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ANALYSIS OF BIN WEATHER DATA FROM DIFFERENT PERIODS FOR THE CITY OF NIŠ

Marko G. Ignjatović[1], Mirko M. Stojiljković[1], Goran D. Vučković[1], Bratislav D. Blagojević[1]

[1]University of Niš, Faculty of Mechanical Engineering, Serbia

Abstract. *This paper presents a comparison of bin weather data for the City of Niš, over two time periods (2002-2009 and 2014-2021). The data are essential for estimating energy consumption for heating and cooling of buildings. Using weather records for the period spanning two decades (2002-2021), bin weather data ranging from the minimum to the maximum values of the outdoor dry bulb temperature recorded in this period were calculated with 2°C increments in six equal daily shifts. Hourly measurements of dry bulb temperature, relative humidity and atmospheric pressure were used in the performed calculation, and the results are presented in tabular form. These results are suitable for building energy analysis using the basic or modified bin method, especially for applications with air-to-water and air-to-air heat pump systems. In addition, one can notice that there is a tendency of shortening the heating periods and prolonging the cooling periods because of the increased recorded air temperatures.*

Key words: *Energy analysis, Bin weather data, Bin methods, Niš, Serbia*

1. INTRODUCTION

In the last few decades, it has become evident that climate change presents a real threat, and immediate actions should follow in order to reduce the negative impact it has on nature and human civilization. According to the Intergovernmental Panel on Climate Change (IPCC) [1], rising average temperature of the planet on both the global and regional level, frequent occurrence of extreme weather and melting of glaciers are only several negative examples of climate change.

The main cause of climate change is the extensive use of fossil fuels that releases enormous amounts of CO_2 into the atmosphere, which is one of the most important greenhouse gases (besides methane, fluoridized gasses and NO_x) and the baseline parameter for global warming.

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Corresponding author: Marko Ignjatović
University of Niš, Faculty of Mechanical Engineering, Serbia
E-mail: marko.ignjatovic@masfak.ni.ac.rs

Fossil fuels are most intensively used in the building, transport, and energy sectors. The building sector accounts for more than 40% of final energy in the EU [2] and more than 36% of CO_2 emissions [3] with a larger share originating from heating and air conditioning uses. Similar applies to the Republic of Serbia according to [4]. Increasing outdoor air temperature changes building energy balance and energy consumption in such a way that there is an increase in space cooling energy consumption (for warmer climates) and a reduction in space heating energy consumption (for colder climates). The associated costs follow this trend. For most regions of Serbia (except mountainous ones), especially in urban areas, building energy consumption for space heating and space cooling is necessary to maintain occupant thermal comfort, and it would be interesting to see how these offset over the selected period.

Nowadays, building energy consumption is very important and engineers, compared to past times, give special consideration to energy savings and increased building energy efficiency in order to minimize related energy costs and the environmental footprint.

To quantify how much energy a certain building will use, it is essential to perform energy analysis. Starting from the energy crisis back in the 1970s and with the increased development of computing technologies, methods for building energy consumption prediction have been improved, starting from the simplest, i.e. the degree day method, to the highly sophisticated numerical methods implemented in the state of the art building energy performance simulation software. All building energy performance methods [5-7] can be steady-state, quasi steady-state and dynamic (transient). Modeling approaches can be either forward modeling or data-driven modeling. Furthermore, energy analysis methods can be either simplified methods or simulation methods. Nearly all simplified methods are based on the steady-state models, and simulation methods are all based on the quasi-steady-state or dynamic models. Simplified methods require less data and are appropriate for simple systems and applications. If only one measure is used, methods are called single-measure methods. The most used of these methods is the degree day method. If several measures are used, methods are called multiple-measure methods. The basic bin method is the best known of these methods. Common for all simplified methods is that they are easy to comprehend, do not require special computer skills and can be used by vast majority of users.

Degree day data are available for most of the cities in Serbia [8] but the bin weather data have been calculated only occasionally [9], although these data have been published for other countries and the bin methods have been used for analysis [10-17]. The aim of this paper is to present the bin weather data for the City of Niš and to see how these data have changed over selected periods and how they can relate to building energy consumption. 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-air dry bulb temperature.

2. BIN METHODS AND BIN DATA

The basic bin method is developed on the premise that all the building loads (especially exterior loads, i.e., transmission and infiltration) can be expressed as a linear function of outdoor air dry-bulb temperature, while not considering variations in solar and latent loads (important for space cooling energy analysis). The method can account for part load

performance of HVAC equipment and is suitable to be used for energy analysis of heat pump systems (air-to-water and air-to-air), both during heating operation (calculation of seasonal COP) and cooling operation (calculation of seasonal EER).

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 [5, 7, 10-12]:

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

where:

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

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

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

$$Q_{tot} = \sum_{i=1}^{m} Q_{bin,i} \quad (2)$$

where m represents the total number of temperature bins.

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

The modified bin method [18] represents an improvement of the basic bin method in a sense that it includes variations of solar and latent loads (internal). Transmission and infiltration loads are treated as temperature-dependent, while internal loads and solar loads are treated as time-dependent. By averaging time-dependent loads and adding them to temperature-dependent loads, overall building loads are expressed as the function of the outdoor air dry-bulb temperature. In addition, latent loads can be expressed as a linear function of air humidity.

3. ANALYSIS OF OUTDOOR AIR TEMPERATURE

Hourly measurements of the outdoor dry bulb temperature, relative humidity and atmospheric pressure were used for the period 2002-2021. This period is divided into two parts, both lasting 8 years: the first includes the years 2002-2009, and the second includes the years 2014-2021. The measurements were obtained from the Republic Hydrometeorological Service of Serbia - Meteorological Observatory Niš and refer to the Meteorological Station which is situated near the city center (longitude 21°54'E, latitude 43°20N, altitude 202m). In the case of missing weather parameters for certain periods, data from the typical weather year were inserted.

The bins were selected to include all temperatures recorded in the analyzed years. The bin weather data were calculated with 2ºC temperature increments in six equal daily shifts (each with 4h duration) for each month of every year and for each year.

To calculate the mean coincident wet bulb temperature for each of the bins, wet bulb temperature for each hour of the observed period was calculated with the following procedure [7].

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

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

with constants:
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 200ºC, the saturation pressure is given by:

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

with constants:
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 the saturation pressure, partial water vapor pressure p_w is calculated using the relative humidity φ :

$$p_w = \varphi p_{ws} \tag{5}$$

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

$$w = 0.62198 \cdot \frac{p_w}{p - p_w} \tag{6}$$

The humidity ratio at the saturation point w_s is calculated using the saturation pressure:

$$w_s = 0.62198 \cdot \frac{p_{ws}}{p - p_{ws}} \tag{7}$$

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

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

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

When the values obtained from Eqs. (8) and (6) coincide, then the estimated temperature t* represents the wet bulb temperature.

4. RESULTS AND DISCUSSION

Using hourly measurements of the outdoor dry bulb temperature, relative humidity and atmospheric pressure, the bin weather data were calculated for every month and each year. These values were divided by the number of years in the period considered, and thus monthly and annual bin data were calculated. In addition, for each bin, mean coincident wet bulb temperature was calculated as the average of the related wet bulb temperatures. Tables 1–12 represent monthly and table 13 represents annual bin data for the City of Niš, for the two periods (values in italic are related to the period 2014-2021). Also, the actual bin data for the City of Niš can be calculated as the average of the corresponding values given in these tables.

Table 1. Bin data for January for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
-18/-16	0	*1*	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	1	*1*	-16.5	*-17.6*
-16/-14	2	*1*	2	*0*	0	*0*	0	*0*	0	*0*	1	*1*	5	*2*	-15.2	*-15.4*
-14/-12	1	*1*	2	*1*	0	*1*	0	*0*	1	*1*	2	*1*	6	*5*	-13.4	*-13.3*
-12/-10	3	*3*	3	*5*	2	*1*	0	*1*	2	*1*	2	*2*	12	*13*	-11.5	*-11.6*
-10/-8	4	*5*	3	*6*	3	*4*	2	*2*	3	*2*	4	*3*	19	*22*	-9.7	*-9.8*
-8/-6	8	*7*	9	*8*	5	*5*	5	*2*	5	*3*	7	*4*	39	*29*	-7.5	*-7.7*
-6/-4	13	*13*	16	*12*	10	*8*	6	*4*	10	*8*	11	*12*	66	*57*	-5.6	*-5.7*
-4/-2	15	*16*	14	*17*	12	*13*	11	*9*	13	*14*	13	*16*	78	*85*	-3.9	*-3.8*
-2/0	18	*20*	18	*20*	11	*14*	8	*12*	11	*16*	18	*21*	84	*103*	-1.8	*-1.8*
0/2	26	*23*	25	*23*	20	*24*	15	*20*	21	*22*	26	*22*	133	*134*	-0.2	*0.0*
2/4	18	*15*	16	*13*	18	*17*	16	*17*	21	*14*	18	*13*	107	*89*	1.8	*1.8*
4/6	7	*9*	7	*10*	15	*12*	17	*9*	15	*13*	12	*14*	73	*67*	3.3	*3.5*
6/8	4	*5*	4	*5*	12	*9*	12	*12*	12	*14*	6	*8*	50	*53*	5.0	*4.9*
8/10	3	*3*	2	*2*	8	*8*	12	*12*	6	*7*	2	*4*	33	*36*	6.1	*6.2*
10/12	1	*2*	1	*1*	4	*5*	9	*10*	2	*6*	1	*2*	18	*26*	7.31	*7.2*
12/14	1	*0*	1	*1*	3	*2*	5	*9*	2	*2*	1	*1*	13	*15*	8.6	*7.7*
14/16	0	*0*	0	*0*	1	*1*	3	*4*	0	*1*	0	*0*	4	*6*	9.5	*9.1*
16/18	0	*0*	0	*0*	0	*0*	1	*1*	0	*0*	0	*0*	1	*1*	10.3	*10.5*
18/20	0	*0*	0	*0*	0	*0*	1	*0*	0	*0*	0	*0*	1	*0*	11.1	—
20/22	0	*0*	0	*0*	0	*0*	1	*0*	0	*0*	0	*0*	1	*0*	11.3	—

Table 2. Bin data for February for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
-18/-16	1	*0*	2	*0*	0	*0*	0	*0*	0	*0*	0	*0*	3	*0*	-17.3	—
-16/-14	2	*0*	2	*0*	0	*0*	0	*0*	0	*0*	0	*0*	4	*0*	-15.3	—
-14/-12	1	*0*	1	*0*	1	*0*	0	*0*	0	*0*	2	*0*	5	*0*	-13.3	—

-12/-10	1	*0*	1	*0*	1	*0*	0	*0*	1	*0*	2	*0*	6	*0*	-11.6	—
-10/-8	1	*1*	2	*2*	2	*0*	0	*0*	1	*0*	2	*1*	8	*4*	-9.8	*-9.3*
-8/-6	6	*3*	6	*3*	2	*1*	1	*0*	3	*1*	3	*2*	21	*10*	-7.7	*-8.0*
-6/-4	10	*5*	13	*5*	6	*2*	5	*1*	4	*2*	6	*2*	44	*17*	-5.8	*-6.1*
-4/-2	14	*8*	13	*11*	9	*5*	7	*2*	10	*3*	13	*5*	66	*34*	-3.9	*-4.0*
-2/0	15	*12*	14	*13*	11	*5*	9	*2*	14	*6*	16	*9*	79	*47*	-1.9	*-2.2*
0/2	19	*17*	18	*18*	16	*12*	14	*7*	16	*10*	16	*15*	99	*79*	-0.1	*-0.1*
2/4	15	*21*	15	*24*	14	*14*	12	*12*	11	*16*	13	*21*	80	*108*	1.4	*1.7*
4/6	12	*18*	11	*15*	12	*19*	11	*11*	10	*15*	14	*17*	70	*95*	3.2	*3.2*
6/8	8	*15*	8	*11*	10	*15*	10	*13*	11	*12*	11	*16*	58	*82*	4.7	*4.7*
8/10	6	*5*	5	*5*	9	*14*	6	*13*	10	*14*	10	*10*	46	*61*	6.2	*6.0*
10/12	1	*4*	1	*4*	8	*9*	7	*10*	10	*12*	4	*7*	31	*46*	7.2	*7.2*
12/14	0	*2*	0	*1*	6	*7*	9	*12*	7	*9*	0	*4*	22	*35*	8.0	*8.2*
14/16	0	*1*	0	*0*	3	*6*	10	*12*	3	*7*	0	*2*	16	*28*	8.9	*9.2*
16/18	0	*0*	0	*0*	2	*2*	7	*8*	1	*2*	0	*1*	10	*13*	9.9	*10.2*
18/20	0	*0*	0	*0*	0	*1*	2	*5*	0	*2*	0	*0*	2	*8*	10.6	*11.0*
20/22	0	*0*	0	*0*	0	*0*	1	*3*	0	*1*	0	*0*	1	*4*	11.4	*11.7*
22/24	0	*0*	0	*0*	0	*0*	1	*1*	0	*0*	0	*0*	1	*1*	11.7	*13.8*

Table 3. Bin data for March for Niš, Serbia

Temperature range	Time period														MCWB	
°C	1-4		5-8		9-12		13-16		17-20		21-24		Total h		°C	
-12/-10	0	*0*	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	1	*0*	-10.9	—
-10/-8	1	*0*	1	*0*	0	*0*	0	*0*	0	*0*	1	*0*	3	*0*	-9.7	—
-8/-6	1	*0*	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	2	*0*	-8.0	—
-6/-4	2	*0*	1	*0*	1	*0*	0	*0*	1	*0*	1	*0*	6	*0*	-5.8	—
-4/-2	6	*2*	7	*2*	1	*0*	0	*0*	2	*0*	3	*1*	19	*5*	-3.8	*-3.2*
-2/0	12	*7*	11	*10*	5	*2*	4	*1*	5	*1*	8	*3*	45	*24*	-1.9	*-1.8*
0/2	17	*19*	19	*18*	6	*4*	4	*2*	6	*5*	12	*8*	64	*56*	-0.0	*0.0*
2/4	18	*22*	19	*26*	11	*12*	6	*6*	10	*10*	15	*17*	79	*93*	1.5	*1.6*
4/6	23	*29*	20	*27*	13	*14*	9	*9*	15	*12*	21	*22*	101	*113*	3.1	*3.3*
6/8	17	*21*	17	*21*	16	*17*	11	*11*	15	*16*	19	*24*	95	*110*	4.5	*4.7*
8/10	11	*12*	12	*9*	14	*20*	14	*11*	14	*20*	16	*21*	81	*93*	5.7	*6.0*
10/12	9	*6*	7	*6*	14	*17*	13	*14*	16	*16*	13	*11*	72	*70*	7.2	*6.9*
12/14	4	*3*	5	*4*	15	*15*	11	*18*	14	*13*	9	*9*	58	*62*	8.4	*7.8*
14/16	1	*2*	1	*1*	12	*9*	15	*14*	10	*12*	4	*4*	43	*42*	9.1	*8.6*
16/18	1	*1*	1	*0*	8	*7*	13	*14*	8	*7*	1	*3*	32	*32*	9.9	*9.5*
18/20	1	*0*	1	*0*	5	*4*	10	*8*	4	*6*	1	*1*	22	*19*	10.9	*10.7*
20/22	0	*0*	0	*0*	2	*2*	7	*8*	3	*5*	0	*0*	12	*15*	11.4	*11.4*
22/24	0	*0*	0	*0*	1	*1*	5	*5*	1	*1*	0	*0*	7	*7*	12.6	*12.3*
24/26	0	*0*	0	*0*	0	*0*	2	*3*	0	*0*	0	*0*	2	*3*	14.2	*13.4*

Table 4. Bin data for April for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
-4/-2	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	1	*0*	-3.5	—
-2/0	1	*3*	2	*2*	0	*0*	0	*0*	0	*0*	2	*0*	5	*5*	-2.2	*-1.4*
0/2	3	*4*	3	*5*	1	*1*	0	*0*	1	*0*	0	*2*	8	*12*	-0.3	*-0.0*
2/4	6	*9*	7	*10*	2	*2*	1	*2*	1	*3*	3	*6*	20	*32*	1.5	*2.0*
4/6	14	*15*	11	*15*	2	*5*	3	*3*	3	*5*	5	*8*	38	*51*	3.6	*3.6*
6/8	22	*20*	18	*19*	4	*7*	2	*4*	4	*6*	11	*13*	61	*69*	5.3	*5.3*
8/10	30	*19*	27	*21*	7	*9*	4	*6*	9	*9*	23	*18*	100	*82*	7.0	*6.9*
10/12	28	*24*	29	*21*	12	*12*	6	*7*	13	*12*	32	*19*	120	*95*	8.6	*8.3*
12/14	9	*15*	13	*14*	18	*16*	10	*9*	22	*14*	23	*22*	95	*90*	9.6	*9.4*
14/16	5	*7*	8	*7*	21	*16*	13	*11*	21	*16*	15	*16*	83	*73*	10.4	*10.3*
16/18	1	*3*	2	*4*	22	*16*	18	*14*	20	*15*	5	*10*	68	*62*	11.2	*11.2*
18/20	0	*1*	0	*2*	18	*15*	21	*15*	15	*14*	1	*4*	55	*51*	11.9	*12.0*
20/22	0	*0*	0	*0*	9	*10*	22	*15*	7	*12*	0	*2*	38	*39*	12.5	*12.7*
22/24	0	*0*	0	*0*	3	*7*	13	*13*	3	*7*	0	*0*	19	*27*	13.1	*13.6*
24/26	0	*0*	0	*0*	1	*3*	4	*9*	1	*4*	0	*0*	6	*16*	14.3	*14.6*
26/28	0	*0*	0	*0*	0	*1*	3	*8*	0	*3*	0	*0*	3	*12*	15.5	*15.9*
28/30	0	*0*	0	*0*	0	*0*	0	*3*	0	*0*	0	*0*	0	*3*	—	*17.1*
30/32	0	*0*	0	*0*	0	*0*	0	*1*	0	*0*	0	*0*	0	*1*	—	*16.8*

Table 5. Bin data for May for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
2/4	1	*0*	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	2	*0*	2.8	—
4/6	3	*3*	2	*2*	0	*0*	0	*0*	0	*0*	0	*0*	5	*5*	4.5	*4.7*
6/8	9	*7*	6	*5*	0	*1*	0	*0*	0	*0*	3	*3*	18	*16*	6.2	*6.2*
8/10	13	*14*	10	*14*	2	*2*	0	*2*	1	*2*	8	*6*	34	*40*	8.0	*8.1*
10/12	22	*32*	17	*26*	2	*5*	1	*3*	5	*5*	16	*19*	63	*90*	9.6	*9.8*
12/14	24	*25*	22	*24*	8	*12*	6	*5*	11	*12*	20	*24*	91	*102*	11.3	*11.4*
14/16	27	*26*	24	*25*	12	*15*	6	*8*	15	*13*	23	*26*	107	*113*	12.6	*12.6*
16/18	18	*12*	19	*15*	13	*16*	12	*14*	17	*20*	20	*20*	99	*97*	13.6	*13.5*
18/20	5	*4*	12	*8*	18	*19*	13	*12*	16	*19*	18	*15*	82	*77*	14.3	*14.3*
20/22	2	*1*	7	*4*	18	*21*	14	*17*	16	*17*	10	*9*	67	*69*	15.3	*15.1*
22/24	0	*0*	4	*1*	18	*16*	15	*20*	15	*15*	5	*1*	57	*53*	16.1	*15.6*
24/26	0	*0*	0	*0*	15	*10*	16	*15*	13	*12*	1	*1*	45	*38*	16.9	*16.7*
26/28	0	*0*	0	*0*	11	*6*	13	*16*	9	*6*	0	*0*	33	*28*	17.9	*17.5*
28/30	0	*0*	0	*0*	5	*1*	16	*9*	5	*2*	0	*0*	26	*12*	18.5	*18.3*
30/32	0	*0*	0	*0*	2	*0*	7	*2*	1	*1*	0	*0*	10	*3*	18.6	*18.6*
32/34	0	*0*	0	*0*	0	*0*	4	*1*	0	*0*	0	*0*	4	*1*	18.9	*19.0*
34/36	0	*0*	0	*0*	0	*0*	1	*0*	0	*0*	0	*0*	1	*0*	20.7	—

Table 6. Bin data for June for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
6/8	1	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	1	*0*	6.4	—
8/10	2	*2*	2	*2*	0	*0*	0	*0*	0	*0*	1	*0*	5	*4*	8.3	*8.6*
10/12	11	*7*	7	*6*	1	*0*	1	*0*	0	*0*	4	*2*	24	*15*	10.1	*10.3*
12/14	16	*14*	9	*11*	2	*2*	1	*1*	4	*1*	8	*6*	40	*35*	11.9	*11.8*
14/16	27	*27*	21	*22*	4	*4*	3	*2*	5	*5*	15	*15*	75	*75*	13.6	*13.7*
16/18	33	*34*	25	*30*	7	*10*	3	*5*	8	*10*	23	*29*	99	*118*	15.0	*15.3*
18/20	19	*19*	21	*21*	8	*13*	7	*7*	12	*13*	27	*23*	94	*96*	16.1	*16.1*
20/22	8	*12*	17	*16*	14	*14*	9	*10*	16	*14*	22	*20*	86	*86*	16.9	*16.9*
22/24	3	*4*	11	*8*	17	*19*	12	*14*	18	*19*	12	*14*	73	*78*	17.5	*17.6*
24/26	0	*1*	6	*3*	22	*20*	13	*15*	18	*18*	6	*7*	65	*64*	18.5	*18.3*
26/28	0	*0*	1	*1*	20	*17*	20	*19*	16	*16*	2	*3*	59	*56*	19.1	*19.0*
28/30	0	*0*	0	*0*	14	*12*	18	*18*	12	*11*	0	*1*	44	*42*	19.7	*20.0*
30/32	0	*0*	0	*0*	7	*6*	18	*17*	6	*7*	0	*0*	31	*30*	20.4	*20.9*
32/34	0	*0*	0	*0*	3	*2*	8	*7*	3	*3*	0	*0*	14	*12*	21.4	*21.6*
34/36	0	*0*	0	*0*	1	*1*	6	*3*	2	*2*	0	*0*	9	*6*	21.9	*21.6*
36/38	0	*0*	0	*0*	0	*0*	1	*2*	0	*1*	0	*0*	1	*3*	21.8	*21.6*

Table 7. Bin data for July for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
10/12	2	*2*	1	*2*	0	*0*	0	*0*	0	*0*	0	*0*	3	*4*	10.6	*10.2*
12/14	13	*5*	7	*3*	0	*0*	0	*0*	0	*0*	3	*1*	23	*9*	12.0	*11.5*
14/16	21	*18*	14	*15*	2	*0*	1	*0*	2	*1*	9	*5*	49	*39*	13.5	*13.6*
16/18	31	*32*	23	*24*	5	*4*	2	*1*	6	*2*	20	*15*	87	*78*	15.2	*15.3*
18/20	31	*33*	32	*32*	6	*7*	4	*4*	8	*9*	26	*29*	107	*114*	16.5	*16.8*
20/22	18	*19*	22	*27*	13	*11*	5	*4*	15	*14*	26	*27*	99	*102*	17.3	*17.4*
22/24	6	*9*	12	*12*	16	*20*	8	*8*	17	*14*	20	*21*	79	*84*	17.8	*17.9*
24/26	2	*4*	9	*6*	17	*24*	12	*14*	18	*18*	11	*13*	69	*79*	18.3	*18.4*
26/28	0	*1*	3	*2*	22	*22*	16	*17*	16	*19*	6	*8*	63	*69*	19.0	*19.1*
28/30	0	*1*	1	*1*	15	*18*	16	*22*	15	*18*	2	*4*	49	*64*	19.6	*19.7*
30/32	0	*0*	0	*0*	15	*10*	18	*18*	12	*13*	1	*1*	46	*42*	20.2	*20.2*
32/34	0	*0*	0	*0*	9	*6*	17	*14*	8	*9*	0	*0*	34	*29*	20.8	*20.7*
34/36	0	*0*	0	*0*	2	*2*	15	*13*	4	*5*	0	*0*	21	*20*	21.0	*21.0*
36/38	0	*0*	0	*0*	1	*0*	6	*8*	2	*2*	0	*0*	9	*10*	20.6	*21.4*
38/40	0	*0*	0	*0*	1	*0*	2	*1*	1	*0*	0	*0*	4	*1*	20.3	*21.9*
40/42	0	*0*	0	*0*	0	*0*	2	*0*	0	*0*	0	*0*	2	*0*	20.6	—

Table 8. Bin data for August for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
8/10	1	*0*	0	*1*	0	*0*	0	*0*	0	*0*	0	*0*	1	*1*	8.8	*8.3*
10/12	2	*3*	2	*3*	0	*0*	0	*0*	0	*0*	1	*0*	5	*6*	10.4	*10.0*
12/14	7	*7*	6	*6*	0	*0*	0	*0*	1	*0*	2	*1*	16	*14*	12.1	*11.5*
14/16	22	*15*	17	*16*	1	*1*	0	*0*	2	*1*	7	*7*	49	*40*	13.9	*13.5*
16/18	40	*34*	34	*29*	5	*4*	4	*2*	7	*5*	24	*15*	114	*89*	15.5	*15.1*
18/20	29	*34*	27	*31*	9	*9*	5	*3*	11	*7*	29	*24*	110	*108*	16.6	*16.4*
20/22	16	*18*	20	*21*	12	*11*	4	*3*	15	*10*	28	*29*	95	*92*	17.5	*17.1*
22/24	4	*9*	10	*11*	18	*17*	8	*7*	18	*13*	18	*22*	76	*79*	18.0	*17.6*
24/26	2	*3*	5	*5*	23	*20*	12	*9*	19	*18*	10	*15*	71	*70*	18.6	*18.3*
26/28	1	*1*	2	*1*	20	*22*	16	*13*	18	*20*	3	*7*	60	*64*	19.1	*18.9*
28/30	0	*0*	1	*0*	15	*18*	19	*19*	14	*20*	2	*3*	51	*60*	19.6	*19.6*
30/32	0	*0*	0	*0*	11	*13*	19	*23*	9	*14*	0	*1*	39	*51*	20.0	*20.0*
32/34	0	*0*	0	*0*	6	*8*	16	*21*	5	*8*	0	*0*	27	*37*	20.3	*20.3*
34/36	0	*0*	0	*0*	3	*1*	11	*18*	4	*5*	0	*0*	18	*24*	20.7	*20.8*
36/38	0	*0*	0	*0*	1	*0*	6	*5*	1	*2*	0	*0*	8	*7*	21.1	*20.8*
38/40	0	*0*	0	*0*	0	*0*	3	*1*	0	*1*	0	*0*	3	*2*	20.9	*20.7*
40/42	0	*0*	0	*0*	0	*0*	1	*0*	0	*0*	0	*0*	1	*0*	22.0	—

Table 9. Bin data for September for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
2/4	0	*0*	0	*1*	0	*0*	0	*0*	0	*0*	0	*0*	0	*1*	—	*2.5*
4/6	1	*2*	2	*2*	0	*0*	0	*0*	0	*0*	0	*0*	3	*4*	4.4	*4.1*
6/8	5	*5*	4	*5*	0	*0*	0	*0*	0	*0*	2	*2*	11	*12*	6.2	*5.9*
8/10	14	*5*	13	*6*	0	*0*	0	*0*	2	*1*	6	*5*	35	*17*	8.0	*7.8*
10/12	21	*12*	19	*15*	5	*3*	4	*0*	7	*3*	17	*8*	73	*41*	9.8	*9.6*
12/14	27	*25*	25	*24*	11	*7*	7	*3*	13	*8*	21	*12*	104	*79*	11.5	*11.1*
14/16	26	*33*	25	*27*	12	*8*	6	*5*	13	*10*	23	*21*	105	*104*	13.1	*12.8*
16/18	17	*22*	18	*21*	14	*16*	10	*7*	17	*14*	28	*29*	104	*109*	14.2	*14.0*
18/20	8	*9*	9	*13*	18	*18*	12	*12*	22	*18*	16	*22*	85	*92*	14.9	*14.8*
20/22	1	*4*	4	*4*	16	*18*	11	*10*	18	*17*	6	*10*	56	*63*	15.6	*15.4*
22/24	0	*1*	1	*2*	18	*18*	13	*13*	14	*17*	1	*7*	47	*58*	16.3	*16.1*
24/26	0	*1*	0	*0*	14	*15*	21	*13*	7	*15*	0	*3*	42	*47*	16.8	*17.0*
26/28	0	*1*	0	*0*	8	*10*	16	*22*	4	*8*	0	*1*	28	*42*	17.7	*17.4*
28/30	0	*0*	0	*0*	3	*4*	11	*18*	2	*5*	0	*0*	16	*27*	18.4	*17.9*
30/32	0	*0*	0	*0*	1	*2*	6	*8*	1	*2*	0	*0*	8	*12*	18.6	*18.6*
32/34	0	*0*	0	*0*	0	*1*	2	*4*	0	*1*	0	*0*	2	*6*	19.6	*19.6*
34/36	0	*0*	0	*0*	0	*0*	1	*4*	0	*1*	0	*0*	1	*5*	20.1	*20.4*
36/38	0	*0*	0	*0*	0	*0*	0	*1*	0	*0*	0	*0*	0	*1*	—	*22.1*

Table 10. Bin data for October for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
-2/0	1	*0*	1	*1*	0	*0*	0	*0*	0	*0*	0	*0*	2	*1*	-1.0	*-0.8*
0/2	3	*3*	4	*4*	1	*0*	1	*0*	2	*0*	3	*0*	14	*7*	0.6	*0.9*
2/4	7	*7*	8	*8*	2	*1*	1	*0*	3	*1*	5	*3*	26	*20*	2.2	*2.3*
4/6	10	*9*	10	*10*	4	*3*	3	*0*	6	*2*	9	*7*	42	*31*	4.1	*4.2*
6/8	15	*21*	18	*26*	7	*8*	4	*3*	9	*8*	12	*15*	65	*81*	5.8	*6.1*
8/10	27	*29*	23	*27*	10	*14*	8	*8*	10	*17*	16	*22*	94	*117*	7.8	*7.7*
10/12	28	*24*	25	*17*	12	*16*	8	*11*	13	*15*	25	*21*	111	*104*	9.5	*9.2*
12/14	19	*16*	19	*18*	16	*17*	9	*11*	20	*15*	27	*25*	110	*102*	11.2	*10.7*
14/16	10	*9*	11	*8*	18	*16*	14	*12*	22	*19*	17	*18*	92	*82*	12.4	*11.9*
16/18	4	*4*	4	*4*	16	*18*	8	*11*	19	*16*	8	*10*	59	*63*	13.5	*13.3*
18/20	0	*2*	1	*1*	16	*13*	15	*17*	12	*16*	1	*2*	45	*51*	13.9	*14.1*
20/22	0	*0*	0	*0*	11	*9*	22	*15*	5	*8*	1	*1*	39	*33*	14.9	*14.9*
22/24	0	*0*	0	*0*	7	*6*	16	*16*	2	*5*	0	*0*	25	*27*	15.9	*16.1*
24/26	0	*0*	0	*0*	4	*2*	9	*12*	1	*2*	0	*0*	14	*16*	16.8	*16.4*
26/28	0	*0*	0	*0*	0	*1*	5	*6*	0	*0*	0	*0*	5	*7*	17.3	*16.8*
28/30	0	*0*	0	*0*	0	*0*	1	*2*	0	*0*	0	*0*	1	*2*	18.3	*18.4*

Table 11. Bin data for November for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
-6/-4	0	*1*	2	*0*	0	*0*	0	*0*	0	*0*	0	*1*	2	*2*	-5.1	*-5.8*
-4/-2	3	*1*	4	*2*	0	*0*	0	*0*	0	*1*	1	*1*	8	*5*	-3.5	*-3.5*
-2/0	12	*4*	12	*8*	3	*2*	0	*1*	3	*2*	6	*4*	36	*21*	-1.5	*-1.4*
0/2	15	*17*	20	*18*	8	*5*	6	*3*	9	*5*	16	*6*	74	*54*	0.4	*0.4*
2/4	27	*21*	23	*20*	13	*12*	8	*8*	14	*11*	18	*19*	103	*91*	2.1	*2.0*
4/6	20	*17*	17	*17*	14	*14*	10	*5*	13	*13*	25	*21*	99	*87*	3.8	*3.8*
6/8	15	*20*	16	*19*	15	*18*	10	*15*	20	*19*	19	*20*	95	*111*	5.5	*5.5*
8/10	13	*17*	13	*13*	18	*20*	14	*10*	23	*22*	16	*21*	97	*103*	7.1	*7.3*
10/12	9	*10*	7	*9*	17	*15*	11	*17*	17	*16*	8	*11*	69	*78*	8.8	*8.7*
12/14	3	*7*	3	*9*	13	*12*	20	*16*	11	*14*	7	*8*	57	*66*	9.9	*9.9*
14/16	3	*3*	2	*3*	9	*10*	20	*15*	6	*8*	4	*5*	44	*44*	10.9	*11.0*
16/18	0	*1*	1	*1*	6	*6*	10	*14*	3	*5*	0	*2*	20	*29*	12.2	*12.0*
18/20	0	*1*	0	*1*	2	*3*	6	*10*	1	*3*	0	*1*	9	*19*	13.1	*12.9*
20/22	0	*0*	0	*0*	1	*2*	2	*3*	0	*1*	0	*0*	3	*6*	14.7	*14.1*
22/24	0	*0*	0	*0*	1	*1*	2	*2*	0	*0*	0	*0*	3	*3*	15.3	*15.0*
24/26	0	*0*	0	*0*	0	*0*	1	*1*	0	*0*	0	*0*	1	*1*	16.5	*16.0*

Table 12. Bin data for December for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
-10/-8	1	*1*	2	*1*	0	*0*	0	*0*	0	*1*	1	*1*	4	*4*	-9.3	*-9.5*
-8/-6	3	*2*	5	*3*	2	*0*	0	*0*	2	*1*	2	*1*	14	*7*	-7.4	*-7.6*
-6/-4	8	*7*	7	*5*	4	*3*	3	*2*	6	*1*	7	*4*	35	*22*	-5.8	*-5.6*
-4/-2	16	*12*	17	*16*	9	*7*	5	*3*	10	*7*	13	*9*	70	*54*	-3.5	*-3.7*
-2/0	22	*18*	21	*20*	18	*14*	17	*7*	18	*10*	21	*15*	117	*84*	-1.8	*-1.8*
0/2	19	*30*	23	*27*	22	*20*	19	*15*	20	*24*	21	*29*	124	*145*	0.0	*0.2*
2/4	17	*28*	13	*26*	14	*27*	12	*21*	17	*28*	19	*32*	92	*162*	1.9	*2.1*
4/6	10	*13*	10	*12*	15	*25*	13	*24*	16	*25*	14	*16*	78	*115*	3.6	*3.7*
6/8	14	*5*	14	*6*	14	*13*	15	*19*	13	*11*	12	*9*	82	*63*	5.4	*5.1*
8/10	7	*3*	8	*3*	12	*6*	16	*13*	12	*8*	7	*4*	62	*37*	6.8	*6.3*
10/12	4	*3*	2	*3*	7	*3*	10	*7*	4	*5*	3	*3*	30	*24*	8.3	*7.5*
12/14	2	*1*	1	*1*	3	*3*	8	*8*	3	*2*	3	*1*	20	*16*	9.4	*8.4*
14/16	1	*1*	1	*1*	2	*2*	3	*3*	2	*1*	1	*0*	10	*8*	10.0	*9.7*
16/18	0	*0*	0	*0*	2	*1*	2	*2*	1	*0*	0	*0*	5	*3*	11.4	*10.6*
18/20	0	*0*	0	*0*	0	*0*	1	*0*	0	*0*	0	*0*	1	*0*	12.5	—

Table 13. Annual bin data for Niš, Serbia

Temperature range °C	Time period												Total h		MCWB °C	
	1-4		5-8		9-12		13-16		17-20		21-24					
-18/-16	1	*1*	3	*0*	0	*0*	0	*0*	0	*0*	0	*0*	4	*1*	-17.1	*-17.6*
-16/-14	4	*1*	4	*0*	0	*0*	0	*0*	0	*0*	1	*1*	9	*2*	-15.3	*-15.5*
-14/-12	2	*1*	3	*1*	1	*1*	0	*0*	1	*1*	4	*1*	11	*5*	-13.4	*-13.4*
-12/-10	4	*3*	5	*5*	3	*1*	0	*1*	3	*1*	4	*2*	19	*13*	-11.5	*-11.6*
-10/-8	7	*7*	8	*9*	5	*4*	2	*2*	4	*3*	8	*5*	34	*30*	-9.6	*-9.7*
-8/-6	18	*12*	21	*14*	9	*6*	6	*2*	10	*5*	12	*7*	76	*46*	-7.6	*-7.7*
-6/-4	33	*26*	39	*22*	21	*13*	14	*7*	21	*11*	25	*19*	153	*98*	-5.7	*-5.8*
-4/-2	55	*39*	55	*48*	31	*25*	23	*14*	35	*25*	43	*32*	242	*183*	-3.8	*-3.8*
-2/0	81	*64*	79	*74*	48	*37*	38	*23*	51	*35*	71	*52*	368	*285*	-1.8	*-1.8*
0/2	102	*113*	112	*113*	74	*66*	59	*47*	75	*66*	94	*82*	516	*487*	-0.0	*0.1*
2/4	109	*123*	102	*128*	74	*85*	56	*66*	77	*83*	91	*111*	509	*596*	1.8	*1.9*
4/6	100	*115*	90	*110*	75	*92*	66	*61*	78	*85*	100	*105*	509	*568*	3.5	*3.6*
6/8	110	*119*	105	*117*	78	*88*	64	*77*	84	*86*	95	*110*	536	*597*	5.2	*5.2*
8/10	127	*109*	115	*103*	80	*93*	74	*75*	87	*100*	105	*111*	588	*591*	7.0	*6.9*
10/12	138	*129*	118	*113*	82	*85*	70	*79*	87	*90*	124	*103*	619	*599*	8.8	*8.6*
12/14	125	*120*	111	*116*	95	*93*	86	*92*	108	*90*	124	*114*	649	*625*	10.5	*10.1*
14/16	143	*142*	124	*125*	97	*88*	94	*86*	101	*94*	118	*119*	677	*654*	12.2	*12.0*
16/18	145	*143*	127	*128*	100	*100*	90	*93*	107	*96*	129	*134*	698	*694*	13.9	*13.7*
18/20	93	*103*	103	*109*	100	*102*	97	*93*	101	*107*	119	*121*	613	*635*	15.0	*15.0*
20/22	45	*54*	70	*72*	96	*98*	98	*88*	95	*99*	93	*98*	497	*509*	16.1	*15.9*
22/24	13	*23*	38	*34*	99	*105*	93	*99*	88	*91*	56	*65*	387	*417*	16.9	*16.8*
24/26	4	*9*	20	*14*	96	*94*	90	*91*	77	*87*	28	*39*	315	*334*	17.8	*17.6*
26/28	1	*3*	6	*4*	81	*79*	89	*101*	63	*72*	11	*19*	251	*278*	18.7	*18.4*
28/30	0	*1*	2	*1*	52	*53*	81	*91*	48	*56*	4	*8*	187	*210*	19.3	*19.4*
30/32	0	*0*	0	*0*	36	*31*	68	*69*	29	*37*	1	*2*	134	*139*	20.0	*20.1*
32/34	0	*0*	0	*0*	18	*17*	47	*47*	16	*21*	0	*0*	81	*85*	20.6	*20.5*
34/36	0	*0*	0	*0*	6	*4*	34	*38*	10	*13*	0	*0*	50	*55*	21.0	*20.9*
36/38	0	*0*	0	*0*	2	*0*	13	*16*	3	*5*	0	*0*	18	*21*	20.9	*21.3*
38/40	0	*0*	0	*0*	1	*0*	5	*2*	1	*1*	0	*0*	7	*3*	20.7	*21.1*
40/42	0	*0*	0	*0*	0	*0*	3	*0*	0	*0*	0	*0*	3	*0*	20.9	—

From the previous tables, the bins with higher frequencies annually are 16-18ºC (frequencies 7.97% and 7.92% for the first and the second period, respectively) and 14-16ºC (frequencies 7.73% and 7.47% respectively for the analyzed periods). One can notice that there is a strong reduction in the number of occurrences for bins related to outdoor temperatures when temperature is below 0ºC during the second period, and in average this reduction is 41.45%. For winter design outdoor temperature (for Niš -14.5ºC) or below, this reduction is much higher and has the value of 76.39%. Similar applies for the summer design outdoor temperature (for Niš +35ºC) or above, where reduction of 32.62% occurred. The largest increase of occurrence is noticed for bins between 2ºC and 6ºC and above 22ºC, in average 13.35% and 9.02% respectively. The presented data suggest that, compared to building energy needs for the first period, there is a small change in energy needs for space heating (reduction), and not so small a change in energy needs for space cooling (increase).

The previous statement can be illustrated with the outdoor temperature frequency curve (Fig. 1). Assuming that heating is needed when the outdoor temperature is below 11ºC (average for the bin 10-12ºC) and cooling when outdoor temperature is above 21ºC (average value for the bin 20-22ºC), during the second period (2014-2021) there is approximately a 100-hour reduction of heating time (4101h compared to 4193h during first period), but on the other hand there is an increase of cooling time (1542h compared to 1433h during first period). This suggests that there is a slight tendency in offsetting heating energy demand towards cooling energy demand, due to having more hours within a year when cooling is needed, because of the increased average outside air temperature.

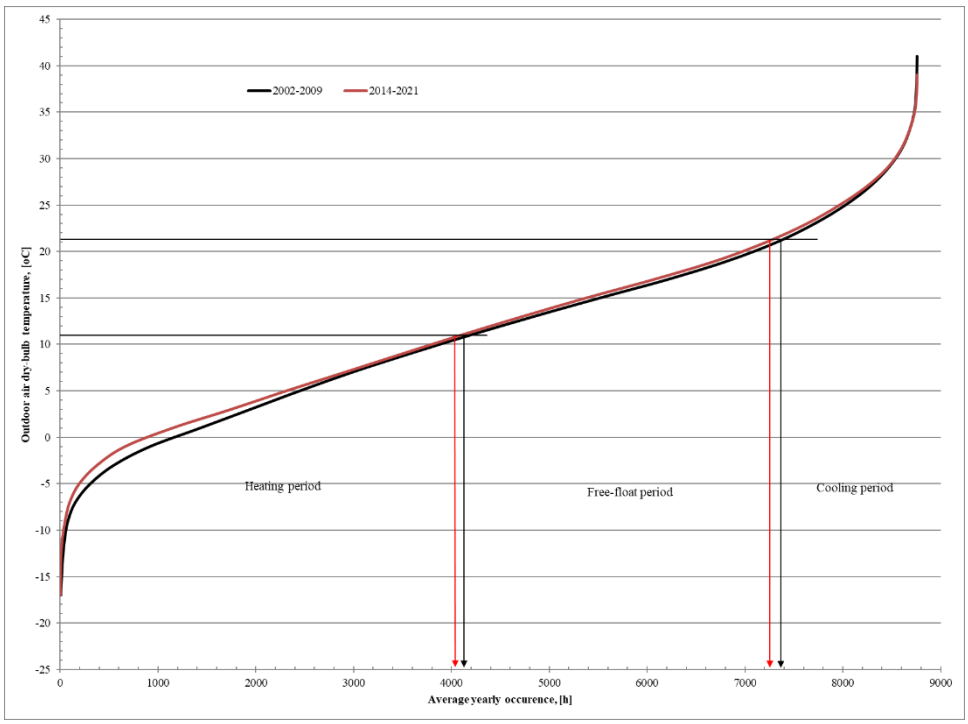

Fig. 1 Outdoor temperature frequency curve for Niš, Serbia

5. CONCLUSION

The data presented in this paper can be useful for a building and HVAC specialist to perform simplified energy calculations for new or refurbished buildings in the City of Niš. Monthly bin data can be used for better part-load energy analysis of designed HVAC systems. In addition, these data show that there is an increase in outdoor air temperature, which translated to increased time when space cooling should be in operation and reduced time when space heating should be in operation. The structure of temperature bin occurrences is such that energy consumption for space heating is lower for the second period, while energy consumption for space cooling is higher for the second period, for each individual building (assuming identical building operation). In order to provide engineers with reliable data for comparison of different HVAC alternatives (especially air-to-water heat pumps), it would be beneficial to provide similar data for other locations in the Republic of Serbia.

NOMENCLATURE

Greek letters:

η efficiency of the HVAC system
φ relative humidity (%)

Latin letters

K_{tot} total heat loss coefficient of the building (kW/K)
N_{bin} number of hours (h)
p_w partial water vapor pressure (Pa)
p_{ws} saturation pressure (Pa)
Q_{bin} energy consumption (kWh)
T outdoor dry bulb temperature (K)
t_b balance point temperature (ºC)
t outdoor dry bulb temperature (ºC)
t^* wet bulb temperature (ºC)
w humidity ratio (kg/kg)
w_s humidity ratio at the saturation point (kg/kg)
w_s^* humidity ratio at the saturation point for wet bulb temperature t* (kg/kg)

Subscripts

i temperature bin
m total number of temperature bins
tot total

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