The Impact of the Climate Model Details on the Accuracy of Power Consumption Calculation of Air Conditioning Units

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Abstract. In assessing the energy efficiency of the building an important role is attributed to the energy consumption of various devices of the air conditioning systems, since it can be calculated only on the basis of the probabilistic distribution of the parameters of the outdoor climate in the construction area. An important aspect of the climate model is the detail with which it provides the repeatability of temperature and relative humidity combinations.

The article examines the results of the energy consumption calculations for an air conditioning system in Moscow based on the initial information provided by the probabilistic-statistical model of the climate, which has been built according to the data of primary observations at the Moscow weather station for 30 years. Moreover, the climatic model has been considered in two options: firstly, the repeatability of combinations of the climate parameters is given for the cells with a 2 °C temperature step and a step of 5 % of the relative humidity; secondly, for cells with a 1 °C temperature step and a step of 2.5 % of the relative humidity. In the first case, the content of the model represents a table of 19x37 cells, in the second case it makes 36x69 cells.

The results of the energy consumption calculation of the air conditioning system "with a second heating" indicate a significant increase in the accuracy of calculations at a smaller step of the climate model. The calculation accuracy has become greater due to more exact determination of the consumption of heat, electricity and water at each combination of the temperature and the relative humidity of the outdoor air and, especially, due to clarification of the transition boundaries from one operation mode of the air conditioning unit to another.

1. Introduction

In recent decades, the construction practice has often used central air conditioning systems (CACS) to maintain the proper temperature and humidity mode in the premises. This is due, firstly, to the increase in the number of rooms with significant heat excess (office, entertainment, sports, etc.). Secondly, in recent years there have been long periods of time with high outdoor air temperature in the spring, summer and autumn seasons [1, 2, 3]. Therefore, the question of heat, electricity and water consumptions in the work of CACS has acquired a great importance [4, 5, 6, 7]. This is also important because the energy saving is one of the priorities of our time.

The specificity of energy is that the products of this industry are almost impossible to accumulate and store, so the energy needs must be predicted and taken into account in advance. In this regard, it is important to accurately determine the energy consumption for air conditioning in the building not only to assess future energy consumption, but also to select the most energy-efficient options for the building maintenance at the design stage [8].

The climatic conditions determine the need for energy, therefore, the form of their setting should reflect the actual and current observation probability of the meteorological parameters and be convenient for use in the calculation of heat, electricity and water consumption. That is why, the climatologic support of calculations of the energy consumption for the air conditioning of the buildings should be presented in the form of a climate model with the information sufficient to calculate the consumption of heat, water, cold and electricity by different CACS [9, 10, 11]. The details of this information can also be essential, since the transition of the air conditioner from one mode to another occurs under certain conditions. The more accurately the climate model sets the transition limits from one regime to another, the more accurate will be the estimates of the energy consumption by an air conditioning unit [12, 13].

2. Methods of investigations

The annual consumption of heat, cold, water and electricity should be performed taking into account the time of consumption of this resource [14, 15]. As the initial climatic information, provision has been made of the probabilistic-statistical climate model [16, 17], which is based on the direct processing of all hourly combinations of the temperature and the relative humidity of the outdoor air for the 30-year period of primary observations at the weather stations. This information has been provided as a table with the cells containing the repeatability of the outdoor air temperature and the relative humidity $pr\,(k, j)$. In these tables, the k index from 1 to K is used to number the cells on the temperature scale and the j index from 1 to J - on the relative humidity scale. Due to the daily course of the climate parameters, calculations of the energy consumption by the CACS plants operating at different times of the day should be performed on the basis of probabilistic and statistical climate models, which have been developed for the appropriate time periods of the 24-hour day. The repeatability of $pr\,(k, j)$ is given in the fractions of 1 from the whole period of the time z_o, hours, accepted by the model for consideration within the year. Since all calculations were performed for the climatic conditions of the city of Moscow, the data of the weather station VDNKh [18] were used to build the climate models.

The study of the influence of the climate model details on the CACS energy consumption has been performed on the models with different cell gradation by temperature and relative humidity. In the option 1, the temperature graduation has made 1 °C and 2.5 % of the relative humidity; in option 2, respectively, 2 °C and 5 %. In this case, in the option 1: $K=69$, $J=36$, and in the option 2: $K=37$, $J=19$.

To calculate the cost of heat, electricity and water in a direct-flow CACS with the second preheating, a computer program written in FORTRAN [19, 20] has been used.

The annual heat, electricity and water consumptions have been calculated by summing up the energy resources at the outdoor environment parameters corresponding to each cell of the probabilistic-statistical climate model, taking into account the transition across the boundaries of the weather zones in which a certain processing of the supply air has been carried out.

The second heating air treatment scheme is more energy consuming than other circuits, but it is able to maintain the parameters of the indoor air in the most accurate way. Therefore, this scheme is widely used now. The CACS with the second heating is running during the year in six weather zones. In the climatic zone 1 the outdoor air is heated in the first stage air heater, the adiabatic humidification and the heating - in the second stage air heater; in the climatic zone 2 the air adiabatic humidification is made up to the state between the winter and summer dew points and the heating is provided in the second stage air heater; in the zone 3 the air is heated in the air heater of the second preheating; in the weather zone 4, in which the parameters of the outdoor air coincide with the those required for the inflow air, the air is not processed; in the weather zone 5 the outdoor air is cooled without drying to reach the moisture content of the summer dew point, it is adiabatically moistened to the parameters of the summer dew point and then heated in the air heater of the second heating to the maximum temperature and relative humidity for the indoor air; in the weather zone 6 the air is cooled in an air cooler to the summer dew point, after which it is heated in the secondary heating air heater to the maximum temperature and relative humidity values of the indoor air.

Since we know the repeatability of $pr\,(k, j)$ climatic parameters in each cell of the climate model and the number of hours of the plant operation during the year depending on the working time of the 24-hour day and the weekends within the year z_0, h, the total need for each resource is determined by the equations (1) - (8):

$$Q_{h1} = \sum_1^K \sum_1^J q_{h1}\,(k,j)\,pr(k,j)\,z_0 \cdot 10^{-3} \tag{1}$$

$$Q_{h2} = \sum_1^K \sum_1^J q_{h2}\,(k,j)\,pr(k,j)\,z_0 \cdot 10^{-3} \tag{2}$$

$$Q_c = \sum_1^K \sum_1^J q_c\,(k,j)\,pr(k,j)\,z_0 \cdot 10^{-3} \tag{3}$$

$$W = \sum_1^K \sum_1^J w\,(k,j)\,pr(k,j)\,z_0 \tag{4}$$

$$N_{h1} = \sum_1^K \sum_1^J n_{h1}\,(k,j)\,pr(k,j)\,z_0 \cdot 10^{-3} \tag{5}$$

$$N_{h2} = \sum_1^K \sum_1^J n_{h2}\,(k,j)\,pr(k,j)\,z_0 \cdot 10^{-3} \tag{6}$$

$$N_{hum} = \sum_1^K \sum_1^J n_{hum}\,(k,j)\,pr(k,j)\,z_0 \cdot 10^{-3} \tag{7}$$

$$N_{vent} = \sum_1^K \sum_1^J n_{vent}\,(k,j)\,pr(k,j)\,z_0 \cdot 10^{-3} \tag{8}$$

where $Q_{h1,}\,Q_{h2},\,Q_c$ – is the heat annual consumption, kWt·h, respectively, for the first and the second heating and cold;

$q_{h1}\,(k, j)$, $q_{h2}\,(k, j)$, $q_c\,(k, j)$ – instantaneous consumption, W, respectively, of the heat for the first and the second heating and cold under weather conditions corresponding to the cells of the climate model relating to the weather zone in which these processes are carried out;

W – annual water consumption, kg;

$w(k, j)$ – instantaneous water consumption, kg/h, under weather conditions corresponding to the cells of the climatic model related to the weather zone in which the humidifier operates;

N_{h1}, N_{h2}, N_{hum}, N_{vent} – the annual electricity consumption, kW·h, respectively, to the operation of the first and second air heater pumps, humidifier pump, main fan of the system;

$n_{h1}\,(k, j)$, $n_{h2}\,(k, j)$, $n_{hum}\,(k, j)$, $n_{vent}\,(k, j)$ – instantaneous electricity consumption, W, to the operation of the air heating pumps of the first and the second heating, respectively; the pump humidifier, the main fan of the system under weather conditions, which correspond to the cells of the climatic model relating to the weather zone where the specified equipment operates.

3. Calculation results

The influence of the details of the climate probabilistic statistical model on the assessment of energy consumption was studied at CACS plants with a direct-flow scheme of the air treatment with a second heating, working around the clock (5928 hours per year) and from 9 a.m. to 18 p.m. of the day (2223 hours per year). During the year, the indoor air temperature changed from 19 ° C to 25 °C, the relative humidity - from 30 % to 60 %. The temperature difference between the indoor and the supply air has been taken equal to 5 ° C. The flow rate of the outdoor air passing through the CACS unit is 10 000 kg/h. The temperature of the cold water in the air cooler makes 7-12 °C. The main results of the calculations are given in table. 1.

The CACS energy consumption depends on the angular coefficient of the beam of the process of changing the thermal-humid state of the air in the room ε or, in other words, on the thermal-moisture ratio of the total heat flow to the moisture flow entering the room. Therefore, the study of the annual energy consumption in the various air treatment processes in the air conditioner has been performed at five values ε from 5 000 kJ/kg to 60 000 kJ / kg.

The electricity consumption for the production of cold can be calculated by knowing the cooling coefficient. Typically, the average season value of the cooling coefficient is 3.5.

Table 1. Annual consumption of heat, cold, water and electricity at different values of heat and humidity ratio of changes in the state of the air in the room.

Heat to humidity ratio kJ/kg	Heat consumption of the first preheating air heater, Q_{h1}, kW·h	Heat consumption of the second preheating air heater, Q_{h2}, kW·h	Cold consumption, Q_c, kW·h	Water consumption, W, kg	Electricity consumption of the pump at the first preheating, N_{h1}, kW·h	Electricity consumption of the pump at the second preheating, N_{h2}, kW·h	Electricity consumption of the humidifier, N_{hum}, kW·h
			Variant 1 of the model, from 9 a.m. to 18 p.m.				
5000	47523.6	237274.0	29288.1	15126.7	76.8	192.7	44.3
10000	87018.1	208003.6	20251.7	24523.5	117.5	191.2	61.0
20000	107308.1	194446.0	17101.1	29313.2	140.3	190.7	69.5
30000	113218.7	190825.4	16356.3	30919.6	145.1	190.4	71.2
60000	118711.6	186917.9	15764.9	32089.6	149.6	190.1	72.8
			Variant 2 of the model, from 9 a.m. to 18 p.m.				
5000	55741.2	245939.7	20561.8	14560.1	86.6	190.6	46.7
10000	100200.1	214470.0	13796.7	24496.4	132.7	190.3	64.9
20000	123128.5	201165.4	11341.6	30203.2	151.9	189.9	73.1
30000	129494.8	197574.2	10788.6	31615.8	155.9	189.8	75.5
60000	135384.6	193754.9	10289.3	32896.5	160.2	189.2	76.2
			Variant 1 of the model , 24 hours				
5000	133458.4	657750.5	59782.9	32699.8	213.0	527.1	110.9
10000	242946.3	576421.6	40006.3	56171.1	325.1	519.0	158.1
20000	298881.2	539051.2	33134.4	68301.3	385.8	517.3	181.8
30000	315157.5	529143.7	31606.0	72179.0	398.4	515.5	186.6
60000	330234.3	519102.1	30451.1	75311.1	410.4	514.1	191.3
			Variant 2 of the model , 24 hours				
5000	156236.5	682633.4	39199.0	32650.8	239.5	525.0	119.2
10000	279249.3	596236.1	25358.5	57722.4	363.7	520.1	169.4
20000	342328.8	558007.3	20578.2	71632.6	416.9	519.6	192.6
30000	359793.5	548392.1	19535.0	75443.4	427.4	517.7	198.7
60000	375959.4	538209.4	18590.2	78725.7	439.6	516.8	201.1

The calculations for both variants of the climate models show, that with increasing values of heat to humidity ratio the heat consumption increases at the first preheating and falls at the second one. The cold consumption is falling, as well. However, the relative accuracy of the calculations becomes greater with higher values of the calculation results, as shown in the table 2.

The fact that the accuracy of the heat consumption calculations is in the range of 14 % – 17.3 %, of cold 29.8 % – 38.9% for the conditions of Moscow may be explained by the fact, that the duration of the period when the heating of the supply air is required is much longer than the cooling period, and the annual consumption of heat is higher than this one of the cold. In addition, the heat consumption depends only on the outdoor air temperature, and the cold consumption depends on the combination of the temperature and humidity, the accuracy setting of which makes a greater influence, than the setting accuracy of a single parameter.

Small differences in the calculation results of the annual heat consumption for the second preheating are quite natural, since they indirectly depend on the outdoor climate. The second heating is carried out from the temperature of the dew point to the temperature lying within the limited borders of the weather zone 4. The current dew point temperature depends on the combination of the

temperature and relative humidity of the outdoor air, and is subject to little changes when transferring from one model to another.

Table 2. Comparison of the annual consumption of heat, cold, water and electricity calculated according to the initial climate data from the two climate models.

Heat to humidity ratio, kJ/kg	Accuracy of calculations, %, of the annual consumption						
	of heat by the air heater at the first preheating	of heat by the air heater at the second preheating	of cold	of water	of electricity by the pump at the first preheating	of electricity by the pump at the second preheating	of electricity by the humidifier
from 9 a.m. to 18 p.m.							
5000	17.3	3.7	29.8	3.7	12.8	1.1	5.4
10000	15.1	3.1	31.9	0.1	12.9	0.5	6.4
20000	14.7	3.5	33.7	3.0	8.3	0.4	5.2
30000	14.4	3.5	34.0	2.3	7.4	0.3	6.0
60000	14.0	3.7	34.7	2.5	7.1	0.5	4.7
24 hours							
5000	17.1	3.8	34.4	0.1	12.4	0.4	7.5
10000	14.9	3.4	36.6	2.8	11.9	0.2	7.1
20000	14.5	3.5	37.9	4.9	8.1	0.4	5.9
30000	14.2	3.6	38.2	4.5	7.3	0.4	6.5
60000	13.8	3.7	39.0	4.5	7.1	0.5	5.1

4. Conclusion

A comparison of the CACS energy consumption with the second heating, which has been got from the climate models in the variants 1 and 2, shows that the initial information in a more detailed form of the option 1 clarifies the result by 14 – 40 %. That is why, it makes sense to develop the probabilistic statistical model in detail.

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