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# ADAPTIVE NEURO-FUZZY SYSTEM FOR ESTIMATION OF BIOPOSITIVITY OF BUILT ENVIRONMENT

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**Abstract:** Negative environmental impact (NEI) is the result of human economic activity, including construction. At first sight, reducing the negative environmental impact and creating a comfortable living environment (LE) seem to be mutually exclusive concepts. Within the framework of research in this area, it is advisable to us e a complex concept of biopositivity of construction objects. This concept will help to determine the balance between reducing NEI and ensuring the comfort, health and well-being of consumers. The literature review did not indicate any researches in which fuzzy logic methods, including fuzzy logic inference models, were utilized to assess the biopositivity of the living environment of residential buildings. Moreover, the existing methods of "post occupancy evaluation" (POE) do not assume the integration of quantitative and qualitative user assessments to manage the quality of the building environment. The paper presents a methodology for assessing the integral index of biopositivity of civil buildings and iterative determination of the values of the LE parameters, at which the comfort of the individual consumer will be ensured. The simulation procedure of adaptive neuro-fuzzy inference system was implemented in MATLAB software using Neuro-Fuzzy Designer. The model was trained on a data set of 843 strings. Instrumentally measured values of LE parameters were used as predictors, and the response was a qualitative user assessment of the LE. The proposed model of the process of forming a comfortable and biopositive LE provides an opportunity to take into account a set of main factors that form the LE, to fix an integral indicator of the biopositivity of a building facility and make a decision on its advanced improvement.

**Keywords:** sustainable development, environmental safety, living environment, biopositivity, design criteria, comfort, health saving

# ОЦЕНКА БИОПОЗИТИВНОСТИ СРЕДЫ ЖИЗНЕДЕЯТЕЛЬНОСТИ ГРАЖДАНСКИХ ЗДАНИЙ НА ОСНОВЕ АДАПТИВНОЙ НЕЙРО-НЕЧЕТКОЙ СИСТЕМЫ ВЫВОДА

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**Аннотация:** Негативное влияние на окружающую среду (НВОС) обусловлено хозяйственной деятельностью человека, в том числе строительной. На первый взгляд снижение НВОС и создание комфортной среды жизнедеятельности (СЖ) видятся взаимоисключающими концепциями. В рамках исследований по данному направлению целесообразно использование комплексного понятия биопозитивности строительных объектов, которое при их оценке позволит определить баланс между снижением НВОС и обеспечением комфортности, здоровья и благополучия пользователей. Проведенный анализ литературных источников не выявил работ, в которых для оценки биопозитивности среды жизнедеятельности гражданских зданий использовались методы нечеткой логики, в то числе модели нечеткого логического вывода. Более того существующие методики «оценки зданий после заселения» (post occupancy evaluation или POE) не предполагают интеграции количественных и качественных пользовательских оценок для управления качеством СЖ. В статье представлена методика оценки интегрального показателя биопозитивности гражданских зданий и итерационного определения значений параметров СЖ, при которых будет обеспечен комфорт конечного пользователя. Процедура моделирования адаптивной нейро-нечеткой системы выво-

да реализована в среде MATLAB с использованием Neuro-Fuzzy Designer. Модель обучалась на выборе из 843 строк. В качестве предикторов использованы инструментально измеренные значения параметров СЖ, а отклик – качественная пользовательская оценка СЖ здания. Предложенная модель процесса формирования комфортной и биопозитивной СЖ предоставляет возможность учитывать совокупность главных факторов, формирующих СЖ, фиксировать интегральный показатель биопозитивности строительного объекта и принимать решение о его опережающем повышении.

**Ключевые слова:** устойчивое развитие, экологическая безопасность, среда жизнедеятельности, биопозитивность, критерии проектирования, комфорт, здоровьесбережение

## INTRODUCTION

Within the context of the modern pace of life, the development of communications and information technologies, growing urbanization leading to overpopulation of megalopolises, the achievements of post-industrial society, together with the increased mobility of the population of large cities, the change of ideas about the quality of living environment (LE) is inevitable.

In Russia, the creation of a comfortable living environment is one of the priority tasks of the national projects “Housing” and “Ensuring Sustainable Reduction of Uninhabitable Housing Stock”. However, the lack of a clear definition of the concept of “comfort” and methods of its objective assessment significantly complicates the development of effective design solutions [1].

Methods of evaluation of completed construction projects traditionally rely on expert assessments based on technical criteria. However, they often do not take into account an end-user's satisfaction. As response to this challenge, the Post Occupancy Evaluation (POE) methodology, aimed at analyzing user evaluations of buildings after occupancy, began to develop in the 1960s in Western countries [2-5]. Currently, one of the most common POE methodologies is the system developed by the Center for Built Environment (CBE) at the University of California, Berkeley. This methodology suggests the use of Likert scales to assess user satisfaction with various aspects of SL and allows benchmarking buildings to identify problem areas and suggestions for improvement [7].

However, within the framework of the abovementioned methods, quantitative assessment of the LE parameters and qualitative user assessment of L factors are considered separately. Integration of qualitative and quantitative assessments supported by modern mathematical and system-technical methods will allow us to create a refined model of forming a comfortable environment for successful management of its characteristics.

One of the most complex concepts in the field of ecological safety of construction is biopositivity. According to A.N. Tetior's definition, the biopositivity of buildings and structures implies their ability to integrate organically into ecosystems, minimize negative environmental impact (NEI), contribute to the restoration of nature and provide a high quality of life for users [7, 8]. However, the concepts of reducing the negative environmental impact and creating a comfortable environment are often viewed as mutually exclusive.

The introduction of biopositivity as an integral indicator of LE allows us to consider the problem in a comprehensive way, seeking to determine the balance between environmental safety and user comfort.

The objective of this study is to integrate the qualitative user assessment of the biopositivity of LE with instrumentally measured values of LE parameters through the development of an adaptive neuro-fuzzy inference system (ANFIS). This approach will allow to fix the integral index of biopositivity of a construction object and plan its advanced improvement.

## MATERIALS AND METHODS

The authors have formed a system of 36 factors of biopositivity of LE of residual buildings. The factors are subdivided into 10 groups:

1. Factors determining the parameters of climatic conditions of the territories adjacent to the building;
2. Factors determining the spatial comfort of the internal environment of the building;
3. Factors determining the ergonomics of space;
4. Factors determining satisfaction with the quality of finishing materials;
5. Factors determining visual comfort;
6. Factors determining acoustic comfort;
7. Factors determining thermal comfort;
8. Factors determining air quality;
9. Factors determining water quality;
10. Factors determining the operation of the building as a whole.

Based on the formed system of factors [9] of biopositivity LE for administrative buildings, a survey has been developed to collect initial data for the subsequent mathematical modeling.

To obtain a sample, 843 respondents - users of 11 administrative buildings in Moscow were interviewed. The respondents were practicing specialists in the field of design and construction of buildings and structures. Within the framework of the survey the respondents were offered 36 questions. Each of them corresponds to the factors of biopositivity of LE [10], as well as 1 generalizing question, within the framework of which it was necessary to assess the overall comfort of the building in which they are located.

Each of the 37 questions required selecting 1 of 7 verbal judgments that characterize the degree of comfort of the environment for each factor. The following verbal judgments were used:

- Absolutely discomforting;
- Discomfortable;
- Relatively uncomfortable;
- Neutral;
- Relatively comfortable;
- Comfortable;
- Absolutely comfortable.

In general, these judgments correspond to a 7-point Likert rating scale. The results of user ratings were coded on a scale of -3 to 3, where 0 is neutral, for further statistical analysis.

Next, a regression model was developed where the qualitative biopositivity scores of each environmental factor are the predictors and the building biopositivity score is the response. The purpose of this step is to identify the most significant environmental factors for modeling fuzzy inference systems. The slide shows the results of the analysis of variance. The model explains about 88% of the variability in the response. Significant factors were determined on the basis of P-value, those predictors with P-value less than 95% and multicollinear predictors were eliminated [11].

As a result, 25 significant factors remained. This is a lot for modeling fuzzy inference, for which it is recommended to use 5 input parameters [12]. To determine 5 significant factors for modeling adaptive neuro-fuzzy inference system, the predictors were sorted by the modulus of regression coefficient. Thus, it was determined that the significant factors for modeling ANFIS are: the quality of finishing materials (VOC emission), the level of natural lighting, the level of artificial lighting, the level of penetrating airborne noise, and air temperature.

Simultaneously with the survey, instrumental measurements [13] of the following parameters were carried out in each room or zone (in case of open office layout) for further modeling of the adaptive neuro-fuzzy inference system: VOC concentration; CO2 concentration; concentration of fine particles PM 2.5; CEO measured in a separate zone or office of the object under study; illumination of the working surface; light pulsation; penetrating noise level; air temperature; air humidity.

Measurements of air temperature and humidity, VOC concentration, CO2 concentration, concentration of fine particles, light pulsation, working surface illumination were carried out by the Climate Guard mobile indoor climate measuring station. ClimateGuard is a hardware-software complex that allows collecting, analyzing and transmitting information on indoor climate parameters to external information systems. The Climate Guard station registers the

values of indoor climate parameters using the following sensors:

- Concentration CO2 - mh-z19b;
- Temperature, humidity – bme280;
- VOC - bme680;
- Light pulsation - as7262;
- Illumination of the working surface - bh1750;
- Concentration of fine particles - pms7003;

Air flow velocity was measured with a Testo 425 thermoanemometer. To measure the level of penetrating airborne noise, a noise meter ECOFIZIKA 110A and a microphone VMK-205 were usedConcentration of fine particles.

## RESULTS AND DISCUSSION

Neuro-fuzzy network construction will be performed in MATLAB program software, using Neuro-fuzzy designer extension package, the interface "rule viewer" of which allows to iteratively select the values of environmental parameters and immediately see their influence on the overall level of biopositivity of the object.

As part of the objective of developing a methodology for selecting or iteratively selecting a combination of values of environmental parameters, which will ensure the comfort of the end user of LE, it seems necessary to reduce the number of terms of five input linguistic variables. When using 5 input variables with 7 linguistic terms in each, the model will be considered numerically and linguistically complete, but the number of rules will be 16807. The use of such a large rule base is impractical due to limited computing power. When reducing the number of terms of input variables to 5, it is proposed to combine the terms "Absolutely Discomfortable" and "Discomfortable" into a group under the term "Discomfortable", and the terms "Absolutely Comfortable" and 'Comfortable' into a group under the term "Comfortable". When using 5 input parameters with 5 terms in each, the number of product rules will be 3125.

If the number of terms of input linguistic variables is reduced to 3, it is also proposed to combine the terms "Relatively discomforting", 'Neutral' and "Relatively comfortable" into a group under the term "Neutral". If 5 input parameters with 3 terms each are used, the number of production rules will be 243.

Note that if 7 and 5 linguistic terms are used in each input parameter, the response surfaces of the output functions are more detailed relative to the system in which 3 linguistic terms are used in the input parameters. Also, in the case of more detailed response surfaces it is possible to note the presence of clearly limited areas of the surface, reflecting one or another linguistic term of the output variables. However, within the framework of solving the problem of developing a methodology for assessing the biopositivity of construction solutions, taking into account the limited computing power, it will be reasonable to adopt in the development of an adaptive neuro-fuzzy output system 5 input variables with 3 linguistic terms in each.

Moreover, this decision can be justified by the methodology adopted in [14], where the user's assessments of the comfort of SL on a 7-point scale (from -3 to 3) were combined into 3 groups according to the principle similar to that adopted in this paper:

• The group "Discomfortable" combines the therms "Absolutely Discomfortable", "Discomfortably Discomfortable";

• The group "Neutral" combines the terms "Relatively Discomfortable", 'Neutral' and "Relatively Comfortable";

• The group "Comfortable" combines the therms "Absolutely Comfortable", "Comfortable".

Thus the following input variables are defined:

- Quality of finishing materials: VOC emission. Therms: discomforting, comfortable, neutral.
- Level of natural light. Therms: discomforting, neutral, comfortable.
- Level of artificial light. Therms: discomforting, neutral, comfortable.
- Level of penetrating airborne noise. Therms: discomforting, neutral, comfortable.

- Air temperature. Therms: discomfort, neutral, comfortable.

As ANFIS implements Sugeno's fuzzy inference system as a dataframe [15, 16], a data set should be adopted to train the neural network, in which user ratings of the overall biopositivity of the building's SL coded based on a 7-point rating scale will be the response, and instrumentally measured values will be used as predictors:

– VOC concentration (ppm);
– ALF (%);
– Illumination of the working surface (lx);
– Penetrating airborne noise level (dBA);
– Air temperature (°C).

The 843 rows raw data array was divided into train and test samples in the ratio of 360 to 483 rows. The model was trained at 150 epochs [17]. Based on the training results, the model error was 0.0714.

According to the modeling results, the model of user's perception of the values of LE factors. In the Neuro-fuzzy designer extension package, the "rule viewer" interface allows to iteratively select such a combination of values of environmental factors that will allow to achieve a high index of biopositivity of LE and user comfort (Fig. 1).

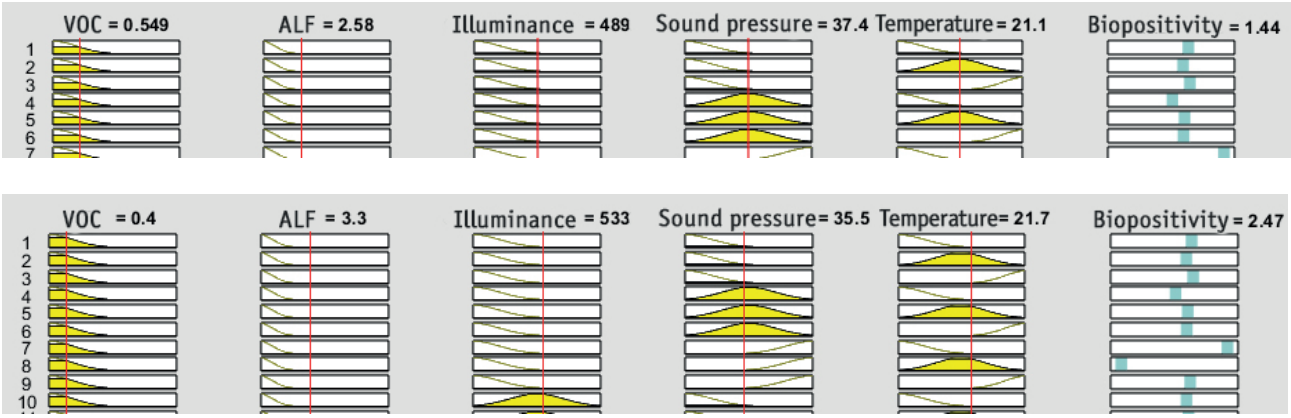



*Figure 1. The Rule viewer interface of Matlab software, which allows iterative selection of co-combinations of the values of the biopositivity factors of the LE*

As part of the analysis of modeling results it is necessary to investigate the function of integral index of biopositivity of LE (Biopositivity) at different combinations of input parameters.

The function of the integral biopositivity index at input parameters VOC concentration and sound pressure level has the following form (Figure 2).

The diagram shows that the greatest value of the Integral Index of Biopositivity comes at sound pressure values of less than 45 dBA and VOC concentration levels of less than 1 ppm, which are optimal for the human body. If the recommended MPC of VOCs is exceeded and the recommended sound pressure level is exceeded, the Biopositivity value is the lowest.

The function of the Integral index of biopositivity at input variables Temperature of air and Illumination of working surface has the form (Figure 3).

The graph shows that the greatest value of the Integral index of biopositivity is achieved at levels of natural and artificial lighting levels optimum for the human body, which is described in Section 1.2 of the article. At the value of illumination of the working surface in the range of 400-700 lux and the value of air temperature in the range of 21-23 °C the value of the Integral index of biopositivity is the greatest.

The function of the Integral Biopositivity Index with the input variables Quality of finishing materials: VOC emission and Illumination of the working surface has the form (Figure 4).

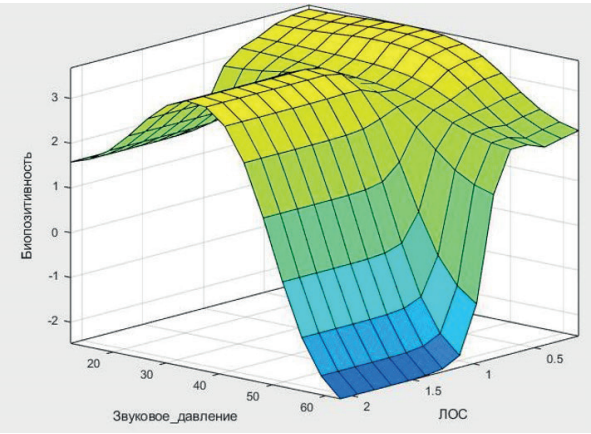



*Figure 2. Function Integral biopositivity indicator with input variables VOC concentration and sound pressure level*

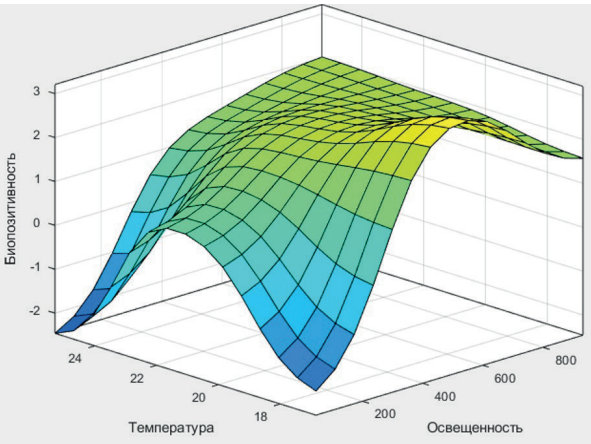



*Figure 3. Function Integral indicator of biopositivity with input variables Temperature and Illuminance*

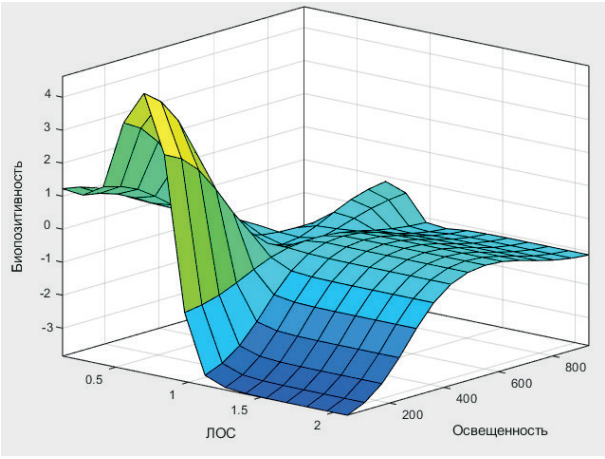



*Figure 4. Function Integral biopositivity index with the input variables VOC concentration and Sound pressure level*

The diagram demonstrates that the greatest value of the Integral index of biopositivity is achieved at values of VOC concentration up to 1 ppm and values of illumination of the working surface up to 400 lux. The lowest value of the Integral index of biopositivity is achieved at maximum VOC concentration and minimum illumination of the working surface.

Based on the study of adaptive neuro-fuzzy inference system it can be drawn a conclusion that the model to a large extent logically describes the subjective human perception of biopositivity factors of the environment [18]. Thus, the developed model should be used to solve the problem of iterative selection of combinations of environmental parameters that ensure the comfort of the end user of an administrative building.

The assessment of the biopositivity of building objects must account for a significant number of both internal and external environmental factors that are related to both design decisions and operational modes, along with the subjective perception of the biopositivity of environmental factors by building users.

From the point of view of quality management and life cycle management of a building project, especially the longest stage of the life cycle such as operation, assessment as benchmarking is not a sufficient tool to improve the quality of the object. In order to realize the advanced planning of increasing the integral indicator of biopositivity of the object, it is necessary to use the methodology of assessment of biopositivity of the construction object and the subsequent iterative determination of the values of the parameters of LE (diagrammatic interpretation is presented in Figure 5), at which the comfort of the user of the construction object will be ensured, which consists in performing a number of interrelated steps:

1. Analysis of project documentation and management company documentation to examine which of the biopositivity factors are present at the facility.
2. Conduct a user survey. Using the survey form presented in Annex 1 of this study to conduct a survey of regular users of the facility. In

order to achieve a representative sample, it is necessary to survey at least 30% with the number of regular users up to 1000 people, at least 25% with the number of regular users from 1001 to 2000 people, at least 20% with the number of regular users from 2001 to 3500 people, at least 15% with the number of regular users from 3501 to 5000 people, at least 10% with the number of regular users from 5001 to 10000 people [19, 20].

3. Conducting instrumental measurements of environmental parameters: VOC concentration; CO2 concentration; concentration of CEO, concentration of fine particles PM 2.5; CEO measured in a separate zone or office of the object under study; illumination of the working surface; light pulsation; penetrating noise level; air temperature; air humidity.

4. Coding the respondent's answers on a numerical scale from -3 to 3 in increments of 1 to allow for regression analysis of the results.

5. Conducting regression analysis of the coded responses of respondents. Determination of significant factors of biopositivity of LE on the basis of P-values of each environmental factor, which are predictors within the regression model. Determination of significant factors for neuro-fuzzy network modeling by ranking the moduli of the regression coefficients of the predictors. For further modeling of the neuro-fuzzy network, 5 predictors with the highest values of regression coefficient modules are taken as significant modeling factors.

6. Building a refined regression model to assess the significance of the model and verify the absence of multicollinearity.

7. Modeling of adaptive neuro-fuzzy inference system in MATLAB software program.

8. Fixing the integral indicator of biopositivity of the construction facility.

9. Iterative determination of the combination of the values of the parameters of LE, at which the comfort of the user of the construction facility will be ensured in the interface “rule viewer” of the extension package Neuro-fuzzy designer of the Matlab software program.

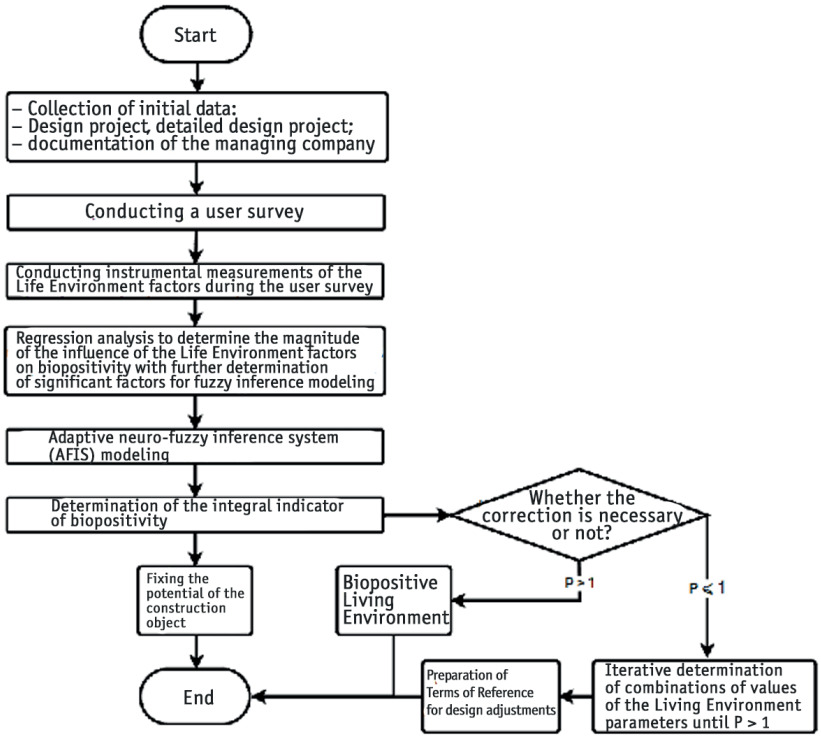



*Figure 5. Flow chart of the methodology of biopositivity assessment and subsequent iterative determination of combinations of values of environmental parameters, which ensure the comfort of the user of a facility*

## CONCLUSIONS

As part of this study, an adaptive neuro-fuzzy model has been developed for iterative determination of combinations of the values of the parameters of the LE, at which the comfort of the users of the administrative building will be ensured. The response function of the output variable Biopositivity at different combinations of input variables has been analyzed. The adaptive neuro-fuzzy network to a large extent correctly describes the subjective human perception of the biopositivity of the factors of LE.

The methodology for assessing the biopositivity of a construction facility (on the example of an administrative building), which allows to fix the integral indicator of biopositivity of a construction facility and plan its advanced increase. The methodology can be widely applied in the management of construction facilities and used in the formation of technical specifications for the reconstruction and design of various types of residential buildings.

As the sampling of user assessments of the biopositivity factors of LE and instrumentally measured values of environmental factors of different types of civil buildings increases, the retrained adaptive neuro-fuzzy inference systems will be useful in determining the normative values of LE parameters.

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