АРХИТЕКТУРА

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MODERN REQUIREMENTS FOR FORMATIVE FACTORS OF THREE-DIMENSIONAL SPATIAL ORGANIZATION OF MID-RISE RESIDENTIAL BUILDINGS WITH ENERGY-SAVING TECHNOLOGIES

Abstarct. The requirements for formative factors of three-dimensional spatial organization of a building with energy-saving technologies are formulated. A mathematical model for monitoring the parameters of heating, ventilation and air conditioning system based on the temperature and humidity level is proposed. An algorithm for cooling, heating and controlling the level of humidity in the building, which is based on the ideal Carnot cycle, has been developed. It is shown that the calculation of the energy-saving system of heating, ventilation and air conditioning system should be based on the calculation of the maximum efficiency factor taking into account the consideration of all sources of heat and moisture in the premise. Determining the maximum of the objective function can be used to determine the optimal operating mode of heating, ventilation and air conditioning at the mathematical level.

Keywords: energy-saving technologies, residential building, heating, ventilation, air conditioning, humidity level, Carnot cycle.

1. Introduction

The introduction of energy-saving technologies in the construction of heating, ventilation and air-conditioning systems for residential premises (HVAC), which meet modern environmental standards and are cost-effective in terms of operation, implies an analysis of the requirements for formative factors of three-dimensional spatial organization of buildings.

The analysis of literature on this topic showed significant differences in the general approaches to the development of the optimal HVAC scheme for residential premises of different number of floors [1, 2, 8], public complexes, the interior of which can vary greatly [3], and “clean room” production facilities [4], including medical laboratories [5]. Nowadays, the optimization of HVAC systems is impossible without the control systems that were considered at the level of smart home systems and the concept of the Internet of Things (IoT) [6, 7]. As shown above, the key factor to be considered in the mathematical modeling of HVAC systems of residential premises is the three-dimensional spatial organization of the building, in particular the floor height and the number of floors of the entire building [8, 9]. For example, the efficiency of energy-saving technologies associated with the HVAC heating unit is calculated by determining the unit heat consumption, which in turn can be correlated with the floor height. On the other hand, when designing a ventilation unit for the HVAC system, the floors of the building should be taken into account and the architectural features of the construction of the air shafts should be analyzed, which allows calculating the reduction of heat losses through the upper floor and reduction of the heat transfer resistance of the attic floor cover [8, 9].

Thus, the research carried out on this topic provides an effective toolkit for building a mathematical technique and a universal mathematical model for the optimization of HVAC systems, as well as the formative factors of three-dimensional spatial organization of buildings, which can be distinguished as ***an unresolved part of the overall problem*.** However, it should be noted that the problem presented is extremely large-scale and non-trivial given the need to analyze the mutual influence of the factors discussed above. Therefore, it is proposed to reduce the study of HVAC systems to consideration of typical variants of buildings and, accordingly, to set the mathematical modelling and making methodological recommendations in the field of the formative factors of three-dimensional spatial organization of mid-rise residential buildings with energy-saving technologies as **the research objective**.

2. Methods of temperature and humidity control in the premise

The basic model of a modern HVAC system for residential buildings can be represented on the basis of such functional elements as an external air supply unit, a radiant heating unit and a humidity reduction unit using a liquid or solid desiccant. To build a mathematical technique that is able to adequately describe the processes of heating, ventilation and air conditioning, the following analysis algorithm must be implemented [10-14]:

1. Determine the estimated air temperature in a living space as a function of the relative humidity;
2. Establish the dew point as a function of temperature and relative humidity;
3. Determine water temperature at the exit of the HVAC circuit.

Establishing the dew point allows one to optimally adjust the system and set the water temperature so that when it is fed into the cooling coil, a controlled process of drying the external air is carried out. In turn, determining the water temperature at the exit of the circuit allows estimating the temperature difference and, accordingly, the efficiency of operation in accordance with the developed scheme. An example of the HVAC system analysis algorithm is presented in Figure 1.

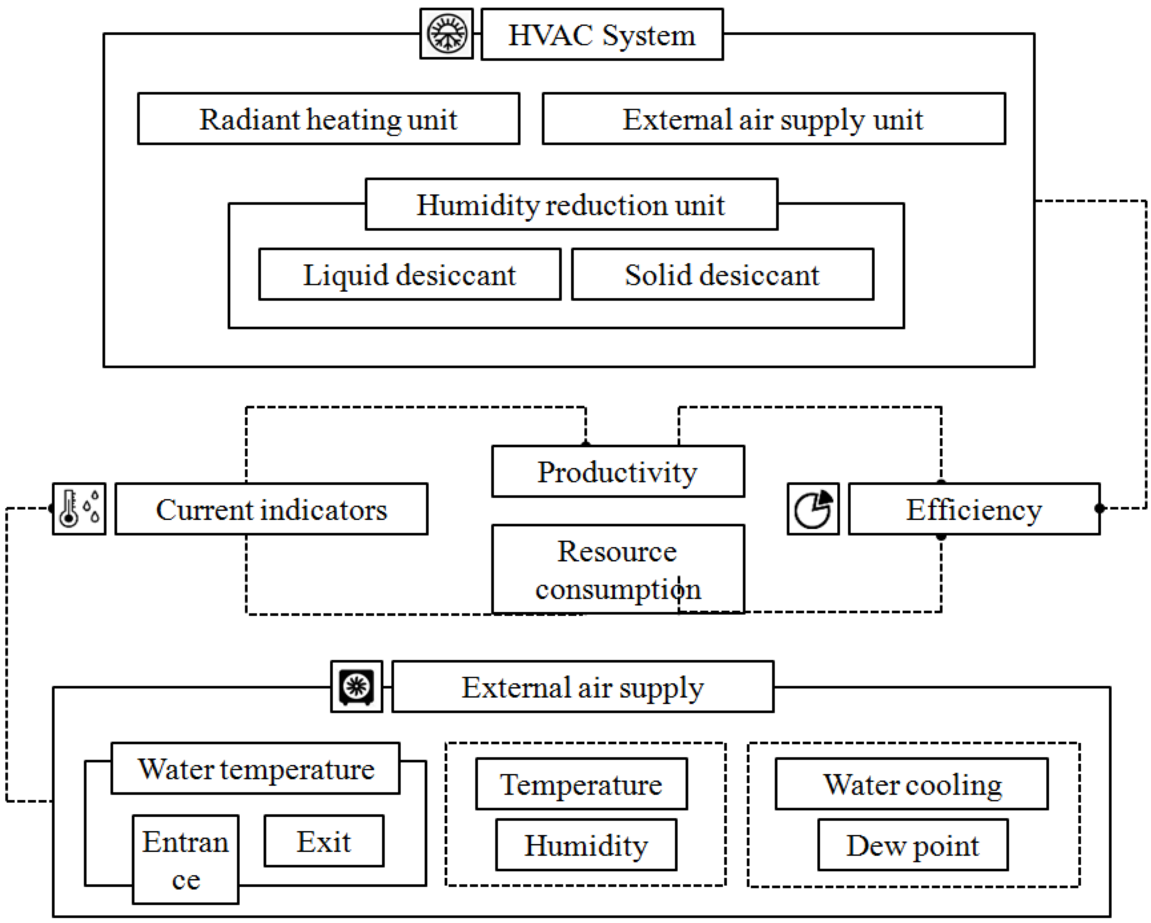

Figure 1. HVAC system optimization algorithm for residential premises.

In case of a radiant heating unit, it is necessary to build a mathematical model within which heat is distributed through a system of radiant heat exchange in accordance with the convection principle. Thus, the radiant heating unit can operate in cooling mode or heating mode. Similarly, other types of radiant panels for heating and cooling should be considered in the extended model by forming a list of groups. In particular, this are a core-based panel of a heated concrete floor [15, 16], a core-based panel of a heated thin floor [17, 18], a capillary radiant panel [19, 20], a metal ceiling-based sandwich structure [21, 22], as well as a panel based on a suspended metal ceiling with optimization of thermal convection [23, 24]. The core-based panel of a heated concrete floor corresponds to the basic concept of floor heating, where plastic or metal pipes with reinforced concrete rods are fixed in the concrete environment. More cost-effective is the method of building a core-based panel of a thin floor of light structural materials, which is suitable for the installation of floor heating with high thermal inertia, which is achieved by laying the pipes directly into the insulation plate with the corresponding seams. Capillary radiant panels are made of plastic pipes of a minimum diameter of about 2.5 ± 0.5 mm with a minimum interval between adjacent pipes of 10 ± 5 mm. It is most important to determine the structural material when building a sandwich structure of a metal ceiling-based radiant panel. To date, the best performance has been obtained for models based on copper, aluminum and steel. The design of a panel based on a suspended metal ceiling with an optimized mechanism of thermal convection causes the inclusion in the calculation of the fact that when using radiant panels for cooling the surface temperature should be higher than the dew point temperature of the surrounding air to avoid condensation on the panel surface. Accordingly, this limits the cooling capacity of the panel of this type per unit area.

According to the HVAC optimization model, the effectiveness of each technological approach should be correlated with its productivity and resource consumption at the level of the Terms of Reference, through specifying the scope of application in a particular case.

3. Modelling of temperature and humidity control

The mathematical model of the temperature and humidity control system in a living space can be built on the basis of the ideal Carnot cycle model and further expanded by taking into account the mutual influence of the air cooling and drying processes, the distribution of consumed power, restrictions on the area of heat transfer, as well as the level of losses in the real cooling-heating cycle. According to this model, all sources of heat and moisture, as well as their relative location are analyzed at the first stage.

To build the objective functions that determine the efficiency of the HVAC system, it is necessary to determine as arguments the temperature indicators of the heat sources in the living space as an array $T_{HS}(k)$,, where $k \in [1; K]$. For each k, the difference between the temperature of the heat source and the temperature of the external air $(T_{HS}(k) - T_{EA})$ is determined, as well as the difference between the temperature of the heat source and the temperature of the air in the room $(T_{HS}(k) - T_{EA})$, which, accordingly, allows determining the optimal operating mode of the HVAC system, where the external environment can be used to cool the source, and the heat source is taken into account when heating the room.

The absorption of thermal load [25] is calculated through the total heat removed from all sources in accordance with the temperature difference $(T_{HS}(k) - T_{EA})$:

$$Q_{\mathrm{T}}^{\Sigma} = \begin{cases} \sum_{k=1}^{K} (Q_{\mathrm{T}}(k) \cdot DIF_T) \\ DIF_T = \begin{cases} 0 \; for \; T_{HS}(k) \geq T_{EA} \\ 1 \; for \; T_{HS}(k) < T_{EA} \end{cases} \end{cases}. \quad (1)$$

Accordingly, the total power consumption calculated for all heat sources can be calculated through the efficiency factor:

$$\begin{cases} W_{\mathrm{T}}^{\Sigma} = \sum_{k=1}^{K} \left(\frac{Q_{\mathrm{T}}(k) \cdot DIF_T}{\eta_k} \right) \\ \eta_k = \frac{T_{HS}(k)}{T_{EA} - T_{HS}(k)} \end{cases}. \quad (2)$$

Thus, the optimal solution for the HVAC system can be calculated through the maximum value of the efficiency factor:

$$\eta_{max}^{\mathrm{T}} = \frac{Q_{\mathrm{T}}^{\Sigma}}{W_{\mathrm{T}}^{\Sigma}} = \frac{\sum_{k=1}^{K} \big(Q_{\mathrm{T}}(k_I) \big)}{\sum_{k=1}^{K} (Q_{\mathrm{T}}(k) \cdot DIF_T / \eta_k)}. \quad (3)$$

Similarly, a calculation should be made for the sources of moisture and power consumption of the corresponding unit of the HVAC system, and the arguments of the objective functions Q_{B}^{Σ} and W_{B}^{Σ} should be obtained, where W_{B}^{Σ} is determined through η^{B}. Accordingly, the objective function is calculated as:

$$\eta_{max}^{\Sigma} = \frac{Q_{\mathrm{B}}^{\Sigma} + Q_{\mathrm{T}}^{\Sigma}}{W_{\mathrm{B}}^{\Sigma} + W_{\mathrm{T}}^{\Sigma}}, \quad (4)$$

which can be simplified by introducing coefficients RAT_{T} and RAT_{B}:

$$\eta_{max}^{\Sigma} = \frac{1}{\frac{RAT_{\mathrm{T}}}{\eta^{\mathrm{T}}} + \frac{RAT_{\mathrm{B}}}{\eta^{\mathrm{B}}}}, \quad (5)$$

where

$$RAT_{\mathrm{T}} = \frac{Q_{\mathrm{T}}^{\Sigma}}{Q_{\mathrm{B}}^{\Sigma} + Q_{\mathrm{T}}^{\Sigma}} \quad (6)$$

$$RAT_{\mathrm{B}} = \frac{Q_{\mathrm{B}}^{\Sigma}}{Q_{\mathrm{B}}^{\Sigma} + Q_{\mathrm{T}}^{\Sigma}} \quad (7)$$

Determining the maximum of the objective function η_{max}^{Σ} can be used to determine the optimal operating mode of HVAC at the mathematical level.

4. Conclusions

The study allows formulating the requirements for formative factors of three-dimensional spatial organization of the building with energy-saving technologies. A mathematical model for monitoring the parameters of the HVAC system is proposed, which is based on the analysis of the temperature and humidity level in the residential building. An algorithm has been developed for cooling, heating and controlling the level of humidity in the building, which is based on the ideal Carnot cycle. The calculation of the energy-saving HVAC system should be based on the calculation of the maximum value for the efficiency factor, taking into account the consideration of all sources of heat and moisture in the living space. It is shown that determining the maximum of the objective function can be used to determine the optimal operating mode of HVAC at the mathematical level.

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