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Comparative analysis of the energy performance of an air handling unit with two-stage heat recovery operating in the different climatic zones of Bulgaria

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Comparative analysis of the energy performance of an air handling unit with two-stage heat recovery operating in the different climatic zones of Bulgaria

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Abstract. A comparative analysis was carried out to establish the energy performance of an air handling unit (AHU) for two-stage heat recovery of the exhaust air. The seasonal coefficient of performance (SCOP) was calculated when AHU is operating in heating mode, as well as COP for the entire unit on an annual basis, taking into account the specific features of the different climatic zones in the Republic of Bulgaria. The results have been compared with the BIN-temperature data for an average climate provided in EN 14825 (Table 37) in order to find out how far this standard will give reliable results for the Bulgarian climate, both in terms of energy consumption and SCOP.

1. Introduction

Changes in the global climate in recent decades led to the adoption of the European Climate Law by the Council of Europe in 2021. It [8] legally obliges EU countries to meet climate targets for both 2030 and 2050.

Achieving the goal of climate neutrality, which significantly reduces greenhouse gas emissions, undoubtedly leads to the use of more and more heat pump units in building heating, ventilation and air conditioning systems gradually replacing the fossil fuels.

The correct use of heat pump units requires a good knowledge of their energy performance in relation to the achievement of buildings with close to zero energy consumption, since nearly 97% of existing buildings need to be renovated [1]. All new buildings after 01.01.2024, which will be designed and put into operation in Bulgaria, according to the current regulatory framework, must have nearly zero energy consumption. For Bulgaria, it is defined as: energy consumption class "A" and 55% required energy from renewable energy sources.

Heat pump units using the energy of the outdoor air are significantly affected by its rapidly changing parameters. Heat pumps are widely used in heating and air conditioning systems. However, their effective use in ventilation systems has been poorly studied in scientific papers. One such option is the use of air handling units with two-stage heat recovery of the exhaust air with a recuperative heat exchanger and a built-in heat pump.

In this article, a comparative analysis was carried out to establish the energy performance of an air handling unit (AHU) for two-stage heat recovery of the exhaust air during their operation in the different climatic zones in the Republic of Bulgaria, as well as a comparison of these results with the data given in the EN 14825 [4] standard.

2. Climatic data

Bulgaria is divided into two main climatic areas - temperate continental and continental-Mediterranean.

In order to more accurately calculate the annual energy consumption, the territory of the country is divided into seven climatic zones (Figure 1). The figure is reproduced from the Bulgarian national code (RD-02-20-3 of 09.11.2022) on the technical requirements for the energy performance of the buildings [2].

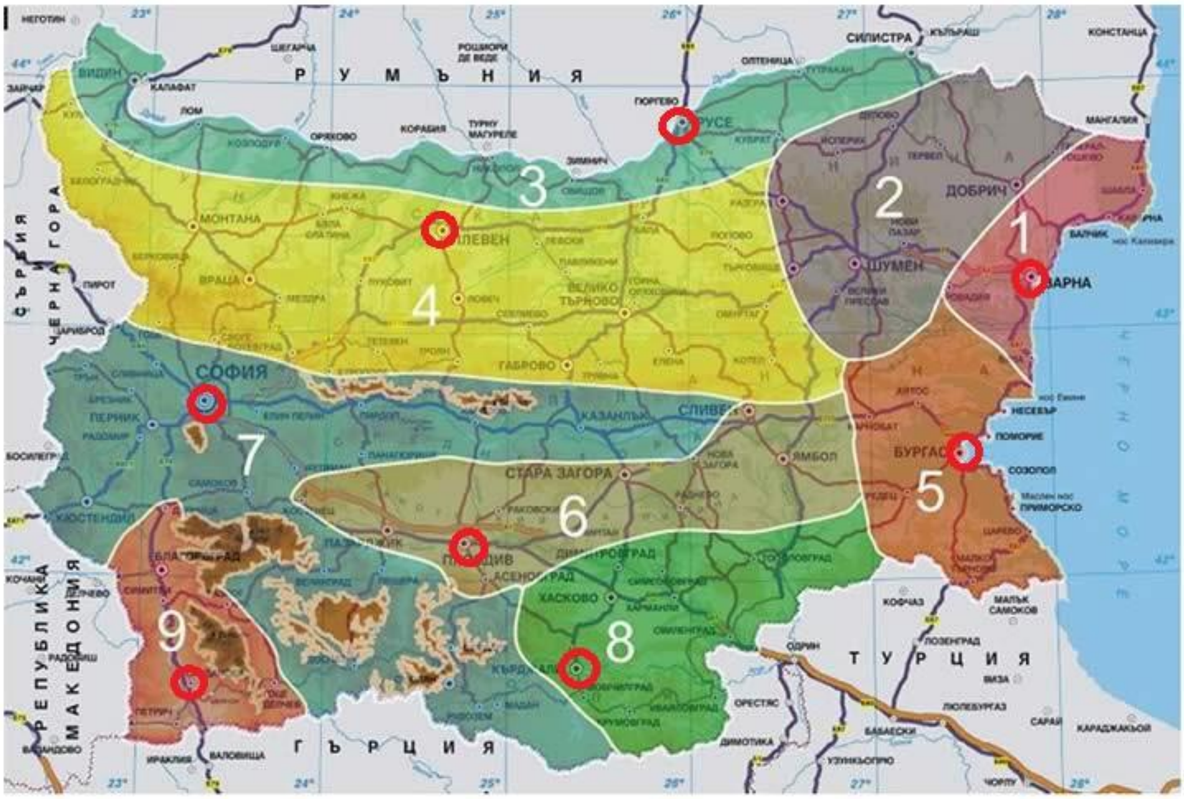

Figure 1. Climatic zones of Bulgaria and representative cities, for which calculations were made for the energy performance of the AHU with two-stage heat recovery of the exhaust air.

In order to calculate the annual energy consumption for each of the climatic zones, one representative city was selected for which there is information regarding the outdoor air parameters in the ASHRAE database - IWEC2. The selected cities are shown surrounded by a red circle in Figure 1 and are as follows: Climatic zone 1 – Varna; Climatic zone 2 - No information available in IWEC2; Climatic zone 3 – Ruse; Climatic zone 3 – Pleven; Climatic zone 5 – Burgas; Climatic zone 6 – Plovdiv; Climatic zone 7 - Sofia; Climatic zone 8 - Kurdjali and Climatic zone 8 - Sandanski.

According to the standard [4], the European continent is divided into three types of climates – average, warm and cold, for determination of the seasonal coefficient of performance. Each one characterizes the frequency of certain outdoor temperatures: average - Strasbourg, warm - Athens and cold - Helsinki. Bulgaria falls in the average climate zone.

Using the BIN-temperature data from the standard [4] and the data from IWEC2, the cumulative frequencies of the outdoor temperature distribution by hours for each of the zones are shown graphically in Figure 2.

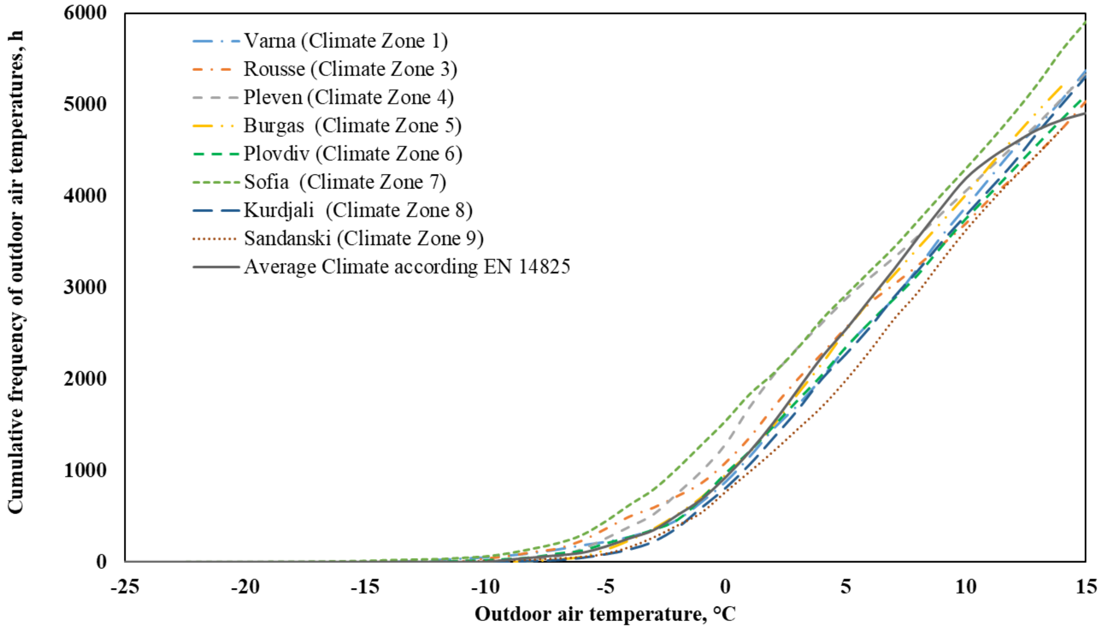

Figure 2. Cumulative frequencies of outdoor temperature distribution for each of the zones and also with the presented data in the EN 14825.

3. Experimental set-up and methodology

As an example, for the comparative analysis, an air handling unit with two-stage heat recovery of the exhaust air by means of a recuperative heat exchanger and a built-in heat pump was used (Figure 3).

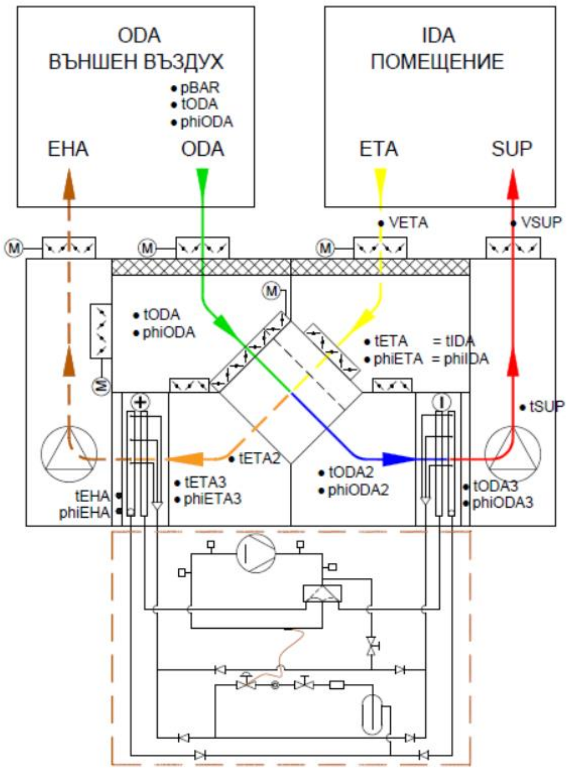

Figure 3. Scheme of the air handling unit with two-stage heat recovery of the exhaust air with recuperative heat exchanger and a heat pump.

The heat pump is conventional with ON/OFF control. To calculate the energy and performance, mathematical models were used, validated with real experimental data for the area of the city of Sofia, which falls in Climatic Zone 7. The air handling unit is installed in Technical University of Sofia in a small lecture hall to maintain the indoor air quality (IAQ) in it. The mathematical models and the methodology for calculating the annual energy consumption are presented in detail in [3]. The study [3] shows that the AHU works at full capacity down to -2 °C outdoor air temperature, and from -1.9 to +12 °C with partial load from 100 to 14 %. Below -2 °C, the AHU cannot achieve the setpoint of 22 °C dry bulb air temperature in the room and the temperature in it drops to 18.5 °C.

It is important to note that the defrosting factor practically does not affect the work of AHUs with built-in heat pumps and this does not lead to a reduction of SCOP, which is described in detail in the proposal for a European standard by Luigi Schibuola [9].

To carry out the calculations, it is assumed that the AHU works with a nominal flow rate of 1500 m^3/h and with an efficiency of 61% at the temperature of the plate heat exchanger. It is also assumed that the supply and exhaust air flows are balanced. The work schedule is 24 hours a day, 7 days a week and 365 days a year.

The full technical data of the AHU are presented in Table 1.

Table 1 - Technical data of the AHU with two-stage heat recovery

AHU main technical data: DamVent VEDA max.e2 - 02 SN:10000015		
Maximum flow rate:	2000	m^3/h
Total cooling capacity:	12.9	kW
Total heating power:	24.5	kW
Recuperator		
Recover heat capacity:	16.1	kW
Temperature efficiency:	65	%

4. Results

The energy performance of the considered system with two-stage recovery is highly dependent on the parameters of the outside air, since the built-in heat pump is "air-to-air". This raises the question of how far the BIN data presented in Table 37 of the standard [4] will give reliable results, both in terms of energy consumption and SCOP.

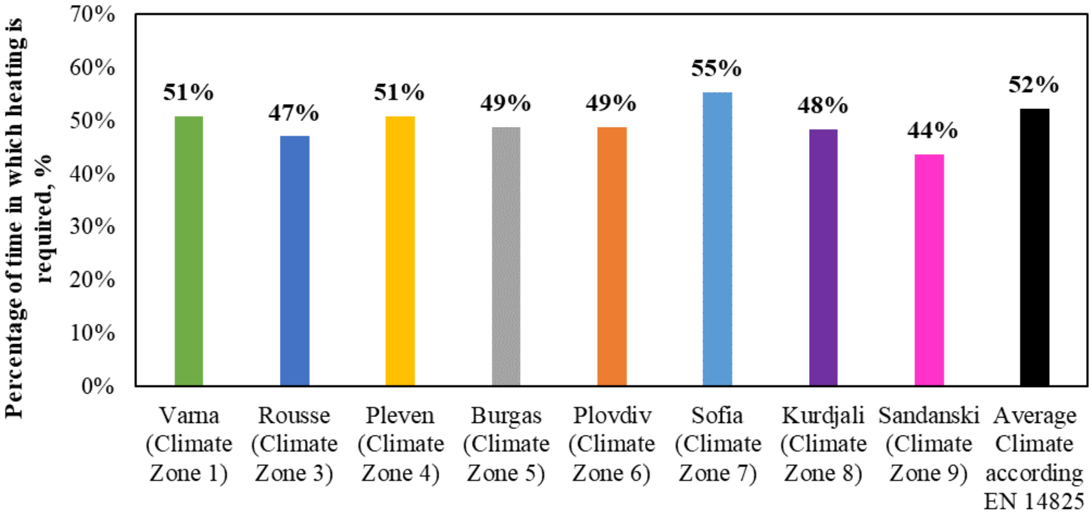

Figure 4. Percentage of the time during which the AHU will work in heating mode relative to one year (8760 hours).

A study in Poland [5] by Piotr Kowalski and Paweł Szałański in 2019 shows that for the Polish climate the data in the standard [4] does not provide good results.

Table 2. Annual distribution of work modes

Climate Zone 1 - Varna			Climate Zone 3 - Rousse		
Mode	Working hours, h	Portion	Mode	Working hours, h	Portion
Heating	4455	51%	Heating	4121	47%
Cooling	752	9%	Cooling	1288	15%
Ventilation	515	6%	Ventilation	580	7%
Recirculation	2573	29%	Recirculation	2289	26%
Free-cooling	465	5%	Free-cooling	482	6%
Climate Zone 4 - Pleven			**Climate Zone 5 - Burgas**		
Mode	Working hours, h	Portion	Mode	Working hours, h	Portion
Heating	4450	51%	Heating	4276	49%
Cooling	1155	13%	Cooling	900	10%
Ventilation	531	6%	Ventilation	588	7%
Recirculation	2199	25%	Recirculation	2487	28%
Free-cooling	425	5%	Free-cooling	509	6%
Climate Zone 6 - Plovdiv			**Climate Zone 7 - Sofia**		
Mode	Working hours, h	Portion	Mode	Working hours, h	Portion
Heating	4279	49%	Heating	4852	55%
Cooling	1186	14%	Cooling	731	8%
Ventilation	542	6%	Ventilation	411	5%
Recirculation	2336	27%	Recirculation	2456	28%
Free-cooling	417	5%	Free-cooling	310	4%
Climate Zone 8 - Kurdjali			**Climate Zone 9 - Sandanski**		
Mode	Working hours, h	Portion	Mode	Working hours, h	Portion
Heating	4235	48%	Heating	3827	44%
Cooling	1013	12%	Cooling	1490	17%
Ventilation	602	7%	Ventilation	621	7%
Recirculation	2484	28%	Recirculation	2231	25%
Free-cooling	426	5%	Free-cooling	591	7%

From the data presented above, it can be seen that the AHU operates in recirculation mode in a fairly narrow range for all zones on average 27% or 2382 hours. For AHUs operating with ON/OFF controlled compressors, this has a negative impact on the IAQ, because the concentration of carbon dioxide increases, as can be seen from an article [6] by Martin Ivanov.

According to EN 14825 the reference SCOP is defined as: “Reference SCOP = reference annual heating demand divided by the annual electricity consumption.”

The results of SCOP calculations for each of the climate zones in the manner described above, using the algorithm and mathematical models described in [3] are presented graphically in Figure 5.

SCOP calculated by the BIN-temperature method with the data from EN 14825 and with the mathematical models for the operation of the specific AHU described in [3] is 5.79. The deviation of the values for the different climate zones is in the range of -0.9% to 1.1%, compared to 5.79, and the average value of all climate zones, except for Climate Zone 2, is precisely 5.79. This shows that for the conditions of Bulgaria the calculation of SCOP does not depend significantly on the data for the climatic zone, the calculations with the data presented in EN 14825 give sufficiently accurate results for engineering practice.

Also, sufficiently accurate results compared to the standard EN 14825 gives the quicker two-temperature method proposed by Palkowski [7].

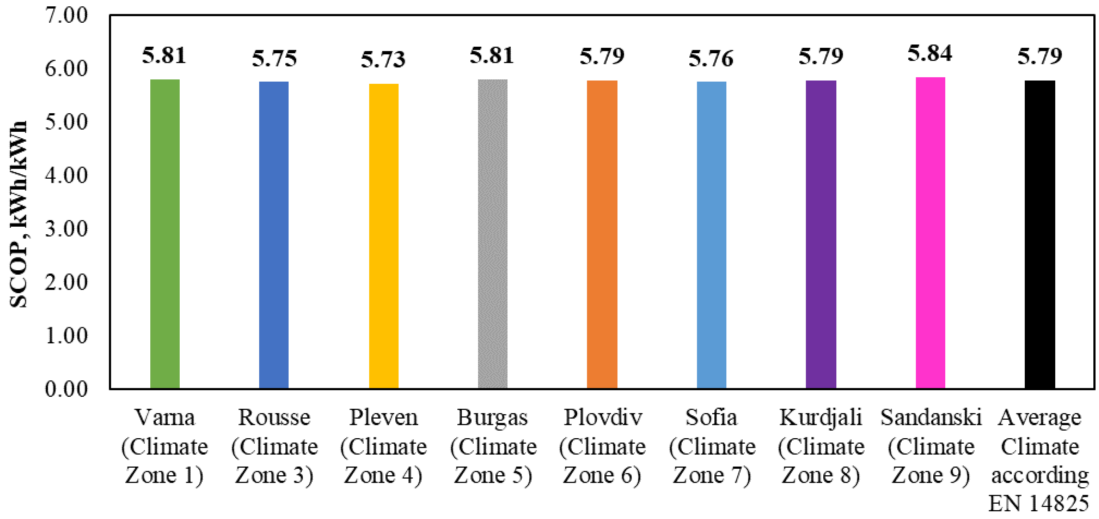

Figure 5. Seasonal coefficient of performance depending on the climate zone.

The different climatic zones have a significant impact on the operation of the AHU with two-stage heat recovery of the exhaust air in terms of energy consumption - seasonal and annual, as well as on the annual COP of the AHU. Seasonal and annual electricity consumption is presented for each of the considered zones in Figure 6.

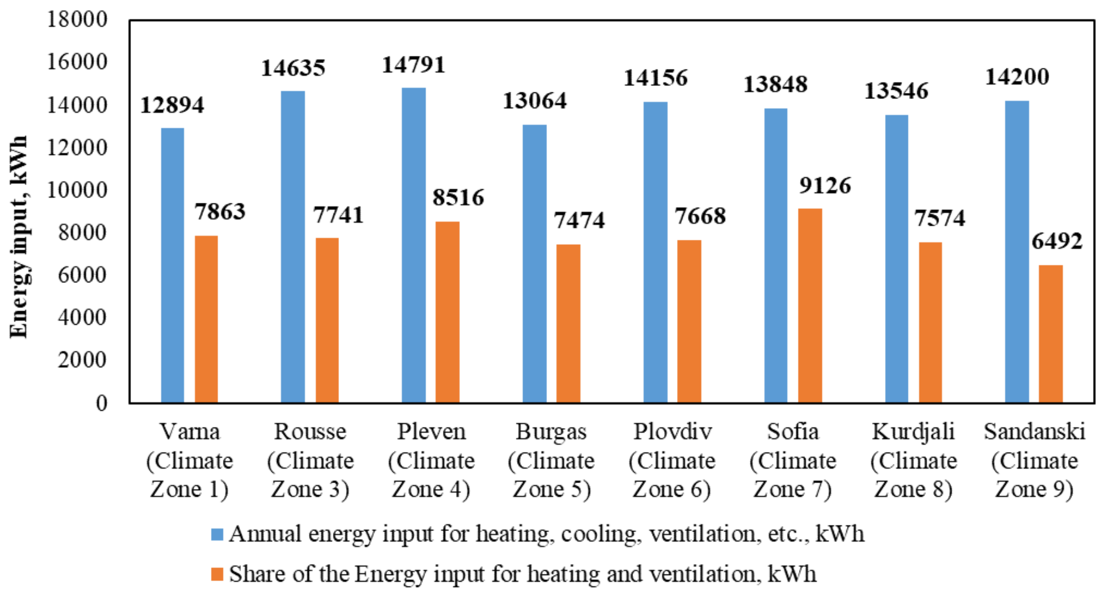

Figure 6. Seasonal and annual consumption of electricity by climatic zones

The COP of the AHU on an annual basis change from 3.57 to 4.16 depending on the specific conditions of the climatic zone. The annual COP of the entire AHU for each climate zone is shown in Figure 7.

In the case of AHU with two-stage recovery with a built-in heat pump it is important to note that the low values of COP on annual basis for the warmer climate zone is due to the fact that in „recirculation", "free-cooling" (using colder outdoor air than the one in the room to cover small cooling loads) and "ventilation" modes the unit practically does not utilize heat from the exhaust air.

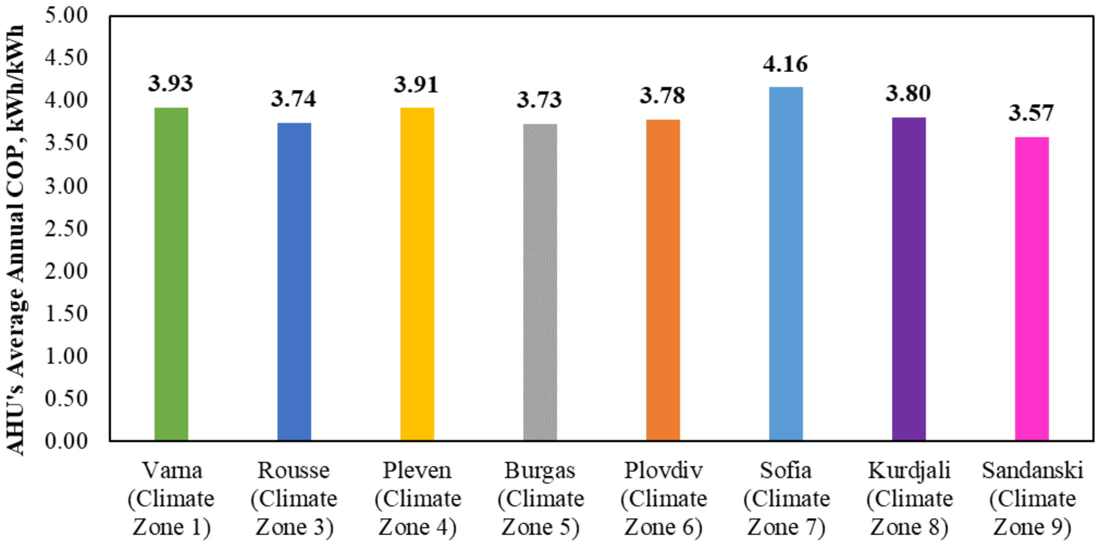

Figure 7. Annual COP of the AHU for the respective climate zone

5. Summary

- The cumulative frequencies of the hourly outdoor temperature distribution for each of the climate zones were estimated with the data from IWEC2, as well as with the average climate BIN-temperature data from EN 14825.
- The energy performance of an air handling unit with two-stage heat recovery operating in the different climatic zones of Bulgaria was researched.
- Calculated SCOP with the data from IWEC2 for the different climatic zones of Bulgaria was compared to the BIN-temperature data provided in Table 37 from EN 14825.
- For the purpose of engineering practice in Bulgaria, the average climate BIN-temperature data presented in EN 14825 gives good enough results for the calculation of SCOP.

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