Comparison of the completeness of the climate probability-statistic model and the reference year model

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Abstract. Evaluation of the building energy efficiency, which has been admitted as a criterion of the energy safety, provision shall be made of determination of the energy consumption by the heat microclimate maintenance systems in the rooms. It can be be calculated only according to the data of the probability of the outdoor climate distribution in the construction region. The model correspondence to its design technological processes is an important aspect. That is why there is a vital question of how to provide the completeness of information using different climatic models for calculation of the processes, which occur differently in time. This work is aimed at comparing the completeness of all the possible combinations of temperature and relative humidity, as well as their repeatability in different climatic models. On the one hand, each particular model of the climate should more fully describe the possible weather situation of the construction area, affecting the calculation result. On the other hand, the model should not be limited by any restrictions of extra "qualities" and the climatic parameters that are not used in a particular task. Currently, the reference year climate model, which is presented in the European standard ISO 15927-4:2005, is the most widely used in the world. This model is the most appropriate for calculations of transient processes of the thermally resistant objects. However, the determination of the annual energy consumption by air conditioning systems with instantaneous processing outdoor air, is more consistent with the probabilistic-statistical model of climate. It represents a table with the cells containing the frequency of occurrence of temperature and relative humidity spaced at 1 ^{o}C of temperature and 5 % of relative humidity. The article compares the completeness of information, which is provided by each model and calculated on the basis of each of two models of heat, cold and water consumption by air conditioning plants. The comparison has been made for installations of the inlet air supply processing according to the schemes of cocurrent flow with secondarypreheating and cocurrent flow with by-pass (direction of a part of the air in the bypass of the spraying chamber). The results of the comparison of the probabilistic field of combinations of the outdoor air temperature and the relative humidity of the two models confirm the higher completeness and accuracy of the probabilistic-statistical model in the description of heat and humidity status of the outdoor air of several years. The calculations showed that the energy consumption by air conditioning systems, which has been obtained on the basis of two climate models, differ from each other in 3.8 % of warmth, 1.6 % of water, 53.8 % of cold and electricity. The results confirmed, that during the calculations of the cold consumption, the distortion in the distribution of the enthalpy of the outside air, which depends on the distribution of temperature and relative humidity during the cooling period, leads to significant errors.

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1. Introduction

The climatic model, which is put in the calculations and provides data on the frequency of occurrence of combinations of the outdoor air temperature and relative humidity, is an important factor in evaluation of the energy consumption by the devices of central air-conditioning systems being the criterion of the energy security of the country. Rosguidromet has more than 1600 active meteorological stations [1]. Therefore, the task of developing climatic models for a large number of points on the territory of Russia may be surely solved. Since the mid-1970s, the average surface air temperature on the territory of the Russian Federation is increasing with an average rate of 0.43°C per decade, which is more than two and a half times higher than the global warming rate [2].

That is why, the climate models should be periodically updated according to the latest data measured on meteorological stations. Unlimited possibilities of the climate data computer processing [3] made the probability-statistic model [4] a promising one in the form of the actual data repetition not only for 24 hours, but also for express values of temperature and relative humidity of the outdoor air. The model does not require intermediate processing to get probabilistic characteristics. In addition, a direct climate processing for any part of time within 24 h is necessary for calculations of the energy consumption by the devices of the air conditioning facilituies [5].

The climate model of a "reference" year [6], [7], [8], [9], [10] is considered now as one of the most common and informative in the world. Methods of the primary measurement data processing at the meteorological stations is presented in the European standard ISO 15927-4:2005 “Hygrothermal performance of building – Calculation and presentation of climatic data – Part 4: Hourly data for assessing the annual energy use for heating and cooling”.

It provides hourly values of various meteorological and actinometric parameters for all months of the year, selected from a multi-year sample so that the average monthly characteristics of the climate data get closer to their average multi-year values, and their scatter reflects as fully as possible the variation of individual parameters of each month [11], [12], [13].

This model meets well the needs of the tasks associated with non-stationary of thermal processes in time and necessary attention to the properties of the object under investigation. For processes, which are practically inertion-free, for example, for treatment of outside air by heating, humidification, drying or cooling, the content in the data climate model, information about the sequence of the outdoor air parameter changes in time is redundant. Ensuring this requirement, we reduce possibility of providing all the climate parameter values that took place over a multi-year period.

In addition, in [11], [12], [13] it is proved that the fewer climate parameters the model covers, the closer a “reference” year one becomes closer real distributions of combinations of these parameters in the multiyear average view. Probability-statistic model does not have such shortcomings, as it is based on the direct processing of the original initial data measurements at the weather stations, and the model can provide the real probability distribution of the parameters of any dimension, which has really occurred.

2. Initial data for the climate model design

The aim of this work is to compare the coverage of all possible combinations of temperature and relative humidity, as well as their frequency of occurrence in the two climate models: probability-statistic one, containing in itself all the mentioned combinations, which took place over a multi-year period within the selected time interval of 24h, and a “reference” year, representing one of the possible year realizations.

The models, which have been developed on the same primary climatic basis for the city of Moscow, have been taken for comparison. Processing has been made of meteorological data [14] for the period from 1 January 1981 to 31 December 2010 according at the VDNKh station. The repeated distribution of heat and humidity parameters of the outdoor air were developed for the following 8 different time intervals of different duration during 24 hours: 24h as a whole, from 9 am to 18 pm, from 18 pm to 9 am, from 8 am to 20 pm, from 20 pm to 8 am, from 7 am to 15 pm, from 15 pm to 23 pm and from 23 pm to 7 am.

The results of statistical analysis of repeated complexes of the temperature with the relative humidity of the outdoor air *t-φ* and the enthalpy with moisture content of outdoor air *I-d* have been registered in the tables of their distribution in hours and in %. Moreover, the frequency of occurrence of combinations of *t-φ* and *I-d* are defined as for the whole year and for each month separately. In the tabulation, the following spacing has been adopted: temperature 1 °C, relative humidity 5 %, enthalpy 1 kJ/kg, moisture content of 1 g/kg of dry air.

Repeatability in % was calculated as the ratio of the number of hours of the parameter observation at each of the two-dimensional gradation spacing to the total number of hours within the considered time interval.

The data of the reference year were reformatted into the same tables of the probability-statistic model. In table 1 shows the duration of the combinations of temperature and relative humidity in Moscow in the period from 8 am to 20 pm of the day.

Table 1. The frequency of occurrence, h (number of hours per year in the average multiyear view), combinations of temperature and relative humidity of the outdoor air from 8 am to 20 pm

Temperature, °C	Relative humidity, %						
	10÷20	20÷25	25÷40	40÷60	60÷80	80÷100	Total per year
Reference year							
38÷32							0.00
32÷30				2.90			2.90
30÷20		0.00	41.38	228.70	98.01	7.98	376.08
20÷10		0.00	66.80	228.70	322.36	310.01	927.86
10÷0		0.73	33.40	133.58	304.21	493.71	965.63
0÷ -10			2.18	42.84	227.25	396.42	668.68
-10÷-20				5.81	93.65	109.63	209.09
-20÷-28					15.25	12.34	27.59
-28÷-30					2.18		2.18
-30÷-32							0.00
Total per year		0.73	143.76	642.52	1062.91	1330.09	3180.00
Probability-statistic model							
38÷32	0.07	0.37	4.36	2.47			7.27
32÷30			3.72	8.63			12.36
30÷20	0.07	1.02	64.28	275.42	132.39	14.47	487.66
20÷10	0.44	1.45	61.06	253.29	319.29	243.03	878.56
10÷0	0.07	0.86	24.89	132.38	265.94	476.90	901.05
0÷ -10		0.07	3.16	54.40	229.17	391.18	677.98
-10÷-20			0.23	7.87	85.03	99.18	192.32
-20÷-28				0.22	11.83	9.53	21.58
-28÷-30					0.73	0.16	0.88
-30÷-32					0.36		0.36
Total per year	0.66	3.77	161.70	734.69	1044.74	1234.44	3180.00

3. Results of comparison of repeated climate parameter combinations

From the data of table 1 for both models it may been concluded, that combinations of the heat and humidity of the outdoor air at temperatures above 32 °C in the model of a reference year, which are rarely observed in reality, are absent, whereas in the probability-statistic model they have a year repeatability of 2.29 %. The cold part of the year is shorter in the reference year. It begins from the temperature of -30°C, whereas in the probability-statistic model it is represented by a temperature of -32 °C. The probability-statistic model shows the probability of combinations of values of heat and humidity settings ranging from 15 % RH, and a reference year gives only 25 %.

Attention shall be paid to the fact that the repeated temperature distribution of the year are much closer to each other in both models than the repeated distribution of the relative humidity. These discrepancies are particularly noticeable and important for the calculation of the cooling demand in the warm period of the year, as in this season the absolute humidity of outdoor air is significantly higher than in the cold period of the year.

The differences in the distributions of the frequency of the temperature and relative humidity occurrence of the outside air may be seen in the figure 1. Repeated temperatures and the relative humidity are deferred on the vertical scale. The curves of the probability-statistic model are smooth, because they cover all combinations of parameters that took place over 30 years, and the reference year curves have significant jumps as a reference year represents a single implementation.

However, it should be noted that a reference year quite closely reflects the pattern of change of the frequency of occurrence of temperature and relative humidity within different gradations. With all this, deviation of the frequency of occurrence of the temperature in the reference year from this one in the probability-statistic model achieves more than 5 – 6 h, and repeatability of the relative humidity in a point differs by more than 6 hours.

a) b)

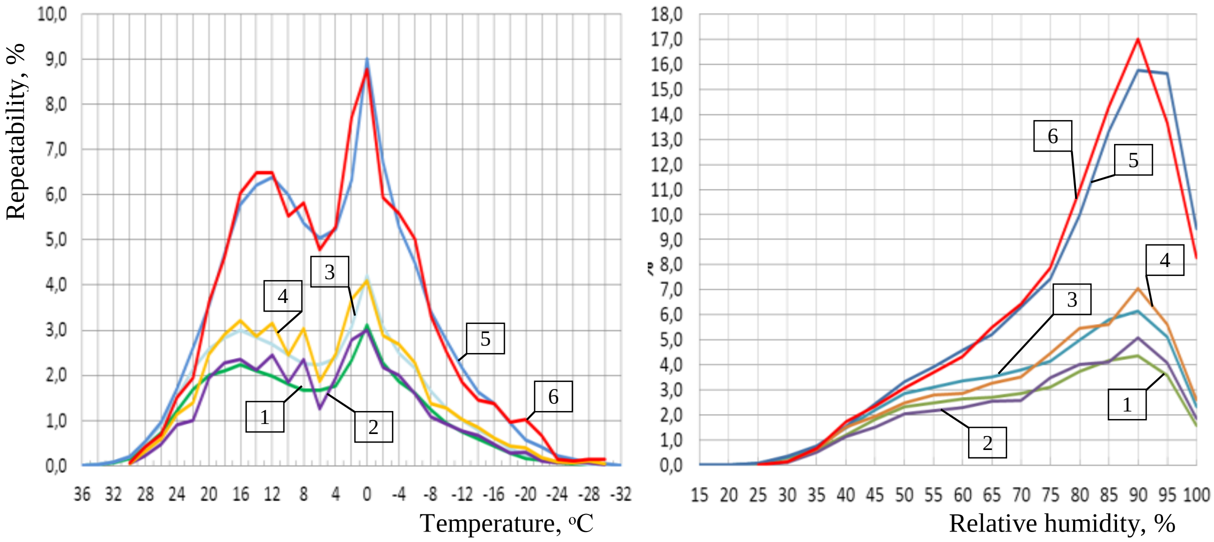

Figure 1. Repeatability of a) temperature, b) relative humidity of outdoor air, %, according to the duration of the studied time interval within 24 h. Symbols within the time interval for probability-statistic model: 1 – from 9 am до 18 pm, 3 – from 8 am to 20 pm, 5 – 24 hours as a whole; for the reference year: 2 – from 9 am to 18 pm, 4 – from 8 am до 20 pm, 6 – 24 hours as a whole

4. The influence of the initial climatic information on the results of the calculations of energy consumption by air conditioning systems

A comparison of the outdoor air parameters in different climate models is not sufficient for explanation of the main idea of this article. It is important to determine how the distortion of the frequency of occurrence of combinations of the outdoor air temperature and relative humidity affects the results of the assessment in the average years of the energy consumption by air conditioning systems.

Provision has been made of comparison of the energy consumption by air conditioning systems, which serve the premises of the auditorium. The difference in the calculations is explained by different initial climate information provided probability-statistic model and the reference year model. The cocurrent flow units have been chosen as follows a) with a second preheating and b) with a partial redirection of the outdoor air flow aside the sections of the humidifier and air cooler (with bypass) or by providing the same parameters of the inflow air in the system with controlled humidification and cooling processes.

Calculation of consumption of heat, water, cold and electricity to the compressor drive of a refrigeration machine has been carried out on the basis of the most energy efficient method of the outdoor air processing for each combination of its temperature and relative humidity. All field of the outdoor air parameter combinations was divided into several zones, which are energetically suitable for processing according to certain schemes that have been developed by A A Rymkevich [15], [16] and A J Kreslin' [17].

For example, 7 zones are allocated for a unit with secondary pre-heating. In the first sequence, the air is heated in the first stage preheater, being adiabatically humidified and then heated by the second stage heater; in the second zone, the air is adiabatically humidified and then heated by the heater of the second stage; in the third zone the air is only heated by the heater of the second stage; the air enters the room without treatment from the fourth zone ; in the fifth zone there is the polytropic cooling with air humidifying, in the sixth zone the polytropic cooling is provided with drying, in the seventh area, the air must first be heated, then polytropically cooled with dehumidification, and then re-heated. For the controlled process schemes of humidification and cooling, provision is made of 6 zones, each having a designed outdoor air treatment.

The auditorium was operated from 8 to 20 h 3180 hours per year. The inside air temperature during the year varied from 20 to 25 ^{o}C , relative humidity from 30 to 60 %. The heat -humidity ratio of the change of the air condition in the rooms has been taken as the same throughout the year, equal to 30 000 kJ/kg.

Consumption of the supplied inflow air to the rooms makes 10 000 m^3/h. The working temperature difference between the inner and the supply air is taken equal to 5 ^{o}C. The temperature of the cold water in the air cooler is 7-12 ^{o}C. Some generalized results of the year energy consumption calculations are shown in table 2

Table 2. The comparison of annual energy consumption by air conditioning systems derived from different initial climate models

Climate model	Heat consumption by air heater of first stage, kW·h	Heat consumption by air heater of second stage, kW·h	Water consumption, kg	Cold consumption, kW·h	Electricity consumed by the compressor, kW·h
System with second pre-heating					
Probability-statistic	202 016	302 860	37 223	21 897	2 018
Reference year	209 645	308 805	36 616	11 192	1 126
System with bypass or controlled humidification and cooling processes					
Probability-statistic	402 463	0	39 752	12 077	424
Reference year	418 490	0	39 385	5 574	196

As it follows from the table 2, for the conditions of Moscow discrepancies in the description of temperature-humidity characteristics of the cold period of the year provided by the two considered climate models, do not greatly affect the forecasts of the heat consumption of the air heaters and the water consumption for humidification of the supply air within the average years view. At the same time, as far as the estimation of the cold consumption is concerned and, as a consequence, the cost of electricity to the compressor drive, the difference from each other constitutes 48.9% – 53,8%. This discrepancy, in our opinion, is due to the discrepancy in the estimation of the probability distribution of the relative humidity in the warm season of the year, which has been mentioned in the previous section of the article. Just an uncompletely correct description by J D Pecker [18] and Y J Kuvshinov [19] of the humid climate characteristics during the development of engineering calculation methods of heat, cold and water consumption by the air conditioning systems has led to serious distortions in the estimation of the cold consumption in the warm period of the year [20].

The probability-statistic model contains information over a multi-year period, and the reference year is the unique implementation of possible combinations of temperature and relative humidity of the outdoor air. Hence, the probability-statistic climate model provides a more complete and realistic probability distribution of the outdoor air parameter combinations and the calculations of energy consumption by air conditioning systems made based on it are more precise.

5. Conclusions

1. Climate models must fully meet the requirements of the task. The model should not be burden by its "advantages", which are not required in the task.
2. The probability-statistic climate model covers more completely all the outdoor air parameters, which took place within the multi-year period under examination.
3. The probability-statistic climate model perfectly meets the energy consumption calculations during the water treatment by the air conditioning systems.

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