UČESTALOST TEMPERATURA SPOLJAŠNJEG VAZDUHA GRADA NIŠA

BIN WEATHER DATA FOR CITY OF NIŠ

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U radu je prikazan postupak generisanja učestalosti temperatura spoljašnjeg vazduha za predele u kojima postoje časovna merenja meteoroloških podataka u cilju procene potreba za grejanjem i hlađenjem građevinskih objekata. Korišćenjem meteoroloških podataka, prikupljanih u kontinuitetu po pravilu duže od 5 godina, učestalost temperatura spoljašnjeg vazduha, sa konačnim vrednostima temperaturskog opsega i po delovima dana može se odrediti. Za određivanje potreba osetne toplotne energije neophodna su merenja temperature vazduha po suvom termoemetru na časovnom nivou, ali je za određivanje potreba latenente toplotne energije neophodno koristiti i merenja relativne vlažnosti i apsolutnog vazdušnog pritiska. Dobijeni rezultati se koriste u analizama energetskih potreba objekta baziranim na osnovnoj ili modifikovanoj BIN metodi.

Ključne reči: *energetska analiza; BIN metode; BIN klimatski podaci; Niš*

This paper presents a way to generate bin weather data for regions where hourly meteorogical data are being collected in order to provide necessary weather input database for estimation of energy consumption for heating and cooling of buildings. Using weather records for sufficient period of time, preferably more than 5 years, bin weather data raging from minimum to maximum values of outdoor dry bulb temperature recorded in the location should be calculated with finite temperature increments in adequate number of daily shifts. For the purpose of obtaining sensible energy consumption, hourly measurements of dry bulb temperature are necessary, but in order to take into account latent energy consumption hourly values of relative humidity and the atmospheric pressure are needed as well. The derived results should be in form suitable for building energy analysis using basic or modified bin method.

Key words: *Energy analysis; Bin methods; Bin weather data; Niš*

1 Introduction

In order to quantify how much energy certain building uses, performing energy analysis is of great importance. Energy analysis plays an important role in developing an optimal HVAC and architectural design for new buildings and in determining cost effective modifications to existing buildings [1].

There are four major purposes for performing building energy analysis: to evaluate various architectural design concepts; to demonstrate code compliance; to provide estimates of operating and maintenance costs over the lifetime of the building; to improve understanding of how energy is used in buildings [2].

Several models [1-5] are available for estimating building energy consumption, and each of these models has its strengths and weaknesses. These models can be divided into following types: steady-state, quasi-steady-state and dynamic. Furthermore, energy analysis methods can be either simplified methods or simulation methods. Nearly all simplified methods are based on steady-state models, and simulation methods are all based on quasi-steady-state or dynamic models. Simplified methods require less data and are appropriate for simple systems and applications. If only one parameter is used, methods are called single measure methods. The most commonly used of these methods is a well known Degree-Day method. If several parameters are used, methods are called multiple measure methods. The bin method is the best known of these methods. The common for all the simplified methods is that they are easy to comprehend, do not require special computer skills and can be used by vast majority of engineers.

Current practice in Serbia, widely accepted by HVAC engineers, is that for estimating heating energy consumption, fixed-base Heating Degree-Day method is used for all building types and the cooling energy consumption is not calculated at all. In order to include cooling energy consumption, either cooling degree-days should be calculated or the other method should be used. Since the bin method incorporates calculation of both heating and cooling energy consumption, it represents a good alternative to current practice in Serbia, especially because advanced computer skills are not required and it is easy to comprehend.

Degree day data are available for most of the cities in Serbia but the bin weather data are not regularly available. The aim of this paper is to present the way to generate bin weather data for cities in Serbia where hourly meteorogical records exist. The bin weather data can be defined as the number of hours in one year when the outdoor dry bulb temperature was in each of a set of equally sized temperature intervals (bins) of outdoor dry bulb temperature [1, 6].

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Temperature increments representing bins are arbitrary, but the accuracy of the energy analysis increases when increments decrease. In most cases the increments have the value of 2°C, but also they can obtain other values (i.e 2.8°C or 3°C).

Number of daily shifts into which the values of outdoor dry bulb temperatures are going to be classified is also arbitrary, but widely accepted practice is to select 3 or 6 equally sized daily shifts representing occupied and unoccupied periods of building use.

2 Bin methods

When heat loss coefficients of building, system efficiency or balance point temperature are not sufficiently constant (case in most non-residential buildings), the degree day method should not be used (like it is the case now in Serbia). For these applications using basic and modified bin method can yield good results for annual energy consumption. These procedures can account for the part load performance of HVAC equipment and specifically used for analysis of heat pump systems.

The basic bin method consists of performing instantaneous energy calculations at many different outdoor dry bulb temperature conditions, t_i, and multiplying the results by the corresponding number of hours, $N_{bin,i}$, in the bin centered on temperature t_i [1, 6, 7, 8]:

$$Q_{bin,i} = N_{bin,i} \cdot \frac{K_{tot}}{\eta} \cdot (t_b - t_i)^{\pm} \tag{1}$$

where K_{tot} is total heat loss coefficient of the building, η is efficiency of the HVAC system and t_b represents balance point temperature (value of outdoor temperature bellow or above which heating or cooling is required).

In Eq. (1), the plus superscript refers to heating energy consumption and only positive values should be counted. For cooling energy consumption only negative values should be counted.

In order to obtain total energy consumption Eq. (1) is applied for each bin, and these values are summed.

$$Q_{tot} = \sum_{i=1}^{m} Q_{bin,i} \tag{2}$$

where m represents total number of temperature bins.

Eq. (1) and Eq. (2) refer only to sensible energy consumption. Since, in most of buildings latent loads occur as well as sensible, latent energy consumption should be calculated using mean coincident wet bulb temperature of each bin.

The modified bin method recognizes that the building loads are both time and temperature dependant. For calculation of building energy consumption usually two periods are used representing occupied and unoccupied period [1].

3 Meteorogical database, psychrometrics and bin weather data

In order to generate corresponding number of hours for each bin, $N_{bin,i}$, hourly measurements of outdoor dry bulb temperature are needed for sufficient period of time, preferably more than 5 consecutive years. These hourly values should then be classified into intervals with a constant temperature increment and selected number of daily shifts. This procedure has to be repeated for every month and every year of the time period. Results of these calculations must be averaged over the whole time period and represent corresponding number of hours $N_{bin,i}$.

If, in energy analysis, latent energy is to be taken into account, mean coincident wet bulb temperature for each of the bins has to be calculated. For calculation of mean coincident wet bulb temperature, hourly values of relative humidity and atmospheric pressure are needed. Calculation of wet bulb temperature for each hour of the observed period can be performed with the procedure which follows [9].

Saturation pressure p_{ws} is calculated as the function of outdoor dry bulb temperature. For the temperature range -100°C to 0°C, the saturation pressure is given by:

$$\ln(p_{ws}) = \frac{C_1}{T} + C_2 + C_3 T + C_4 T^2 + C_5 T^3 + C_6 T^4 + C_7 \ln(T) \tag{3}$$

where
C_1 = -5.674 535 9 E+03
C_2 = 6.392 524 7 E+00
C_3 = -9.677 843 0 E-03
C_4 = 6.221 570 1 E-07
C_5 = 2.074 782 5 E-09
C_6 = -9.484 024 0 E-13
C_7 = 4.163 501 9 E+00

For the temperature range 0 to 200°C, the saturation pressure is given by:

$$\ln(p_{ws}) = \frac{C_8}{T} + C_9 + C_{10} T + C_{11} T^2 + C_{12} T^3 + C_{13} \ln(T) \tag{4}$$

where
C_8 = -5.800 220 6 E+03

C_9 = 1.391 499 3 E+00
C_{10} = -4.864 023 9 E-02
C_{11} = 4.176 476 8 E-05
C_{12} = -1.445 209 3 E-08
C_{13} = 6.545 967 3 E+00

After calculating saturation pressure, partial water vapor pressure p_w is calculated using relative humidity φ:

$$p_w = \varphi \cdot p_{ws} \quad \textbf{(5)}$$

Afterwards, the humidity ratio w is determined as a function of measured atmospheric pressure and calculated partial water vapor pressure:

$$\boldsymbol{w} = 0.62198 \cdot \frac{p_w}{p - p_w} \quad \textbf{(6)}$$

Humidity ratio on saturation point w_s is calculated using saturation pressure:

$$w_s = 0.62198 \cdot \frac{p_{ws}}{p - p_{ws}} \quad \textbf{(7)}$$

Finally, the wet bulb temperature t^* is estimated, and the humidity ratio w' is calculated:

$$w' = \frac{(2501 - 2.381 \cdot t^*) \cdot w_s^* - 1.006 \cdot (t - t^*)}{2501 + 1.805 \cdot t - 4.186 \cdot t^*} \quad \textbf{(8)}$$

where w_s* is the humidity ratio on saturation point for temperature t^*, and it is calculated using Eq. (3), Eq. (4) and Eq. (7)

When values obtained from Eq. (8) and Eq. (6) coincide, then the estimated temperature t^* represents coincident wet bulb temperature. Firstly, these values have to be attached to temperature bins and then averaged over the whole time period. Results represent mean coincident wet bulb temperature for appropriate bin.

If the atmospheric pressure is not being measured hourly or if there are no records of atmospheric pressure, barometric pressure for location for which bin data are being calculated can be used in previous equations in order to derive mean coincident wet bulb temperature. Barometric pressure, for certain location, is a function of the latitude Z, and can be calculated from the following equation:

$$\boldsymbol{p} = 101325 \left(1 - \frac{2.25577}{10^5} Z\right)^{5.2559} \quad \textbf{(9)}$$

Calculated corresponding number of hours and mean coincident wet bulb temperature represent bin weather data for selected location.

4 Bin weather data for City of Niš, Serbia

Following the above described procedure, bin weather data for city of Niš in Serbia have been generated using hourly measurements of outdoor dry bulb temperature, relative humidity and the atmospheric pressure for the period 2002-2017 (except 2010, 2011 and 2012). The measurements were obtained from Republic Hydrometeorological Service of Serbia-Meteorological observatory Niš and refer to Meteorogical station which is situated near the city center (longitude 21°54’E, latitude 43°20’N, altitude 202m).

Bin weather data have been calculated with 2°C temperature increments in six daily 4h shifts for each month of every year and for each year. These values were averaged, and thus monthly and annual bin data have been calculated. In this paper only bin data for the selected winter (January) and summer (July) month in Niš, as well as annual bin data are presented.

Table 1. Bin data for January

Temperature range [°C]	Time period							MCWB °C
	1-4	*5-8*	*9-12*	*13-16*	*17-20*	*21-24*	*Total h*	
-18/-16	1	1	0	0	0	0	2	-17.16
-16/-14	1	1	0	0	0	1	3	-15.3
-14/-12	2	2	1	0	1	2	8	-13.4
-12/-10	4	5	2	1	2	3	17	-11.57
-10/-8	6	6	5	3	3	5	28	-9.73
-8/-6	8	9	6	5	5	7	40	-7.66
-6/-4	13	13	10	7	11	13	67	-5.74
-4/-2	13	14	13	11	14	13	78	-3.96
-2/0	18	18	10	10	12	17	85	-1.91
0/2	24	24	20	15	18	22	123	-0.15
2/4	16	14	16	14	19	17	96	1.75
4/6	8	8	13	13	13	11	66	3.3
6/8	5	5	11	12	13	8	54	4.99
8/10	3	2	8	12	6	3	34	6.13
10/12	1	1	5	10	4	1	22	7.36
12/14	1	1	3	6	2	1	14	8.31
14/16	0	0	1	3	1	0	5	9.36
16/18	0	0	0	1	0	0	1	10.39
18/20	0	0	0	1	0	0	1	11.11

Table 2. Bin data for July

Temperature range [°C]	Time period							MCWB °C
	1-4	*5-8*	*9-12*	*13-16*	*17-20*	*21-24*	*Total h*	
10/12	1	1	0	0	0	0	2	10.30
12/14	11	6	0	0	0	2	19	11.80
14/16	20	15	1	0	2	8	46	13.49
16/18	31	23	5	1	5	18	83	15.03
18/20	31	31	6	5	8	25	106	16.33
20/22	19	24	13	4	14	26	100	17.11
22/24	7	12	17	9	16	20	81	17.68
24/26	3	8	19	12	18	12	72	18.13
26/28	1	3	22	16	17	8	67	18.81
28/30	0	1	16	17	16	4	54	19.49
30/32	0	0	13	19	12	1	45	20.14
32/34	0	0	8	17	9	0	34	20.68
34/36	0	0	3	14	5	0	22	20.98
36/38	0	0	1	7	2	0	10	20.95
38/40	0	0	0	1	0	0	1	20.50
40/42	0	0	0	2	0	0	2	20.64

Table 3. Annual bin data

Temperature range [˚C]	Time period							MCWB ˚C
	1-4	*5-8*	*9-12*	*13-16*	*17-20*	*21-24*	*Total h*	
-18/-16	1	2	0	0	0	0	3	-17.23
-16/-14	2	2	0	0	0	1	5	-15.31
-14/-12	3	2	2	0	1	3	11	-13.39
-12/-10	5	5	3	1	3	4	21	-11.54
-10/-8	9	8	6	3	5	7	38	-9.70
-8/-6	15	19	8	6	8	11	67	-7.66
-6/-4	31	33	18	13	20	27	142	-5.76
-4/-2	49	54	31	21	33	42	230	-3.84
-2/0	76	77	44	37	46	68	348	-1.87
0/2	102	107	66	54	68	98	495	-0.03
2/4	112	106	76	56	79	112	541	1.76
4/6	103	99	79	59	77	120	537	3.44
6/8	121	116	83	71	87	120	598	5.21
8/10	121	112	85	74	91	120	603	6.90
10/12	134	117	88	77	91	112	619	8.69
12/14	124	116	95	89	101	108	633	10.37
14/16	140	121	93	90	98	100	642	12.05
16/18	143	127	103	83	104	111	671	13.75
18/20	96	104	103	99	103	99	604	14.92
20/22	46	70	97	98	95	86	492	15.90
22/24	17	37	99	98	85	55	391	16.74
24/26	7	19	92	87	79	30	314	17.67
26/28	3	5	79	88	65	17	257	18.51
28/30	0	2	50	84	51	7	194	19.26
30/32	0	0	33	67	32	2	134	19.97
32/34	0	0	19	47	19	0	85	20.53
34/36	0	0	7	37	13	0	57	20.95
36/38	0	0	1	15	4	0	20	21.04
38/40	0	0	0	3	1	0	4	20.65
40/42	0	0	0	3	1	0	4	21.03

From the above table it is clear that the bins with the highest frequencies annually are 16-18°C (frequency 7.7%) and 14-16°C (frequency 7.3%).

In fig. 1, outdoor temperature frequency curve is plotted. From this curve it can be seen that for a typical air conditioned building in Niš heating is needed for approximately 4,400 h and cooling for approximately 1,300 h. The heating is needed when the outdoor temperature is bellow 12°C and the cooling when outdoor temperature is above 22°C.

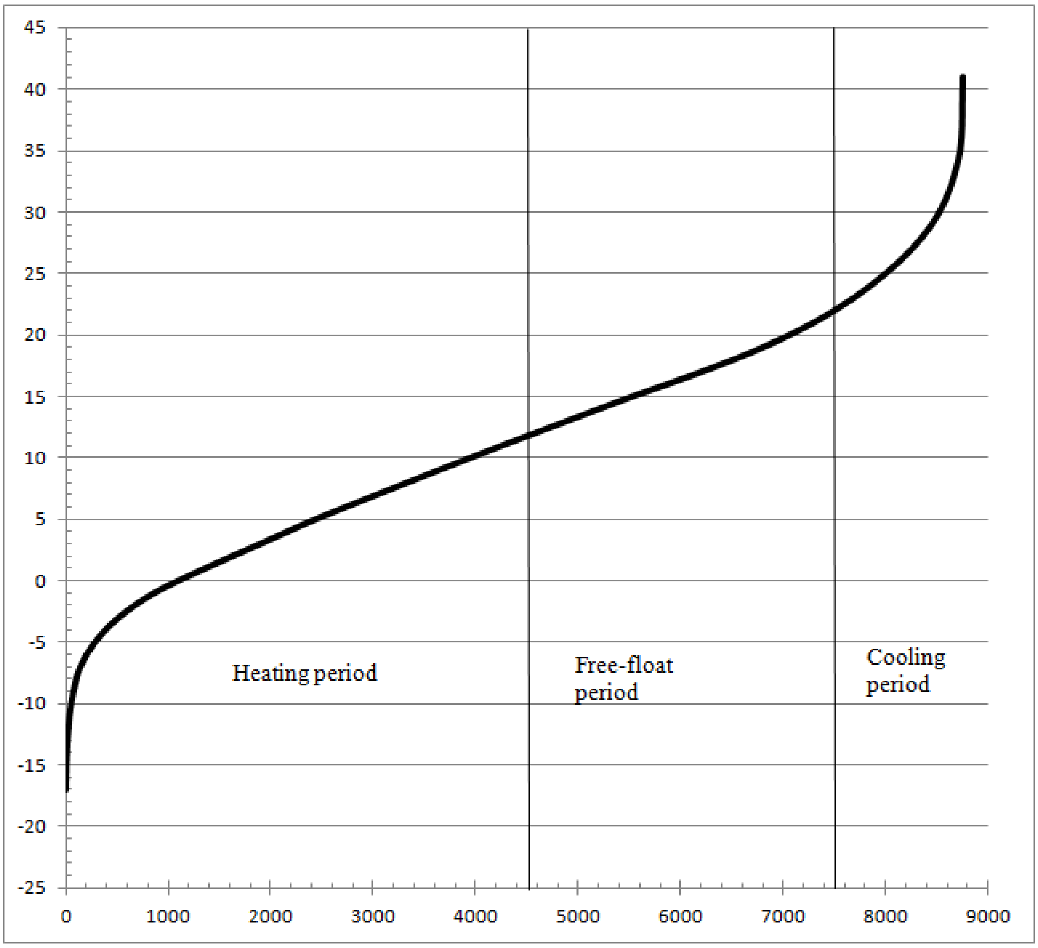

Figure 1. Outdoor temperature frequency curve for Niš, Serbia

5 Conclusions

Described procedure for bin weather data generation can be useful for building and HVAC specialist in order to obtain necessary weather inputs to perform simplified energy calculations for new or refurbished buildings using one of the bin methods. These data are of special interest for air-to-air or air-to-water heat pump applications if equipment performance are provided. The procedure can be applied for other cities where described meteorological data exist. Monthly bin data can be used for better part-load energy analysis of designed HVAC systems.

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Nomenclature

η efficiency of the HVAC system
K_{tot} total heat loss coefficient of the building (kW/K)
N_{bin} number of hours (h)
Q_{bin} energy consumption (kWh)
t_b balance point temperature (°C)
t outdoor dry bulb temperature (°C)
p atmospheric pressure (Pa)
ln natural logarithm
p_{ws} saturation pressure (Pa)
T outdoor dry bulb temperature (K)
p_w partial water vapor pressure (Pa)
φ relative humidity (%)
w humidity ratio (kg/kg)
w_s humidity ratio on saturation point (kg/kg)
t^* wet bulb temperature (°C)
w_s^* humidity ratio on saturation point for wet bulb temperature t* (kg/kg)

Z altitude (m)
Subscripts
i temperature bin
m total number of temperature bins
tot total

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