Chinese Business Review, Jan.-Mar. 2024, Vol. 23, No. 1, 1-12
doi: 10.17265/1537-1506/2024.01.001

Operating Parameters of the District Heating Substation Cooperating With the Installation of Technological Air Conditioning With High Efficiency of Heat Recovery

Żarski Kazimierz, Kryża Mariusz
HVAC, Luzino, Poland

The article analyses the problem of determining the operating parameters of the district heating substation cooperating with the air heating system in technological air conditioning systems equipped with heat exchangers with high efficiency of heat recovery. Attention was paid to the correct selection of heat exchangers for the heat output balance depending on the heat recovery protection algorithms against a drop in the temperature of the heat transfer surface below 0 ℃. Critical parameters were determined in Polish climatic conditions, at which the operation of the heat recovery exchanger in the air conditioning system is switched off or limited. It has been proven that the proper functioning of the district heating substation cooperating with the installation of air conditioning with high heat recovery efficiency requires the use of two heat exchangers with different characteristics, equipped with properly selected temperature control systems. The optimal model of cooperation between the technological air conditioning system and the heating substation was also indicated.

Keywords: ventilation of operating theatre, air conditioning, flow control in heating circuit

Introduction

The design of technological air conditioning requires the fulfilment of stricter conditions than in the case of systems in public facilities. Although hospitals are public facilities (health services), the installations used in them are of a technological nature. Maintaining air purity and proper microbiological conditions, especially in rooms with high air purity requirements, such as operating rooms in hospitals and precision production rooms in industrial plants, is an essential issue in the design of technological air conditioning systems (Charkowska, 2022). Air parameters inside air-conditioned rooms (temperature, relative humidity, and air velocity) are determined within the framework of technological requirements (HTM, 2022; Design, 2022). Permissible deviations of parameters, which are much smaller than in the case of air conditioning of rooms in public buildings, are also important. The operation of the air-conditioning system must be precise, and this is how the system with such requirements is defined. In air conditioning systems heaters are installed, in which the heat carrier supplied from the district heating substation heats the conditioning air. It is therefore necessary to maintain precisely the temperature of the air directed to the air-conditioning system, regardless of external climate conditions and

Żarski Kazimierz, Ph.D., independent HVAC expert, Luzino, Poland.
Kryża Mariusz, Ph.D., HVAC designer, Luzino, Poland.
Correspondence concerning this article should be addressed to Kryża Mariusz, 4 Brzozowa str., PL-84-242 Luzino, Poland.

internal disturbances. And this depends on the adopted solutions both in the installation supplying heat to the heaters, as well as in the secondary circuits (installation) and primary circuits (heating network) of the district heating substation. In design practice (Design, 2022; Zarski, 2014), quite often the design of the district heating substation cooperating with the air conditioning or ventilation systems prepared on the basis of too general data, which do not allow for the proper selection of devices and operational parameters of the substation. This results in incorrect functioning of automatic control systems and the inability to maintain the correct temperature of the air supplied to the air conditioning system. Correct solutions should appear in the area of:

- selection of the heat exchanger in the district heating substation, in accordance with the balance of heat demand,
- selection of the method of protecting the heat exchanger in the air conditioning unit against the temperature drop of the heat transfer surface,
- selection of the proper air temperature adjustment algorithm in the air handling unit,
- selection of correct parameters of static and dynamic characteristics of control valves in the circuits of the heating substation.

Selection of the Heat Exchanger and Selection of the Method of Protecting the Heat Exchanger in the Air Conditioning Unit Against a Drop in the Temperature of the Heat Transfer Surface

Input data for the design of the district heating substation should be obtained by the designer from the Contractor. They may accept data from the cooperating designer of the air conditioning system and the heating system to heat the air, as long as they are bound by a business or civil law contract. If the co-worker is a separate entity within the meaning of economic law, then the only source of data may be the Contractor associated with the designer of the interchange with an employment contract or a civil law contract. The following data are necessary for the proper execution of the heat node design (Zarski, 2014).

(a) Thermal load table Φ at different outside air temperature t. It should be remembered that technological air conditioning requires the adoption of extreme external climate conditions that are stricter than in other public facilities, e.g. in offices. An exemplary table is given below.

Table 1

Example of Heat Demand for Air Conditioning at Different Outdoor Air Temperatures

t_e (°C)	Φ (kW)
-24	336.00
-20	255.11
-16	184.18
-12	123.20
-8	72.18
-4	62.22
0	52.27
4	42.31
8	32.36
12	22.40
16	12.44
19	4.98

The values in the table result from the temperature efficiency of heat recovery in different intervals of the outside air temperature. These data should be provided by the designer of the air conditioning system.

(b) Method of protecting heat exchangers for heat recovery in air conditioning units against “freezing”. The optimal solution is the so-called “gradual bypass”, i.e. bypassing the exchanger, to which a certain part of the heated external air is directed so that the temperature of the heat transfer surface does not fall below 2-3 ℃. Incorrect solutions include bypassing the exchanger with the entire air stream or temporarily shutting down the air supply system in the central unit in order to “defrost” the exchanger. The latter method is unacceptable in technological air conditioning.

(c) Type and operating parameters (supply and return temperature) of the heat carrier, e.g. GP30 (30% propylene glycol solution), supply/return temperature: e.g. 65/55 ℃ and the available pressure difference in the system.

(d) Method of controlling the power of air heaters: two-way valve, three-way valve, pump mixing.

(e) Location of air conditioning units: outside, in a heated technical space.

For exemplary calculations, technological air conditioning with an air conditioning stream of 15,000 m^3/h. In order to select the heat exchanger, the demand for thermal power in the full spectrum of the outside air temperature should be determined. The demand for heat flux depends on the temperature of the outside air and the temperature efficiency of heat recovery in the air conditioning unit, also depending on the temperature of the outside air. In Table 2, the limit value of heat recovery efficiency (at which there is no unacceptable decrease in the temperature of the heat transfer surface) is given as a function of the temperature of the external air (AIR, 2012).

Table 2

Borderline Temperature Efficiency of Heat Recovery as a Function of External Air Temperature (AIR, 2012) in an Exchanger With a Maximum Efficiency of 80%

t_e (℃)	η_t (%)
-24	50
-22	55
-20	60
-18	65
-16	68
-14	72
-12	75
>-10	80

During a period of outside temperature lower than -10 ℃, the supply air flow through the heat recovery exchanger shall be reduced. As mentioned, a complete shut-off of the supply air stream is not beneficial as it leads to an increase in the design heat output and to a greater unevenness of the heat exchanger power range in the heat node. Based on the borderline heat recovery efficiency, it is possible to determine the amount of heat demand to heat the air conditioning air as a function of the outside air temperature. The results of the calculations are illustrated in Table 3. Calculation formulas are generally known.

Table 3

Thermal Power Demand (Heat Flux) Φ in the Air Conditioning Heating System at Different Outside Air Temperature t at the "Liquid" Bypass of the Heat Recovery Exchanger

t_e (℃)	η_t (%)	Φ (kW)
-24	50	617.25
-22	55	530.83
-20	60	449.92
-18	65	374.46
-16	68	324.81
-14	72	268.85
-12	75	226.33
-10	80	170.08
-8	80	159.10
-6	80	148.15
-4	80	137.17
-2	80	126.19
0	80	115.23
2	80	104.25
3	80	98.75
4	80	93.27
6	80	82.29
8	80	71.33
10	80	60.35
12	80	49.38
14	80	38.42
16	80	27.44
18	80	16.46
19	80	10.98

The spectrum of heat demand is significant, the quotient of minimum and maximum heat output is 0.0178, so the operation of the heat exchanger under minimum load conditions should be checked. A significant reduction in the mass flow in the plate heat exchanger may result in a loss of heat transfer capability due to the transition to the laminar motion zone with a very small Reynolds Number. In such conditions, heat exchange disappears and adverse phenomena occur in the functioning of automatic control systems (hunting), which leads to unacceptable errors in the temperature control of the air directed to the air conditioning system. Below an example of the selection of the exchanger (data in Table 3) under conditions of maximum heat demand is shown.

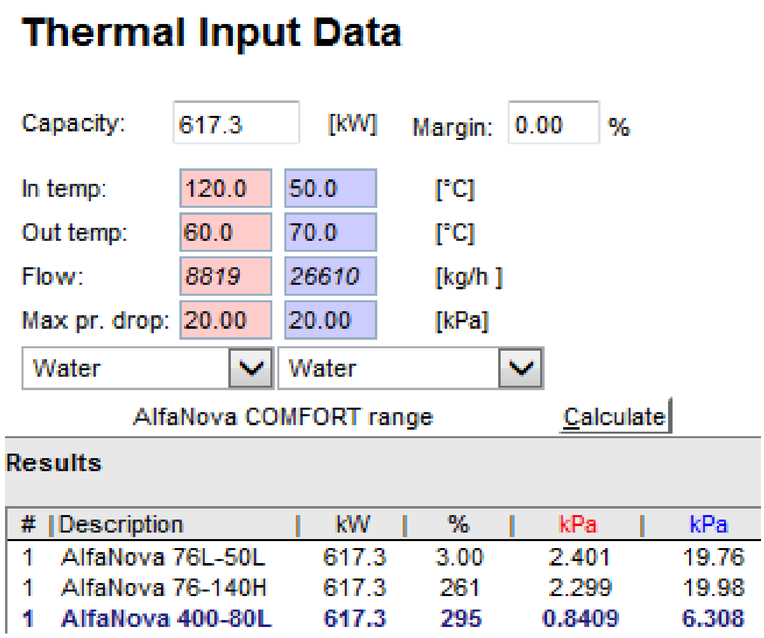


Figure 1. The results of the selection of the heat exchanger in the district heating substation under design conditions (CAS 200). The selected exchanger was distinguished.

Checking the operation of the exchanger under minimum load conditions requires determining the temperature of the water supplying of the system under these conditions. It was determined using the GRAPH program.

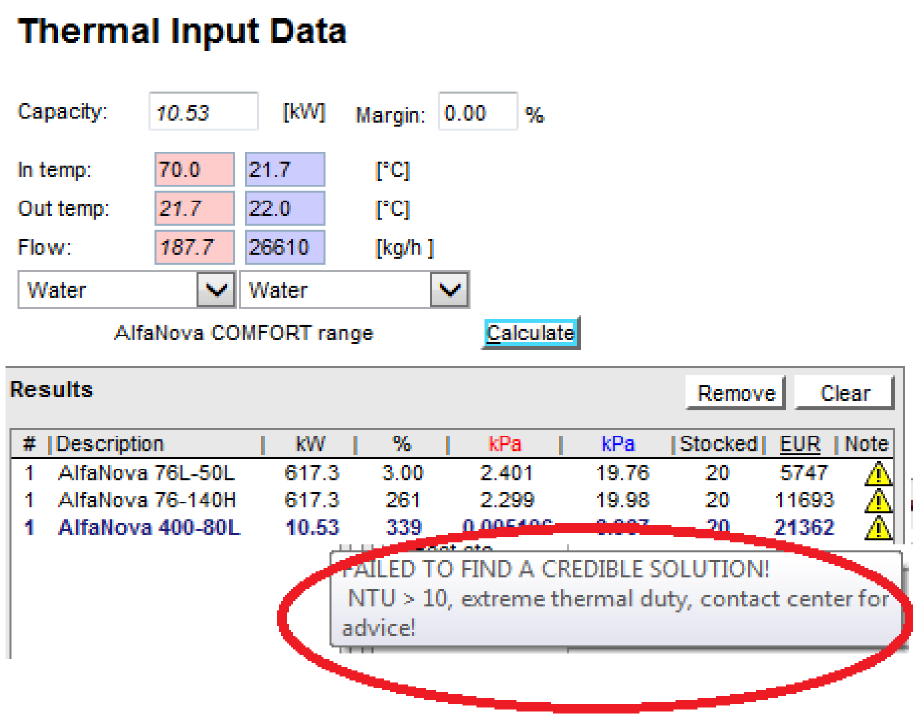


Figure 2. Results of the simulation of the operation of the heat exchanger in the district heating substation under minimum load conditions (CAS200).

The message indicates that the standard NTU (number of thermal unit) value is exceeded, which does not ensure the proper functioning of the heat exchanger. The analysis above leads to the conclusion that in the air conditioning system with the use of a heat recovery exchanger with high temperature efficiency, two heat exchangers should be designed and switched depending on the temperature of the external air. In Table 4, an example of the allocation of thermal power to two heat exchangers is given.

Table 4

Assignment of Heat Output to Heat Exchangers in the Heating Node

t_e (ºC)	Φ (kW)	Exchanger
-24	617.25	
-22	530.83	
-20	449.92	
-18	374.46	
-16	324.81	
-14	268.85	
-12	226.33	Exchanger 1
-10	170.08	
-8	159.10	
-6	148.15	
-4	137.17	
-2	126.19	
0	115.23	
2	104.25	
3	98.75	
4	93.27	
6	82.29	
8	71.33	
10	60.35	Exchanger 2
12	49.38	
14	38.42	
16	27.44	
18	16.46	
19	10.98	

Selection of the Proper Air Temperature Control Algorithm in the Air Handling Unit

There are three possibilities of controlling the temperature of the air conditioning air, thus the power of the air heater.

(a) Adjustment by means of a two-way valve

In Figure 3, such a method of adjustment is shown.

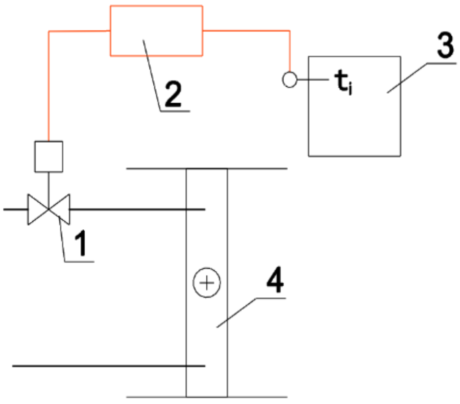


Figure 3. Temperature control in a room (or in a supply air) with a two-way valve (Zarski & Kryza, 2022). Designation: 1—two-way valve, 2—regulator, 3—temperature sensor, 4—ventilation air heater.

This is a quantitative regulation. By closing the valve, the heat carrier flux is changed and, as a secondary effect, the return temperature is lowered. This is the correct method of regulation to ensure that the temperature of the water returning to the heating network is sufficiently low.

(b) Adjustment via three-way valve

This adjustment is shown in Figure 4.

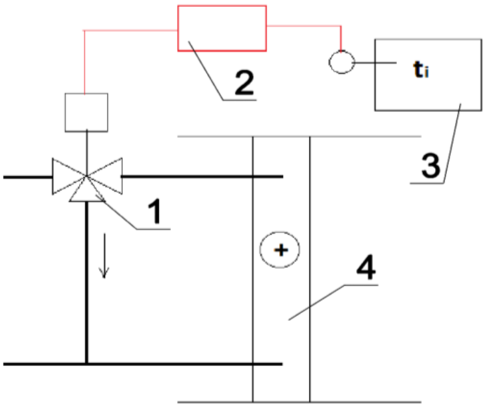


Figure 4. Temperature control in a room (in a supply stream) with a three-way valve (Zarski & Kryza, 2022). Designation: 1—three-way valve, 2—regulator, 3—temperature sensor, 4—ventilation air heater.

It is also a quantitative regulation, wherein the flow of the heat carrier flowing between the heat exchanger and the three-way valve is approximately constant. It is a system unfavourable from the point of view of the district heating substation. The stream guided bypassing the heater increases the temperature of water returning to the heating network, which is an unfavourable phenomenon. This phenomenon occurs particularly drastically when designing the air conditioning section with one exchanger at the heat recovery system switching point. For example, with the data as in Table 3. At outdoor air temperature - 10 ℃, there turn water temperature is equal to approx. 55 ℃, so the temperature of water returning to the heating network is approx. 57 ℃ to 58 ℃.

(c) Adjustment via a mixing system

This method of adjustment with the pump installed in the supply line is quite often used by designers. It is illustrated in Figure 5, which also shows the pressure system in the hoses.

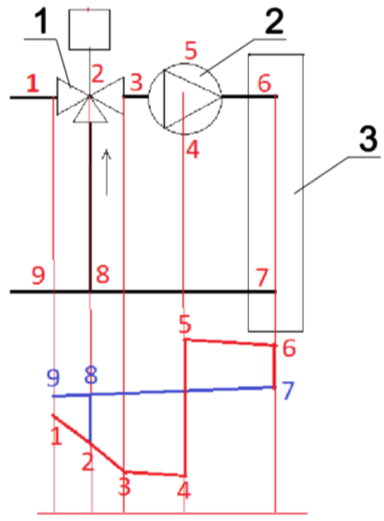


Figure 5. Room temperature control (in the supply stream) by means of pump mixing-pressure system (Zarski & Kryza, 2022).
Designation: 1—three-way valve, 2—pump mounted on the power cable, 3—ventilation air heater.

Assumedly, this is a qualitative regulation: at a constant flow through the heater, the temperature of the heat carrier supplying the heater is regulated. Unfortunately, in the layout shown in Figure 5, there is no basis for proper operation in a complex, especially in extensive heat supply system to heaters. Proper operation of the mixing system with the pump in the supply line requires pressure inversion. If there is more pressure in the supply line than in the return line (generated by the pump at the heat exchanger) at the point where the heater circuit is switched on, then the mixing line will have reverse flow or loss of flow. The heater will be supplied with a heat carrier with unchanged temperature. The control system will react to an excessively high air temperature, therefore will send an open signal to the three-way valve, which, when fully opened, will cause a loss of flow in the conduit supplying the heat carrier from the heat exchanger. The air temperature will decrease and then the valve will start to open, so that after a while it will start to close due to too high air temperature. This is another case of "hunting", this time in the heater control valve. The pump mixing system is correct when the pump is mounted in the mixing line, as shown in Figure 6.

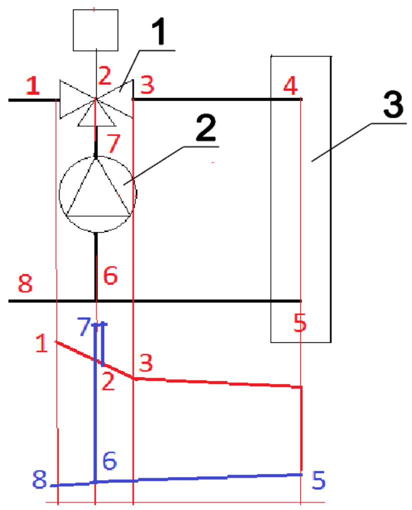


Figure 6. Room temperature control (in the supply flow) by means of pump mixing with the pump in the mixing line—pressure system (Zarski & Kryza, 2022).
Designation: 1—three-way valve, 2—pump mounted on the mixing cable, 3—ventilation air heater.

The control valve is redundant in this diagram, it is enough to adjust the speed of the pump by means of a frequency inverter. At a sufficiently low speed, the pump will not be able to overcome the differential pressure between the supply and return lines and the flow in the mixing line will disappear. The optimal temperature control system in the process air conditioning system is a system with a two-way valve using a balancing valve or a differential pressure control valve.

Selection of Correct Parameters of Static and Dynamic Characteristics of Control Valves in the Circuits of the Thermal Node

The static characteristics of the control circuit (valve with pipelines, fittings, and other components, e.g. flow meters) depend on the pressure loss quotient when flowing through a fully open valve to the total pressure loss in the controlled circuit. The pressure loss at the flow of liquid through the valve at full opening can be calculated from the formula:

$$\Delta p_z = \frac{\rho}{1000}\left(\frac{V}{K_{vs}}\right)^2 \quad (1)$$

where:

Δp_z—pressure loss at liquid flow through the valve, bar,

K_{vs}—valve flow rate at full opening, m^3/h,

V—liquid volume flow, m^3/h,

ρ—density of the liquid, kg/m^3, at the appropriate temperature.

The volume flux of the heat carrier at a given pressure difference before and after the valve (pressure loss in the valve) can be calculated from the formula:

$$V = \left(\frac{V}{V_o}\right)_{\frac{h}{ho}} K_{vs}\sqrt{\frac{1000}{\rho}\Delta p_z} \quad (2)$$

where:

$\left(\frac{V}{V_o}\right)_{\frac{h}{ho}}$—the relative volume flow determined at the relative degree of opening, e.g. on the basis of Table 5,

K_{vs}—low coefficient of the control valve, m^3/h,

Δp_z—pressure loss at the flow through the valve, bar,

ρ—density of the liquid, kg/m^3.

Table 5 shows an example calculation of the degree of opening of the control valve, with the value of the authority A = 0.7 with changing flow of the heat carrier. With a decreasing degree of the valve opening, the flow rate decreases, and so the loss of pressure in the heat exchanger, pipelines, and fittings decreases in the power of 2. With constant pressure loss in the circuit, the greater the pressure loss, the smaller the degree of opening. Characteristic distortion occurs, leading to shifting of the valve operation to the area of lower opening.

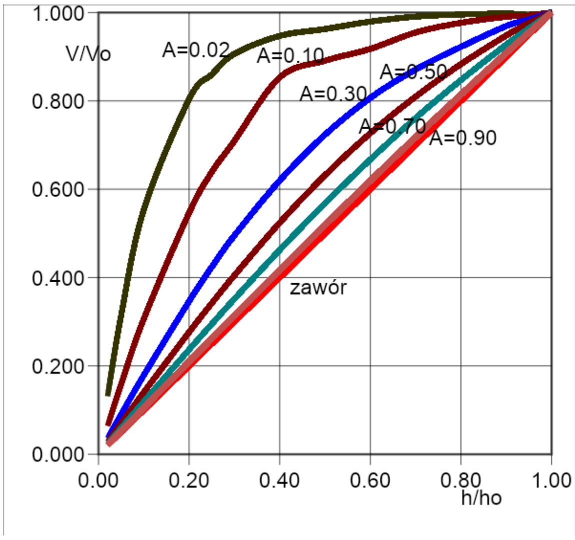
Table 5

Sample Calculation of the Volume Flux of the Heat Carrier in the Regulated Circuit at a Given Pressure Difference (Loss of Pressure in the Circuit) and Different Degree of Opening of the Control Valve, With the Value of Authority A = 0.7 (Author's Study)

h/h_0	Valve V/V_0	V/V_0 in the regulated circuit
1.00	1.00	1.00
0.95	0.72	0.78
0.90	0.57	0.64
0.80	0.40	0.46
0.70	0.32	0.37
0.60	0.28	0.33
0.50	0.26	0.31
0.40	0.25	0.30
0.30	0.23	0.27
0.20	0.18	0.21
0.10	0.10	0.12
0.05	0.05	0.06

Notes. h/h_0: valve opening degree, V/V_0: relative volume flow.

In valves with low authority, there is a significant distortion in the flow characteristics of the valve in the regulated circuit, which means the occurrence of areas of "insensitivity" and regulatory "hypersensitivity". This is illustrated in Figure 7.



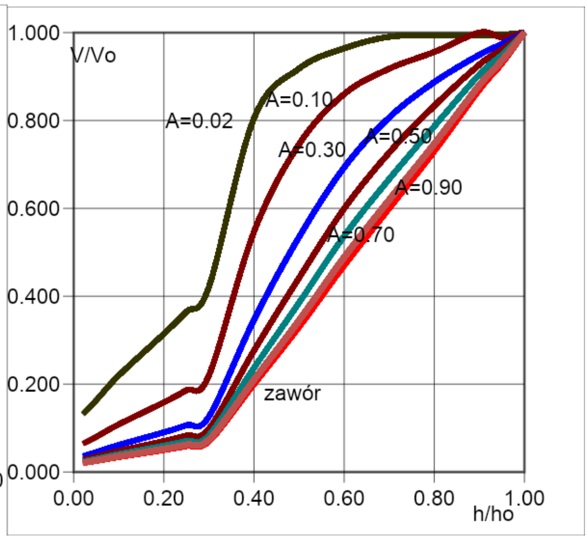


Figure 7. Control valve characteristics and control circuit characteristics at different control valve authority values (left: linear profile, right: "split" profile).

It is recommended to use control valves with a profile similar to the exponential one. This ensures proper operation of the valve with authority not less than 0.3. Figure 8 shows the flow characteristics of the control valve with an exponential profile depending on the authority in the regulated circuit (Zarski, 2014).

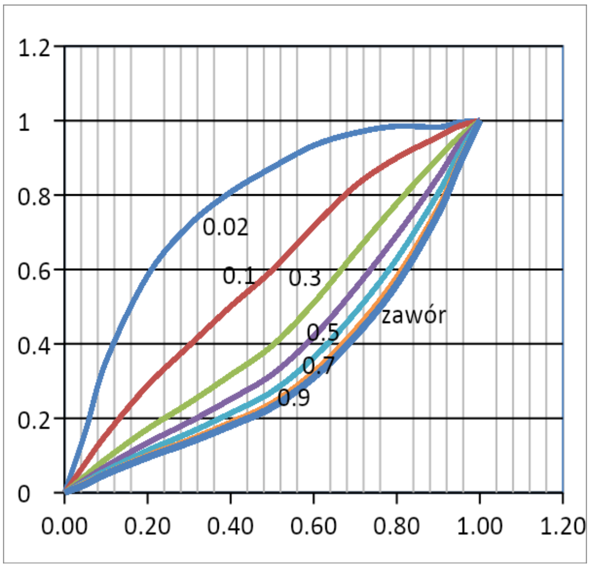


Figure 8. Change in flow characteristics of the control valve depending on the authority (exponential profile) (Zarski, 2014).

When selecting the dynamic parameters of the control valve, it should be taken into account that the inverse of the valve stem speed should not be greater than 3 s/mm. The use of valves with a lower speed of stem movement, such as for heating installations, does not provide a sufficiently precise regulation of the air temperature in the air conditioning system.

Conclusions

The article touches upon the selected correct cooperation of technological air conditioning systems with the district heating substation. Failure to meet certain standards by the air conditioning system and associated installations prevents the proper design and functioning of the district heating substation. Critical points in the design of air heating systems in technological air conditioning systems and the design of the heating node cooperating with this system are:

- Obtaining from the Contractor the correct data of the heat balance: heat demand table at different temperatures of the external air, operational parameters of the installation, and information about the heat exchanger control algorithm for heat recovery in air conditioning units.
- Proper selection of heat exchangers in the heat node when using heat exchangers for the recovery of ventilation heat with high efficiency (above 50%)—2 heat exchangers should be used to cover the spectrum of heat demand. The usage of one heat exchanger leads to a malfunction of the plate heat exchangers.
- Proper adoption of extreme external climate conditions, sharper than in the air conditioning of comfort.
- Adoption of the heat recovery bypass control algorithm as a “gradual bypass”, which ensures avoiding a step change in the heat output and the associated possibility of not meeting the control parameters of the prepared air.
- Adoption of the high authority of the control valves in the ventilation circuits, which allows the proper functioning of the exchanger in the area of low heat load.
- Adoption of the appropriate dynamic parameters of the control valves, which allows avoiding a temperature control error of the medium supplying the installation.

- The usage of a proper method of adjusting air-conditioning heaters: a system with a two-way valve or a system of mixing with a pump in the mixing line.

Meeting these conditions will ensure proper cooperation between the district heating substation and the air conditioning system. Any “conflict” in the set of critical points will prevent proper operation of the installation, thus not ensuring proper microclimate conditions in air-conditioned rooms.

References

AIR1, AIR2. (2012). Program for modelling of humid air changes (Author’s work).

CAS200. (n.d.). Program for dimensioning of heat exchangers, Alfa Laval design of air conditioning system in operating theatre in hospital in town in Poland (data in the Author’s possession).

Charkowska, A. (2022). Ventilation and air conditioning systems in hospitals—Available solutions, cost optimization, for hospitals.pl, access 02.2022

Design. (2022). Design of air conditioning system in operating theatre in hospital in (town in Poland, data in the Author’s possession).

GRAPH. (n.d.). Program for creating a regulation curve for heating installation (Author’s work).

HTM. (2022). *Heating and ventilation system, health technical memorandum 03-01*. UK: Department of Health.

Żarski, K. (2014). *Thermal nodes in urban heating systems.* Warsaw: Information Centre “Installation technology in construction”.

Żarski, K., & Kryża, M. (2022). Conditions for correct cooperation of the heat node with the air conditioning system of the hospital operating blocks. Instal 3/2022, p. 5.