Method for Household Refrigerators Efficiency Increasing

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Abstract. The relevance of working processes parameters optimization in air conditioning systems is proved in the work. The research is performed with the use of the simulation modeling method. The parameters optimization criteria are considered, the analysis of target functions is given while the key factors of technical and economic optimization are considered in the article. The search for the optimal solution at multi-purpose optimization of the system is made by finding out the minimum of the dual-target vector created by the Pareto method of linear and weight compromises from target functions of the total capital costs and total operating costs. The tasks are solved in the MathCAD environment. The research results show that the values of technical and economic parameters of air conditioning systems in the areas relating to the optimum solutions’ areas manifest considerable deviations from the minimum values. At the same time, the tendencies for significant growth in deviations take place at removal of technical parameters from the optimal values of both the capital investments and operating costs. The production and operation of conditioners with the parameters which are considerably deviating from the optimal values will lead to the increase of material and power costs. The research allows one to establish the borders of the area of the optimal values for technical and economic parameters at air conditioning systems’ design.

1. Introduction
The decrease in consumption of material and energy resources is the urgent problem at all stages of lifecycle of technical objects. Economy at all stages is reached by decrease in capital and operating costs on condition of preservation of the required quality level. It is possible to achieve decrease in capital and operating costs at preservation of the qualitative level, optimizing system parameters. It is extremely important, but difficult task which solution is quite often complicated by the multifactorial nature of dependence of the studied effects of key parameters that is typical in any complex system. It is possible to classify air conditioning systems as such systems [1-4]. However, it is often possible to mark some main subtasks of optimization and to apply the methods of reducing decomposition, reducing dimension of the task. Multi-purpose character of optimization tasks can become one more problem.

The actuality of issues of increase in efficiency of use of material and energy resources is also realized in scientific and technical community, and also at the national level. The authors also brought up these issues repeatedly in the works [5-10].
2. Problem definition

The problem of technical and economic optimization of parameters of air conditioning systems is solved in this work.

The total cost of system, the amount of the operating costs and depreciation charges, repair and technical maintenance connected with operation of air conditioning system, the minimum differences of temperatures in conditioner heat exchangers (the evaporator and the condenser) with the set system refrigerating capacity are considered as the criteria of optimization. At optimization of differences of temperatures we optimize capital and operating costs on the cooling machine of the conditioner [11-13]. The criteria of optimization will represent the target functions of the variable parameters which are subject to optimization. The optimal variant should correspond to the minimum of the target function.

3. Theoretical part

The solution of the problem of optimization is performed by the method of simulation modeling in the MathCAD environment. The complexity of the optimization task in some cases was decreased by the method of reducing decomposition. At the same time restrictions are imposed on changes of a part of factors while other factors vary without restrictions. In particular, in our research we accept values of the factors which are not subject to optimization as constants.

It is proposed to investigate the multi-purpose character of optimization tasks differentially, separately considering the provided target functions, and also creating the target vector representing the linear combination of target functions [14]. The coefficients of the linear form of the target vector represent the weight coefficients considering the importance for the optimization task of this or that criterion, setting, thus, the compromise of targets.

The interpretation of results is carried out in a graphic form. The proposed methods of decomposition will not affect quality and conclusions as it will be shown below. However, the results obtained for borders of areas of the optimal values of key parameters of air conditioning system are also defined with the accuracy, sufficient for technical application.

On the basis of data on economic parameters of air conditioning system, obtained by processing of data of a number of firms [15] the linear approximations of dependence of cost of separate important components of system from the defining factors are obtained. We will consider the variants of target functions proposed in the model.

The target function of the total cost structurally represents the amount of cost of the evaporator, condenser, compressor and fans of the evaporator and condenser [16] which generally depend on temperatures of condensation, outside air and the minimum differences of temperatures in the condenser, and temperatures in the evaporator (1):

\[ C_T(t_p, \Delta t_u, t_n, \Delta t_k) = C_c(t_p, \Delta t_u, t_n, \Delta t_k) + C_e(t_p, \Delta t_u, t_n, \Delta t_k) + C_k(t_p, \Delta t_u, t_n, \Delta t_k) + \\
+C_{kmp}(t_p, \Delta t_u, t_n, \Delta t_k) + C_{bu}(t_p, \Delta t_u, t_n, \Delta t_k) \]

(1)

where \( C_T \) - the function of cost of the conditioner, \( C_c \) - the function of cost of the evaporator, \( C_k \) - the function of cost of the condenser, \( C_{kmp} \) - the function of cost of the compressor, \( C_{bu} \) - the function of cost of the fan of the evaporator, \( C_{k\Delta} \) - the function of cost of the fan of the condenser, \( t_p \) - the air temperature indoors, \( t_n \) - the temperature of outside air, \( \Delta t_u \) - the minimum difference of temperatures between the cooled air and the boiling refrigerating agent, \( \Delta t_k \) - the minimum difference of temperatures between outside air and the condensed refrigerating agent.

The target function of the sum of operating costs and deductions also structurally represents the sum of the deductions connected with depreciation, technical maintenance and repair and the operating costs connected with the cost of the electric power consumed during the operation of the conditioner [17-19]. The electric power is consumed by electric drives of the compressor and fans of the evaporator and the condenser of the conditioner. The function of the sum of operating costs is written as (2):
\[
C(t_p, \Delta t_p, t_s, \Delta t_s) = C_e \left( t_p, \Delta t_p, t_s, \Delta t_s \right) \times \left[ 1 + \frac{\alpha_{\text{min}}}{100} + \frac{\alpha_{\text{max}}}{100} \right] \left[ 1 + \frac{\alpha_{\text{min}}}{100} + \frac{\alpha_{\text{max}}}{100} \right] + T_1 \cdot T_2 \cdot \left( N_{\text{comp}} + N_{\text{ev}} + N_{\text{bk}} \right) \cdot 10^{-3} \cdot Z
\]

where \( \alpha_{\text{min}}, \alpha_{\text{max}}, \alpha_{\text{max}}, \alpha_{\text{max}} - \) the deductions on installation, commissioning, depreciation, technical maintenance and repair, \%, \( T_1 - \) the period of operation of the conditioner, days/year, \( T_2 - \) the period of operation of the conditioner, hour/day, \( N_{\text{comp}}, N_{\text{ev}}, N_{\text{bk}} - \) the power of the electric drive of the compressor, fan of the evaporator and fan of the condenser, \( W, Z - \) the rate of payment of the electric power, rub./kW·h.

The power of the electric drive of fans is defined by the product of performance on the created pressure which during the work on network should be equal to losses of pressure in channels of heat exchangers. The performance of fans is defined depending on thermal loading of heat exchangers via which they pump over air, and on the accepted change of air temperature at its passing via heat exchangers.

At modeling we accept the assumption that losses of pressure of the fan are equal to losses of pressure in the heat exchanger. Thus, the energy costs for pumping of air depend in the model on thermal loading and air temperatures at input and output of heat exchangers.

We also accept as the assumption that thermal loading and consumption of air through the air cooler of the conditioner which is in the variant considered in the work the evaporator of the cooling machine remain invariable as they are defined by parameters of the room for which the conditioner [20] works. Other parameters, such as loading of the condenser, power of the compressor and drive of the fan of the condenser, will change depending on change of temperatures of evaporation, condensation or outside air.

4. Practical importance of researches

The results of modeling provided further are obtained for the room with the total volume of 150 m³, about 50 sq.m. Heat inleakages to the room through external barriers at temperatures of air higher than 30 °C, and also from heat release of devices and people in the of are estimated at the level of 21775 W. The thermal power of heat inputs on condition of absence of moisture precipitation in the air cooler represents, thus, the thermal loading of the heat exchanger – the air cooler, that is the calculated refrigerating capacity of the conditioner. The air temperature maintained in the room (20 °C), and the temperature of the air returned to the room after cooling in the evaporator, (10 °C) remain invariable at the optimization. In this regard the evaporator fan performance should also be invariable.

The minimum of the total cost of the conditioner, i.e. the minimum of the capital investments is chosen as the purpose of optimization for the first function. For the second function the purpose is the achievement of the minimum of the total deductions and expenses connected with operation of the conditioner. The parameters at which the required values of criteria, or conditions imposed on them are reached are optimal.

We will consider the decision of two separate, but important enough problems of optimization of the technology parameters of the conditioner – the minimum differences of temperatures of heat carriers in heat exchangers – the evaporator and the condenser. We carry out the optimization in each parameter independently, imposing restrictions for other parameter. The target functions are at the same time parametrical functions of one variable.

where pareto (<1) is the weight multiplier (vector coordinate in space of the purposes).

The neutral compromise of the purposes with the weight multiplier 0.5 is considered as an example. The results of the optimization are presented graphically (figure 1 and 2).
Figure 1. The function of the dual-target Pareto optimization of the minimum difference of temperatures in the evaporator:
trace1 - the temperature of condensation 40 °C; trace2 - the temperature of condensation 50 °C; trace3 - the temperature of condensation is 60 °C.

Figure 2. The function of the dual-target Pareto optimization of the minimum difference of temperatures in the condenser:
trace1 - the temperature of outside air 30 °C; trace2 - the temperature of outside air 40 °C; trace3 - the temperature of outside air 50 °C.

As it is difficult in advance to give preference to these or those purposes of optimization from two considered ones, the search of the compromise between these decisions in the Pareto multi-purpose optimization is necessary [14]. For this purpose we will consider the target function as the sum of two functions introduced by us above with weight multipliers, creating, thus, the vector of the compromise purpose (3):

$$C_{cp} (t_p, \Delta t_p, t_n, \Delta t_n) = pareto \cdot C \cdot (t_p, \Delta t_p, t_n, \Delta t_n) + (1 - pareto) \cdot C_2 \cdot (t_p, \Delta t_p, t_n, \Delta t_n)$$  (3)

We make the optimization of the minimum difference of temperatures of heat carriers in the conditioner evaporator – between the boiling refrigerating agent and the cooled air – at the set
temperatures of condensation and the invariable minimum difference of temperatures of heat carriers in the condenser equal to 10 °C. We carry out the optimization of the minimum difference of temperatures of heat carriers in the condenser of the conditioner at the set temperatures of outside air, permanent boiling point and the minimum difference of temperatures of heat carriers in the evaporator equal to 10 °C. in both variants of optimization the change of temperature of the outside air cooling the condenser also remains invariable.

The characteristic of the optimization (figure 1) is the presence of the minimum of the function. At reduction of the minimum difference of temperatures the value of the heat-exchanging surface of the evaporator grows that leads to decrease in the area of its heat-exchanging surface and the power of the fan of the condenser. At the same time the cost of the evaporating block is increased and the cost of the compressor and condenser block is decreased.

In the field of optimal values of the minimum differences of temperatures of heat carriers in the condenser of the conditioner (figure 2) the extremum of function has the smaller radius of curvature that determines the narrower range of optimal values being from 3 … to 11 °C and meeting the minimum capital investments and operating costs.

In general the results of researches of target functions show the possibility of obtaining optimal solutions on the criterion of the minimum capital investments and operating costs. The optimum on the considered target functions are located closely at the overlapping pieces of area of change of the optimized parameter in the range from 5 to 15 °C – at the extremum of target functions.

At the same time, it is necessary to notice that at exit out of limits of the specified range the values of functions begin to change rather strongly, deviating from the minimum. The changes of the value of the considered functions in this range are insignificant therefore this range of values of the minimum difference of temperatures of heat carriers in the evaporator and the condenser can be recommended for the choice at design, guaranteeing the minimum of the capital investments and operating costs.

The analysis of the obtained results shows that technical and economic optimization of technical parameters of conditioners is necessary at the stage of design as it promotes the solution of problems of decrease in the expense of material and energy resources, both at the production stage, and at the operational stage.

### 5. Conclusion

1. The technical and economic optimization of technical parameters of conditioners is necessary at the stage of design as it promotes the solution of problems of decrease in the expense of material energy resources, both at the production stage and at the operational stage.
2. Production and operation of conditioners with parameters considerably different from the optimal values will lead to growth of cost value of production, increase in the capital investments and operating costs of the consumer.
3. It is reasonable to consider the requirements of optimization of technical and economic parameters at the choice of air conditioning system for a specific object.
4. Application of optimal solutions allows to save material and energy resources that has a great social significance as development of humanity inevitably faces the limitation of resources available to the person on the earth and the environmental problems arising at their production and processing.

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