Influence of Properties of the Room on Parameters of Regulators of the Automated Climatic Systems

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ABSTRACT

A number of solutions to cope with the problem of reducing power consumption by automated climate control systems are discussed in the paper. Interrelationships between the individual parameters of indoor thermal stability and the automatic control of climate systems were studied. The expression for calculating transmission coefficient of the controller was derived. The effect of structural room characteristics on the total energy consumption by indoor climate control systems is established. Conclusions are illustrated by numeric calculations with use of the developed computer program and graphic examples.

INTRODUCTION

Currently, the successful development of construction industry depends on the improved energy performance of buildings, structures and facilities, as well on the quality assurance of the indoor climate.

According to the adopted International Standard ISO 50001:2011 «Energy management systems - Requirements with guidance for use», any energy purpose comes to a certain outcome, or achievement, established for the implementation of energy policy, with view of improving energy efficiency.

Energy efficiency is characterized by measurable outcomes related to energy efficiency, energy use and energy consumption [4]. The indoor climate of buildings represents the state of indoor environment, which affects humans and is characterized by thermal parameters of air and enclosure structures, relative humidity and air mobility [5].

With view of the above, designing and operation of buildings should be aimed at the best (optimal) solution of the following objective: to ensure the set-point values of indoor climate serviced by automated climate control systems, against the minimal energy consumption.

As regards its substantive structure, this paper describes the study on the relationships between the individual parameters of the indoor thermal stability and the regulatory impact of automatic control systems (ACS). We analyzed the effect of structural room characteristics on the total energy consumption of the airflow processing unit, in order to ensure energy saving. The final result is illustrated by numeric simulation with use of the developed computer program and graphic examples.

METHODOLOGY

That said, we take into account that the solution of a system of differential and algebraic equations for non-steady heat conduction within enclosure structures of a room and heat transmission across their surfaces, according to the finite-difference scheme, was reviewed in the papers [7, 8]. The authors [7, 8] obtained a simpler and more transparent ratio resulting from the general equation of heat balance of a room [1] and the equation of heat flux from the automated climate system Q_{acs} [10], which links the controlled parameter – the air temperature – with perturbing and regulatory thermal effects:

$$t_{a.j+1} = \frac{Q_c + K_{reg} t_{a.0} + \Sigma\lambda_{ch} S_{se} t_{1,j+1} + B t_{out.a}}{K_{reg} + A + B}, \tag{1}$$

where Q_c is the current value of convective heat flux from the internal heat sources in a room, W; K_{reg} – transfer coefficient , W/K shows in this case, by how many watts should the Q_{acs} value be changed when the t_a / $t_{a.0}$ deviation makes 1 K; t_a – indoor air temperature, °C; l_{ch} – thermal conductivity of the surface material and coefficient of convective heat exchange over it, W/(m^2· K); S_{se} – area of solid enclosures, m^2; $t_{out.a}$ – outdoor air temperature, °C; $B = \Sigma K F_l + L c_a \rho_a$,W/K; $\sum K F_l$, W/K – the sum of products of heat transfer coefficients K_l, W/(m^2·K), outdoor “light” fencing (conditionally instantaneous, e.g., windows) across their area F_l, m^2; L – uncontrolled indoor air change, m^3/s, i.e., outdoor air flow rate (through infiltration); c_a and ρ_a – respectively, air specific heat thermal capacity, J/(kg·K) and density, kg/m^3; $A = \Sigma\lambda_{ch}\ S_{se}$.

In other words, the indoor room temperature at j+1^{-th} step is obtained as a weighted average of the components, which reflect the impact of all heat inflows and outflows. This impact is provided by the convective part of heat gain Q_c, as well as by other thermal characteristics: set-point temperature $t_{a.0}$ (control), surface temperature $t_{1,j+1}$ (convective heat transfer), and outdoor air temperature $t_{out.a}$ (heat transfer through the “light” fencing and heat loss from heating infiltration air).

In foreign countries similar approaches to analysis of the heat exchange processes may be found, for instance, in a source [3]. Independent conclusion is given in work [9].

It should be noted that maintaining the specified thermal regime within a building implies the organization of interacting and interconnected heat flows in a complex architectural and structural system, with a variety of its constituents – enclosing constructions and engineering equipment, where each is an energy carrier and an energy transmitter at the same time. The key feature is the need to pay attention not only to enhancing the heat-protective performance of the building parts, but also to technical solutions related to the processes in ventilation and air conditioning systems (ACVS), which are inevitably associated with energy consumption.

Consequently, the proposed method is based on the assumption that the total thermal stability of the «room-ACVS-ACS» system is defined by heat absorption index of a room and the ACS control action. This follows directly from the back-to-back connection of units corresponding to the room and ACVS in the scheme of automatic indoor climate control (see Figure 1) [6].

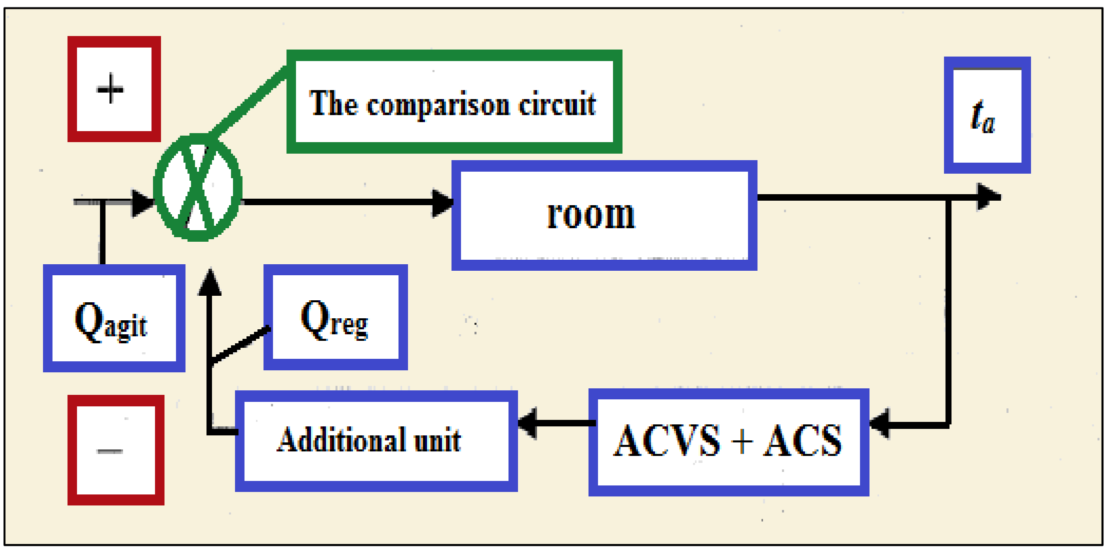

Figure 1. Functional diagram of the «room-ACVS-ACS» system.

Accordingly, in conditions of dynamic thermal processes, the periodic pattern of thermal perturbation Q_{agit} and the regulatory impact of automatic control systems Q_{acs} or , in the general case, Q_{reg} (see Figure 1), the formula [10]

$$Q_{acs} = -K_{reg}\left(t_{a,j} - t_{a.0}\right), \quad (2)$$

implies that:

$$A_{Q_{acs}} = K_{reg}\, A_{ta}, \quad (3)$$

where A_{Qacs} and A_{ta} – fluctuations' amplitudes for Q_{acs} and t_a.

Therefore, if the required A_{Qacs} value is known, the desired K_{reg} value can be calculated as the ratio:

$$K_{reg} = A_{Q_{acs}} / A_{ta}, \tag{4}$$

where A_{ta} is accepted according to comfort conditions, as stipulated by the GOST (RF National State Standard) 30494-2011 [2], or by technological requirements.

By definition [6]:

$$A_{Q_{acs}} = A_{Q_{agit}} K_{ass}, \tag{5}$$

where:

$$K_{ass} = A\left(1 - B \cdot R_{dyn}\right) B_O, \tag{6}$$

here, A_{Qacs} – the total fluctuation amplitude of perturbing heat impact effects, W, both the convective and radiant; K_{ass} – assimilation coefficient for variable heat gains (dimensionless).

$$R_{dyn} = \frac{A_{ta} P_{room}}{A_{Q_{agit}}}, \tag{7}$$

where: R_{dyn} – dynamic regulation coefficient for ventilation, or air conditioning systems (dimensionless), P_{room} – heat absorption rate of a room, W/K; A and B – parameters that generally depend on the applied control law and some other conditions.

Under P-control law, we can roughly take: when $R_{dyn} > 0.75$ A= 1.15, B=1; when $R_{dyn} < 0.75$ A=1, B=0.9. The B_o value is a correction factor to K_{ass}, under condition that $q_c < 1$ (also dimensionless).

Comparison of expressions (4) and (5) sets:

$$K_{reg} = \frac{A_{Q_{acs}}}{A_{ta}} = \frac{A_{Q_{agit}} A\left(1 - B \cdot R_{dyn}\right) B_O}{A_{ta}} = A\left(\frac{A_{Q_{agit}}}{A_{ta}} - BP_{room}\right) B_O, \tag{8}$$

If the expression (8) results in $K_{reg}<0$, it means that the inherent thermal stability of a room is sufficient for maintaining the internal temperature within the specified range and the special automatic control for t_a deviation is not required [10].

Further study allows us to trace the influence of structural characteristics of a room on the total energy consumption needed for air intake treatment. This can be done by applying values of main walling area, or thermal properties of the construction materials as the input program variables.

Initial calculations were performed for varying room geometry. It should be noted that generally the floor height of actual buildings has a fixed value and differs only slightly between different objects. Therefore, we can manipulate (increase or decrease) only the area of a floor and a ceiling. This can be done either by retaining the length of external wall along with changing the room depth or, vice versa, by keeping the depth and changing the length and, accordingly, the area of the external wall and its windows. Dimensions of the internal walls and partitions would be altered only under the first option.

Notably, the air change rate generated by an automated climate system (ventilation system or air conditioning) should remain constant, both by sanitary standards, and due to the fact that thermal perturbations Q_{agit} could be considered roughly proportional to the floor area. Therefore, the total system air capacitance G, kg/h, would also vary proportional to this area, so we can only compare the specific energy consumption attributed to the heat capacity of the air intake mass flow rate $Gc_B/3.6$, W/K. This ratio has a dimension of K·s and represents actually a product of the mean temperature difference for the calculation period (heating or cooling air intake in the unit), by the length of this period.

RESULTS

Based on the above algorithm, the authors made calculations using the computer program developed in Fortran language. A fragment of the program results is presented below – calculations of the parameters' values included in the expressions (2) - (8) and the total specific energy consumption for heating the air intake during the heating season, under varying room geometry (see Figure 2) , as well as the graphic illustration of obtained relationships (see Figures 3 and 4).

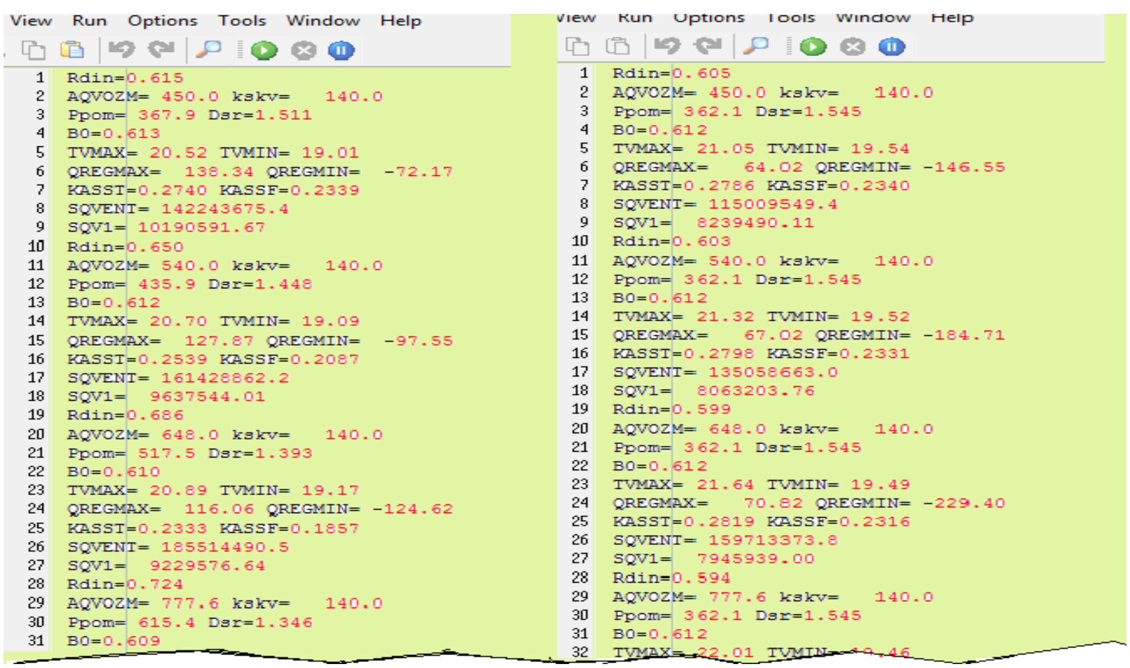

Figure 2. Fragment of the displayed computer program under the varying room geometry.

Figure 3 demonstrates the dependence of specific energy consumption from the relative floor area for the option with the varying room depth.

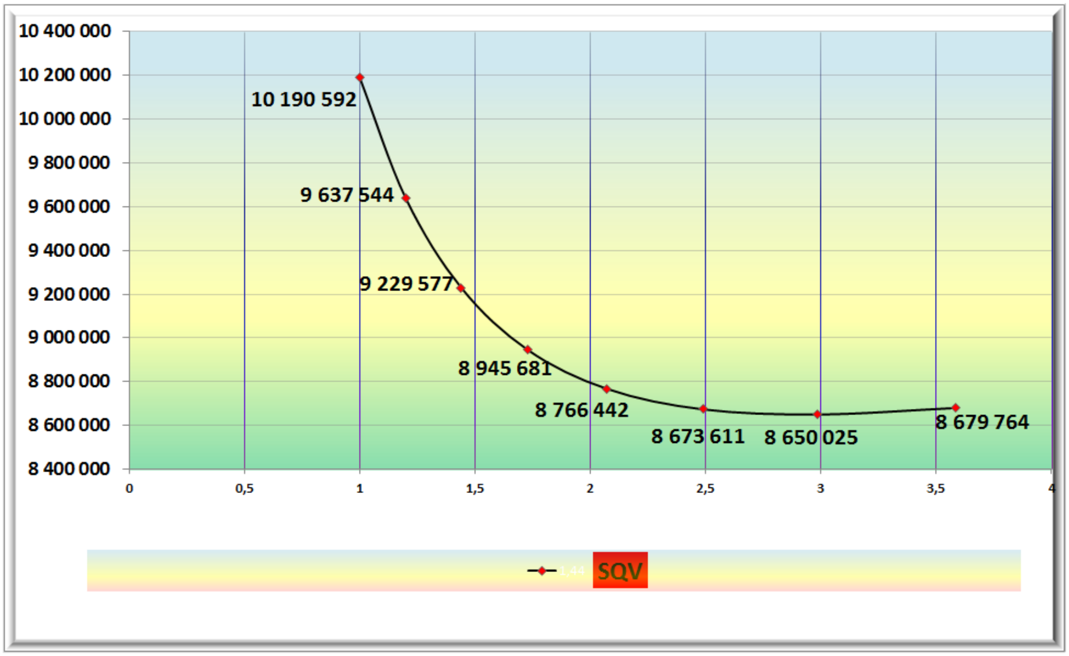

Figure 3. Dependence of specific energy consumption for the option with the varying room depth.

Analysis of this dependence shows that changing the floor area within the enclosing structures and maintaining the same length of the external wall contributes significantly to the reduced total energy consumption and, consequently, to the lower energy/output ratio of engineering equipment. Specific energy saving in automated climate control systems is achieved, to a certain extent, through the optimized indoor heat response.

The calculation results for the second method under the varying room geometry are presented in Figure 4. This option demonstrates the dependence of specific energy consumption from the relative floor area, against the varying external wall length and the available windows.

In this option, the dependence reveals a different pattern: the diagram has a quite distinct minimum indicating the optimal size of the room, where power consumption could be minimized through the use of the inherent thermal stability. Further increase in the length of the external wall leads to the increase in the glazing area (referred to the «light» fencing), increases the overall heat response and, ultimately, to an increase in energy consumption and the need to strengthen the ACS control action.

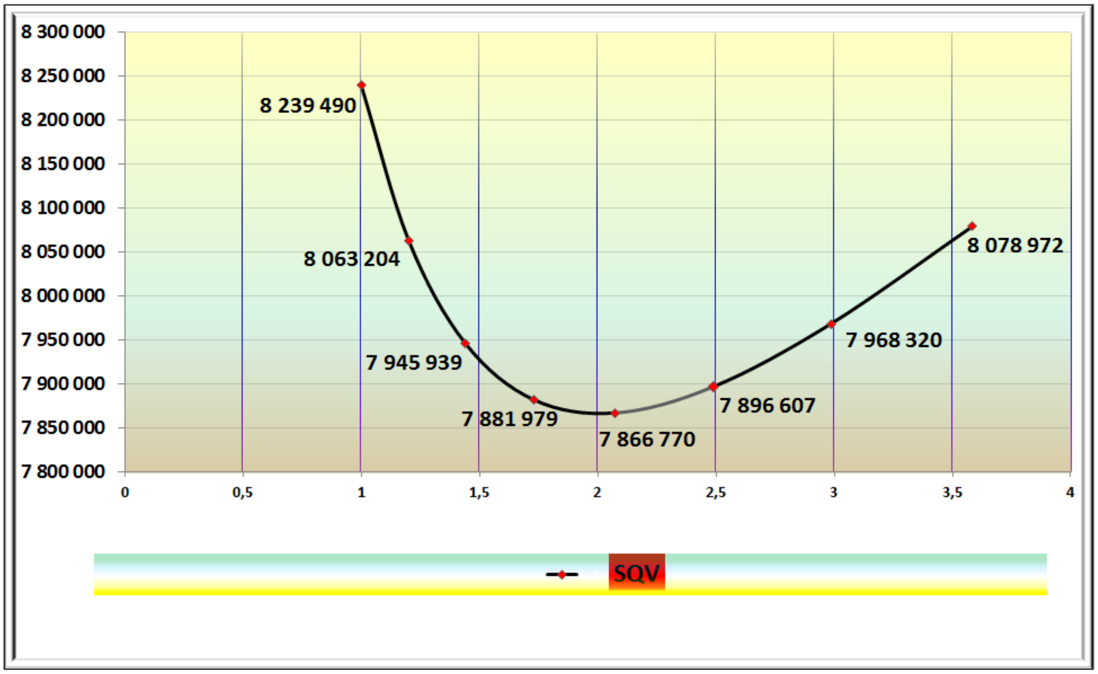

Figure 4. Dependence of specific energy consumption for the option with the varying length of the external wall.

CONCLUSIONS

Thus, the results of these studies call our attention to the relationships between the space-planning room characteristics and parameters of automated climate control systems. Consequently, the energy saving requirements should be considered at early stages, in the development of architectural and structural design of buildings, structures and facilities, in order to ensure the set-point values of indoor climate, along with minimizing the energy consumption by the engineering equipment.

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