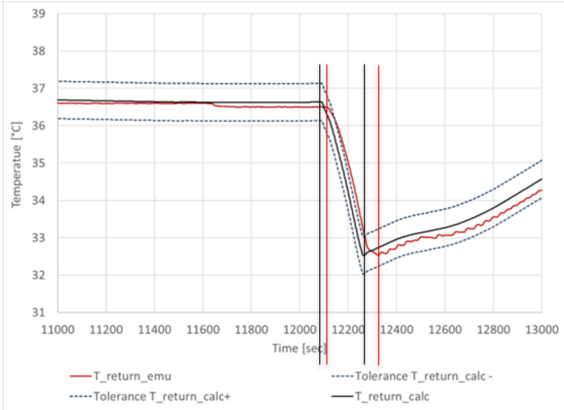

Figure 14 Detail of emulated temperature delay and test rig time response during defrost

Test C

Condition C was the only case in which the unit exhibited steady-state behaviour under both the EN 14511-3 and compensation method (Figures 15), resulting in comparable test durations. The COP obtained with the compensation method was slightly higher but remained within the measurement uncertainty. When the test with the compensation method was extended (Figures 16), an oil recovery routine was observed approximately every 4 hours—an effect not detected under the EN 14511-3 procedure due to its shorter duration. If the data collection period is extended to capture the entire routine, a reduction of about 5.3% in COP is observed compared with the value obtained using the current standard. In this case, the supply temperature averaged over the entire data-collection period increased to 36.7 °C because of the compressor ramp-up.

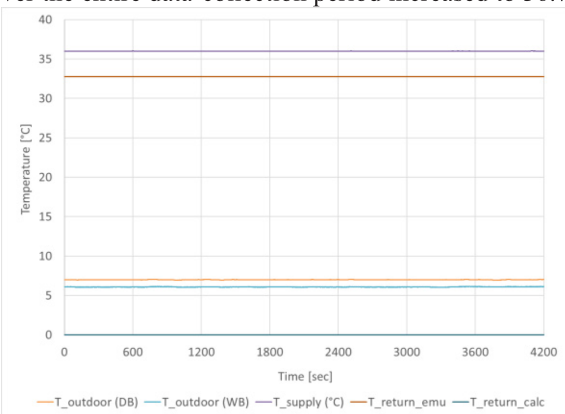

Figure 15: Test C according to EN14511-3: temperature patterns

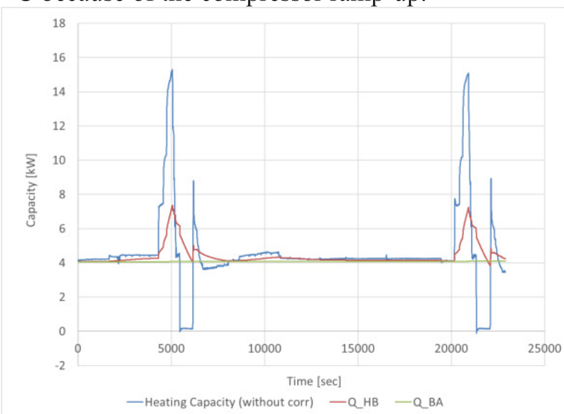

Figure 16: Heat pump capacity and building loads during the oil recovery routine

Test D

Condition D represents the minimum building load. In many cases, including this one, the minimum unit capacity exceeds the required load, forcing the heat pump into thermostat-driven on–off cycling.

Current standards address this by imposing steady-state testing at outlet-water temperatures higher than those corresponding to the actual load, such that the hypothetical average temperature during cycling matches the required value; the resulting COP is then corrected using a degradation factor. By contrast, the compensation method allows the unit to operate under its native control logic and thus captures its actual behaviour under low-load conditions.

Figures 19 and 20 present the resulting temperature profiles—water supply and return temperatures at the heat pump and air DB and WB temperatures—using the EN 14511-3 procedure and the compensation method, respectively, highlighting the steady-state versus on–off operation.

In the EN 14511-3 test, the average outlet-water temperature rises to approximately 32.5 °C and the effective heating capacity reaches about 150% of the required load. Under the compensation method, the outlet-water temperature remains at the target 30 °C and the delivered capacity closely matches the demand (−1.33%). As a result, the COP measured according to EN 14511-3 is roughly 11 % higher than that obtained using the compensation method, largely due to the imposed steady-state conditions. However, this COP must ultimately be reduced through the application of the prescribed degradation factor.

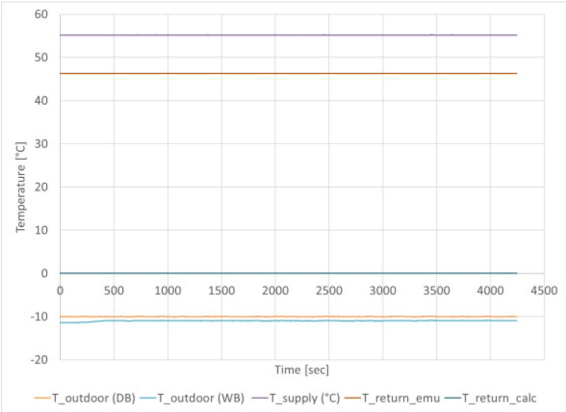

Figure 17: Test D according to EN14511-3: temperature patterns

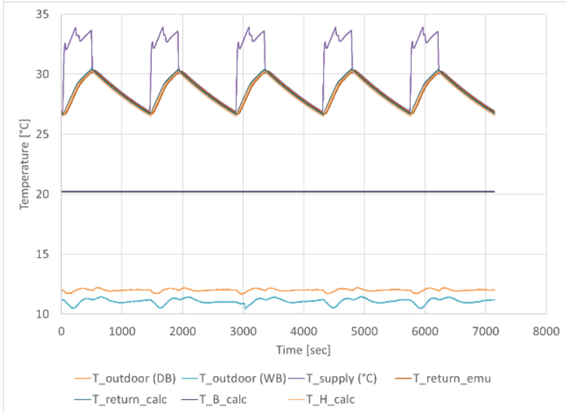

Figure 18: Test D according to Compensation Method: temperature patterns

At this test point, the overall test durations are comparable between the two methodologies. The compensation method requires a data collection period that encompasses at least three on–off cycles; in this study, five cycles were considered resulting in a total test duration of approximately 119 minutes.

Figures 9 and 10, all permissible deviations defined by the compensation method guidelines were fully respected.

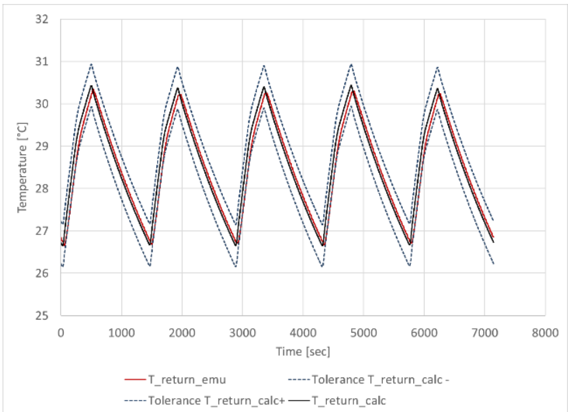

Figure 19: Calculated and emulated return temperatures with permissible deviation bands (±0.5 K) at each step.

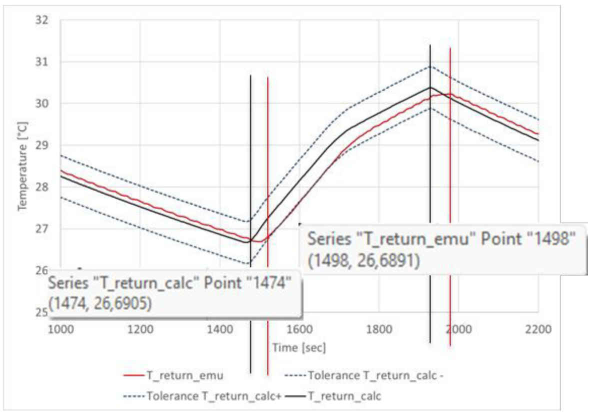

Figure 20: Detail of emulated temperature delay and test rig time response during defrost

3.3. Comparison

Table 1 synthesize the final results by comparing, for each test point, the performance obtained with the two methodologies. Specifically, it reports the share of the building part load met by the heat pump, the average supply-water temperature, and—specific to the compensation method—the applied load to the unit under test expressed as a percentage of the EN 14825 building load. The table also presents the percentage deviations of the key performance indicators calculated on the basis of those obtained under the current standard, highlighting how the control strategy used in the compensation method affects the overall performance assessment.

Table 112 Heat pump performance comparison between standard and compensation method: load share, supply temperature, and percentage deviations of key indicators

	TEST CONDITION				EN 14511-3/ EN 14825	COOMPENSATION METHOD			RELATIV DEVIATIONS		
	T_outdoor air (DB)	T_outdoor air (WB)	T_supply	Part-Load Ratio	T_supply	T_supply	Δ_Q_BA*	Δ_Q_HB*	Δ_Heating Capacity	Δ_Electric input	Δ_COP
Test	°C	°C	°C	%	°C	°C	%	%	%	%	%
E	-10	-11	55	100	55,15	54,16	-0,88	-2,06	0,24%	3,47%	-3,12%
A/F	-7	-6	52	88	51,96	52,09	-0,23	0,19	2,57%	12,0%	-8,45%
B	2	1	42	54	42,03	41,96	0,35	-0,90	-1,39%	2,97%	-4,24%
C	7	6	36	35	36,00	36,06	2,04	0,41	4,46%	2,86%	1,55%
C**	7	6	36	35	36,00	36.7	2.05	4.46	9,93%	16,04%	-5,26%
D	12	11	30	15	32,26	30,00	3,51	-1,96	-60,5%	-55,8%	-10,7%
D***	/	/	/	/	/	/	/	/	/	/	2,66%
D****	/	/	/	/	/	/	/	/	/	/	-9.40%

*Percentage deviations relative to the building part load (calculated from average values)

** COP including the oil recovery routine

*** COP degraded by using default factor of 0,90

**** COP degraded by using typical calculated factor of 0,99

Figures 21 and 22 illustrate how each method meets the load, with condition D clearly highlighting the ability of the compensation method to allow the unit's native control strategy to deliver the appropriate capacity. Since the unit does not have a real electrical backup heater, the heat pump cannot cover the load below the bivalent point (-10 °C) during load-based testing.

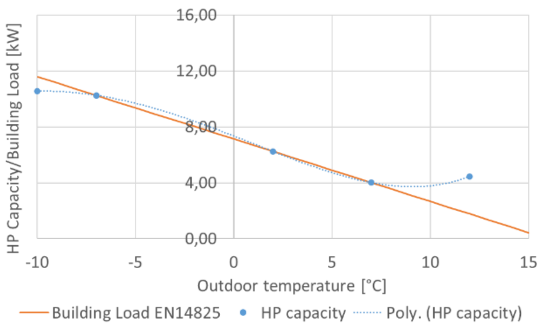

Figure 21: Building load fulfillment by the heat pump under the standard-method testing.

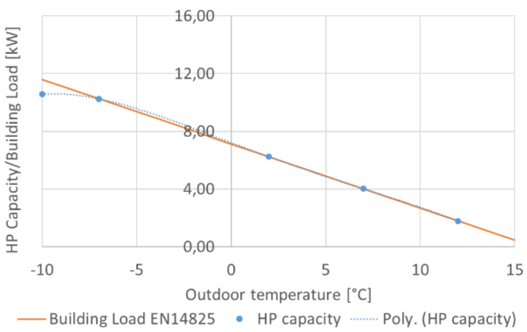

Figure 22: Building load fulfillment by the heat pump under the compensation method testing.

Analysis of the data in Table 1 shows that the two methods differ in average supply-water temperature only at test conditions E and D. At condition E, the discrepancy arises because EN 14511-3 accounts for the backup heater through a post-test calculation, operating the unit alone to reach the target temperature, whereas the compensation method simulates the backup contribution in real time, resulting in a lower delivered temperature. At condition D, as previously explained, EN 14511-3 requires increasing the outlet-water temperature so that the average supply temperature—computed over a hypothetical on–off cycle based on the ratio of effective capacity to required load—matches the target value.

Regarding the applied load (Q_BA), the compensation method closely reproduces the EN 14825 building demand across all test points. Only condition D exhibits a higher percentage deviation compared to the other points. This is because, at lower load conditions, even small absolute differences between the applied and required load translate into proportionally larger relative deviations, amplifying the apparent discrepancy in percentage terms.

Concerning the heat transferred to the building, it depends directly on the heat pump capacity. The main difference occurs at condition E, where the unit does not have a real auxiliary heater; thus, the observed difference reflects the contribution of the backup heater.

With regard to effective capacity, the most pronounced differences occur at condition C and condition D. At the condition D, when the test performed with the compensation method is extended in duration, it reveals the occurrence of an oil-recovery routine. This routine temporarily increases the supply-water temperature and reduces COP—effects that are not captured under the EN 14511-3 procedure due to its shorter test duration. At condition D, using the compensation method, the unit delivers nearly the required heat, whereas under EN 14511-3 it supplies approximately 150% of the demand.

In terms of COP, conditions A/F, C, and D—including the oil-recovery routine—exceed the 5% threshold typically attributed to measurement uncertainty. The larger deviations at these points are primarily due to the differing operating behaviors imposed by the two procedures: for condition A/F, this is caused by the occurrence of defrost; for condition C, by the oil-recovery routine; and for condition D, for the ON-OFF operation.

It is also noteworthy how the deviation between the two methods at condition D is influenced by the degradation factor. When the default value of 0.9 is applied, the difference reduces from -10.67% to 2.66%. However, using a degradation factor of 0.99—commonly observed when determined through a specific test—the difference rises again to -9.40%.

A similar observation can be made in terms of seasonal energy efficiency. Table 2 summarizes the resulting impact on Seasonal Energy Efficiency Indicators. Overall efficiency decreases by approximately 13% when the default degradation factor is used and the oil-recovery routine is not considered. This difference increases to 15% when the more commonly observed degradation factor of 0.99 is applied and the oil-recovery routine at condition C is included. As a result, the unit is reclassified from A+++ to A++, corresponding to a reduction of one energy label class.

Table 23 Seasonal efficiency indicator: percentage deviations

Seasonal Energy Efficiency Indicators					
	SCOPon	SCOPnet	SCOP	ηs	QHE (kWh)
*	-13%	-13%	-13%	-13%	15%
**	-14%	-14%	-14%	-14%	16%
***	-14%	-14%	-14%	-14%	16%
****	-15%	-15%	-15%	-15%	18%

*COP at D condition degraded by default factor of 0.90 and with no oil-recovery at C condition

** COP at D condition degraded by typical factor of 0,99 and with no oil-recovery at C condition

*** COP at D condition degraded by default factor of 0.90 and with oil-recovery at C condition

**** COP at D condition degraded by typical factor of 0,99 and with oil-recovery at C condition

4. Conclusion

A test campaign was conducted on an air-to-water heat pump and the comparative assessment demonstrates that the compensation method provides a more realistic representation of heat pump operating behaviour under varying load conditions, particularly at low temperatures and below the unit's minimum capacity. Unlike the EN 14511-3 procedure—which imposes steady-state conditions and relies on post-test adjustments (backup heater at condition E and degradation factor at condition D)—the compensation method captures the dynamic behaviour of the unit's native control strategy, producing more accurate estimates of both delivered capacity and efficiency.

The most significant discrepancies occur at low outdoor temperatures, where defrost cycles vary in length, and at low-load conditions, where EN 14511-3 overestimates heating capacity and COP due to elevated supply temperatures and the elimination of cycling effects. At condition C, the extended test duration also reveals the occurrence of an oil-recovery routine, which is not detected under the standard test.

When these effects are incorporated into the seasonal evaluation, the resulting overall efficiency decreases by approximately 13% to 15%, leading to a one-class downgrade of the unit's energy label.

These findings highlight the importance of testing methodologies that reflect real operating conditions and indicate that the compensation method offers a more representative framework for evaluating the performance of modern, modulating heat pumps.

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