How to assess the reliability of performing the comfort function by a residential building

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Abstract. Residential buildings should provide comfort for occupants. This can be ensured by the following elements: thermal, moisture, odor, vibration and noise protection and other indicators. The purpose of this research is to assess the reliability of performing the comfort function by residential buildings, which depends on the probabilities of failure-free operation of the above elements. To do that it is necessary to represent its elements in the form of serial and parallel connections of elements. This representation is made difficult by different functional specifications of elements. In addition, the moment and probability of the comfort function failure is difficult to predict. The set objectives were achieved using theoretical and experimental calculation methods. The authors propose the method for defining the time and probability of the comfort function failure and develop the methodology for designing statistical distributions and finding the best distribution law assessing the probability of structural failure and reliability.

1. Introduction

A large number of scientific papers are currently aimed at issues connected with ensuring the reliability of residential buildings with regard to maintaining comfortable conditions for occupants to stay in such residential units [1]. The authors emphasize the importance of monitoring the condition of these operated units, regular building structural surveys and feasible assignment of geometric parameters and operating modes.

The residential building should provide comfort for occupants. It is ensured by the following elements: thermal protection, moisture protection, odor protection, noise protection, compliance with the requirements of the service limit state, vibration protection, lighting, insolation, acoustics and others [2].

To assess the reliability of performing the comfort function by a residential building, it is necessary to represent its elements in the form of series-parallel connections. This representation is made difficult by different functional specifications of the elements. Besides, the moment and probability of the comfort function failure is difficult to predict, because the relevant statistical data are insufficient.

In this regard, the following method of defining the time and probability of the comfort function failure is proposed.

2. Theory

The reliability of performing the comfort function by a building depends on the probabilities of failure-free operation of the listed elements. The data are presented in the table.

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Table 1. Reliability of performing the comfort function by a residential building

Parameter	Failure criterion
Thermal protection	Condensation on the inner surface of the wall
Moisture protection	Breakdown of vapor-proof barrier, horizontal and vertical waterproofing
Odor protection	Feeling of discomfort for occupants
Noise protection	Exceeding the standard values of the sound insulation index
Compliance with the requirements of the service limit state	Occurrence of deflections exceeding the admissible limit values
Vibroprotection	Exceeding the limits of the vibration frequency and amplitude
Lighting	The area of windows referred to the area of the room
Insolation	Time of insolation of the room below the standard
Acoustics in the room	The reverberation time exceeding the normalized limits

Suppose that the probability of elements failure and the cost of their elimination are known [3]. The unifying functional specification of all elements (or the factor uniting them) is the cost of failure elimination. From this point of view, all elements are homogeneous, which allows combining them into parallel-sequential elements.

The probability of occurrence (P) of any given value characterizing the technical condition of the enclosure can be identified theoretically (Figure 1 curve 3).

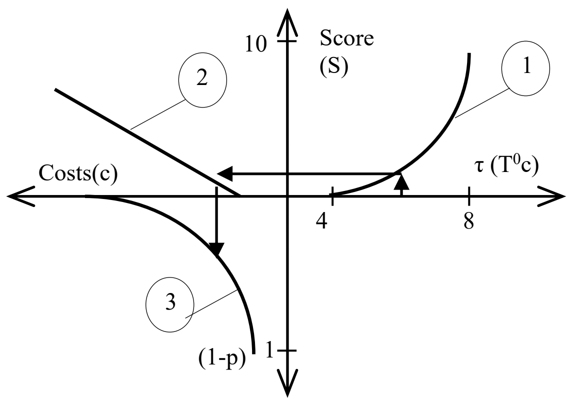

Figure 1. Probability of occurrence of a certain value, characterizing the technical condition of the enclosure

Performance deterioration of most elements of the comfort function occurs over time, which can be taken into account by calculation. An example would be the accumulation of moisture in the enclosing structures over the years of operation, resulting in deterioration of its thermal characteristics [4]. Consequently, the number of points (S) increases for a particular structure as well as throughout the comfort function as a whole. By grouping elements in different combinations, it is possible to achieve such a situation when the total costs for eliminating all failures combined into one group will be as close as possible to the lowest directive charges value.

Elimination of failures in the comfort function is an expensive maintenance. Therefore, directive charges should be taken as depreciation charges. The last aspect increases over the time of the building operation. Thus, failures of the comfort function elements can not be eliminated immediately. Relevant measures should be planned every 10-20 years.

For each element of the comfort function three indicators can be obtained: the probability of failure; the time before the first failure; the cost of eliminating the failure. This information allows creating a reliability scheme of the comfort function.

Thermal protection is ensured by thermotechnical indicators of the enclosing structure, for which the difference between the inside air temperature and the temperature of the inner surface of the enclosing structure is standardized. This standard value is determined by Construction Rules 50.13330.2012 “Thermal Protection of Buildings”. The limit value of the temperature difference is the one that causes the appearance of condensation on the inner surface of the enclosing structure.

Under such conditions the relationship between S and τ is expressed as follows:

$$S = \exp\left(-6{,}907 + 1{,}151\tau(t)\right). \tag{1}$$

Within the limits of $\tau \leq 4$ that corresponds to $S = 1$, the enclosing structure is functioning properly. There is a probability that under certain conditions the value will be equal to or exceed the normative $\tau \geq 4^\circ$ C.

In this case, the thermal characteristics of the structure will constantly deteriorate. Eventually, the temperature on the inner surface of the enclosing structure will reach the dew point, which means its failure to thermal protection. At the same time, there will be an increase in the number of points (Fig.1 curve 1).

3. Experiment

The data on the minimum annual temperatures were statistically processed. They were recorded by 21 meteorological stations in the Samara region.

Taking the temperature distribution as normal, the calculated value of the outdoor air temperature occurrence of 0.98 can be obtained by formula 2 for buildings with greater responsibility for energy consumption when heating:

$$T_{\min}^{0,98} = S_\gamma - 2{,}1\sigma, \tag{2}$$

where S_γ is the mathematical expectation of the minimum annual temperature.

An alternative to this method is the use of the double exponential Gumbel distribution. The best possible value of the minimum temperature for a given period can be defined with the following dependence:

$$X(t) = u + \left(\frac{1}{\alpha}\right) \times \ln(t). \tag{3}$$

Suppose that the state of comfort for an occupant in the room can be estimated with the help of 10-point system. In this connection: 10 points correspond to such state of a person when he physiologically can not stay in the room. The number of points that estimate the degree of comfort is the sum of points for all elements of the comfort function. Point 1 corresponds to the completely comfortable state of the person, which is similar to the state when all elements of the comfort function are within the requirements of regulatory documents.

For a number of reasons, the dependence between the numerical value characterizing the state of the element χ and the number of points S can be expressed with an exponent, according to the following formula:

$$S(t) = \exp\left(\beta + \alpha \times \chi(t)\right). \tag{4}$$

Having defined the boundaries $\chi(t)$ over time, we can assign the maximum point 10 to the most unfavorable value $\chi(t)$, and between these boundaries write a specific function $S(t)$.

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Thus, for each year it is possible to calculate the number of points for all elements of the function, and (when the total is 10) to fix the time of its achievement. This time will define depreciation charges.

By the same time, there will have been a need for major repairs (adjusting to standardized quality) of all system elements.

Any deterioration of thermal characteristics can be corrected by spending additional funds for insulation of the enclose (Figure 1, line 2)

4. Results and discussion

The costs for eliminating failures of the comfort function elements are very high – they can not be included in the group of operational costs. The obvious costs here are those necessary for major repairs, limited by depreciation charges. The latter depend on the time of the building operation.

To investigate the reliability scheme of the comfort function, it is necessary to consistently connect parallel connected groups of elements. The latter are taken on the basis of the condition of maximum approximation to the lowest amount of costs for eliminating elements' failure consequences to the amount of depreciation charges for the t-th year.

The measures aimed at eliminating the consequences of elements failures in the function of energy efficiency and comfort includes major repairs [5]. The need for major repairs is determined by the physiological reaction of a person to the deterioration of conditions in the premises. The physiological reaction of a person is expressed in points (according to the ten-point system). When the point is 10, a person can no longer be indoors and remain in normal condition (in all aspects). Point 0 corresponds to the absolutely comfortable state of the occupant. In the technical aspect this means that all the technical parameters of the element are in the condition not worse than the normative one. Point 10 corresponds to the occupant's complete discomfort. From the technical point of view this means that all the technical parameters of the element expressed in points sum up to 10. This does not mean that all the technical parameters of the elements have become worse than normative.

We assume that for each element the dependence "point – time" is defined by the expression close to exponential, because most processes in nature, technology, sociology follow the exponential law. The probability of failure of a technical element (connected with construction) increases exponentially over time. We assume that the repair of each failed element is made to the condition that meets its quality regulatory requirements. Accordingly the costs are calculated. Time of achieving point 10 defines the year when it is necessary to effect costs for eliminating consequences of failures, respectively. The sum of depreciation charges is defined.

Thus, the probability of failures and the cost of their elimination should be defined, in the general case, as a function of time.

The time of the building operation before major repairs is defined by the rate of decrease in the elements reliability due to the accumulation of damage in them. Thus, over time, depreciation charges accumulate, and in the year of major repairs they reach a certain value, which appears to be directive costs for eliminating the failure of the energy efficiency and comfort function/

5. Conclusion

When assessing the reliability of the system, various methodological problems arise, often related to technical and economic issues. The list of problems begins with such a concept as "system failure". This concept is not obvious, as the construction system - a residential building in this research paper, as a rule, is multi-purpose. Thus, for example, the residential building should be strong, safe for its occupants, protect them from the influence of atmospheric forcing, provide sound insulation and functioning of engineering systems, etc. And all these functions should be performed simultaneously.

However, the number of failed elements in the operated building can not be unlimited - once there will come the moment when failures complicate the safe operation of the residential building.

These examples show the complexity of the concept "system failure", as well as the building reliability reserves, which nowadays still can not be theoretically taken into account.

Therefore, for each element, it is necessary to know the costs for eliminating the failures that have occurred. By grouping elements in different combinations, it is possible to achieve such a situation when the total costs of eliminating all failures combined into one group will be as close as possible to the lowest directive charges value.

In this paper, in general most of the calculations were made using probabilistic methods with extensive application of modern computer technologies. Probabilistic calculations are considered to be the most modern and promising.

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