Comparison of Technical Solutions of Microclimate Systems for Mobile Data Centers

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Abstract. The operation of the equipment is possible provided that the optimal values of the parameters of the microclimate of the air environment are provided and maintained: its purity, temperature and humidity. Server equipment is a source of heat, the presence of which increases the air temperature and can lead to emergencies in the work of the data center.
The article describes in detail the requirements for the air parameters in the data center. The supply air temperature should be below the normalized temperature in the data center. At the same time, the moisture content of the supply air should not exceed the value corresponding to the normalized value of the "dew point". Violation of this condition may lead to the occurrence of an electrostatic discharge, which is categorically unacceptable for working electrical equipment.
Keywords: thermodynamic potential, evaporative (adiabatic) cooling, artificial (machine) cooling of external supply air.

СОПОСТАВЛЕНИЕ ТЕХНИЧЕСКИХ РЕШЕНИЙ СИСТЕМ ОБЕСПЕЧЕНИЯ МИКРОКЛИМАТА МОБИЛЬНЫХ ЦЕНТРОВ ОБРАБОТКИ ДАННЫХ

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Аннотация.
Работа оборудования возможна при условии обеспечения и поддержания оптимальных значений параметров микроклимата воздушной среды: его чистоты, температуры и влажности.Серверное оборудование является источником теплоты, наличие которой повышает температуру воздуха и может привести к аварийным ситуациям в работе ЦОД.
В статье подробно описаны требования к параметрам воздуха в ЦОДе. Температура приточного воздуха должна быть ниже нормируемой в ЦОД. При этом влагосодержание приточного воздуха не должно превышать значения, соответствующего нормируемому значению «температуры росы». Нарушение этого условия может привести к возникновению электростатического разряда, что категорически недопустимо для работающего электрооборудования.
Ключевые слова: термодинамическийпотенциал, испарительное (адиабатное) охлаждение, искусственное (машинное) охлаждениенаружногоприточного воздуха.

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The modern digital economy is impossible without the use of IT equipment. It is located in data processing centers (data centers). The data center includes machine rooms (server rooms) and a number of other auxiliary rooms [1].

The operation of the equipment is possible provided that the optimal values of the parameters of the microclimate of the air environment are provided and maintained: its purity, temperature and humidity. Server equipment is a source of heat, the presence of which increases the air temperature and can lead to emergencies in the work of the data center.

Therefore, for the trouble-free operation of the data center equipment, it is necessary to remove heat, that is, to cool the machine rooms. For this purpose, air conditioning systems (SC) are used. The SC includes various technical elements necessary to perform the required functions. These functions are diverse and depend on the purpose and characteristics of the object.

Depending on the specific operating conditions of the facility (normalized indoor air parameters, excess heat and moisture, outdoor air parameters, etc.), it is possible to use different methods (technological schemes) to ensure and maintain microclimate parameters.

Modern data centers are characterized by a wide variety of initial operating conditions, which leads to a corresponding variety of technical solutions. In addition, any technical solution has its own values of technical and economic indicators, often contradictory.

Therefore, when developing a technical solution of the IC, it is necessary to take into account the whole complex of factors that also affect installation, automation, operation and market conditions.

Mobile data centers (MCCS) occupy the largest segment of the data center market, both in terms of energy and financial indicators.

Air conditioning systems should create normalized microclimate parameters in the facility at the minimum necessary costs for their construction and operation [2].

The supply air temperature should be below the normalized temperature in the data center. At the same time, the moisture content of the supply air should not exceed the value corresponding to the normalized value of the "dew point". Violation of this condition may lead to the occurrence of an electrostatic discharge, which is categorically unacceptable for working electrical equipment.

Traditionally, the following variants of technical solutions for air conditioning systems are used:

– systems using the thermodynamic potential of outdoor supply air ("free cooling principle");

– systems with evaporative (adiabatic) cooling and humidification of external supply air;

– systems with artificial (machine) cooling of external supply air.

The first group of systems is usually called ventilation systems (SV), the second – ventilation systems with adiabatic (evaporative) cooling, and the third group – air conditioning systems (SC).

Possible options for technical solutions of systems depend on the initial conditions that determine the specifics of a particular object (room or group of rooms). These include [2, 3]:

– normalized air parameters in the working area of the premises;

– estimated (expected) intake of heat, moisture, harmful substances;

– minimum (minimum-necessary) outdoor air consumption;

– design parameters of the outdoor air;

– functional and technical characteristics of the equipment.

Evaporative cooling systems implement one of the possible cooling options for data centers.

In these systems, the "technology" of evaporative air cooling is used. With adiabatic humidification with water, there is an increase in air humidity (moisture content and relative humidity) and a decrease in its temperature. Such a technical solution is called an evaporative cooling system (SPI).

The energy consumption of the air conditioning system is one of the main indicators for a reasonable choice of its technical solution.

The amount of resources required depends on both the fundamental decision of the system and the modes of its functioning. Consistent consideration of the initial conditions of a particular object makes it possible to reasonably form variants of technical solutions for air conditioning systems [2, 3].

When forming a technical solution for a ventilation and/or air conditioning system, it is necessary:

– set ranges of indoor air parameters (optimal and/or permissible, depending on the class of the CDO);

– determine the calculated values of heat input;

– calculate the air exchange (flow rate of supply and exhaust air);

– set the values of the calculated parameters of the outdoor air;

– to identify the modes of operation of the cooling system for the annual cycle of its operation;

– to select the equipment of individual subsystems;

– to determine the energy and economic indicators of the cooling system of the facility.

The normalized air parameters in data center machine rooms are prescribed by ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) – "American Society of Heating, Cooling and Air Conditioning Engineers" and developers and operators of data centers usually focus on them.

The optimal (recommended) and permissible air parameters at the entrance to the server equipment, depending on the class of the object (A1, A2, A3, A4), are presented in Table 1 and Figure 1 [4].

Table 1 – Optimal and permissible air parameters in the data center

DIAPASON	Class	Dry thermometer temperature, Tst, °C	Air humidity range ϕ, %	Dew point temperature range, Tr, °C	Maximum dew point temperature, Tr max, °C
Recommended	**All classes**	**18 - 27**	**Not higher than 60**	**5,5 – 15**	**15**
Acceptable	**A1**	**15 - 32**	**20 – 80**	**–**	**17**
	A2	**10 - 35**	**10 - 35**	**–**	**21**
	A3	**5 - 40**	**8 – 85**	Not lower than - 12	**24**
	A4	**5 - 45**	**8 – 90**	Not lower than - 12	**24**

The normalized temperature ranges of the "dew point" determine the boundaries of the moisture content values, which are shown in Figure 1.

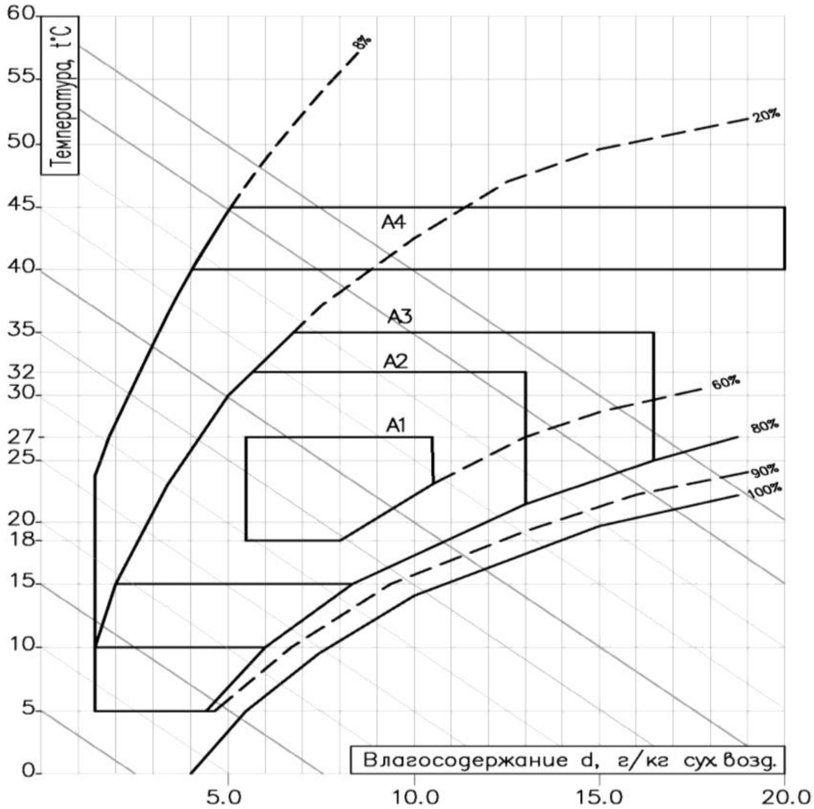

Figure 1 – Diagram (i-d) with ranges of optimal and permissible air parameters in the data center

It is recommended to determine the operating range of air parameters in the "cold" corridor of the data center based on the purpose and functions of the data center being developed in accordance with the terms of reference.

After determining the range of possible changes in the air parameters in the "cold" corridor, engineering decisions should be made to ensure the specified air parameters of the "cold corridor" in the year-round operational cycle with priority for the use of engineering solutions that meet the requirements of ecology and energy efficiency [4].

Let's consider the operating conditions of the cooling system (ventilation and/or air conditioning) in various outdoor temperature ranges using the thermodynamic (i-d) diagram of humid atmospheric air (Figure 2).

The analysis will be carried out for the conditions of ensuring the recommended (optimal) or permissible air parameters in data centers of different classes with an operating temperature difference (difference) (tu - tp) = 10 ° C.

When the outdoor air parameters (see diagram) have values in the temperature ranges (8 ... 17) ° C and moisture content (5.6 ... 10.7) g / kg, it is possible to ensure the recommended (optimal) values of air parameters in Class A1 rooms. At the same time, a direct-flow treatment scheme of the supplied outdoor air is used, realizing its thermodynamic potential.

At outdoor temperatures below 15 ° C, it is possible to provide the necessary temperatures at the inflow in the range (8 ... 17) ° C using either a direct-flow circuit or a circuit with recirculation.

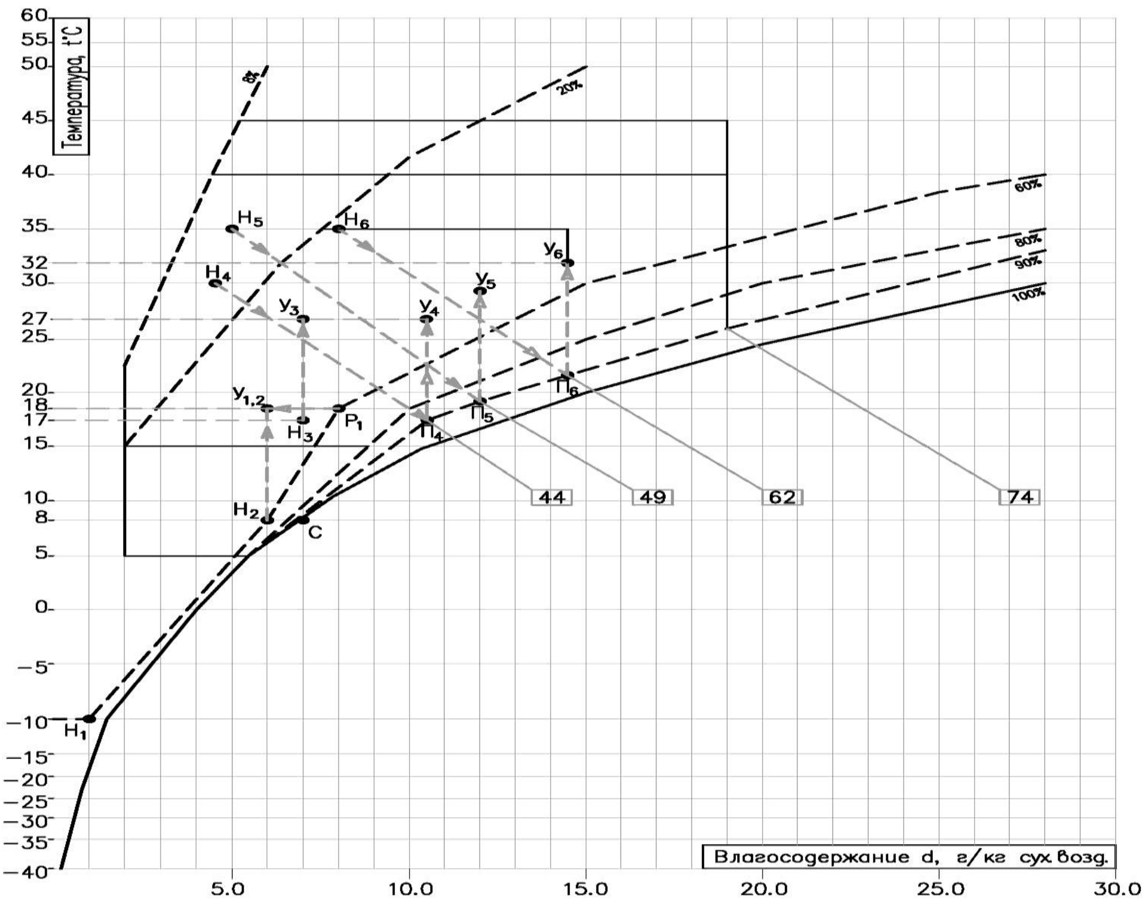

Figure 2 – Diagram of humid air with different values of outdoor air parameters

If the outdoor air temperature is 15 °C, and the moisture content value is below 5.6 g/kg, then the indoor temperature will be 25 °C, and the moisture content value will be below the normalized (required) value of 5.6 g/kg. Consequently, the temperature corresponds to the recommended (optimal) value, and the moisture content corresponds to the permissible class A1. When the moisture content value is higher than the normalized (required) value equal to 5.6 g/kg, parameters (both in temperature and moisture content) corresponding to the recommended values of Class A1 are formed in the premises.

At values of specific enthalpy of outdoor air (see diagram) in the range (24 ... 25) kJ/ kg, it is necessary to use evaporative (adiabatic) air cooling. Then the supply air temperature will be about 8 ° C, and the minimum recommended temperature in the room will be 18 ° C, with moisture content values of more than 5.6 g/kg, which corresponds to the Class A1 range.

It is possible to provide recommended indoor parameters corresponding to Class A1 at values of specific enthalpy of outdoor air no more than 44 kJ/kg (see diagram).

The use of evaporative (adiabatic) cooling in the range of specific enthalpy of outdoor air (44 ... 49) kJ / kg, allows to provide normalized ranges of permissible parameters in Class A1 rooms.

A consistent analysis of the values of specific enthalpy of outdoor air allows us to draw the following conclusions:

- in the range of specific enthalpy (49 ... 62) kJ/kg, it is possible to provide acceptable parameters in Class A2 rooms;
- in the range of specific enthalpy (62 ... 74) kJ/ kg, it is possible to provide acceptable parameters in rooms of classes A3 and A4.

Moreover, these restrictions are related to the normalization of the dew point, which determines the moisture content values. Indoor air temperatures are always below the maximum allowable values. The results of the performed analysis are presented in Table 2.

Table 2 – Conditions of use of evaporative cooling

Outdoor air parameters		Air Processing scheme	Supply air parameters		Indoor air parameters		Class of normalized parameters
***t,*°C**	***d,*g/kg(s.v.)**		***t,*°C**	***d,*g/kg(s.v.)**	***t,*°C**	***d,*g/kg(s.v.)**	
8...17	**5,6...10,7**	Direct - flow	**8...17**	**5,6...10,7**	**18...27**	**5,6...10,7**	A1 (recommended)
Less than15	**Less than 10,7**	Direct-flow or recirculated	**8...17**	**5,6...10,7**	**18...27**	**5,6...10,7**	A1 (recommended)
15	**Less than 5,6**	Direct - flow	**15**	**Less than 5,6**	**25**	**Less than 5,6**	A1(acceptable)
Specific enthalpy of outdoor air i, kJ/kg		Air treatment scheme	Supply air parameters		Indoor air parameters		Class of normalized parameters
			***t,*°C**	***d,*g/kg (s.v.)**	***t,*°C**	***d,*g/kg (s.v.)**	
24...25		Evaporative cooling	8,0	6,5	18,0	6,5	A1 (recommended)
25...44		Evaporative cooling	8...16	6,5...10,7	18...26	6,5...10,7	A1 (recommended)
44...49		Evaporative cooling	16...18	10,7...12,2	26...28	10,7...12,2	A1 (acceptable)
49...62		Evaporative cooling	18...22	12,2...15,7	28...32	12,2...15,7	A2
62...74		Evaporative cooling	22...25	15,7...19,0	32...35	15,7...19,0	А3иА4

Thus, the data given in the table make it possible to determine the conditions for the expedient use of evaporative cooling systems in data processing centers.

The question of the need to use technical means of artificial air cooling is solved depending on the requirements for the air parameters in the server rooms (i.e. technological conditions) and the design parameters of the outdoor air in the climatic area of the data center location. The values of the calculated parameters of outdoor air for 36 points (cities) of the Russian Federation are given in the Codes of Rules [5, 6].

Consideration of possible parameters of outdoor air in the warm season is necessary to make a decision on the use of refrigerating machines to reduce the value of the specific enthalpy of moist atmospheric air sent to the "cold" corridor of the data processing center.

Analysis of climatological information allows us to conclude that for most regions of the Russian Federation (except for southern coastal cities such as Sevastopol, Sochi, Yalta and a number of others), using evaporative cooling, it is possible to provide acceptable air temperature values not exceeding 32°C.

Thus, when the outside air temperature is below the minimum required at the inflow, the system operates according to a scheme with variable recirculation.

In the range of outdoor air temperatures, from the minimum required at the inflow to the maximum required, a direct-flow circuit is used.

To ensure an acceptable temperature range in the warm season (from 27°C to 32°C), a direct-flow circuit is also used.

When the temperature value in the "cold" corridor reaches 32 ° C, it is necessary to consider and analyze the value of the specific enthalpy of outdoor air and its duration in the climatic region of the data center location, in order to determine the need to use artificial cold.

Depending on the values of the normalized air parameters in the data center (for the prescribed classes of servers), the calculated value of the enthalpy of outdoor air is determined and a conclusion is made about the possibility (or limitation) of using an evaporative cooling system for the data center in question.

For example, for classes A3 and A4, the calculated value of the outdoor air enthalpy is 74 kJ/kg. Therefore, there are no restrictions on the use of evaporative cooling, since for all cities listed in the Rulebook [5], the calculated value of the outdoor air enthalpy is less than 74 kJ/kg.

In addition to stabilizing the air temperature in the cold corridor, it is also necessary to provide normalized values of relative humidity and/or moisture content. The evaporative cooling system requires deep demineralization of water and fine spraying of water [4].

As a rule, fine atomization of water is achieved at a water pressure of about 100 atm. The use of the hydrodynamic effect proposed by us makes it possible to disperse water with an average diameter of water droplets of the order of 13 microns at a water pressure of no more than 10 atm. [9, 10, 11].

To intensify mass transfer in the "small droplets–air" system, it is necessary to create a relative movement of water and air droplets. This movement for finely dispersed water droplets creates turbulent pulsations of the flow, which, in turn, gives an arched element when working in the air.

The air flow passing through the arched element is transformed into a system of intense vortices, which, picking up small droplets, provide intensive transfer of water vapor from the boundary layer of the droplet into the air [10, 11].

In the methodological recommendations [4], it is proposed to take into account the estimated air consumption per 1 kW of server power, which is (250 - 300) m^3/h. Then, from the heat balance equation, the calculated temperature drop (difference) required for the assimilation of excess heat in the object is determined as follows

$\boldsymbol{Q_p = c_b \cdot G_p \cdot (t_y - t_p)}$,

$(\boldsymbol{t_y - t_p}) = \boldsymbol{Q_p} / [\boldsymbol{c_b} \cdot (\boldsymbol{L_p \cdot p_в}) / 3600] = \mathbf{1{,}0} / [1{,}0 \cdot (300 \cdot 1{,}2) / 3600] = \mathbf{10}$ °C

where Q_p is excess heat in the room, kW;

c_b is the specific mass heat capacity of the air, kJ / (kg * °C);

G_p - mass flow rate of supply air, kg/h;

r_v – air density, kg/m^3;

t_p - supply air temperature, °C;

t_u is the temperature of the air removed from the room, °C.

Comparative analysis of data center cooling systems

We will conduct a comparative analysis of the evaporative cooling system with the "classical" system operating on the basis of a steam compression refrigeration unit.

Initial data:

– the specified air parameters are shown in Table 1;

– the number of server racks and heat dissipation from them: Q_{cdo} = (2 X 5) = 10 kW;

– for 1 kW of server power, the volume of air L_v = 300 m^3/ h is supplied;

– temperature difference (working difference):

$(t_u – t_p) = Q_{cdo} / [s_v * (L_p * r_v) / 3600] = 1{,}0 / [1{,}0 \cdot (300 \cdot 1{,}2) / 3600] = 10°$ With;

– the values of the outdoor air temperature and its duration for the climatic conditions of Moscow are presented in [7];

– the repeatability of combinations of enthalpy and moisture content of outdoor air in Moscow per year per day as a whole (probabilistic and statistical climate model) is given in tabular form in [8].

The following variants of cooling systems are considered:

– evaporative (adiabatic) cooling with humidification;

– "machine" cooling of the supply outside air in the cooler of the central air conditioner;

– air cooling in the direct evaporation air cooler installed in the engine room.

Average values of tariffs for Moscow enterprises:

– water: 50.0 (rub / m^3);

– electricity: 6.0 (rubles / kWh).

Calculations were carried out according to the normative methodology [8]. The results of the calculations are presented in Table 3.

Table 3 - Calculation results

Name of the indicator or parameter	Conditional designation	Dimension	Cooling system options		
			Evaporative cooling	Central air conditioning	Direct evaporation air cooler
Heat dissipation from server racks	Q_{CDO}	kW	**10,0**		
Volume flow rate (air exchange)	L_B	m^3/h	**3 000**		
Massair consumption	G_B	kg/sec	**1,0**		
Totalwater consumption	$\sum Gw$	m^3/month	**3,60**	**-**	**-**
Electric power consumption of the pump	N_H	kW	**0,010**	**-**	-
Electric power consumption of the fan	N_B	kW	**0,045**	**0,045**	**-**
Electrical power consumption of the refrigeration system installation	N_X	kW	**-**	**1,45**	**1,34**
Energy efficiency coefficient	PUE	-	**1,006**	**1,15**	**1,34**
Fan power consumption	$Э_в$	kW· h	**33,5**	**33,5**	-
Electricity consumption by the pump	$Э_n$	kW· h	**5,0**	-	-
Electricity consumption by the refrigeration system installation	$Э_h$	kW· h	**-**	**375**	**860**
Total (total) electricity consumption	$Э$	kW· h	**38,5**	**408,5**	**860**
Total (total) electricity costs	Z	Russian Rubles (per month)	**230**	**2 450**	**5 160**
Security of the recommended parameters of Class A1		%	**89**	**100**	**100**

Conclusions Based On The Results Of The Calculation

Evaporative cooling systems are capable of providing the recommended (optimal) parameters of class A1 at values of specific enthalpy of outdoor air below 42 kJ/kg and permissible parameters of class A1 – at values of specific enthalpy of outdoor air below 49 kJ/kg.

In the range of values of the specific enthalpy of the outside air (42...62) kJ/kg, it is possible to provide acceptable parameters of class A2, in the range (62...74) kJ/kg - permissible normalized air parameters in server rooms of classes A3 and A4.

If the recommended (optimal) parameters of Class A1 are maintained, it is possible (in certain climatic regions) to "violate" (lack of security in duration) the normalized parameters.

If the recommended parameters of class A1 must be constantly provided in the facility (the duration of unsecurity is zero), then it becomes necessary to use a refrigeration unit using artificial cold.

During the feasibility study of technical solutions, indicators (energy, cost, etc.) of competing options for data center cooling systems should be compared.

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