EVALUATION OF A HEATING SYSTEM WITH A HEAT PUMP ACCORDING TO THE MODE OF INPUT DATA

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ABSTRACT

The paper is focused on evaluating a heating system with an air source heat pump using the bin method. The main goal of the paper is to find the difference between three modes of input outside air temperature data in the calculation. Outside air temperatures are used in three modes, an hour based calculation, monthly frequencies and annual frequencies based calculations.

Key words: *Bin Method, Heat Pump, Seasonal Performance Factor*

1 INTRODUCTION

A heat pump is a machine which is needed for providing low-temperature renewable energy, but it is necessary to deliver energy with a higher potential. The delivered energy is usually electric energy from non-renewable energy sources. Given that, it is important to care how much of the delivered electric energy the heating system is consuming. It is possible to calculate how much electric energy a heating system will consume before the system is installed.

The COP (Coefficient of Performance) is used for the evaluation of the efficiency of a heat pump. To have a classified value of the coefficient we need to calculate it according to known temperature conditions in a specified period. The COP is defined as a quotient of the energy supplied by the heat pump and the electric energy input.

There are variable working conditions in a heating system during the season. The temperature of heating water varies in connection with the outside air temperature as well as the required heat load. The heat pump capacity drops as ΔT rises, the heating load rises proportionally and, at some point, the heat pump capacity is exceeded. At this moment, a backup heater is used.

A heating system with a heat pump is evaluated by the Seasonal Performance Factor, denoted as $SCOP_{net}$ for electrically driven heat pumps [4,5]. This is a factor of the average seasonal heat pump's efficiency in the active mode. It is necessary to consider the heat pump's technical quality, the heating system's parameters and its temperature conditions, but also the ratio of the heat pump output and the actual heat load [2]. When the weather varies hour-by-hour, the demand set for the heating equipment varies. The basic equation for calculating $SCOP_{net}$ is described below:

$$SCOP_{net}=\frac{\text{heat delivered over the heating season (by heat pump+bybivalent source)}}{\text{energy input (heat pump drive+auxiliarydevices+bivalent source)}}$$

2 PRINCIPLE OF CALCULATION

The computational evaluation of a heating system with a heat pump was carried out using the bin method. This method is applied in standard [1]. The bin method is an energy calculation method used in the prediction of the annual (monthly, hourly) heat pump performance. Every bin is defined by the mean temperature and duration. The calculation is based on the performance characteristics of the heat pump given in products' standard and on other characteristics of the products as included in the system.

The evaluated heat pump system's boundary comprises the heat pump, the heat source system, the attached storages and electrical back-up heaters. Auxiliary components connected to the system are considered as well.

The real operating time of the air-source heat pump was calculated in each bin. The running time depends on the heating capacity, given by the operating conditions, and on the heat pump requirement, given by the distribution system. The operating time has to be calculated as the quotient of the heat demand in an interval (for space heating and hot water preparation) [kWh] and the real heat pump's available performance [kW] in the bin. The operating time is always shorter than or as long as the duration of the bin.

Hot domestic water preparation takes precedence over space heating. At the lowest outside air temperatures in winter, it could happen that the available time is utilized for hot water and there is not available time for space heating. As the outside air temperature increases, the time available for heating increases, too. While the performance of the heat pump is not high enough to ensure the energy needs of the house, the back-up heater turns on. Then, both energy sources work together. The backup heater is determined by a parallel operation mode and respective temperatures, the balance point temperature and the low temperature cut-out. Using these temperatures, the energy fraction of the heat pump and the backup operation can be determined and the energy consumption can be calculated. In the parallel operation mode of the backup heater, the heat pump is not switched off at the balance point temperature. The backup heater only supplies the part of energy requirement that the heat pump cannot deliver [1].

The electric energy consumption in the heating and hot water mode had to be calculated in each bin. The electric energy consumption for the heat pump operation was calculated. The electric energy consumption of auxiliary equipment (like pumps) was calculated as the multiple of the working time of the heat pump [hours] and the input power of auxiliary equipment [kW]. The input power of auxiliary equipment in the hot water mode was 0.1 [kW] and in the heating mode 0.3 [kW]. The electric energy consumption of the back-up heater was calculated in each bin, too.

The output data were balanced during the entire year in every bin. The computational method does not take into account the time of the high electricity tariff. Nor does it take into account if the heat pump reaches the maximum working temperatures.

The bin is a statistical temperature class for the outdoor air temperature, with class limits expressed in temperature units. The cumulative frequency only depends on the outdoor air temperature and does not take into account solar and thermal gains. [1]

3 INPUT DATA AND CALCULATION PROCEDURE

The heat pump in this case is used for hot domestic water preparation and space heating in a single-family house. Hot domestic water heating has priority over space heating so the calculation was split into two parts. The calculation was done in the Excel spreadsheet. The heat pump was chosen with a suitable compressor and coolant to be able to ensure hot water during the summer time.

A low-temperature energy heat pump extracts air from the outside. The heat pump rated power is 8 kW in conditions A7/W35 °C. More accurate characteristics of the heat pump are shown in Fig. 2.The backup heater is an electric boiler. The bin data are based on long-term weather measurements from Praha Ruzyne, Czech Republic. The lowest outside air temperature was – 15.1 °C, the highest temperature was 30.7 °C, the mean outside temperature was 7.9 °C.

The family house has one floor and an attic. The living area is 240 m^2. The heat load of the house is 16 kW at a nominal outside temperature of 12 °C. The space heating demand is 28 900 kWh.year^{-1}. The space heating demands are separated into months in Fig 1. The amount of the monthly energy demand was respected in each bin. The space heating requirement of a bin was calculated by a weighting factor which is derived from evaluating the cumulative frequency of the outdoor air temperature by means of cumulative heating degree hours.

The heating season is defined by an outside air temperature lower than 13 °C. The heating system never operates during June, July and August. Under these conditions, the heating period has 234 days.

The energy demand for hot domestic water heating is 4.3 kWh.person^{-1}.day^{-1}. Four people are calculated to live in the house so the total energy demand is 6 280 kWh.year^{-1}. The time of the heat supply is spread out throughout the day (100 %) in the hour based bin method as follows [3]: 35% from 0 a.m. to 5 p.m., 50 % from 5 p.m. to 8 p.m. and the remaining 15 % from 8 p.m. to 0 a.m. The reduction of the hot water consumption during summer is not considered.

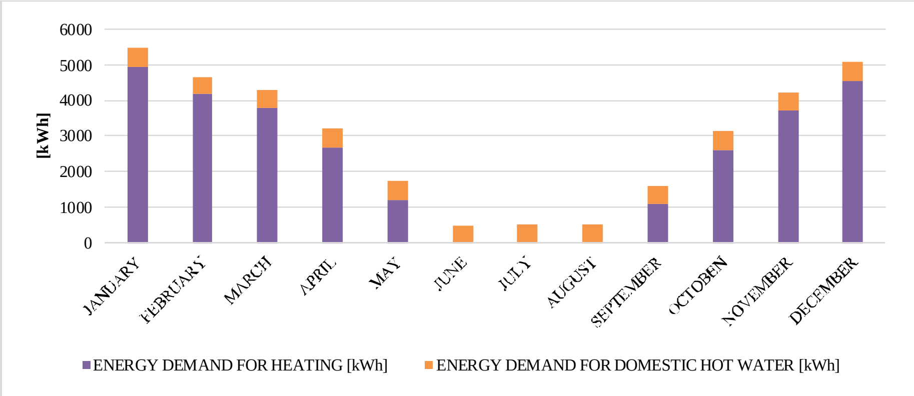

Fig. 1 Energy demands in the evaluated single-family house

The performance of the heat pump and the COP needed to be calculated according to the outside air temperature and the temperature outgoing from the condenser in each bin. To determine the data for the whole range of source and sink temperatures, linear inter- and extrapolation between the test points were applied.

The water temperature outgoing from the condenser is 55 °C in the hot domestic water mode. The designed temperature of the heating water going into the heating system is 45 °C and the temperature gradient is 10 °C. The heating water temperature is converted according to the outside air temperature in other words quality control system. An additional charge to the heating water temperature, for covering losses in heat exchangers etc., is 2 °C.

This calculation was made in three variants according to the mode of the input outside air temperature bin data.

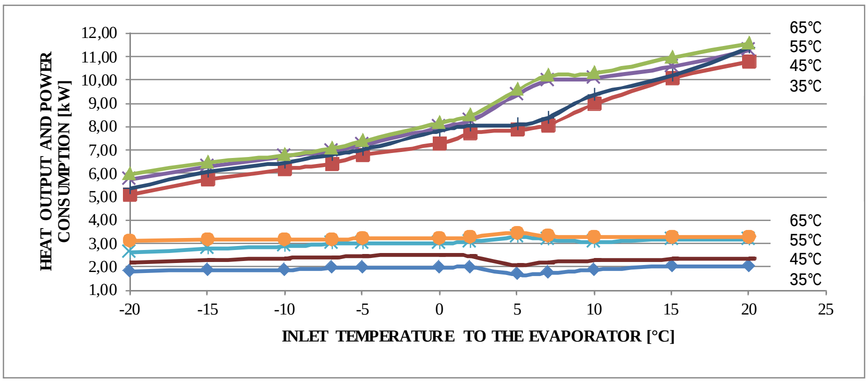

Fig. 2 Heat pump's properties measured by the manufacturer

3.1 Evaluation based on hourly bin data

Hour based data of the outside air temperature were used in the calculation. There were 8760 bins with a duration of one hour in the calculation.

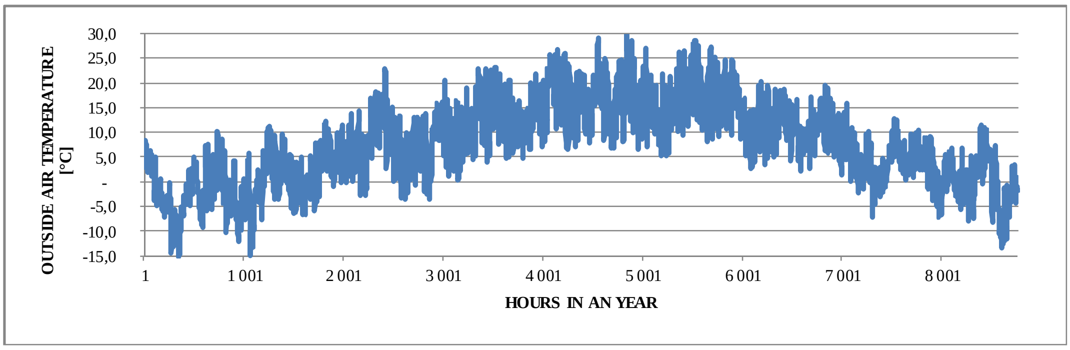

Fig. 3 Temperature bin data for each day of the evaluated year

3.2 Evaluation based on monthly frequency of outside air temperature

The frequency of the outside air temperature was calculated during each month. The number of hours in each bin was calculated with the outside air temperature step 1 K. Praha Ruzyne has the following temperature bin data for the month of January and July, see Fig. 4.

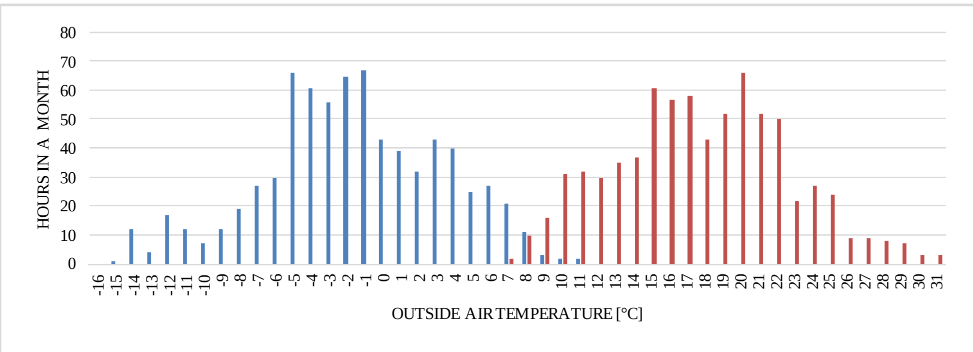

Fig. 4 Temperature bin data for the month of January and July

3.3 Evaluation based on annual frequency of outside air temperature

The frequency of the outside air temperature was calculated during one year. The number of hours in each bin was calculated with step 1 K. Praha Ruzyne has the following temperature bin data for an annual calculation period, see Fig. 5.

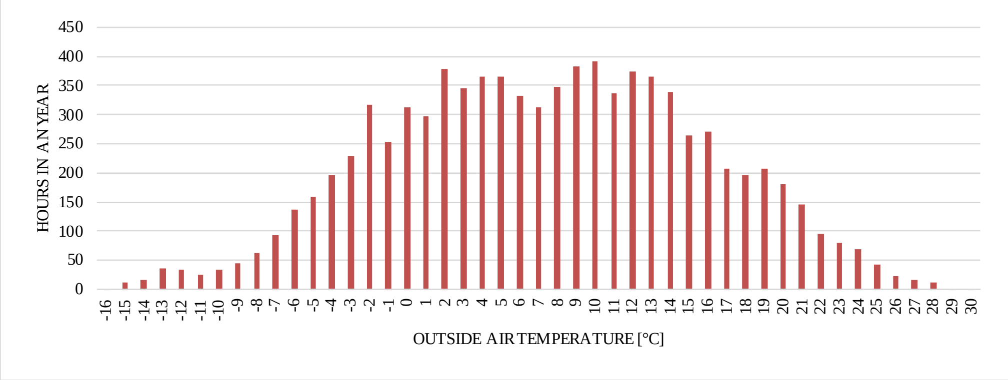

Fig. 5 Temperature bin data for the evaluated year

4 OBTAINED RESULTS

The results obtained in the evaluation of the heating system in the three modes of outside air temperature data are summarized in Tab. 1. From the comparison of the obtained results, we can see that there are no greater differences than by tens of kWh. The results from these three evaluations are comparable in the perspective of the whole year evaluation.

Calculated values	Units	Hour	Month	Year
Amount of heat from heat pump delivered into heating system	kWh	33 520	33 337	33 754
Energy for heat pump operation	kWh	9 282	9 160	9 231
Energy demand of auxiliary devices	kWh	1 126	1 116	1 127
Output of back-up heater	kWh	1 660	1 842	1 426
COP of heat pump	-	3.61	3.64	3.66
Seasonal performance factor	-	2.92	2.90	2.86

Tab. 1 Results obtained from the evaluation

If the results are examined in more detail, there are considerable differences in the temperature bins. The greatest difference in the results in Tab.1 is in the output of the back-up heater. The differences are shown in Fig. 6, specifically the back-up heater performance calculated for all 1 K temperature bins (evaluation based on monthly frequencies and the annual frequency of the outside air temperature).

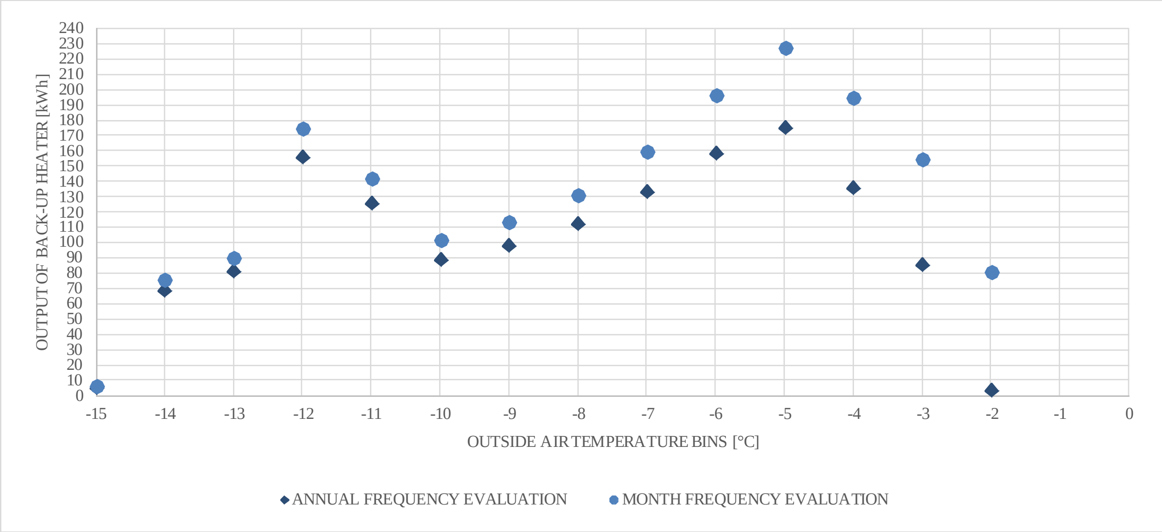

Fig. 6 Results of the output of the back-up heater for monthly frequencies and annual frequency evaluation

5 CONCLUSION

While designing a heating system with a heat pump, it is important to calculate how much electric energy the system will consume. The amount of primary electricity consumption should be an important aspect for the designer as well as the investor. There is a comparison of three modes of the input outside air temperature data in this paper – hour based, month based and annual based outside air temperature bin data. From the obtained results, we can assume that the difference is very low in the annualized scale. When the results are under the microscope, it is possible to find out that the results, mainly the annual frequency and also the monthly frequency, differ more than could be acceptable for an exact energy balance. For the initial energy balance, month based bin temperature data could be adequate, but for the exact energy balance, the use of outside air temperature data based on hourly measurement is justified.

Acknowledgement

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Literature

[1] EN 15316-4-2. *Method of calculation of system energy requirements and system efficiencies: Part 4-2: Space heating generation systems, heat pump systems*. 2008.

[2] ANSI/ASHRAE STANDARD 116-2010. *Methods of Testing for Rating Seasonal Efficiency of Unitary Air-Conditioners and Heat Pumps*. 2010.

[3] ČSN 060320. *Hot Domestic Water Preparation*. 2006.

[4] EN 14825. *Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance*. 2014.

[5] MATUŠKA, Tomáš. Parametry pro hodnocení efektivity tepelných čerpadel: COP a SCOP. *TZB-info* [online]. 2015, 2015-10-21 [cit. 2015-12-14]. ISSN 1801-4399. Dostupné z: http://vytapeni.tzb-info.cz/tepelna-cerpadla/13196-parametry-pro-hodnoceni-efektivity-tepelnych-cerpadel-cop-a-scop

[6] MATUŠKA, Tomáš. ŠOUREK, Bořivoj. Výpočet ročního provozu tepelného čerpadla intervalovou metodou podle TNI 73 0351. *Praha: Topenářství Instalace 07/2014*, poř. číslo 286, ročník 48, s. 42-48. ISSN 1211-0906.

[7] KRAINER, Robert. BAŠTA, Jiří. Intervalová metoda pro hodnocení efektivity provozu tepelných čerpadel. Alternativní zdroje energie 2010. *Praha: Společnost pro techniku prostředí*, 2010, s. 273-281. ISBN 978-80-02-02241-1.