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COMPARISON BETWEEN CALCULATED AND MEASURED SEASONAL COEFFICIENT OF PERFORMANCE OF AN AIR-TO-WATER HEAT PUMP

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Abstract: *This paper investigates the real-world gap between manufacturer-declared and field-measured seasonal efficiency values (SCOP) for an air-to-water heat pump. The study evaluates both adapted SCOP using standardized methods—EN 14825 and mean outdoor temperature—and real SCOP based on operational data of a heating system for a single-family residential building near Sofia, Bulgaria. The analysis reveals performance degradation of up to 30% compared to declared SCOP, primarily due to oversizing and insufficient modulation of the compressor, leading to frequent cycling under part-load conditions. Using regression-based bin calculations and multiple climate data sources (NASA, ASHRAE), the paper quantifies the energy impact of these deviations on building classification, demonstrating a shift from energy class A to B depending on the SCOP used. The study contributes to the optimization of system design, highlights the need for climate-adapted efficiency metrics, and offers a reproducible approach to aligning theoretical and real-world performance for energy certification and audit purposes.*

Keywords: *Air-to-Water Heat Pumps, Efficiency, Effectiveness, COP, SCOP*

INTRODUCTION

Nowadays heat pump systems are widely used for heating and cooling in Europe. The electrically driven vapor-compression units can efficiently transfer heat from renewable sources (RES). Over the past decade, the European heat pump market has nearly tripled, driven by their crucial role in decarbonisation and the transition to sustainable energy consumption.

Under Directive (EU) 2024/1275 on the energy performance of buildings, Member States are required to promote the implementation of highly efficient technologies in new and existing buildings, including those using energy from renewable sources. In this context, heat pumps are classified as renewable energy equipment and play an important role in achieving the EU's goal of becoming a climate-neutral continent by 2050 (European Parliament and Council, 2024).

In response to European requirements, Bulgarian legislation has also been refined. According to Regulation No. RD-02-20-3 of November 9, 2022, on the technical requirements for the energy performance of buildings, from 2024 all newly constructed buildings must be designed so that at least 55% of their energy for heating, cooling, ventilation, domestic hot water, and lighting comes from RES (Ministry of Regional Development and Public Works, 2022).

Among the most commonly used heat pump technologies in building heating are air-to-water, water-to-water systems. The particularly widespread use of air-to-water heat pumps is due to their flexibility in installation and high level of comfort. However, the efficiency of air systems is highly dependent on external climatic conditions. These types of systems are used in both residential and public buildings and are available in two main designs: monoblock and split (separate outdoor and indoor units).

The energy efficiency of these systems in heating mode is usually expressed by the seasonal coefficient of performance (SCOP), which is declared by the manufacturer based on laboratory tests in accordance with standardized test conditions. These conditions are defined in European standard EN 14825, which provides a methodology for calculating the seasonal energy efficiency

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of heating and cooling heat pumps operating at partial load. The standard introduces three climate profiles (“cold”, “average” and “warm”) and specifies temperature regimes and correction factors for additional electricity consumption, defrost cycles are excuded. EN 14825 aims to provide a more realistic assessment of efficiency by reflecting typical conditions for the entire heating season, rather than just at rated capacity (CEN, 2016). The SCOP value determines not only the system's electricity consumption, but also the energy class of the building and the share of energy from RES taken into account when preparing the energy certificates for newly constructed or existing buildings.

Despite the widespread use of declared SCOPd values for design assessments, more and more studies show significant discrepancies between them and the actual measured seasonal efficiency SCOPm. In existing installations, deviations of 20–30% are observed compared to the declared values, which is due to climatic differences, insufficient control adaptation, incorrect system sizing and real defrost cycles (Bayer & Pruckner, 2024).

Another key factor for reduced efficiency is inappropriate system sizing and low modulation. The heat pumps often operate below the minimum modulation threshold at moderate outdoor temperatures, leading to frequent on/off cycles and low efficiency. Even when buffer tanks are used, the benefits remain limited unless the system is properly integrated with building automation. Therefore, a significant and still poorly researched question arises: does the adapted SCOPd (based on local climate conditions) approach is close enough to the actual SCOP calculated based on real-world data? This relationship between theoretical models and empirical data is critical for realistic assessment of system efficiency and for energy certification and energy audit of buildings.

The four most popular methods for assessing the adapted SCOP we analized, finding the EN 14825 method to be the most accurate and reliable, as it takes into account not only local climate data but also the heating load of the building. Another widely used method in Bulgaria is based on the mean outdoor temperature during the heating period, due to its simplicity and the possibility for quick assessment (Dimchev, Terziev & Ivanov, 2024).

In this regard, this article aims to verify the relevance of SCOP calculations based on field measurements to the adapted SCOP based on local climate data for both methods: according to EN 14825 and according to the mean outdoor temperature for the heating period.

EXPOSITION / METHODOLOGY

Description of the heat pump system

Field data from the operation of a heat pump system serving as a heat source in a single-family residential building has been collected and processed for the purposes of this article. The house has a reference floor area of 160 m^2, with two floors of 80 m^2 with underfloor heating installed. The system is equipped with a 300 L boiler with a coil and a 300 L buffer tank. The single line diagram is shown in Fig. 1.

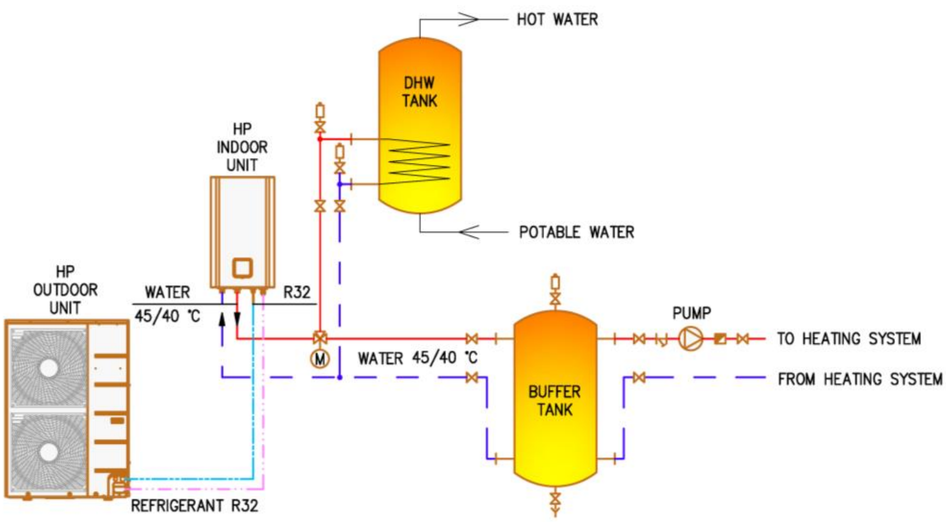

Fig. 1. Diagram of the heating system

The heat pump operates with R32 refrigerant, split type, with a nominal heating capacity of 16.0 kW (minimum 8.5 kW @ 36Hz, maximum 18.2 kW @ 76Hz and air/water conditions of A7/W45). The measured data covers a period of a little bit more than two months - from January 1, 2025, to March 9, 2025. The data was collected entirely with the manufacturer's equipment and software. The measurements were recorded every 30 seconds and included all necessary parameters such as water temperature at the condenser inlet and outlet, outside air temperature (dry bulb), water flow rate, electronic expansion valve (EEV) position, defrost cycle information, appliance electrical current, and more. The SCOP declared by the manufacturer based on laboratory tests conducted in accordance with the requirements set out in standard EN 14825 at a heat transfer fluid water with a temperature of 55/50 °C is 2.81, and at 35/30 °C it is 4.84. Through interpolation, we obtain SCOP = 3.82 for heat transfer fluid parameters of 45/40 °C.

Location and climate data

The single-family residential building is located in the village of Bosnek, Pernik municipality (near Sofia-city). This location falls within Cimatic zone VII "Sofia and the Sub-Balkan Valley" which has a long heating period starting on October 15 and ending on April 23, with 191 days (4584 hours) and a design outdoor temperature of -16 °C. The average outdoor air temperature for the heating period is 3,8 °C, according to Regulation No. RD-02-20-3 of November 9, 2022, on the technical requirements for the energy performance of buildings (Ministry of Regional Development and Public Works, 2022).

The declared SCOP must be adapted based on climate data for the climatic zone in which the heat pump will operate. This climate data must be structured in the form of bins. Since a significant gap in the Bulgarian regulation is the lack of bin-structured data, for the purposes of this article, data for Sofia from the ASHRAE IWEC 2 database was used.

To calculate the SCOP based on the measured data, outdoor air temperature data for the entire 2024-2025 heating period from NASA's The POWER Project website was used. A comparison was also made between the measured outdoor air temperatures from the NTC thermistor of the heat pump and the data from NASA's website. The comparison shows an average deviation of +0.42 °C between the value measured by the NTC sensor and the database, which gives us reason to use the data from NASA's climate data website for the entire heating period as it was mentioned above starting on October 15 and ending on April 23. Fig. 2 shows the bin data from the three sources: NASA (4817 hours), ASHRAE (4890 hours) and EN 14825 for average climate (4580 hours).

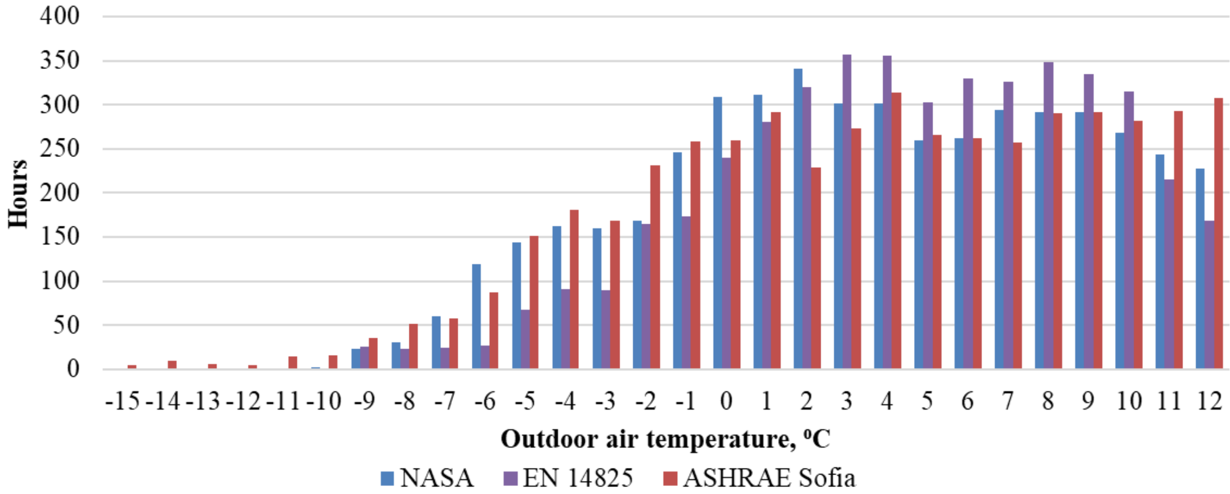

Fig. 2. Compariosn between the bin data from the different sources

RESULTS

The results of the measured parameters show oversizing in terms of the heating capacity of the heat pump unit relative to the heating load of the building. The heating load is calculated as 8.13 kW at -15 °C and the balance point where the heat loses will match the heat gains for the exact building will be at 12.6 °C. The setpoint of the heat pump is to maintain a constant supply temperature to the buffer tank of 45 °C, which in reality varies from 41.7 to 47.1 °C. The heat pump is with one twin DC rotary compressor Mitsubishi-Electric model MVB42FCBMC-L, with frequency control ranging from 26 to 76Hz.

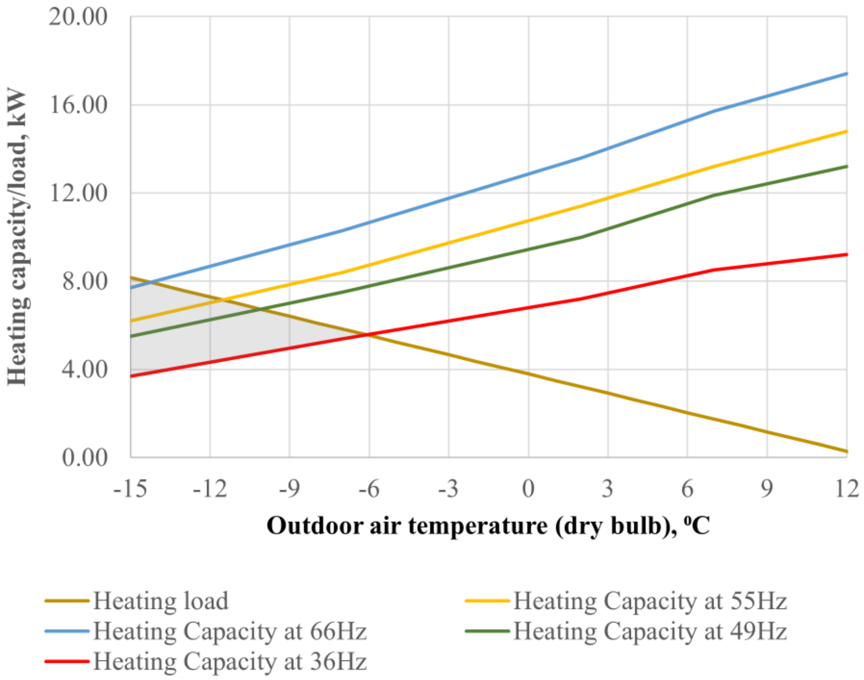

Fig. 3. Heating capacity of the heat pump unit at different operating frequencies

Fig. 3 illustrates the relationship between the building heating load and the heating capacity of the heat pump at different compressor frequencies (36, 49, 55, and 66 Hz) across the full outdoor temperature range. Although the manufacturer states that the inverter can modulate down to 26 Hz, no capacity data are provided for this minimum frequency. Based on the trends visible in the graph, an extrapolated 26 Hz curve would intersect the heating-load line at approximately −4 °C. Below this temperature the heat pump would still be able to meet the load, but at any warmer outdoor condition the heating capacity at 26 Hz would exceed the demand, indicating that the unit cannot operate in steady-state and must rely on cycling. This creates a wide modulation gap, between the load line and the 36 Hz curve, where the heat pump is forced into frequent on/off operation. Such cycling leads to increased start-up losses, reduced heat-exchanger effectiveness, and ultimately a measurable reduction in seasonal performance compared to the laboratory-declared coefficient of performance (COP) and SCOP values. The higher-frequency curves (49–66 Hz) further show a near-linear increase in capacity with rising outdoor temperature, confirming that the machine is sized to meet peak load conditions but is unable to sufficiently reduce its output under the part-load conditions that dominate more than 90% of the operating hours. Consequently, oversizing combined with limited compressor modulation represents a primary reason for the discrepancies observed between calculated and field-measured SCOP.

Comparison between the manufacturer-declared COP (COPd) and the field-measured COP (COPm) as a function of outdoor air temperature is presented in Fig. 4, highlighting the impact of the modulation mismatch described previously. The declared COP shows a strong linear increase with rising temperature (slope 0.0826, R^2 = 0.9974), reflecting idealized laboratory conditions. In contrast, the measured COP follows a noticeably flatter trend (slope 0.0485, R^2 = 0.9827), resulting in a progressively wider gap between the two curves toward mild temperatures. This pattern indicates that the heat pump does not realize the efficiency gains expected at higher outdoor temperatures, and the real system operates with consistently lower performance than predicted. The measured COP values therefore provide a more realistic representation of the unit’s seasonal behavior and highlight the limitations of relying solely on declared data when estimating SCOP.

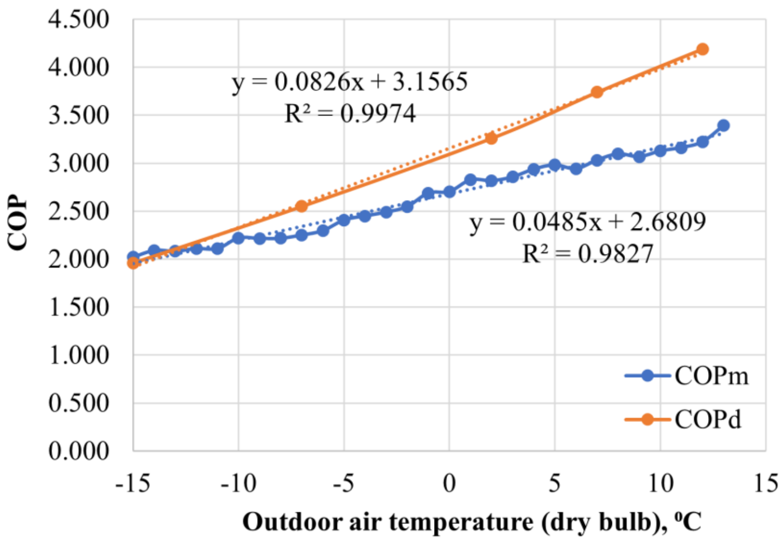

Fig. 4. Declared (COPd) vs. the calculated COPm based on field measurements

Based on the regression equations derived for COPd and COPm, both the declared and the measured seasonal coefficients of performance (SCOPd and SCOPm) can be calculated using standard temperature-bin methods. These calculations stand for $SCOP_{ON}$ in therms of EN 14825. By applying the linear COP–temperature correlations to each outdoor temperature bin and weighting the COP values by the number of annual operating hours in that bin, it is possible to obtain seasonally averaged performance indicators that reflect either laboratory-declared behavior (SCOPd), adapted (SCOPd, adapted) to the local climate conditions or field-based performance (SCOPm). This approach ensures full comparability between the two datasets and allows a quantification of the discrepancy between ideal and actual operation under identical climatic conditions. Moreover, using regression-based COP estimation avoids the need for

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incomplete or missing manufacturer data at certain frequencies and provides a continuous, reproducible method for evaluating seasonal performance using any climatic dataset.

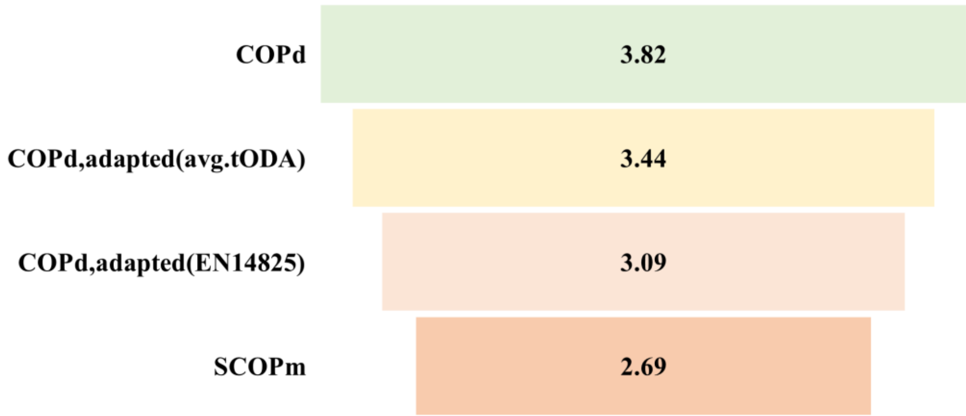

Fig. 5. SCOP at the different levels of degradation

The declared COP (COPd) is 3.82. When adjusted using the average outdoor temperature distribution, the adapted value decreases to 3.44, representing a reduction of about 10%. Applying the EN 14825 climate bins yields a COPd,adapted of 3.09, or approximately 19% lower than the declared value. The SCOP calculated from the field-measured COP (SCOPm) decreases further to 2.69, which is about 30% below the initial declared COP. These steps clearly show how each level of adaptation progressively lowers the expected seasonal efficiency.

The energy consumption of the single-familiy house located in Climatic zone VII was simulated on a quasi-stationary model, based on monthly climate data using the software product EAB Software v. HC 1.0. The impact of different SCOP values on the specific nonrenewable primary energy consumption for the single-family building, expressed as EPn,ren, is shown on Fig. 6. As expected, higher SCOP values lead to lower calculated energy consumption: using the declared SCOP of 3.82 results in approximately 74 kWh/m²·a, while the climate-adapted values of 3.44 and 3.09 yield 79.35 kWh/m²·a and 84.87 kWh/m²·a respectively. When the field-measured SCOP of 2.69 is applied, the specific energy consumption increases to around 92.69 kWh/m²·a. Compared against the threshold of 83 kWh/m²·a defined in the Bulgarian methodology, the building meets energy class A only when SCOPd or SCOPd,adapted(meanODA) are used, whereas SCOPd,adapted(EN14825) places it above the limit for class A, and SCOPm shifts the rating also to class B. This comparison demonstrates how the choice of SCOP—declared, climate-adapted, or field-measured—can directly influence the final energy class of a building.

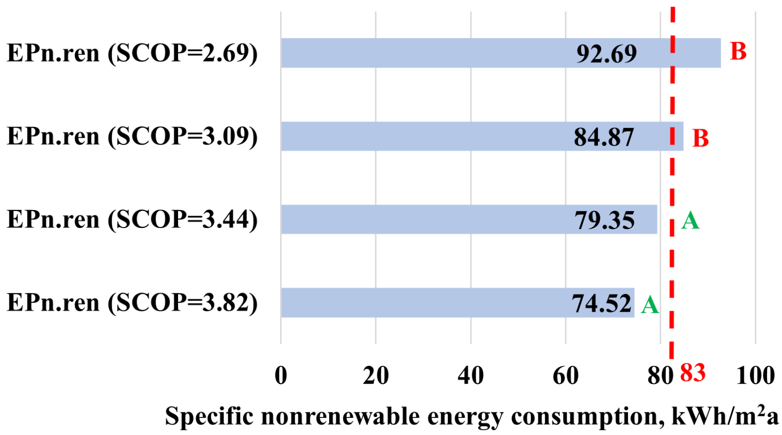

Fig. 6. Impact of different SCOP values on the specific nonrenewable primary energy consumption

CONCLUSION

This study demonstrates the significant gap between manufacturer-declared SCOP values and the actual seasonal performance of an air-to-water heat pump system in real-world conditions. The analysis confirmed that while the declared SCOP of 3.82 may be valid under standardized laboratory settings, it is not representative of practical installation.

When adapting the SCOP using average outdoor temperatures and EN 14825 climate bins, the seasonal efficiency decreased by 10% and 19%, respectively. However, the most critical finding is the further reduction of SCOP to 2.69 based on actual field data—representing a 30% degradation from the declared figure. This decline is largely attributed to system oversizing and insufficient compressor modulation, which forced the heat pump into frequent cycling during the majority of the heating season.

The implications of these findings extend to building energy certification, as reliance on optimistic SCOP values can lead to misclassification of energy performance classes. For example, while the declared SCOP suggests the building qualifies for energy class A, the measured SCOP reclassifies it to class B, reflecting higher nonrenewable primary energy consumption. Thus, for realistic and responsible building design, it is essential to incorporate climate-adapted or field-based SCOP values, especially in energy audits, regulatory compliance, and energy performance predictions.

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