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CONTROLLABILITY OF INDOOR AIR QUALITY PARAMETERS IN A TEST CHAMBER OF ZOOLOGICAL INSTITUTE

OCENA MOŻLIWOŚCI REGULACJI PARAMETRÓW KLIMATU WEWNĘTRZNEGO W KOMORZE BADAWCZEJ INSTYTUTU ZOOLOGII

A b s t r a c t

Breeding laboratory chambers require a wide range of indoor air parameters, which implies the need to use special equipment for air treatment and very accurate and fast automatic adjustment. The article presents the results of an experimental study conducted in the existing breeding chamber. The work is based on numerous observations as well as on-site measurement series of indoor climate parameters. The conclusions seem to be important for future design projects.

Keywords: indoor air quality, climatic chamber, close control air conditioning, laminar air flow, comfort

S t r e s z c z e n i e

Komory hodowlane są przykładem pomieszczeń o bardzo wysokich wymaganiach w zakresie parametrów powietrza wewnętrznego, co z kolei implikuje konieczność zastosowania specjalnych urządzeń w wykonaniu higienicznym oraz bardzo dokładnej i szybkiej regulacji parametrów. W artykule przedstawiono wyniki badań parametrów powietrza w ujęciu dynamicznym w istniejącym obiekcie Instytutu Zoologii UJ. Wnioski z przeprowadzonych analiz mają duże znaczenie dla projektowania systemów klimatyzacji tego typu obiektów.

Słowa kluczowe: jakość powietrza wewnętrznego, komfort wewnętrzny, precyzyjna regulacja parametrów powietrza, laminarny przepływ powietrza

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Designations

Φ_N – heat exchanger nominal capacity [kW]
Φ – transient heating capacity of the air heater [kW]
V_a – air flow rate [m^3/h]
t_{out} – air temperature at the outlet of the heat exchanger, [°C]
t_{in} – air temperature at the inlet to the heat exchanger [°C]
t_{sN} – supply water temperature in nominal parameters [°C]
t_s – water temperature at the inlet of air heater [°C]
t_r – water temperature at the outlet of air heater [°C]
m_{wN} – nominal water mass flow rate [kg/s]
$c_{p,a}$ – specific heat of air at constant pressure [kJ/(kg*K)]
M – mixing ratio of the water in a 3-way mixing valve [–]
a – exponential parameter of the heat exchanger [–]
LPHW – Low Pressure Hot Water Heater coil

1. Introduction

Laboratory breeding chambers are the examples of rooms, where very high requirements of the internal climate quality at a wide range of air parameters, go hand-in-hand with the need for accurate and fast automatic adjustment of the indoor comfort level parameters. Unfortunately, due to some unfavorable characteristics of certain air treatment and control system components, achieving these two objectives simultaneously is very difficult. The article contains an analysis of thermodynamic and technical impact of various characteristics of the selected items of the existing air conditioning installation at the breeding chamber laboratory of the Institute of Zoology of Jagiellonian University in Kraków.

2. Analysis of the indoor air parameters required for breeding chambers

Breeding chamber tested for the research is a tight, hermetic room (without windows), equipped with the necessary technology to carry out the experiments, which in this case involve breeding of rats. The following table lists the basic requirements concerning the indoor climate, set out in the regulation of the Minister of Agriculture [3], as well as in the analyzed literature [5]. Those two were compared with the requirements laid down by the Institute of Zoology, on which base the project was realized. Several important pieces of information come out from the table below. The first one is the high ventilation air exchange rates, which are obligatory due to the secretion of breeding animals and unpleasant smell of rats. The second one is that, in the documents [3, 5] there is no data on either accuracy of temperature control, or air velocities in the breeding area of the room. As it can be seen in the table 1, the Institute has set the highest and widest requirements of those three, which – in the existing conditions – became very difficult to acquire by the A/C system installed and finally made the reason for the job reported.

Table 1

The requirements of the internal climate parameters for breeding chambers

Parameter	Unit	Regulation [3]	Article [5]	The requirements of the Institute of Zoology
Temperature	[°C]	20–24	20–22	10–37 (±1 K)
Relative humidity	[%]	55 (±10)	55 (±5)	50–80% (±5%)
The minimum room exchange rates	[1/h]	15–20	10–20	15
Acoustic pressure level	[dB]	35	–	–
Air velocity	[m/s]	–	–	–

3. Dimensioning of air conditioning equipment for the breeding chamber

General characteristics of the test chamber are: partitions made of stainless steel, properly insulated brick exterior wall, hermetic, airtight, non-absorbable walls and surfaces, lack of windows (see Fig. 1).

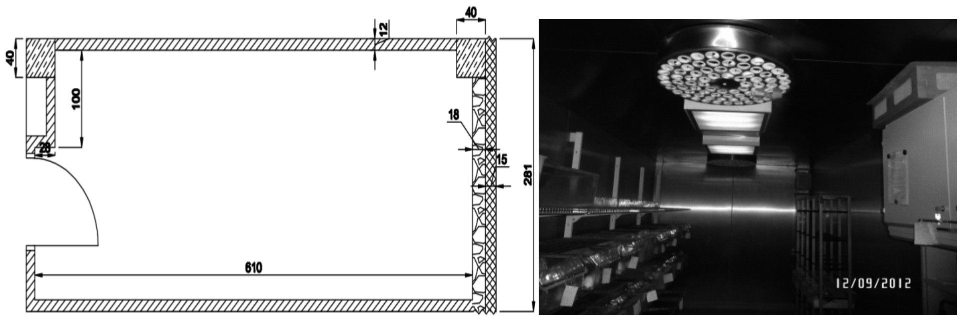

Fig. 1. Projection of the test chamber. On the right – photo of its interior

During the first step of the work reported, detailed thermal calculations of air treatment processes were provided, in order to make an assessment of existing A/C system components sizes and characteristics. As the result of those, the final scheme of the installation was set, like the one shown in the Fig. 2.

When sizing the components of Air Handling Unit (AHU), it was crucial to remember, that the indoor air parameters have to be adjusted and stabilized precisely and continuously, all year around – 8760 hours in a year – regardless the random changes of the external air parameters, as well as the impacts of the safety control devices and procedures installed for the AHU's equipment protection (i.e. protection of cross flow recuperator and LPHW coil against freezing, startup of each of the heat exchangers, set point change, abrupt change in air flow, etc.) Due to the multitude of problems, which disrupt the regulation process, this paper is limited to the analysis of the impact of two issues, which – according to the authors – have a dominant influence on the quality of indoor comfort in the chamber, ie:

a) distribution of the conditioned air in the room's space,
b) impact of control valve's actuator and LPHW heat exchanger's operating characteristics.

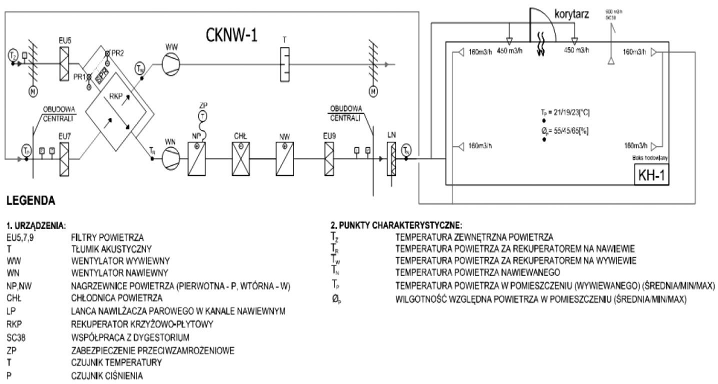

Fig. 2. Technological scheme of the AC system operating in the tested breeding chamber

4. Comparison of the room's air distribution systems

To achieve the most convenient distribution of air parameters in the tested room, two basic air discharge solutions were compared: mixing (induction) of air discharge devices and ceiling laminar displacement air flow. Laminar air discharge devices require a large area of ceiling to minimize the air discharge velocity. One of system's characteristic features is a homogeneous unidirectional airflow, achieved at low air speed. It offers very high ventilation efficiency and a very high level of thermal comfort (i.e. low value of the Draft Ratio – DR). Using the advantages of the laminar discharge and aiming for high comfort level of the controlled space in the test chamber, we were provided with detailed calculations for sizing the installation, when applying this kind of distribution system. As the result, two laminar diffusers were selected, for which the air velocity along the height of the room was determined. Subsequently, the designed installation framework was characterized by the airflow supply, V_N = 2700 m^3/h and air flow exhaust, V_W = 2830 m^3/h. This system was finally chosen for comparison with the existing mixing (induction) air supply system (see Fig. 1), consisting of 2 spin slot diffusers with a capacity 305 m^3/h each and 4 exhaust grilles with a capacity 160 m^3/h each. For the proposed laminar air flow system, based on the characteristics of software selected by the manufacturer, the values of air velocity in the test zone of the chamber (height between: 0.5 and 2.0 m) were determined (between 0.10 to 0.15 m/s). Assuming, that the Turbulence Factor (Tu) for laminar airflow is not grater then 5%, DR comfort index values were calculated for sample air temperature (t_a = 20°C). The final result of these calculations proved, that the DR index value in such case is between 5.0% and 10.0% PD (Percentage of Dissatisfied) and since that, the controlled space of the chamber performs at the highest comfort level (class I according to [5]). On the other hand, the existing air supply system is characterized by high values of the turbulence factor (Tu up to 40%) and uneven airflow speed, which decreases, as the air is moving away from the diffuser. Using manufacturer's simulation program [7] it was determined that the air velocity in the room's space can vary from 0.32 m/s (h = 2.0 m) and 0.18 m/s (h = 0.5 m). For these air velocity values and the air temperature applied (t_a = 20°C), the range of DR index is respectively between the values: 50% and 23.0% PD. As it could be forecasted, these values are much higher than those for laminar discharge system and they are outside of the III[rd] category of comfort (in accordance with [5]).

4.1. *On-site* tests for indoor comfort parameters in the breeding chamber validation

Table 2

Summary of the measurement points

Mesurement point	Air temperature	Air velocity	Draft factor
	t_a	w_a	DR
[–]	[°C]	[m/s]	[% PD]
1	20	1,5	446,7
2	20	0,11	11,7
3	20	1,23	331,1
4	20	0,3	44,9
5	20	0,2	26,3
6	20	0,32	49,0

Since the comfort index values for the applied distribution system are on the edge of "satisfaction range of the end-user", it was compulsory to validate the air velocity in particular points of the chamber space. During the experiments, the air velocity – as well as the air temperature – were measured (with laboratory anemometer and Cu-Const thermocouples). The values were averaged for an over 1-hour period of time and recorded simultaneously at 6 individual test points. Table 2 shows the example of air velocity measurement, which proved that the "a priori" calculations made with the software were valid (besides points 1 and 3 which are situated outside the test zone of the chamber – close to the air diffuser and the wall). As the result, it can be finally stated, that the air distribution system chosen for the analysed project is not the main cause of problems with indoor climate parameters control.

5. Control loop characteristics of the LPHW coil

The main problem that occurs in the close control air conditioning systems, is maintaining the comfort parameters of indoor air in a specific, narrow range of deviation from the set point, as well as the high stability of the signal waveform in real time, regardless of the interferences caused by: user (exploitation and operating procedure), dynamic changes of the outside air parameters, as well as the technical and operational characteristics of the individual items involved within the temperature control loop (as shown in the Fig 3). After the preliminary examinations, it was concluded, that the air temperature control instability was primarily caused by the properties of the technical equipment involved in the control process of LPHW coil – especially valves and actuators.

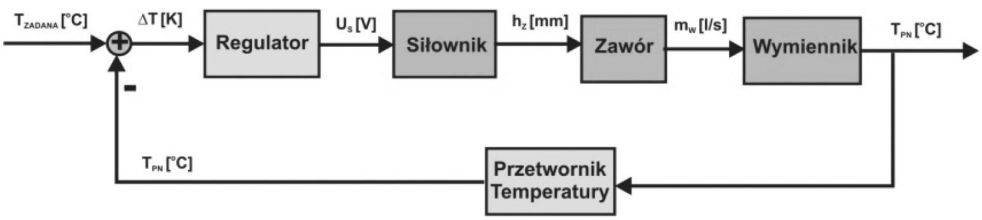

Fig. 3. Block diagram of the heater's temperature control loop

5.1. Valve and actuator operating characteristics

The control loop of the LPHW heater operating in the experimental installation consisted of a 3-way mixing control valve, featuring: equal percentage characteristic (Fig. 4), the flow rate factor k_{vs} = 1.60 m^3/h and the minimum flow rate factor k_{vr} = 0.032 m^3/h. The latter factor is also referred to as a "range of controllability" of the valve, as it gives out the minimum value of water flow, upon which the valve maintains the flow control characteristic declared by the manufacturer (below this value it is "unknown zone of control"). Based on those two, the valve's range is defined by the ratio $R = k_{vs}/k_{vr}$. The tested valve was characterized by the value of R = 50. The control characteristic of the applied actuator is of a step-wise type (Fig. 5).

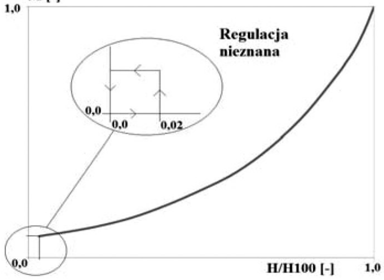

Fig. 4. Equal percentage valve characteristic

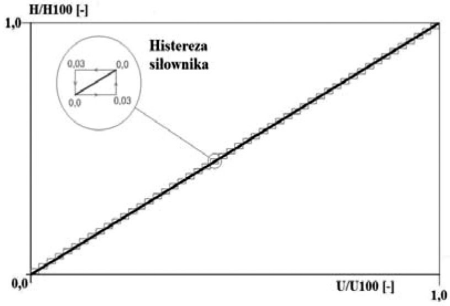

Fig. 5. Control characteristics of a step-wise actuator

5.2. Low Pressure Hot Water coil characteristic

The goal of mathematical modeling of the analyzed heat exchanger was to acquire a capacity control characteristic, describing the change of the air temperature, as a function of mixing degree of 3-way valve placed at the inlet of the heat exchanger (see the model in the Fig. 6). Assuming that the mass flow rate of the water flowing through the LPHW coil is constant, the mixing ratio M of the control valve is the key factor, the water inlet temperature depends on. The M coefficient is defined as the ratio of the water mass flow rate, flowing through the valve from the heat generation system (m_w with t_{sN} temperature), to the nominal heat exchanger water flow (m_{wN} = idem). Scheme of the hydraulic system model is shown in Fig. 6. The final control curve characteristic was determined by applying the Trefny's model [1].

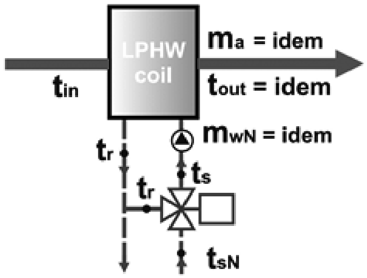

Fig. 6. Model of the tested heat exchanger

The main assumptions used in the calculations:
- V_a = 610 m³/h (idem),
- t_{out} = 37°C (idem),
- t_{in} = var ∈ <–20÷37°C>,
- t_{sN} = 70°C (idem),
- Φ_N = 11.59 kW,
- m_{wN} = 760 kg/h = 0.21 kg/s (idem),
- $c_{p,a}$ = 1.005 kJ/kgK.

Control characteristic of the heater was determined by the following formulas:

$$\Delta t_a = t_{out} - t_{in} = \frac{\Phi(M)}{m_a \cdot c_{p,a}} \tag{1}$$

$$\Phi(M) = \Phi_N \cdot \frac{1}{1 + a \cdot \left(\frac{1-M}{M}\right)} \tag{2}$$

where:

$$a = \frac{t_{sN} - t_{rN}}{t_{sN} - t_{\mathrm{in}N}} \tag{3}$$

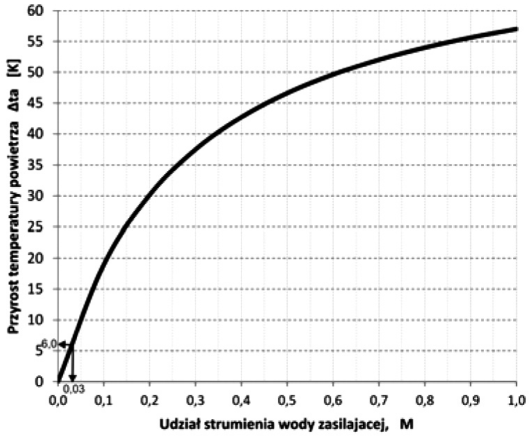

Fig. 7. Control characteristic of the tested LPHW coil

The simulations were performed for a variable temperature of the heater's air inlet. The air temperature rise in the heater is presented as a function of relative water flow (*M*) supplied through the control valve (see Fig. 7).

5.3. The maximum error of air temperature control loop

When analysing the temperature control loop (Fig. 3), it can be concluded, that – as the result of maximum "dead zone" value of water flow performed at the inlet of the heat exchanger – the maximum air temperature deviation at the outlet of the heater can be finally derived from the control characteristics of the heat exchanger (Fig. 7). Because the control signal flowing through both devices of the temperature control loop is in a serial connection manner (Fig. 3), the maximum value of the output signal's "dead zone" is the result of the maximum "errors" of both devices – the valve and the actuator. As the tested valve hysteresis was equal $\Delta M = 2\%$ (at the starting point, as a result of the range $R = 50$ – see Fig. 4), while the hysteresis of the actuator declared by the manufacturer's technical information equals $\Delta U = 3\%$ (see Fig. 5). This means, that the maximum possible deviation ("static displacement") of the output signal of the complex object, made of actuator and control valve (which is also an input signal to the heat exchanger) may reach, in the worst case, the value of 3%. Consequently – based on the determined heat exchanger characteristic – the maximum outlet air temperature deviations can reach 6.0 K (Fig. 7).

6. Conclusions

Based on the analyses and on-site experiments conducted in a real, operational breeding chamber, it can be concluded, that obtaining high comfort indexes in such "unusual space", can be acquired by maintaining accuracy and stability of the air parameters supplied by the Air Handling Unit. High quality control devices, such as a valve or an actuator, can help achieving this goal. Similar value of importance should be also paid to other issues, such as:

- indoor air distribution structure and components applied,
- range of indoor parameters required (should be as narrow as possible),
- stability of flow control in the hydraulic systems supplying the heat exchangers,
- finally, the most attention should be paid to the control structure and strategy at the initial range of capacity of each heat exchanger applied.

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