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Estimation of Seasonal Efficiency of Air-to-Water Heat Pump Used in Heating Mode for Different Climatic Zones in Bulgaria

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Abstract

In this paper, an investigation and assessment of the impact of the external air temperature measurement frequency on the bin distribution and subsequent determination of the Seasonal Coefficient of Performance (SCOP) are made. In this order, two different calculation methods are used. The first one is the method defined by the standard EN 14825. The other one is the method of dynamical hourly system simulation. In this approach, the outdoor temperature is measured at 10 minutes intervals, whereas the heat pump power data as a function of the outdoor air temperature is provided by the manufacturer. The possibility of using the normal bin distribution for SCOP calculation is investigated. A graphical representation of the results is provided for three different cities in Bulgaria. The obtained results demonstrate that the calculated data from the different methods are coherent only under certain conditions. Comparing the results from the two methods for calculation of SCOP it can be seen that the relative difference between them reaches up to 9% and is varying according to the climate conditions of the considered location.
Using the method of dynamical hourly system simulation in the design process gives an opportunity to ensure the high energy efficiency of heating systems. The results for the heat pump (HP) spent energy and the seasonal performance $SCOP_{on}$ are directly used by the energy efficiency consultants for modeling of HP systems.

Keywords: SCOP; Air-to-Water Heat Pump; Bin Method; Normal Distribution.

1. Introduction

Recently, the use of air source heat pumps (ASHP) for residential heating and domestic hot water supply systems has been increased significantly. The reason for this is that according to Directive 2009/28/EC [1] the devices that use aerothermal energy are recognized as systems with a renewable energy source. The air source heat pumps successfully replace traditional heat sources due to their relatively low cost and the availability of a cost-free heat source - the outdoor air.

The operating characteristics of the air source heat pump depend on the building heating and cooling loads and the outdoor air temperature. Due to the variable outdoor air temperature during the heating season, the assessment of the seasonal performance of the heat pumps should be done by dynamic system simulation. The Bulgarian standard BDS EN 14825:2016 suggests the bin method to be used for the seasonal performance coefficient calculation of ASHP.

The basic performance parameter of an air-to-water heat pump is the Seasonal Coefficient of Performance (SCOP). The determination of SCOP in the design and the energy audit of building systems is of paramount importance. In both cases, climate data for the building location is required. A number of authors have considered the problems associated with the SCOP calculation of the air-to-water heat pumps [5], [6], [7], [8], [10] and [11]. On the other hand, EN 14 825: 2016 [2] sets out the ways to assess the seasonal performance of air-to-water heat pumps (HP) used to maintain the microclimate in buildings. The well-known bin method is in its core.

According to the climate classification in [2], EN 14825:2016 divides Europe's territory into 3 major climatic zones: Colder, Average and Warmer and provides bin distribution for each of them. These distributions reflect the long term temperature statistics in three representative European cities: Helsinki for the Colder zone (T_{design} = -22), Strasbourg for the average zone (T_{design} = 10) and Athens for the Warmer zone (reference winter outdoor air design temperature T_{design} = 2). The EN14825:2016 [2], however, excludes the peculiarities of the change of the outdoor air temperatures within a specific year and for other location of the building.

When conducting energy audits of buildings and industrial systems, it is necessary to identify the consumed energy for heating and/or cooling demands and the efficiency of the used air-to-water heat pump. A similar procedure requires the use of climatic data for a specific location and for a particular year. These data can be obtained from some of the many internet sites with climate data or by performing own measurements. In the present study, data obtained from the Automatic Meteorological Station of the Technical University of Varna and information available at www.stringmeteo.com [7] are used. The meteorological station of Technical University of Varna is a model Davis

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Vantage Pro II and has GPS coordinates N043°13'23.15", E027°56'18.39".

Different frequency of temperature measurement is used. The data from Meteorological station of Technical University of Varna are every 10 minutes and those from StringMeteo.com are at interval of 3 hours. The aim of this study is to analyze and to evaluate the effect of the frequency of the outdoor air temperature measurement on the bin temperature distribution. The subsequent determination of the SCOP will provide information about the appropriate number of the processed data with the help of which acceptable results with good accuracy are obtained. Therefore, this paper considers the possibility of using bin temperature distributions obtained using the normal distribution. In some EU Member States, the normal distribution is used for construction of bin distributions [3].

The different geographic areas of the Republic of Bulgaria are characterized by very different climate. For the heating season, comparative calculations of SCOP and the energy consumed by the air-to-water heat pump are made for 3 cities in Bulgaria - Varna, Pleven and Plovdiv. The bin temperature distributions presented in [2] and the data obtained from the meteorological station of Varna Technical University and from www.stringmeteo.com [7] are used. The calculations are performed according to the methodology in Annex F: "Calculation example for SCOPon and SCOPnet – Application to a fixed capacity air-to-water heat pump used for floor heating" [2]. The Building Energy Signature and the heat pump`s Declared capacity data from [2] are used. The analysis is performed for an air-to-water heat pump, integrated with an electric heater as a backup system.

The analysis is performed for a heat pump with outdoor air as heating source, integrated with an electric heater as a backup system, used for buildings located in different Bulgarian climatic zones.

2. Material and method

2.1 Bin - method

The bin-method is used to model the climate and the evaluation of the heat pumps seasonal performance. The bin contains the number of hours during the heating/cooling periods during which the outdoor air temperature is within 1°C around the integer values.

The bin-method is used here to determine the bin distribution for the heating season of three different Bulgarian cities: Varna (43.12°N, 27.49°E), Pleven (43.20°N, 24.43°E) and Plovdiv (42.12°N, 24.44°E). The duration of conventional heating seasons is presented in Table 1.

Table 1. Design temperatures, design loads and weather characteristics for the selected climates

	Design Temperatur [°C]	Design Load [kW]	Duration of the Heating Season	Degree Days
Varna	-11	12	21/10 – 20/04	2400
Pleven	-17	14,4	16/10 – 23/04	2700
Plovdiv	-15	13,6	24/10 – 06/04	2400

When analyzing the data depicted in Fig. 1 and Table 1, the difference in climate among the selected cities is seen: Pleven, in the northern part of Bulgaria, is characterized by a low outdoor air temperature of -13°C, outdoor air design temperature (T_{des}) of -17°C, and bin mode of 0°C; Varna is located in the Northeast Bulgaria on the Black Sea Coast and has T_{des} value of -11°C with a minimum outdoor air temperature of -8°C (mode 7°C); Plovdiv is located in South Bulgaria and has T_{des} value of -15°C with a minimum outdoor air temperature of -14°C (mode 0°C).

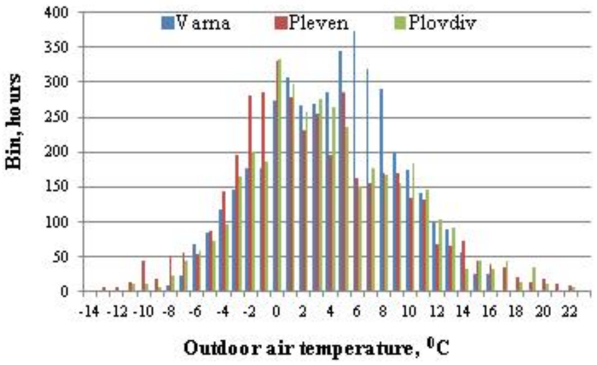

Fig 1. Bin distribution for the heating season in Varna, Pleven, and Plovdiv (Bulgaria).

2.2 Normal bin distribution

In order to assess the performance of the operation of the air-to-water heat pumps, the Italian Standard UNI/TS 11300 - 4 [9] proposes to use bin - distribution of outdoor air temperature obtained on the basis of its normal distribution. For calculation of these distributions the following are used: average monthly temperature for specific location, outdoor air design temperature and average monthly solar radiation above horizontal plane. This approach facilitates the process of estimating the seasonal performance of heat pump systems but does not allow to do this for a particular heating season. For this reason, in this study an approach has been developed in which, with the help of a minimal amount of meteorological internet data, distributions that are as close as possible to the real ones are obtained. The use of information for maximum, minimum and average monthly temperatures has been accepted. The mode of the desired normal distribution is calculated as the average outdoor air temperature for the heating season. Numerical experiments with outdoor air temperature measurements for a given location at a high frequency were conducted to determine the standard deviation. Normal distribution is sought for which the sum of the mean square deviations from the measured one is the smallest. The standard deviation set for this normal distribution is recommended for use in constructing normal distributions during other heating seasons. The testing of the methodology is carried out with climatic data for the city of Varna, Bulgaria and was applied to the cities of Pleven and Plovdiv.

2.3 SCOP of HP air-to-water in heating mode

For the calculations, the data from [2] for the Building Energy Signature (BES) and Declared Heat Capacity (DHC) data as in Annex F, "Calculation Example for $SCOP_{on}$ and $SCOP_{net}$ - Application to a fixed capacity air-to-water heat pump used for floor heating", are used. The characteristics of the building and of the heat pump are shown in Fig. 2.

SCOP is defined as the ratio of reference annual heat consumption by the building and the annual electrical energy consumption by the heat pump [2].

The mean seasonal COP of the heat pump, $SCOP_{net}$ and of the whole system composed of electric air-to-water heat pump and electric heaters, $SCOP_{on}$, are evaluated according to the following equations:

$$SCOP_{net} = \frac{Q_{HP}}{E_{HP,us}} \quad (1)$$

$$SCOP_{on} = \frac{Q_b}{E_{HP,us} + E_{bu}} \quad (2)$$

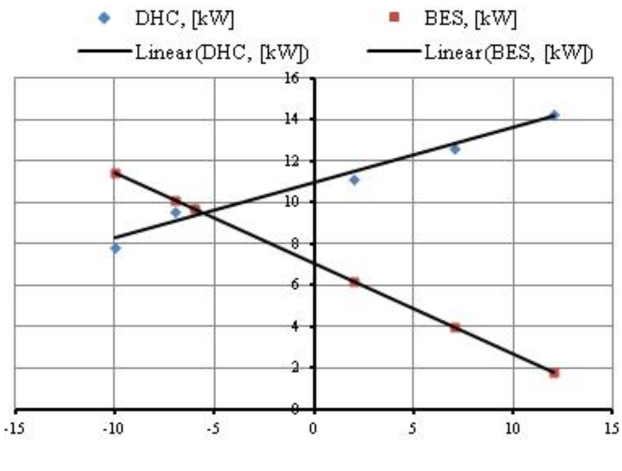

Fig 2. Building energy and Input heat pump power as a function of the outdoor temperature.

3. Results and discussion

3.1 Comparing of bins at different frequencies of temperature measurement

In this paper, the air-to-water heat pump SCOP dependence on the outdoor air temperature frequency of measurement is investigated. Data from outdoor air temperature measurements performed by Technical University of Varna automatic meteorological station are used. The measurements are performed every 10 minutes. Bin distributions are constructed using measured temperatures *every* 10 minutes, 30 minutes, 1 hour, 3 hours, 6 hours and average daily temperatures - Tabl. 2.

Table 2. Comparing of bins at different frequency of temperature measurement

Frequency of measu-rement	Bin distribution, hours				
	-7	2	7	12	Mean temp.
10 min	8	294	330	116	5,14
30 min	11	286	348	131	5,19
1 h	11	288	343	131	5,18
3 h	9	315	326	177	5,17
6 h	12	288	342	126	5,05
Daily average	12	240	576	144	2,21

Regardless of the differences in bins, the average seasonal temperature is approximately the same regardless of the measurement frequency. This means that bin distributions obtained with a lower frequency of measurement can be used for practical calculations.

To calculate the seasonal coefficient of energy conversion of the air-to-water heat pump the following is determined: the building heat demand for the heating season; the heat supplied by the heat pump and by the additional heat source; the electrical energy used by the heat pump. The results of the SCOP calculation are presented in Table 3 for bins obtained at different temperature reading frequency.

On the graphs in Figs. 3 and 4 the results of Table 3 for heat demand, energy input, and SCOP are presented.

Table 3. SCOP for HP at a different frequency of temperature measurement in Varna

	Outdoor air temperature measured:	Annual heating demand, kWh	Annual energy input including electric back up heater, kWh	$SCOP_{on}$	$SCOP_{net}$
1	Every 10 minutes	22 482	6 137	3,57	3,67
2	Every 30 minutes	20 875	5 697	3,66	3,67
3	Every 1 hour	20 896	5 702	3,66	3,67
4	Every 3 hour	20 910	5 705	3,66	3,67
5	Every 6 hour	21 143	5 631	3,66	3,67
6	Average daily	20 774	5 774	3,69	3,69

The results in Table 3 show:

- $SCOP_{on}$ and $SCOP_{net}$ are almost independent of the outdoor temperature measurements;
- the building heat consumption, determined at a measurement frequency of 10 minutes, is the closest to the amount of actual heat demand;
- the same statement applies to the electricity consumed by HP;
- by decreasing the frequency of the measurements, both heating demand and energy input including that of electric back up heater are reduced.

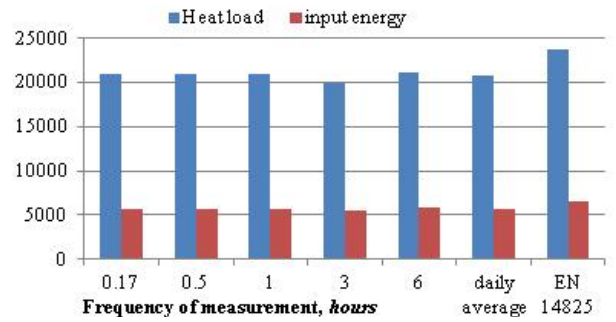

Fig 3. Comparison of the heat demand the input energy for the analyzed building and the input energy for the analyzed heat pump with different climatic data.

3.2 The normal outdoor air temperature distribution

The statistical method for determining the normal distribution of random variable is used to determine the normal distribution of outdoor temperature bins using Microsoft Office Excel, the NORMDIST function and Data/Data analysis/ Descriptive Statistics**.**

The normal temperature distribution is calculated as a random variable in the climate change data interval with a measurement frequency of 3 hours. The result is compared to climate data.

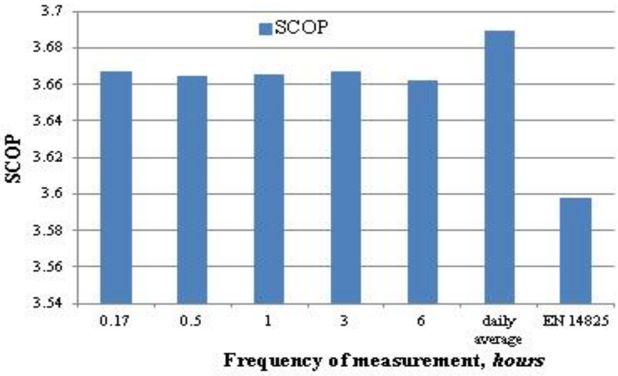

Fig. 4. Comparison of the SCOP for the analyzed heat pump with different climatic data.

The implemented methodology is the one developed in the present study. The average temperature for the heating period during the analyzed year is used as mean. A numerical experiment is performed to determine the standard deviation. The value at which a minimum mean deviation between normal distribution and real measured bins is obtained, is used. In Table 4, the data and the criteria for their selection are presented, that are necessary for calculating the real normal distribution for Varna, Pleven and Plovdiv. The results are shown in Figs. 5a, 5b and 5c.

Table 4. Data and criterion for calculation Real Normal Distribution

Data and criterion	Varna	Pleven	Plovdiv
Mean	5,41	3,22	3,59
Standart deviation for RND	5	6	6
Mean square deviations, hours	4,17	6,5	5,43

The calculated results for SCOP for Varna are presented in Table 5. The results of this study show that the normal distribution obtained at minimal mean deviation from the actual bins is very close to the deviation obtained according to the metodology given in the standard.

3.3 Comparison of Climate Data results and the standard EN 14 825 for "Average" and "Colder" heating season

A comparison between Climate Data results with a measurement frequency of 3 hours and the standard EN 14 825 for "Average" and "Colder" heating season is made. The results are shown in Figs. 6, 7 and 8 and in Table 5.

In Fig. 6, the results for the calculated bins are shown, using the climatic data for Varna. The obtained data are compared with the bins from the reference heating season "Average". On this graph, the coincidence is the greatest. It can be stated that Varna corresponds to its affiliation with "Average".

From the data in Figure 7 it is apparent that the bins of the climate data for Pleven do not cover either the bins of "Average" or the "Colder", as the difference with "Colder" is greater. However, the difference in SCOP is negligible for "Average" but for "Colder" is 20.7%. It can be stated that Pleven also belongs to "Average".

The results for Plovdiv, presented in Fig. 8 also show that the climate data for this city are between "Colder" and "Average" and do not have a good match with any of them. The difference in SCOP is essential for "Colder" 25% and negligible for "Average". It can be stated that Plovdiv also belongs to "Average".

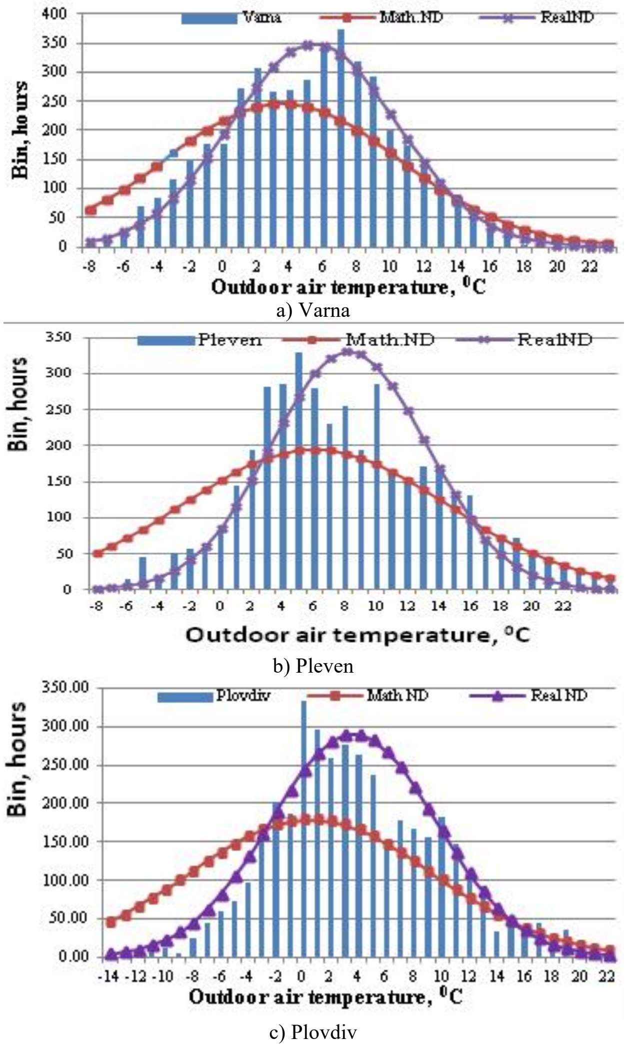

Fig 5. Bin distribution during the heating season provided by: weather data of the location (air temperature every 3 hours); mathematical normal distribution (Math ND) of random value; normal distribution in line with real conditions (Real ND) in a) Varna b) Pleven and c) Plovdiv (Bulgaria).

Table 5. Seasonal COP

	Location	Annual heating demand, kWh	Annual energy input including electric back up heater, kWh	SCOP	$SCOP_{ne}$	Deviation for $SCOP_{on}$
1	Varna	20 910	5 705	3.665	3.67	1.5%A
2	VarnaMND	21 921	6 234	3,52	3,58	2,5%A
3	VarnaRND	20 315	5 535	3,67	3,68	1,7%A
4	Pleven	24 765	7 332	3.38	3.61	6.4%A; 20.7%C
5	EN 14825 C	41 224	14 703	2.80	3.26	-
6	EN 14825 A	23 679	6 582	3.61	3.65	-
7	Plovdiv	21 251	6 080	3.50	3.59	3.2%A; 25%C
8	EN 14825 A	23 679	6 582	3.61	3.65	-
9	EN 14825 C	41 224	14 703	2.80	3.26	-

The results for the spent HP energy and the seasonal efficiency $SCOP_{on}$ are directly used by the energy efficiency consultants in the modeling of HP systems.

The use of the methodology in the design process gives the opportunity to ensure the high energy efficiency of the heating systems.

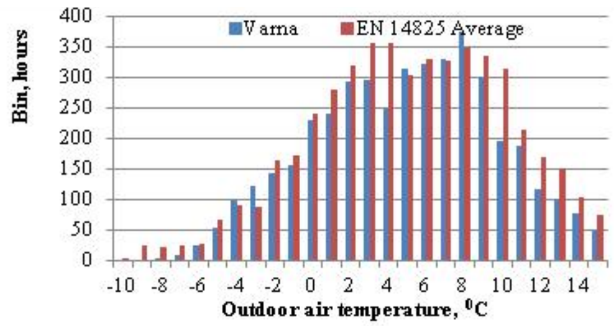

Fig. 6 Bin distribution during the heating season in Varna (Bulgaria) provided by a) weather data of the location (air temperature every 3 hours); b) bin to the reference heating season "Average" of EN 14 825.

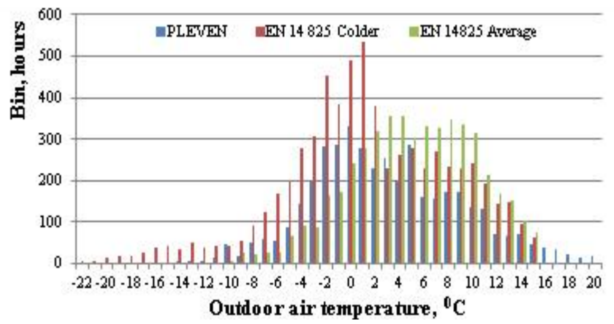

Fig.7 Bin distribution during the heating season in Pleven (Bulgaria) provided by a) weather data of the location (air temperature every 3 hours); b) bin to the reference heating season "Average" of EN 14 825; c) bin to the reference heating season "Colder" of EN 14 825.

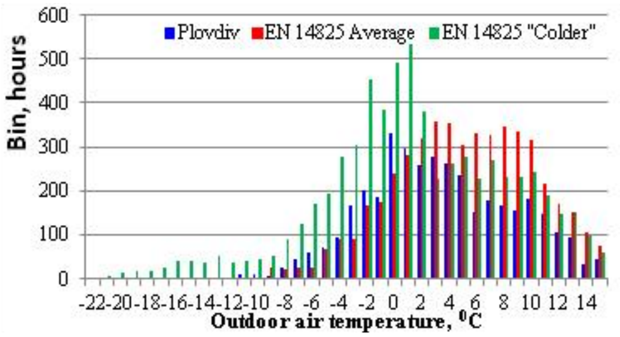

Fig. 8 Bin distribution during the heating season in Plovdiv (Bulgaria) provided by a) weather data of the location (air temperature every 3 hours); b) bin to the reference heating season "Average" of EN 14 825; c) bin to the reference heating season "Colder" of EN 14 825.

4. Conclusions

For the design needs a measurement frequency of 3 hours is sufficient to determine SCOP but when it comes to energy efficiency audits, a frequency of 10 minutes most accurately describes the amount of energy consumed to provide comfort in the building.

The normal distribution, calculated using the methodology proposed in this paper, is suitable for designing HVAC systems as well as for energy audits.

The bins of EN 14825 are also not suitable for energy efficiency audits of HVAC systems that work with air-to-water HP. They are suitable for designing these systems.

The use of the methodology in the design process and in the energy efficiency audit of buildings and industrial systems gives the opportunity to ensure the high energy efficiency of the heating systems

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Nomenclature

Q_b - reference annual building heat demand;
Q_{HP} – reference annual heating demand from HP, kWh
$E_{HP,us}$ - annual electricity consumption by HP, kWh;
E_{bu} - required power of the additional heat source - the electric heater;
$SCOP_{net}$ - COP value of the HP;
$SCOP_{on}$ - COP value of the whole system, composed of electric air-to-water heat pump and electric heaters.
MND - Mathematical Normal Distribution.
RND - Real Normal Distribution.

References

1. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009.
2. European standard EN 14825: 2016.
3. Naldi C. et al., Climate influence on seasonal performances of air-to-water heat pumps for heating, Energy Procedia, 81 (2015) 100 – 107.
4. https://www.stringmeteo.com.
5. Jones A. et al., Joint-Frequency Bins versus Conventional Bin Weather Data in Analysis of HVAC System Operation, Proceedings of the Ninth International Conference for Enhanced Building Operations, Austin, Texas, November 17 - 19, 2009.
6. Dongellini M., Dynamic modeling and seasonal performance evaluation of air-to-water heat pump systems, PhD Thesis – Bologna. 2017.
7. Rusev D. et al., Analysis of the operation of air-water heat pump unit in winter mode, XXIIIst symposium with international participation SISOM & ACOUSTICS, Bucharest, Romania, 2012.
8. Kinab E., D. Marchio, Ph. Rivieri, Seasonal Coefficient of Performance of Heat Pumps " (2008), International Refrigeration and Air Conditioning Conference. Paper 894.
9. Italian standard UNI/TS 11300-4:2016 Prestazioni energetiche degli edifici - Parte 4.
10. Hongtao Meng et al. , Research Status and Application of AirSource Heat Pump Technology, Thermal Science and Engineering, 2018, https//pdfs.semanticscolar.org/aca5.
11. Caroline Haglund Stignor and Tommy Walfridson, Nordsyn study on air-to-air heat pumps in humid Nordic climate, http://dx.doi.org/10.6027/ TN 2019:504, © Nordic Council of Ministers 2019, ISBN 978-92-893-5978-8 (PDF).