Development and Research of a Multi-System for Controlling Comfortable Environmental Parameters

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***Abstract*—The article is devoted to the development of a multi-system for automated control, measurement and management of quantitative and qualitative indicators of the environment of comfortable living spaces in an enclosed space. Here, the issues of controlling object parameters within the limits of normative values, measuring their values, evaluating information flow channels, and generally building parametric and structural models were considered. The assessment of environmental quality indicators, the construction of multi-system parametric and structural models taking into account physical, chemical and biological factors and other components, the classification of informative and non-informative parameters were carried out based on norms and criteria. The characteristics and quality indicators of the parameters were studied in the form of a multi-parameter function, and in order to obtain an adequate model, all external and internal impact factors were taken into account in the form of informative, controlled and uncontrolled external impact parameters. A generalized expression for the quality indicator of the parameters was obtained.**

Along with theoretical studies, engineering solutions were developed - the construction of a structural model of the system, the study of its nodes, and tests were conducted to verify the adequacy of the results.

Keywords—Living space, comfort environment, quality indicator, control, measurement, management, multiparameter multisystem, structural model

I. INTRODUCTION

Currently, the whole world is witnessing the real results of the rapid development and expansion of the Fourth Industrial Revolution. As products of intellectual thinking: artificial intelligence (AI), the Internet of Things (IoT), cybersecurity, robotics, advanced analytics, 5G connectivity and many other technologies, revolutionary changes are taking place in almost all spheres of human life. Due to the creation of a wide network of electronic devices, smart sensors, digital SCADA systems, a huge amount of information is exchanged. Such a wide information connection (exchange) increases the efficiency of operations, expands the geography of new business and other purpose models, innovative services in different infrastructures.limitation to specific form sizes: Custom form sizes cannot be accommodated with OMR technology [].

Among the innovative projects mentioned above, the "Smart Home", "Smart Village", "Smart City" and even greenhouses in the agricultural sector, which have gained popularity in recent years, are being implemented on the basis of "smart" projects. At such a time, the study of the houses or apartments where people live, the workplaces where they work, and even the cabins of the cars they drive as "closed environment" objects has become a pressing issue. Because more than 80% of the time people spend, the active part of their lives is lived in these objects. Therefore, the creation of comfortable conditions and a high-level intellectual environment in such objects makes everyone think and causes interest and competition among all industrial manufacturers.

Creating a comfortable and cozy environment (conditions) in residential buildings serves the comfort of people's lives, their health and longevity. As mentioned, since people spend most of their time in these "closed spaces", the quantitative and qualitative indicators of the air environment inside these spaces should be within the established norms, and ideal guarantees should be created. Because these factors are the main conditions for significantly protecting people's health and well-being. Therefore, when designing residential buildings and other facilities for this purpose, along with a tasteful and attractive design, the reasons (factors) that create comfort and coziness should also be seriously taken into account.

Since the environmental factors, factors, and parameters of the environment located within the space are numerous and different from each other, the solution of the issue becomes quite complicated, and the construction of the model as a whole becomes much more difficult. It is known that the comfort of the environment will depend on the accuracy of the mathematical model built on the basis of its quantitative and qualitative indicators, the accuracy of measurement of the main parameters reflecting all the indicators, and the efficiency of management. All these factors make the problem even more difficult.

People give priority to improving the quality of the environment, meeting their physical requirements, intellectual and psychological perception at the development stages of their lives. At the same time, they strive for the comfort of the spaces where they live and work, and the richness of the microclimate. It is no secret that the assessment of the quality of the environment should be based on scientifically developed norms and criteria. Thus, during the research, the permissible concentration limits of various substances in the natural environment, the degree of physical areas, ecological criteria and indicators should be determined with high accuracy.

II. PROBLEM STATEMENT

To create comfortable conditions in indoor living spaces, the study of the environment, the development of a model reflecting the quantitative and qualitative indicators of the environment, the development of an automated intelligent system using modern methods and tools for highly accurate measurement of parameters, evaluation of results, and intelligent decision-making.

III. SOLUTION TO THE PROBLEM

A complex solution to such a pressing issue is extremely important and requires complex management, measurement and regulation. In order to adequately solve the problem of creating comfortable conditions (environment) in closed facilities, the quantitative and qualitative indicators of the environment should be studied, the physical, chemical, biological, etc. components of the environment, as well as their totality, should be characterized simultaneously. The listed components are vital factors and are different means of the natural environment that condition and determine the vital activity of people and living organisms, natural and natural-anthropogenic objects.

For the peace, comfort and comfortable living of people, a closed environment, microclimate conditions should be created in apartments so that the regulation of parameters inside according to the norms is realistic. For this, air leaks in these spaces should be prevented, their connection with the outside environment should be cut off, and closed facility conditions should be ensured. This does not mean that the facility should be completely isolated from the environment, but rather, external contacts and interventions are envisaged in the management process.

The design of an insulated, airtight building will be comfortable and enjoyable for residents, and will play a key role in their active and productive life in such an environment. Of course, human comfort is a broad concept and cannot be objectively measured. In fact, people tend to perceive their surroundings in a very different and rich way. However, as mentioned, most of them can feel comfortable in a closed environment, and in such conditions, the construction of a model is more suitable for reality.

The factors that are important for ensuring thermal comfort are: convection of air in the room, stabilization of room temperature, surface temperature of building walls and relative humidity. Although indoor air quality is considered the main factor determining the level of human comfort, room acoustics, noise insulation of walls, ceiling and floor, lighting and color design also have a significant impact on the perceived comfort of people. In addition, the regulation of comfort is further complicated by unpleasant environmental heat signs in summer, cool interiors, rapid hot air flow, relative humidity, and in winter, dry air flow inside, and wind.

IV. BUILDING A MATHEMATICAL MODEL OF AN OBJECT.

To express the characteristics and quality indicators of an object in the form of a multi-parameter function, all external and internal influencing factors must be taken into account. In this case, the general expression of the functional dependence between the input-output parameters of the object will be as follows [1]

$$K = f\left(x_1, \ldots, x_i, y_1 \ldots, y_j\right), \quad (1)$$

where $x_1 \ldots, x_i, y_1 \ldots, y_n -$ are informative parameters: $x_1 \ldots, x_i -$ are controlled, $y_1 \ldots, y_n -$ are uncontrolled external influence parameters; K- is a parameter that is a quality indicator.

In function (1), $x_i \ (i = \overline{1,n})$ are informative parameters, and $y_j \left(j = \overline{1,k}\right)$ are a set of external influence parameters, which are determined experimentally, and by solving the mathematical model by parameters, the result - the value of the quality indicator K is calculated. This function is different for different objects and takes a special form.

First, the dependence of the values of the informative parameters x_i between the values of the measurable and controllable quality indicator *K* is studied:

- in the function (1), which reflects the essence of the actual properties and characteristics of the object, ever-changing and increasingly complex processes should be evident;

- the result of applying the same mathematical model to objects with similar and identical properties may be unsatisfactory in assessing all possible quality indicators. In this case, the suitability of the object should be assessed by conducting very important measurements.

In the management process, it should be possible to detect or display any property of the object by referring to the model. All relationships between the initial informative parameters, even various characteristic properties of other objects in the form of groups and the differences between them should be given in a fairly comprehensive form. In general, parameters are divided into informative, controlled and uncontrolled (external influence) parameters.

Despite this classification of parameters, each of them participates to some extent in the assessment of the quality indicator K with the group of informative parameters x_i to one degree or another. The most subtle point that attracts attention here is to find out what percentage of the quality indicator of informative parameters these parameters constitute. Therefore, in order to assess the percentage of informativeness of these parameters, it is necessary to determine all the important combinations and the next classification position of each of them. These positions are associated with the fact in each object that is influenced by various factors y_i. Therefore, due to the accurate assessment of the quality indicator of the object, changes in its internal state are also accurately determined. At the same time, the determined useful properties are systematically listed in a special table. Such a sequential ranking is expressed in a certain mathematical notation, and the boundaries of the assessment are determined by the following expression:

$$|K_1| < |K| < |K_2|, \quad (2)$$

Factors that are excluded from the inequality (2) by their value, but affect the quality factors y_i, that is, hinder the efficient management of the object, should also be taken into account in the model. Thus, the useful information of the object will be restored, and other uncertainties will be determined. It should be noted that such uncertainties spoil the normal management of objects and, as a result, the comfort conditions are permanently violated. As can be seen, if these or other factors that violate the inequality condition (2) are not valuable in management, they are excluded from the model, and if they are even slightly valuable, they are considered as a factor of negative impact on the object and are compensated by counter-effects.

In order to correctly assess all possible characteristics of the object under study, the correlation relationships between the main informative parameters $x_i\,(i=\overline{1,n})$ and all "valuable" non-informative parameters that exist in the range of the quality parameter K, but are not taken into account, should be studied. That is, there is a need to build the functional model (1) in a more perfect - expanded and completed form. Thus, the correlation relationship between the values of Q and y_i of the set of informative parameters $x_i\,(i=\overline{1,n})$ and the values of the set of external influence factors will have the following functional form [1-3]:

$$K=f(x_1,\dots,x_i,\dots,x_n,y_1,\dots,y_m), \tag{3}$$

Here, the useful properties of the object are determined by condition (2), and when estimating *K*, it is necessary to take into account the determination of important conditions for organizing important measurements.

Useful information in the studied objects is not limited in number, but is selected by weight functions in the quality indicator or the absolute values of their differences from each other $|K_2-K_1|$. If this condition is taken into account, then the internal state of the object will change from these external influences, and accordingly, the quality parameter will also undergo a corresponding change. It turns out that the possible values in determining (measuring) informative parameters *x*, the change in the value of each of them separately cannot directly affect any changes in the control object. As can be seen, function (1) reflects all the characteristics of the object, making it possible to study the results of its measurement parameters, the values of the quality indicator and influential external factors (*y*), informative parameters (*x*), and other similar signs, and expresses the existence of correlation relationships between the parameters.

The presented functional model is easily applied to the considered type of objects, thanks to which the characteristics of management are revealed, the determination and evaluation of the quality indicator becomes easier, thus it reflects the characteristics of the concepts developed for the given variables [4, 6, 7]. As can be seen, the characteristics of numerous factors in real multi-parameter objects are very valuable for management and require approaches from various aspects.

Regardless of the complexity of the existing functional and structural models, the possibility of accurate assessment of the actual characteristics of objects, the presence of systematic errors, the inability of functional dependence to fully reflect the characteristics of the object are inevitable. Taking this into account, it is important to determine and calculate the limits of methodological errors based on the proposed multi-parameter measurement concept. At the same time, it is necessary to reduce the values of the errors obtained during the measurement of the indicators of the characteristics of the object to the required and acceptable limits by applying appropriate measurement methods. For this, it is proposed to use tested measurement algorithms [5].

Multiparameter measurements are understood as measurement operations with repetition at the level of parallel measurement channels in the form of a set of heterogeneous parameters X and factors Y that have a significant impact on the state and quality indicator of the object, subsequent assessment of the quality level or state of the object through the *f* functional model of the results obtained for the object under consideration, etc. Thus, a multiparameter multisystem has the ability to collect, measure, process, manage and control an extensive database at the level of multiple information channels, and the generalized structural model of the multisystem is as presented in Fig. 1 below.

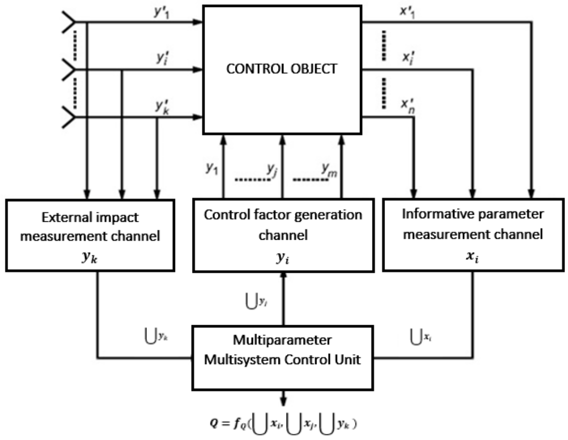

Fig.1. Structural model of a multiparameter multisystem

As can be seen from Fig. 1, this structural model focuses on the important aspects of the primary measurement systems and multi-parameter measurement channels, and in order to increase the measurement accuracy and capabilities of the system, a hybrid multi-system was implemented based on structural-algorithmic-test measurement methods. Hybrid measurement tests and appropriate accuracy criteria were used in the multi-system operation algorithm, and as a result, a structural model was obtained that reflects the general principles for the structural synthesis of a perfect system with multi-parameter, multi-channel automated intellectual capabilities.

In order to keep the measurement error components within permissible limits and ensure measurement accuracy, the development and application of correction algorithms for the errors that arise, the determination and evaluation of the set of parameters, and, ultimately, the determination of the integral indicator are given.

As can be seen, the main accuracy indicator of a multisystem is the assessment of its set of multiple parameters and, as a result, the quality parameter K_{ijk}. In this case, the uncertainty arising in the process of assessing K_{ijk} for the current conditions of the control object should not exceed the maximum permissible value of the error. Thus, when assessing the quality indicator, the accuracy criterion in its structure is synthesized by selecting the metrological characteristics and structure of the measuring channels of the multisystem in order to determine its reliability and ensure its required level. That is, the accuracy criterion, as adopted in the measurement processes, also provides normalized values of metrological characteristics.

The accuracy of the form of metrological characteristics does not have the same effect on the accuracy criterion of the structure of the data acquisition system and the general method of its synthesis. For example, in assessing the accuracy criterion for data acquisition systems on multi-parameter objects, the accuracy criterion for the standard deviation of errors $\sigma_m K$ can be taken as the maximum permissible value.

The nominal value of $\sigma_m K$ for the dynamic limits of the parameters when measuring their values depends on the availability of useful properties of the object in the limits $|K_2 - K_1|$, the required quantization interval dK, and also on the given accuracy parameter k_p [3]:

$$\sigma_m K \leq \frac{|K_2 - K_1|}{k_p N} = \frac{dK}{k_p}, \qquad (4)$$

where $\sigma_m K$ - is the accuracy criterion for the structural synthesis of K-information systems (given as the maximum allowable value of the standard deviation of the system error); $|K_2 - K_1|$ - are the dynamic limits of measurements in estimating K-K; k_p - is the accuracy coefficient in obtaining information from the system; N - is the number of informative connections; $dK = |K_2 - K_1| N$ - is the given quantization coefficient for -K, p -is the given probability of uncertainty.

For the synthesis of the structure of a multisystem in the acquisition of information at the level of standard measurement channels, first of all, the relationships of the metrological characteristics of the information channels of the system are found, which can provide the required accuracy in multiparameter measurements based on the accuracy criterion in accordance with expression (4). The relationship between the system under consideration and some of the accuracy criteria of its measurement channels forms the basis of the synthesis of the structure. Such a parametric arrangement is presented in the opening of the mathematical model (*f*) of a number of considered objects. Thus, the relationship between the mean square trends of random errors and relative errors arising in the information acquisition system is expressed as follows:

$$(\sigma_m K)^2 \geq \left[\sum_{i=1}^{m} (\frac{\partial f_K}{\partial x_i})^2 (\sigma_m x_i)^2\right] + \left[\sum_{j=1}^{n} (\frac{\partial f_K}{\partial y_j})^2 (\sigma_m y_j)^2\right] + + \left[\sum_{k=1}^{s} (\frac{\partial f_K}{\partial y_k})^2 (\sigma_m y_k)^2\right], \qquad (5)$$

where $\sigma_m x_i$, $\sigma_m y_j$ and $\sigma_m y_k$ − are the incomplete accuracy criteria of the measurement channels of the information acquisition system, respectively, or the mean square deviation of the maximum permissible values for the errors of the measurement channels of the information acquisition system in the sample of the object under consideration (OKM);

$\frac{\partial f_K}{\partial x_i}, \frac{\partial f_K}{\partial y_j}$ və $\frac{\partial f_K}{\partial y_k}$ −are the loading - weighting coefficients reflecting the relationships between the parameters x_i, y_i and the changes in the corresponding channels yk with respect to K.

In the considered case, if the function f is differentiable, then the loading coefficients of the information flow channels will be special derivatives of the function f according to the changes in the incomplete x_i, y_i multi-parameter information acquisition system y_k.

The synthesis of operations in information acquisition systems based on formulas (4) and (5) is very important, and in this case the processes will proceed rapidly. For example: let us assume that the total error of the information acquisition system is the same in the services provided by all its measurement channels. Then, the results of the incomplete accuracy criteria and loading coefficients will be accepted equally for all information acquisition systems, that is, the expression for arbitrary i, j, k will be as follows:

$$(\frac{\partial f_K}{\partial x_i})\sigma_m x_i = (\frac{\partial f_K}{\partial y_j})\sigma_m y_j = (\frac{\partial f_K}{\partial y_k})\sigma_m y_k \qquad (6)$$

The mathematical evaluation by expression (6) can be applied to any information flow or information-measurement channels. Thus, from formulas (4) and (5) for the total number of information flow channels, we obtain the main expressions of the incomplete accuracy criteria for each channel:

$$\left.\begin{aligned} \sigma_m x_i &\leq \sigma_m K / \left(\frac{\partial f}{\partial x_i}\right)\sqrt{a}; \\ \sigma_m y_i &\leq \sigma_m K / \left(\frac{\partial f}{\partial y_i}\right)\sqrt{a}; \\ \sigma_m y_k &\leq \sigma_m K / \left(\frac{\partial f}{\partial y_k}\right)\sqrt{a}, \end{aligned}\right\} \qquad (7)$$

where $a = (m + n + s) -$ is the total number of information measurement channels.

The accuracy criterion is taken at the first level of the structural synthesis of the information acquisition system, while the incomplete accuracy criterion is taken as a basis for the synthesis of the information flow channels of the system (7) and allows moving from one level to another.

V. CONCLUSION

The indoor living space, environment, comfort level were analyzed as the object of study, and the issues of evaluating measurement parameters as quality indicators were considered. For this purpose, structural and mathematical models of the multi-parameter multisystem at the level of the control-measurement and management system were developed, and the issues of synthesizing information flow channels were studied.

At the same time, the measurement results, their accuracy, and quality indicators were evaluated based on the relevant criteria, and the synthesis of the structural model was carried out.

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