Model of evaluation the energy-efficient technologies in construction

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Abstract. The article discusses methods of unconditional optimization to solve the problem of choosing the most effective energy-saving technology in construction. The optimization condition has chosen the value of the rate of reduction of energy consumption during operation of the facility. The task of determining the most effective energy-saving technology is to evaluate how quickly the reduction of consumption of the *i*-type of energy occurs. For the solution, unconditional optimization methods were used: the steepest descent method and the gradient method. An algorithm has been developed to search for the minimum value of the function when solving the problem using the coordinate-wise descent method. The article presents an algorithm for determining the unconditional minimum using the Nelder-Mead method, which is not a gradient method of spatial search for the optimal solution. The methods considered are classic optimization methods. If there is a difficulty in finding a function on which the functional reaches its minimum, then these methods may not be effective in terms of convergence. In many problems, in particular, when sufficiently complex functions with a large number of parameters are used, it is most advisable to use methods that have a high convergence rate. Such methods are methods for finding the extremum of a function when moving along a gradient, i.e. gradient descent. The task of finding the minimum function of energy consumption is defined as the task of determining the anti-gradient of the objective function, i.e. function decreases in the opposite direction to the gradient. The direction of the anti-gradient is the direction of the steepest descent.

1 Introduction

Energy conservation is one of the most important tasks of the 21st century. In many ways, it will determine the position of our country in the world and the standard of living of our citizens. It should be recognized that Russia in matters of using energy-efficient technologies lags significantly behind many foreign countries. The issues of using renewable types of energy that can be obtained using natural sources are being actively studied. So, for example, in Russia, the use of solar energy is almost not developing. The production and implementation of solar panels is extremely rare today, even in areas with high insolation. Nevertheless, a lot of research in this area has proved that even in central Russia, the use of solar panels leads to very significant results in terms of energy savings, despite the relatively high cost of equipment.

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Power supply is also a critical energy issue. Of particular relevance is the problem of heat loss, as well as the possibility of accumulating heat, using many new technologies and materials that modern science offers to current production.

Natural sources of energy are enough for their skillful and rational use to bring a huge economic effect and, which is very important in the modern world, have a positive impact on the environment.

Energy saving issues are widely covered in the works of A.G. Vakulko, A.A. Zlobin, G.A. Romanov, I.I. Strykh, S.A. Borgakov, D.P. Omelchenko, I.P. Uvarov , E.L. Strizhakov, A.N. Kolesnikov and many other authors of research in the field of efficient technologies for the use of various types of energy [1, 2] .

The works of the above authors establish the main principles of energy conservation policy of our country in the field of energy saving, determined questions to standardization, certification and metrology in the field of energy saving, and also set the foundations and main vectors of power management at the national level [3]. Issues of state participation in the development of energy-efficient and energy-saving technologies are not excluded from consideration and analysis, including the mandatory state supervision of the effectiveness of work on energy conservation, the implementation of relevant visits to organizations and the obligatory timely accounting of energy resources.

In construction, there are many different areas of energy saving, and one of them is the use of energy-efficient innovative technologies. Unfortunately, a lot of the latest technologies offered by developers are practically implemented on single objects. There is no need to talk about the massive use of energy-efficient technologies in construction, although the relevance of this issue is given no doubt [4, 5]. What is the reason for such a slow penetration of new technological ideas into the production processes of the construction industry? First of all, this is a problem of investment. The developer needs to be sure that the funds invested in the construction based on the use of new technologies will bring the necessary economic effect. Moreover, it is desirable to see this effect as soon as possible. Unfortunately, this is the investment mentality of manufacturers. A long investment process carries significant risks that not every manufacturer is willing to take. At the same time, energy saving - a process whose efficiency can be determined during a certain period of using energy-saving technology [6].

Consequently, the duration of the investment cycle, the condition of uncertainty and, possibly, high risks are obstacles for the mass introduction of modern energy-efficient technologies in the construction industry, which is difficult to overcome now.

In addition, manufacturers are faced with the task of choosing technologies that will create the maximum economic effect in a relatively short time. Maximum efficiency, including economic, can be determined on the basis of solving the problem of finding the optimal solution. The task of determining the most effective energy-saving technology is to evaluate how quickly the reduction of consumption of the *i*- th type of energy occurs [7, 8].

The purpose of this study is to show methods for finding the most optimal technologies in terms of energy efficiency. It uses mathematical tools, in particular, offers a method of descent and Nelder-Mead method [9], which in its essence is not a gradient method, but is one of the approaches to solving optimization problems.

In general, the statement of the problem is as follows. Let the energy-saving technologies that reduce the amount of energy consumption be used in the construction of the facility. During the construction process, *N* energy-saving technologies can be used. Each technology has a certain level of resource costs for its implementation. Efficiency is also different. It is required to find a type of energy-saving technologies that will show the highest rate of energy consumption reduction for a certain period of operation t [10,11].

For the solution, the above methods of unconditional optimization were used, which make it possible to determine the set of innovative methods and technologies that can be used in the construction industry that will bring maximum energy-saving, economic, and environmental effects.

2 Materials and methods

1. The method of coordinate descent.

Let *y (x)* be the function of reducing energy consumption. Then $y^{/}$ is the rate of decrease in energy consumption.

We determine the direction of the search for the minimum alternately along the coordinate axes. The trajectory of the search path for a local extremum is shown in Fig. 1.

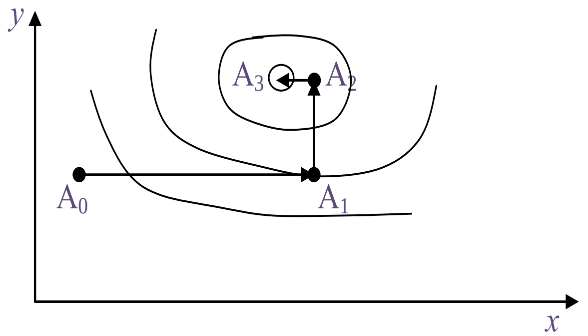

Fig. 1. The trajectory of the search path for a local extremum.

If we consider the problem of determining the spatial variant of descent, then we can take the set of three mutually perpendicular vectors as a basis $\pm\bar{e}_1, \pm\bar{e}_2, \pm\ldots\pm\bar{e}_k$.. The experimentally selected unknowns x_1, x_2, ..., x_k undergo changes one by one. As a result, a search for the minimum value of the function that combines the target and the dependent variables is made in the problem to be solved. This makes it possible to change the independent variables. The solution is presented in the form of the algorithm presented in Fig. 2. A selection of decisions that has several dimensions is replaced by a search having one dimension, but it is performed sequentially, which entails simplifying the search for the minimum value.

Taking into account that the function has only one extremum, we find the step at which $|X_n - X_{n-k}| < \varepsilon$, i.e. the list ends, where ε - represents how accurately the value for the given minimum of the function is determined, k is the number of independent variables of the domain defined the whole set of variables [4] .

If only one minimum value of the function is possible, then this approach is most preferable. The step size *l*, in order to reduce the number of iterations, gradually changes as one moves from the minimum value in one variable to the minimum value in another. Moving along the line occurs until a certain moment, when reaching point A_3 with the size of the range of ε.

The algorithm includes the following steps:

1. The starting point of the search A_0 (x_0; y_0) is fixed as a supporting solution, subject to successive improvement.
2. The search is set when varying the direction of an independent variable x_1 .
3. A step is made in the direction $x_1=x_0+\Delta x$. If $x_1<x_0$, the point x_1 accepted as an improved initial decision. If $x_1 > x_0$, then step is made in the direction of $x_1=x_0-\Delta x$
4. The search continues until the condition:

$$max|x_{i+1} - x_i| \leq \varepsilon \quad (1)$$

Let us check the convergence of the coordinate descent method for the function *f(x;y)*. [5]. Let the level line pass through the initial approximation point (x_0; y_0). There is a region G bounded by a level line. If the conditions are met

$$\frac{\partial^2 f}{\partial y^2} \geq b>0; \quad \frac{\partial^2 f}{\partial x^2} \geq a>0; \quad \frac{\partial^2 f}{\partial y \partial x} \leq c; \quad ab>c^2, \tag{2}$$

then the coordinate wise descent converges to a minimum linearly with their initial approximation points. [6] This question is of very great interest from a practical point of view. Moreover, there are various types of convergence, which, in particular, depend on the function of the target. Depending on the application of unconditional optimization approaches, convergence may also vary. The result will be most determined by the choice of the initial, approximation. The solution depends on the choice of the initial approximation, on its variability and the type of the function under study. The solution algorithm is presented in Fig. 2.

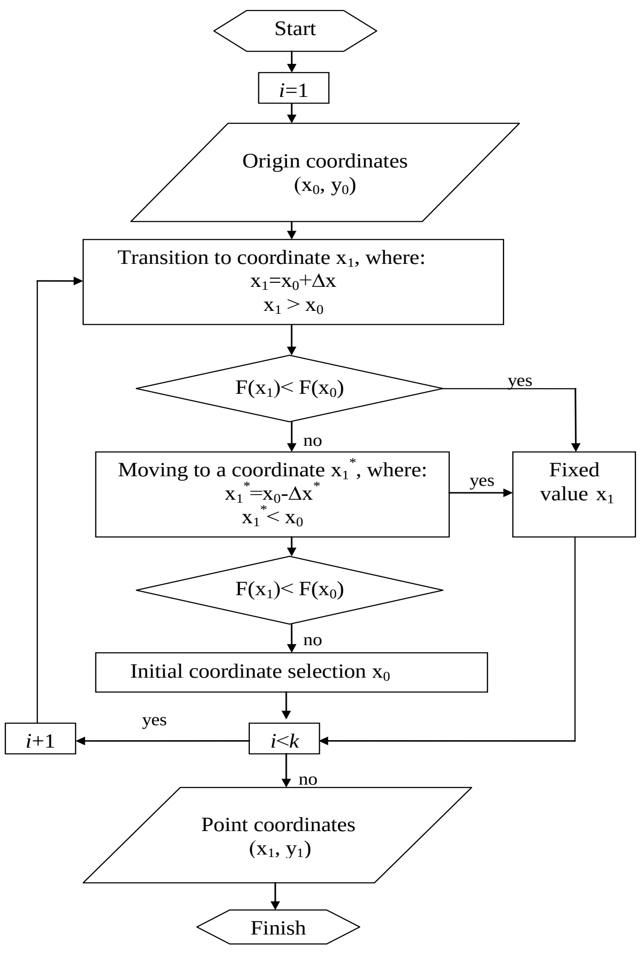

Fig. 2. The algorithm for finding the minimum value.

2. Nelder-Mead Method

It is not a gradient method of spatial search for the optimal solution. It is one of the most reliable and quick options for solving optimization problems. In the considered example, the solution is based on one-dimensional optimization. If, according to the statement of the problem, the reduction in energy consumption will depend on several independent variables, then the methods of multidimensional optimization are applicable

Formulation of the problem. For example, there is a function of a certain number of variables

$$f(x_i^{(1)}, \rightleftarrows x_i^{(2)}, \ldots, x_i^{(n)}) \quad [7].$$

It is defined at every point in the design space.

An unconditional minimum can be found using the algorithm below.

Stage 1. A point is created randomly. $x_i = (x_i^{(1)}, \rightleftarrows x_i^{(2)}, \ldots, x_i^{(n)})$ in the optimization space. At the x_i-points forming the *n*-simplex, the value of the following functional dependencies is f_1=f(x_1), f_2=f(x_2), …, f_n+1=f(x_n+1)

Stage 2. There is a construction of *n*-simplex whose center will be at the point of initial approximation, and the length of the segment *l*. The value of all the upper points of the simplex is determined.

Stage 3. We select from all the upper points of the polyhedron x_h so that the value of the function f_h, x_l is maximum, the value of the function f_l, x_g is minimal with an intermediate value of f_g. After this, it is necessary to reduce f_h.

Stage 4. Find the center of weight of the set of points of the *n*-dimensional simplex with the exception of x_h:

$$x_c = \frac{\sum_{i=1, i \neq h}^{n} x_i}{n} \tag{3}$$

Step 5. Determine how the point x_h is displayed towards x_c. For this, a reflection index $\alpha = 1$ is applied. Thus, the pointx_r where the function is located is determined. The coordinates of the found point are determined using the following formula:

$$x_r = (1 + \text{a})\text{xc -ax}_h \tag{4}$$

Step 6. The function decrease value is calculated. f_r (if this happened in the end) and what position it takes in relation to the values of the function at the following points f_h,f_g,f_l.

The condition fr <fl indicates that the correct direction is selected. This makes it possible to increase the step, i.e. stretching is performed. The result is a new point and a new function value:

$$x_e = (1 - \gamma)x_c + \gamma x_r\,; \quad f_e = f(x_e). \tag{5}$$

In the event that the condition is satisfied $f_e < f_l$, n -simplex expands to a point x_e.

If $f_e > f_l$, then we have too much movement. We assign x_l a value to the pointx_r.

In case if the condition $f_l <$ f_r< f_g is satisfied, then we can conclude that the point is chosen quite normally (i.e. better than the two previous ones). Then the point x_h takes value x_r.

If $f_l >$ f_r>f_g, then in this case the places of values x_r and $x_h$are replaced.

If the condition $f_r > f_h$is satisfied, then the enumeration of options is over.

The result is that $f_r >$ f_h>f_g>f_l.

Stage 7. Using the pointx_s search method, compression is performed, the compression ratio is $\beta = 0{,}5$: $x_s = \beta x_h + (1 - \beta)x_c$. Here we can find the value of the function $f_s = \text{f}(x_s)$. When the condition is met $f_s < \text{f}_h$, point x_h takes value x_s.

If the inequality$f_s > \text{f}_h$ is fulfilled, then the points that were determined initially are the most optimal ones. All the above steps are repeated until the moment when the magnitude of the simplex being built does not become lower than the required accuracy. [8]

Step 8. Verification of convergence.

3 Results

The above methods are classical methods of optimization. If there is a complexity in finding a function in which the functional reaches its minimum, then these methods can be not effective in terms of convergence. In many problems, particularly when used quite complicated function with a large number of parameters, the most expedient to use methods that have greater convergence speed. Such methods include the method of finding an extremum function for motion along the gradient, i.e. gradient descent.

3. Gradient descent method

The problem of finding the minimum function of the energy consumption is defined as the problem of determining the objective function anti-gradient, i.e. the function decreases in the opposite direction to the gradient. The direction of the anti-gradient is the direction of the steepest descent.

Let *F* (*x*) be the rate of decrease in consumption of the i-th type of energy. As in the previously considered methods, we set the point of initial approximation $\vec{z}_0 = (x_0, y_0)$. At this point, the descent begins in the direction of the anti-gradient [9,10]. The accuracy of the solution ε is given.

According to the statement of the problem, *F* (*x*) is a smooth, decreasing function.

The procedure for finding the optimal solution to the problem includes k iterations is completed when the following inequality holds:

$$max|z_{i+1} - z_i| \leq \varepsilon \quad (6)$$

First, an initial approximation point is determined. After that, the iterative sequence will look like this

$$\bar{z}_{k+1} = \bar{z}_k - \lambda_k grad(G(\bar{z}_k)), k = 0,1,2,\dots,m. \quad (7)$$

Step $\lambda_{k\,k}$ is determined using a variety of methods of one-dimensional optimization. The value of λ_k is small, and thus the inequality is satisfied:

$$F(\bar{z}_{k+1}) \leq F(\bar{z}_k). \quad (8)$$

Sorting procedure is completed when the values of the function during the following iterations are not changed, i.e. in each subsequent point, following inequality will be executed

$$F(\bar{z}_{k+1}) \leq \varepsilon; \quad (9)$$

$$|\bar{z}_{i+1} - \bar{z}_i| = 0 \quad (10)$$

Since $\vec{z}$ is a vector, in scalar form its value will be:

$$z_{k+1}^{(0)} = z_k^{(0)} - \lambda_k \frac{\partial G(\bar{z}_k))}{\partial z^{(0)}} \quad (11)$$

$$z_{k+1}^{(1)} = z_k^{(1)} - \lambda_k \frac{\partial G(\bar{z}_k))}{\partial z^{(1)}} \quad (12)$$

$$\dots$$

$$z_{k+1}^{(m)} = z_k^{(m)} - \lambda_k \frac{\partial G(\bar{z}_k))}{\partial z^{(m)}} \quad (13)$$

4 Conclusions

When using the method of finding the extremum of the function in the motion along the gradient, as a rule, a minimum of a smooth function is defined sufficiently fast, but also convergence is observed much faster. Convergence may be caused by the step size. Even for conditional functions, there is the problem of choosing a step. For a small value of λ, an increase in the number of iterations occurs, despite the fact that a small value of the step guarantees convergence. In the case of an increase in λ, convergence may not be observed. Sometimes, when searching for a minimum with a large value of λ, a saddle point arises, and not a minimum, which can be avoided by fractionation of the step. So, when using the gradient descent method with step fractionation, the value λ is determined under the following condition:

$$G(z_{k+1}) = G(z_k - \lambda_k G'(z_k)) \leq G(z_k) - \varepsilon \lambda_k \left| G'(z_k) \right|^2 \tag{14}$$

The efficiency of the method decreases in the case of studies of functions having several extrema [11,12]. But according to the statement of the problem, in this case, the function is not of this type. The task of finding a type of energy-saving technology, the efficiency of which is the highest rate of decrease in energy consumption, can quite correctly be solved by the presented methods.

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