Bin weather data of Varna and their influence on the seasonal efficiency of heat pumps with energy source outdoor air

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Abstract. The seasonal transformation coefficient (SCOP) of a heat pump with a heat source outside air as a function of the temperature of the latter is studied. The bin method was used to determine the climatic data for the city of Varna. Outdoor air temperature data were used and statistical analysis of the data was performed. The average frequency and cumulative distribution of temperature bins values in the period from 2005 to 2019 in the city of Varna is calculated. The results are presented using graphs and tables. In the data stability assessment report, the standard deviation and coefficient of variation were used. The SCOP of a heat pump heating installation operating in Varna has been calculated. All results were compared with those of other studies of the authors under different conditions and with reference data.

1. Introduction

In recent years, heat pumps with a outdoor air as heat source increasingly used. Determining the design load of heating systems with air-to-water heat pump depends largely on the parameters of the outside air in the place where the system operates. The analysis of the heat load of the existing buildings is the basis for making rational decisions to increase the energy efficiency of the system. For this reason, before configuring the system, it is necessary to estimate the amount of energy needed to heat and cool the building in typical weather conditions. These quantities can be much more difficult to estimate than the design loads or the required system capacity, which are usually calculated under a set of design conditions. The many factors such as solar energy, internal heat sources and partial load of the system that affect energy needs vary during the forecasting period and make the calculations that take into account all options quite complex. From reference literature [1], there are two widely used methods for assessment the energy needs of buildings: the degree-days method and the method based on the hourly distribution of the outside air temperature (the so-called bin temperature method). A characteristic feature of both methods is that they are based on models that consider the steady-state heat flow throughout the building envelope.

A significant disadvantage of the degree-days method is that it assumes the efficiency of the heating source is constant and does not depend on the dynamically hourly changing of the external air parameters.

The methodology provided in the legislation of the Republic of Bulgaria for the design of building air conditioning systems covers to a greater extent conventional heat sources and has some missing
links when it comes to heat pumps with outdoor air as heat source. Thus, the thermoeconomic efficiency of the designed system remains in question.

The Bulgarian methodology for calculating the heating load of buildings provides for the use of external temperature, which occurs with a limited duration during the heating period. Most of the time, the heat pump operates in part load mode. For this reason, part load analysis is important for the correct choice of HVAC system.

The stationary approach laid down in the Bulgarian normative documents for calculating the thermal load of buildings is improved with the help of the so-called bin method set in EN 14825 – 2019 [2]. A strength of the bin temperature method is that it is able to estimate the part load of the heating source in HVAC systems with heat pumps [3, 4, 5, 6, 7]. The standard [2] allocate Europe in three climate zone: warmer, average, and colder and suggest the bin temperature data. Bulgaria falls into two of them: average and colder. The use of standardized three climatic zones for Europe and outdoor air temperature bin introduces some inaccuracies in the calculations for the different geographical areas of the same zones.

In [8] the authors published a study which shows that there is a discrepancy in determining the seasonal efficiency ratio (SCOP) for different cities in Bulgaria when using climate bins from EN 14825 and those from the specific climate data. Data on the outside air temperature for one year - 2011 were used, which is disadvantage of this study.

Nevertheless, this article argues that such identification of the climatic features of individual regions of Europe can be misleading, especially in the case of analysis and optimization of air-to-water heat pump systems. It is necessary to develop a mathematical approach to obtain realistic climatic data for the distribution of temperature in the bin as in [9, 10, 3]. This is the main goal of the present study. Also, the SCOP of an air-to-water heat pump with the temperature bins for Varna defined in this article has been calculated and [8], with literature data for these bins from [11] and for Average climate zone from [2]. The results are compared.

The analysis is performed for a heat pump with outdoor air as a heat source, integrated with an electric heater as a backup system, used for building located in Varna. The Building Energy Signature (BES) and Declared Heat Capacity (DHC) data as in Annex H, [2] was used for calculations. Some of the data are: Design Temperature for heating, $T_{designh}$ -10°C; Bivalent Temperature, $T_{biv}$ - 6°C; Capacity of the unit at $T_{biv}$ (A-6fW33) - 9,7kW; Design Load Heating, $P_{designh}$ - 11,46kW; Declared capacity of the unit at $T_{designh}$ 7,8kW; Climate – Average; Operation Limit Temperature (TOL) -10°C; Capacity at TOL - 7,8kW; Supplementary heater – Electric.

2. Climate data

In order to refine the calculation of SCOP in this article a mathematical processing of the measured temperatures by airport meteorological station (latitude 43°14’ N, longitude 27°50’ E, altitude 70 m) for the period from 2005 to 2019 in the city of Varna was made.

In this paper, the dry-bulb temperature bin data for the city of Varna, Bulgaria are determined by an assessment methodology based on monthly outdoor temperatures. The data are calculated from -24.51°C to 42.49°C with a step of 1 degree, in the period from 2005 to 2019 in 8 daily 3-h shifts, and are presented in tabular form.

For the needs of the study are calculated:
- the absolute frequency of temperatures in the interval between -24 and 42 °C;

$$\sum N_{bin_i} = n, \quad (1)$$

where: $N_{bin_i}$ - number of hours of different values of the outdoor dry-bulb temperature; $n$ - total numbers of hours;
- the relative frequency;

$$v_i = \frac{N_{bin_i}}{n}, \quad (2)$$
\[ \sum v_i = 1 \]  

- the relative cumulative frequencies, as a ratio of the accumulated cumulative frequencies \( c_i \) and the total number of measured values \( n \):

\[ \gamma_i = \frac{c_i}{n} \]  

\[ c_i = \sum_{j=1}^{i} N_{bin_j} \]
Figure 1. Average absolute frequency distribution of Nbin values for Varna city from 2005 to 2019 year.

Figure 2. a) Annual total bin data for Varna; b) Cumulative relative frequency.

3. SCOP of Heat pump 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 H, "Calculation Example for SCOP on and SCOP net - Application to a fixed capacity air-to-water heat pump used for floor heating", are used. A similar approach is used in the calculations in [8].

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

\[
SCOP_{\text{net}} = \frac{Q_{\text{HP}}}{E_{\text{HP,us}}} \quad \text{(6)}
\]

\[
SCOP_{\text{on}} = \frac{Q_{\text{fp}}}{E_{\text{HP,us}} + E_{\text{bu}}} \quad \text{(7)}
\]

Where \( Q_{\text{HP}} \) and \( Q_{\text{fp}} \) is the heat produced, \( E_{\text{HP,us}} \) and \( E_{\text{bu}} \) is the electricity consumed by the heat pump and the additional electric heater, respectively.

4. Results and discussion

The results of the calculations of the temperature bins for a climatic year in Varna, as well as their cumulative distribution are presented in figure 1-2.

With the help of meteorological data for the temperature measured 8 times every 3 hours for each 24 hours. The hours in which the temperature is observed within 1°C around the integer values are summarized and arranged in bins.

Yearly total bin data for Varna are shown in figure 2. Temperatures between -17°C and 35°C are observed, and the frequency of very low and very high values is extremely low. The bins have the
highest relative frequency of 4% between 7°C and 15°C during the heating and between 20°C and 23 °C during the cooling.

Figure 3 presents the cumulative distribution of yearly bin data for Varna, which is constructed using the cumulative relative frequency (figure 2). Using the presented curve and taking into account the limits (i.e. 15 °C and 24 °C) of the heating and cooling period, their duration is determined. From figure 3 is determined for Varna - 4,582 hours for heating and 1,566 hours for cooling.

Figure 3. Cumulative distribution of yearly total bin data for Varna city from 2005 to 2019 year. Note: Q_{nd,C,max} and Q_{nd,H,max} are the maximum cooling, heating demand for building, respectively.

Figure 4 compares the results of the distribution of temperature bins for Varna with those of [8] and [11] only for the heating period. The figure shows that there is good coverage between the bins defined in this article for the climate year from 2005-2019 and those from [11], which are determined more than 50 years ago. It can be concluded that in terms of the duration of the heating period and the distribution of temperatures by hours there are no significant changes in the climate. The difference in the results of [8] is due to the fact that the bins were taken only for one year, which was obviously warmer.

Figure 4. Bin temperature distribution in heating period and in temperature interval -18°C and 15°C.

Table 1 presents the results of the calculated SCOPs and compares them with those calculated in [8] and using the data from [2, 11]. The methodology from [2] was used for the calculations.
Table 1. Seasonal COP.

| Source                  | Annual heating demand, kWh | Annual energy input including electric back up heater, kWh | SCOP_{on} | SCOP_{net} |
|-------------------------|-----------------------------|-------------------------------------------------------------|-----------|-----------|
| Chakyrova et. al. [8]   | 20 910                      | 5 705                                                        | 3.66      | 3.67      |
| [11]                    | 17 752                      | 4 893                                                        | 3.63      | 3.65      |
| This paper              | 16 979                      | 4 717                                                        | 3.57      | 3.62      |
| EN 14825-2019 [2]      | 23 558                      | 6 461                                                        | 3.60      | 3.65      |

5. Conclusion

The aim of this study was to calculate ambient dry-bulb temperature bin data for Varna by using a reliable estimation methodology, based on monthly-average outdoor temperatures and solar clearness index. Due to space limitations, only yearly total N_{bin} values (h/year) for Varna are presented in tabular form and in figure. The temperature bins range between -18 °C and 40 °C with the most frequent are the ones between 7°C -15 °C and 20°C -23 °C. The required energy for heating and cooling of buildings is determined using the cumulative relative frequency (figure 1b), the cumulative distribution of the annual data for the total bin (figure 2) and the duration of heating and cooling periods for Varna.

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