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ANALYSIS OF ANNUAL POWER CONSUMPTION BY CENTRAL AIR CONDITIONING SYSTEMS USING THE CLIMATIC DATA STOCHASTIC STATISTICS MODEL

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Abstract. The purpose of the offered research is creation of a method to estimate annual power consumption by central air conditioning systems (ACS), using modern computer possibilities. The developed method is aimed at determining thermal, electric power and water consumption during a year by ACS taking into account their operation in different hours of the day and optimization of the inflow air treatment pattern on the basis of power input minimization. The MGSU Heating and Ventilation Chair has worked out a universal program for computer calculation of ACS power and water consumption. The analysis algorithm is made on the basis of search of the air temperature and relative humidity combinations from minimum to maximum values, which lead to determination of a zone having these combinations. To solve the above tasks provision has been made of a climatic data base to analyze operating modes and calculation of power consumption by ACS operating in various periods during 24 hours. The program computer performance enables multiple variant calculations of power consumption by direct-flow ACS for different purpose premises: a dining room, billiards, sports hall and office.

Keywords: air conditioning systems, power consumption, method, climatic basis, heat and humidity area combinations, bypass, secondary preheating.

1. The Method Climatic Basis

This investigation has being aimed at developing the analysis methods of the year power consumed by central air conditioning systems (ACS), which operate according to different air treatment models. As the climatic basis of this method provision has been made of the stochastic statistics model represented in a Recurrence Period Table according to different average multi-year combinations of the outdoor air temperature, relative humidity and atmospheric pressure. The last parameter is important for the temperature and relative humidity conversion into the air enthalpy. Actual computing utility progress enables a quick and sound weather data statistic analysis, and urgent observations on magnetic media handed by the meteorology experts make this analysis faster without any accuracy losses.

The main advantage of the stochastic statistics model is that it can reflect the air state parameter combination recurrence for any period of time: the whole year, by seasons, by months, 24 hours, as well as any time interval within 24 hours. We have developed the recurrence period Tables of the above mentioned outdoor air parameters for the city of Moscow (Kryuchkova, Malyavina, 2010) for the year as a whole and each month separately. The Tables cover 24 hours and seven intervals within 24 hours, which represent the most typical working hours in various establishments: from 9 a.m. to 18 p.m.; from 18 p.m. to 9 a.m.; from 8 a.m. to 20 p.m.; from 20 p.m. to 8 a.m.; from 7 a.m. to 15 p.m.; from 15 p.m. to 23 p.m. and from 23 p.m. to 7 a.m.

Absence of the time factor shall be considered as a shortcoming of the stochastic statistics model (Malyavina, Payenk, 1984), since the climate parameter distribution surfaces include combinations for any time period within the given 24 hours. For this reason it is difficult to make a direct analysis of the unstable heating mode of the building and its systems. This unsteady issue, which we would like to take into account in the task under examination, means the heat-to-humidity ratio time modification of the air heat and humidity treatment process in a premise. For most of different purpose premises the air heat-to-humidity ratio does not change greatly.

That is why, this model as the fixed time recurrence period values of temperature, outdoor air relative humidity and atmospheric pressure seems to be very progressive, because it enables a rather exact and quick ACS comparative power and water consumption analysis according to different air treatment modes.

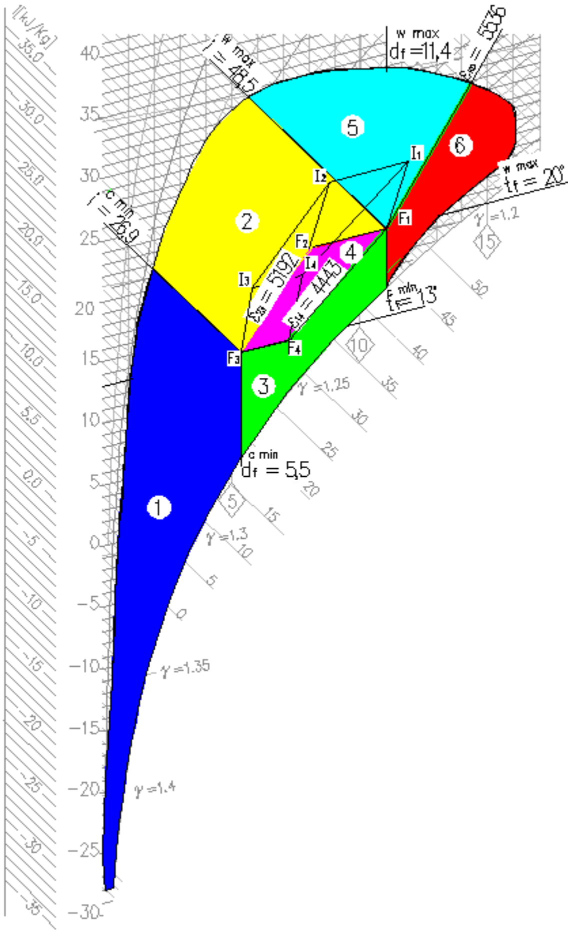

Fig 1. Inflow air treatment zones for maintenance of the interior air optimal parameters at the bypass pattern through a humidification chamber (for cold season)

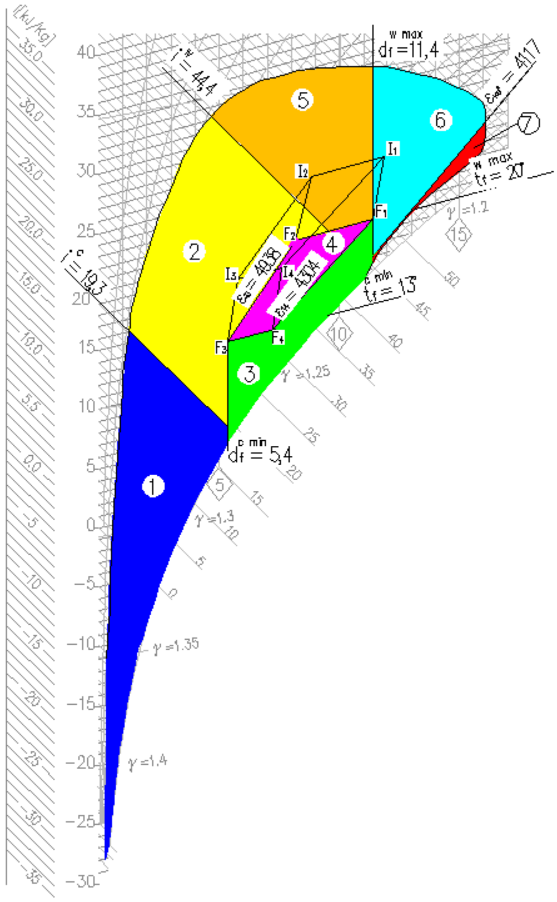

Fig 2. Inflow air treatment zones for maintenance of the interior air optimal parameters using the direct flow pattern with secondary preheating

In the 1st zone – outdoor air heating in a 1st stage air heater, adiabatic humidification and mixing of heated and humidified air ;

In the 2nd zone – mixing of the outdoor air non-treated part with an outdoor air part, which has been humidified in the adiabatic humidification block;

In the 3rd zone – heating up to the inflow air state in the 1st stage air heater ;

In the 4th F1F2F3F4zone – absence of the outdoor air treatment in ACS devices;

In the 5th zone – refrigeration in a surface air cooler;

In the 6th zone- heating in the 1st stage air heater to enable the air state conformity to the points on εкоw line, refrigeration in a surface air cooler.

2. Appointment of the climate parameter combination zones having a definite outdoor air treatment sequence

Provision has been made of a PC universal software for ACS power and water consumption analysis. The calculation algorithm has been done on the basis of the air temperature and relative humidity combination trials from minimal to maximal ones, which lead to determination of a zone having this combination.

Any outdoor climate zone corresponds to an exact air treatment sequence, and the zone borders determine the outdoor air parameter values, which demand a transfer from one treatment mode to another. To build the outdoor climate zones having a definite ACS air treatment sequence provision shall be made of the room indoor optimal parameter zones shown on the i-d diagram.

In the 1st zone – outdoor air heating in a 1st stage air heater, adiabatic humidification and heating in a 2nd stage air heater;

In the 2nd zone – adiabatic humidification and heating in a 2nd stage air heater;

In the 3rd zone – heating up to the inflow air state in the 2nd stage air heater;

In the 4th F1F2F3F4zone – absence of the outdoor air treatment in ACS devices;

In the 5th zone – «dry» refrigeration in a surface air cooler, adiabatic humidification and heating in a 2nd stage air heater;

In the 6th zone- «wet» refrigeration in a surface air cooler and heating in a 2nd stage air heater;

In the 7th zone- heating in the 1st stage air heater to enable the air state conformity to the points on εкоw line, refrigeration in a surface air cooler and heating in a 2nd stage air heater.

The power consumption analysis has been done for four different rooms: an office, a billiards room, a dining room and a fitness room. Air consumption in the air conditioning systems, which serve these premises, has been taken the same and equal to 5475 m^3/h. The heat-to-humidity ratio in the premises are taken as equal ones to satisfy the investigation purpose, i.e. ε^c=8800 kJ/kg for the cold season and ε^w=14500 kJ/kg for the warm season. The required indoor conditions for the premises differ as follows: $19<t_{in}<25$ ºC; $30<\varphi_{in}<60\%$ in the office, $18<t_{in}<25$ ºC; $45<\varphi_{in}<60\%$ in the billiards room, $20<t_{in}<25$ ºC; $30<\varphi_{in}<60\%$ in the dining room; $17<t_{in}<25$ ºC; $30<\varphi_{in}<60\%$ in the fitness room. In the general case the premise design air state will be represented by $I_1I_2I_3I_4$ (fig 1, 2) zone. On fig 1,2 the lines of the heat-to-humidity ratio ε^w warm season cross I_1 and I_2 points. The points I_3 and I_4 of the room air optimal parameter area are crossed by heat-to-humidity ratio slope lines which show the air state modification in the ε^c cold season. These lines have indication of the corresponding operation temperature differences as well as the $F_1F_2F_3F_4$ inflow air parameters. The heat-to-humidity ratios ε^w and ε^c fix location of the zone, which determines creation of all the other external climate zones on the i-d diagram.

Attention shall be focused on the fact, that actually during the year the micro-climate indoor parameters change within the oblique-angled quadrangles, which are limited from the bottom by the minimal possible temperature in the cold season of the year, and from the top – by the maximum allowable temperature in the warm season of the year.

The minimum relative humidity corresponds to a minimum one, which is required in the cold season, and the maximum relative humidity – to the maximum one in the warm season.

Since the normative documents (State Standards GOST *30494-96*) require, that the same t_{in}=25 °C temperature shall not be exceeded in the warm season of the year, the quadrangles have the same upper limit for all the premises under examination.

A rather high minimal humidity in the billiards room is explained by the need to avoid a longer drying of the glued wood.

Different outdoor air treatment devices operate during the year. Provision has been made of examination of a direct flow device with secondary preheating (see fig 3), and the bypass pattern (by-passing the humidification chamber in winter cold season), fig 4.

The fig 1 shows the outdoor air heat and humidity area combinations when different devices operate under the direct inflow air pattern with secondary preheating, and the fig 2 gives a bypass pattern (by-passing the humidification chamber in the winter season) in the billiards room.

Separation into zones is determined by examination of possible outdoor air treatment procedures described, for example, in (Belova, 2006) to make the air reach the required state within the $F_1F_2F_3F_4$ area by the most economical power saving way using the existing device facilities (for theoretical explanation see Rymkevich, 1990).

3. Summarized results

The developed PC software enables power and water consumption estimation for the design period (year, season, month) by each air treatment device in every climatic zone. For example, the above mentioned room, if it functions 24 hours a day and respects the room optimal conditions, may be subject to heat, cold, power and water calculations for the ACS air treatment (see Table 1).

Data of the Table 1 let us conclude, that in Moscow ACS operate nearly the half of the year in the 1st zone, i.e. at the first pre-heating of the outdoor air. Cold consumption in the 5th and the 6th zones shall be required when the outdoor air temperature is higher than 20 ^oC (see fig 2).

So, for the room under analysis all necessary cold is produced by a refrigerating machine and there is no need in any heat exchanger to enable free cooling. The results, which are similar to these ones of the Table 1, make possible calculation of the summarized year consumption of each power and water type to maintain optimal conditions in different premises (see Table 2).

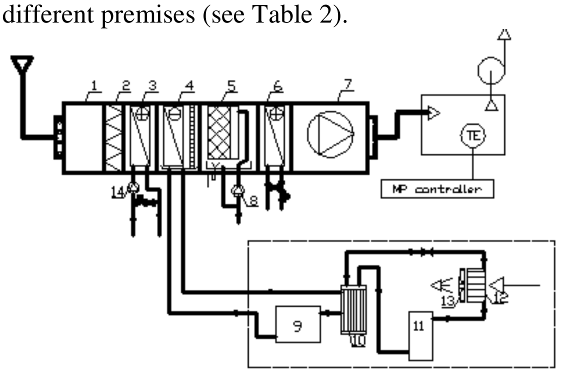

Fig 3 Principal pattern of the air conditioning system with secondary preheating:
(1-inflow unit; 2- filter unit; 3- air heater primary preheating unit; 4- air cooler unit; 5- cellular humidification unit; 6- air heater secondary preheating unit; 7- fan unit; 8- water supply pump to humidification unit; 9- pump central unit of water refrigerating contour; 10 - evaporator; 11- compressor; 12- condenser; 13- condenser cooling fan; 14- pump in the air heater primary preheating unit coil)

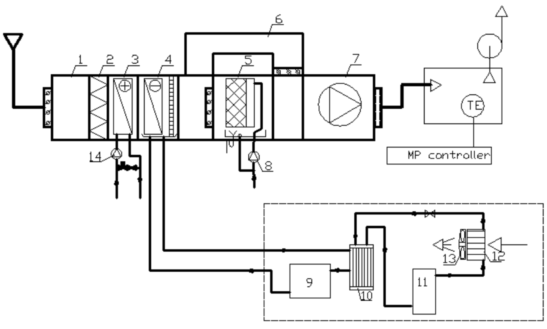

Fig 4. Principal pattern of the air conditioning system with bypassing the cellar humidifier unit:
(1-inflow unit; 2- filter unit; 3- air heater primary preheating unit; 4- air cooler unit; 5- cellular humidification unit; 6- bypass; 7- fan unit; 8- water supply pump to humidification unit; 9- pump central unit of water refrigerating contour; 10 - evaporator; 11- compressor; 12- condenser; 13- condenser cooling fan; 14- pump in the air heater primary preheating unit coil)

Table 1. Annual consumption of heat, power and water by inflow air treatment devices up to optimal parameters in the billiards room (a bypass pattern) for 24- hour operating ACS

Control zone number	1st step pump air heater		Cellular pump humidifier		Cooling machine	Main fan	Operation hours in control zone, h
	Heat consumption MJ	Power consum-ption kW·h	Water consumption kg	Power consum-ption kW·h	Power consum-ption kW·h	Power consumption kW·h	
zone 1	546137	185	38146	49		8416,7	3845
zone 2			4305	50		1241,2	567
zone 3	144703	146				6676,5	3050
zone 4						1834,4	838
zone 5					2053	468,4	214
zone 6	7356	12			2419	551,6	252
Total	698196	343	42452	99	4472	19188,8	8766

The Table 1 makes evident, that the billiards room requires the biggest power consumption either in cold and warm seasons.

It occurs, because the outdoor air heat and humidity parameter combination zone, which coincides with the inflow air optimum, is the smallest one. The largest coincidence zone of the outdoor and the inflow air is in the fitness room. The Table 2 estimates power consumption of each device, which provides the air treatment to get the optimum parameters in different purpose rooms under two options of the inflow air treatment patterns. For better representation of power and water consumption see fig 5 schedules.

It is important to note, that heat and power consumption values estimated according to the existing simplified methods (Samarin, 2007), being supported by the climatic data given in normative documents (Building Norms and Rules SNiP *23-01-99*),* are 1.7 times higher than those, which have been calculated according to the year climate parameter combination distribution and definition of some device operation zones.

Importance of the air conditioning becomes greater due to the permanently increasing heat excess in the rooms and the climate trend to getting warmer. So the method, which enables a justified choice of the most power economical air treatment way , as well as the choice of the interior condition level, is quite actual.

Table 2. Comparison of annual heat, power and water consumption for the inflow air treatment

Room	1st step pump air heater		secondary air heater	Cellular pump humidifier		Cooling machine	Total consumption		
	Heat consump-tion MJ	Power consump-tion kW·h	Heat consump-tion MJ	Water consump-tion kg	Power consump-tion kW·h	Power con-sumption kW·h	Heat consump-tion MJ	Power consump--tion[1] kW·h	Water consump-tion kg
Direct flow pattern with secondary preheating									
Office	224252	219	508403	51744	120	17194	732655	36721	51744
Billiards	472897	313	337559	106950	120	17194	810456	36815	106950
Dining room	259524	239	530190	58500	120	17194	789714	36741	58500
Fitness room	166085	173	465641	40678	121	17194	631726	36676	40678
Bypass pattern									
Office	698196	343	-	42452	99	4472	698196	24102	42452
Billiards	773341	346	-	96470	100	4472	773341	24106	96470
Dining room	755668	357	-	49293	99	4472	755668	24116	49293
Fitness room	597322	330	-	31487	99	4472	597322	24089	31487

[1] power consumption is given taking into account the main ventilator power consumption, kWh

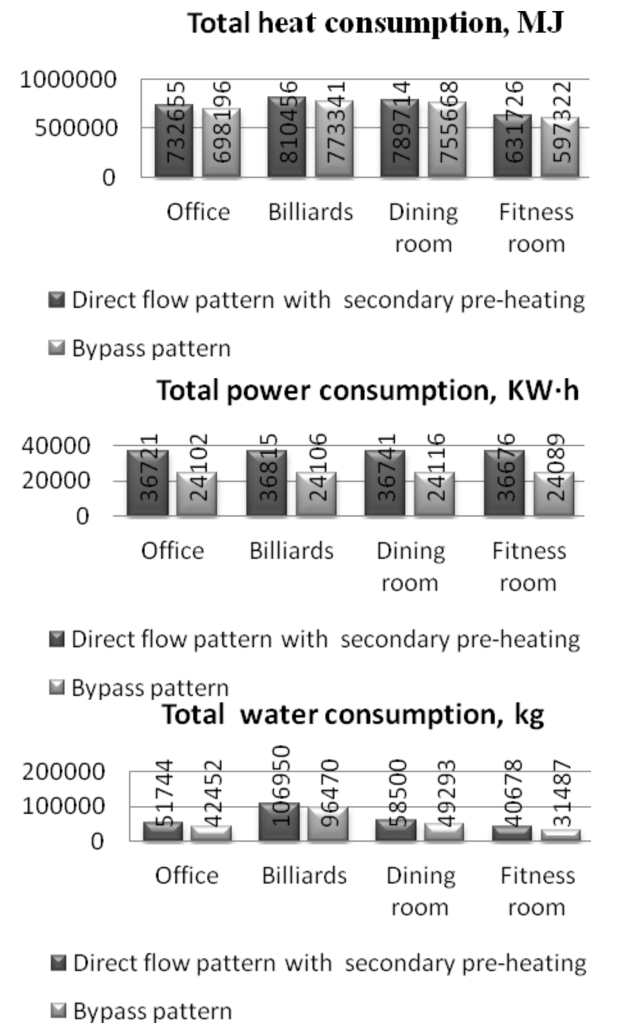

Fig 5. Comparison of annual heat, power and water consumption for the inflow air treatment

4. Conclusions

1. During investigation of the required interior condition influence on power consumption of the air conditioning systems it has been found out, that the power consumption increases, if this zone becomes smaller. Thus, for the billiards room, where the relative humidity lower limit value is limited by 45%, the heat needs for the outdoor air preheating are 10.6% more, than in the office, where the humidity border passes at 30% relative humidity. At the same time in the fitness room the heat needs for inflow air heating are 16% less than in the office room, since the minimum permitted temperature in the hall is 2^{o}C lower than in the office.
2. The widest coincidence zone of the outdoor and inflow air parameters is in the fitness room. Heat consumption of the device, which serves the fitness room, makes 22% (for secondary preheating pattern) and 22.76% (for bypass pattern) less, than this one of the billiards room device, and water consumption is 61.9% (for secondary preheating pattern) and 67.4% (for bypass pattern) less respectively.
3. Possible calculation of each device operation time in a central air conditioning system enables removal of any device or control mode , if it operates shortly during the year. For example, in the billiards room the zone 7 is too small when being served by a direct flow system (see fig 1), that is why the mode 7 may be maintained providing the same control as in the zone 6, especially as the zone 7 climate parameters are out of the external design condition limits.
4. The bypass pattern requires artificial cold consumption in zones 5 and 6. However, in comparison with the secondary preheating pattern, the outdoor air enthalpy, above which the air shall be refrigerated using artificial cold sources, has a higher value. That is why, the refrigeration unit power consumption for a bypass pattern makes 26% of this one for a direct flow pattern with secondary preheating.

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