BIM technologies for the design of active solar heating systems

N Galkina¹², O Gurova¹, and M Govorunov¹
¹Don State Technical University, Gagarin sq., 1, Rostov on Don, 344003, Russia.

E-mail: natash-galkina@mail.ru

Abstract. Building Energy Modeling (BEM) is a complex and diverse process that allows you to achieve better results even with typical design tasks. By using BEM software, it is possible to provide a non-trivial approach to the development of architectural planning and engineering solutions, often combined with each other, to ensure high quality and effective implementation of results. An excellent example of such a process is the use of BEM technology in conjunction with the design of solar heating systems placed on the facades of the building. This approach makes it possible to take into account and practise various subtleties and aspects that are often inaccessible in traditional (without the use of BEM and BIM technologies) design - accurate accounting of heat intake and losses through individual sections of structures, including heterogeneous ones; temperature distribution to individual elements of structures, directly to structures and buildings as a whole, and much more.

1. Introduction

Energy modeling of buildings is one of actual and demanded directions of development of construction sphere. The development of BEM technologies dates back to the 2000s [1]. Since the birth of the considered direction - energy modeling of buildings has undergone many changes; now, it has become what is commonly called the «New stage of development of the construction industry» [2].

As of 2020, it known that thousands of design organizations and construction companies around the world are engaged in the organization of re-equipment and refurbishment of their facilities, introducing various innovations. Energy modeling of buildings was no exception. There are many specialists in this field engaged in the study and development of skills in BEM. However, we should not forget that the basis for designing buildings is primarily the design and development of various architectural, planning and technical solutions, which primarily relate to technologies of a fundamentally different nature. Energy modeling is an information element of design [2], while the basis of construction laid directly by a number of constructive, engineering and technological solutions - principles, materials, structures, systems and processes.

The direct combination of the above elements allows to achieve a fundamentally new - more efficient and optimized result [3]. An excellent example of such symbiosis is the use of BEM technologies along with the introduction of active solar systems classified as energy-saving due to the use of renewable energy source - the Sun. If we pay attention to the principle of solar heating systems in buildings, we can see that the process of introducing solar installations into the building directly correlates with architectural planning and engineering solutions [4]. This is primarily due to the need for more reliable roofing or facade systems that can effectively carry the additional load from the...
installed on them solar systems. This also significantly changes the performance of the thermal protection of the building, through the introduction of additional facade and roofing elements, including effectively absorbing solar radiation (solar collectors) [5]. There is also a significant change in the engineering component of the building, due to the introduction of additional, inexhaustible and almost free source of thermal energy. There is also a significant change in the engineering component of the building as an additional, inexhaustible and almost free source of thermal energy is emerging. In this way, the connection between the introduction of solar heating systems into the building and the use of energy modelling, which takes into account such characteristics as the thermal protection of the building, the performance of its energy systems and the amount of energy consumed, can be clearly seen [6].

2. Relevance

It is known that a standard individual house in the Rostov region with a family of 4 people living in it, according to [7, 8], is characterized by the following data on the total flow of coolant - \( G = 300 \text{ l/day} \), at temperatures in the pipeline: supply - \( t_{w1} = 55^\circ \text{ C} \) and make-up - \( t_{w2} = 15^\circ \text{ C} \).

In this case, the device solar collectors, which act as radiating elements of solar heating systems, due to the small number of floors in the building, is performed on its roof [9]. The result of such a decision is a reduction in heat loss of the building through the roofing.

The thermal resistance to heat transfer is determined by the standard calculation of thermal characteristics, according to the method [10] for two versions of the roof structure in the Rostov region: a traditional gable roof and gable roof with solar collectors on the area of the coverage for the above indicators (with a full fill of one slope), and presented in Table 1.

| Name                   | Thermal insulation, \( R_i \) (m²·K/W) |
|------------------------|-------------------------------------|
| Typical roof structure | 3,94                                |
| Roofing with solar     | Daytime                             |
|                        | 8,11                                |
|                        | At night                            |
|                        | 4,76                                |

From the above data, it can be clearly seen that the installation of solar collectors on a gable roof, if one of its slopes is completely filled, makes it possible to achieve an increase in actual heat transfer resistance, \( R_i \). Which is more than double during daytime, with an average solar intensity of \( I, \text{ W/m}^2 \) for the cold period of the year, according to data [11], and more than 20% during nighttime. Along with the achievement of the above indicators, the installation of solar heating in the building allows you to completely replace the traditional system of hot water supply, and if necessary - partially replace the heating that consumes during operation of gas or electricity in an equivalent proportion of the amount of energy produced. Thus, it is possible to reduce the consumption of traditional (non-renewable) energy, which will be reflected accordingly when determining the energy efficiency class of the building [9] - the main indicator of the criterion evaluation of the data set contained in the energy model of the building (BEM).

3. Problem statement

Achievement of the necessary indicators of quality, energy saving and energy efficiency of a building in the case of application of BEM technologies in the construction of solar heating systems in buildings should be primarily achieved through a cumulative assessment of the architectural and technical solutions being developed, as well as a set of various construction measures. The introduction of solar heating system elements accompanies a multitude of aspects that have an impact on energy, technical, environmental, economic and many other indicators. The use of BEM technologies makes it possible to optimize changes to these indicators, which results in a correlation between two components of the technical sphere as a whole - information and technology.
For example, the following performance indicators can identified for the thermal engineering calculation of the roof with solar collectors, which considered earlier:
- reliability (fail-safe) - the need to maintain the established parameters under design conditions;
- energy efficiency;
- economic efficiency;
- ecological efficiency [12].

In the process of designing any solar system, in order to ensure the aforementioned performance, a number of optimization tasks must be carried out that take into account all the factors affecting it [13]. It should be borne in mind that external influences on the performance of an engineering system, including solar heating, as well as on its performance, are not only direct effects of the main factors, but also indirect, through the combined effects of the aspects in question on each other. In other words, for example, a decrease in the temperature of outdoor air, fuel, °C causes an increase in the relative humidity index, φ, percentage; a temperature increase is the opposite. In addition, there are thousands of such examples. In addition, solar heating systems are seasonal and have very specific hydro technical and heat-and-mass transfer characteristics in terms of physics, which means that they are directly dependent on the environmental indicators. As a result, constant changes in the parameters of the external environment in turn lead to changes in the performance of the solar power plant, in particular its productivity. Consequently, this should take into account in the design. There are many, among other things, variant methods for calculating solar heating systems. However, taking into account this diversity of influencing factors and the principles of the resulting influences dooms the design process to a great deal of difficulties. An effective solution is the use of BEM-technologies, which allow including the mentioned aspects with high accuracy and speed, to select the most appropriate measures and options to solve specific problems, which is the main method of optimization and achieving high efficiency on all criteria (reliability, energy, economic and environmental performance).

4. Theoretical part

The efficiency of solar heating systems is a fundamental indicator that determines, among other things, the amount of substitutable performance of traditional building heat consuming systems. In the existing methodology for calculating solar heat supply systems used in the design, efficiency is expressed in the efficiency (coefficient of efficiency, expressed as a percentage) of a particular system variant, with all its variety of elements and performance characteristics, under certain conditions [14].

Now there are many different manufacturers of solar heating system elements, the main of which is the solar collector. Conditionally, these devices can be divided into two large groups - flat and vacuum (see Figure 1). The first (flat) have lower productivity, but have lower cost and need for maintenance; the second, having higher productivity, have high cost and whimsicality in maintenance. These aspects have a direct impact on the efficiency of the helium plant, and therefore should take into account correction factors when developing design solutions. The same approach accompanies all other elements of solar heat supply systems.

In this regard, and given the diversity of the above elements, and among other things, as previously established, due to the degree of dependence on external factors, in order to achieve the highest performance indicators and, as a result, efficiency, BEM technologies should be used to enable variable design, and the following recommendations should be followed:
- consider the key performance indicators of the equipment selected in terms of the technical and economic feasibility of each option used;
- optimise architectural and planning solutions for the elements of the helium plant to implement, taking into account the thermal protection performance of the building in each option;
- optimize engineering solutions for heat consumption systems, including through the introduction of intermediate elements;
- in addition to the principle of substitution of energy produced, use the principle of recovery [15].
These principles are in many ways fundamental. However, their application in many respects is only possible due to BEM-technologies that allow to quickly take into account the variety of parameters. The use of solar heating systems in buildings in itself determines the growth of efficiency by all criteria. Nevertheless, without the introduction of elements of energy modeling in the design process is impossible to achieve the highest performance indicators, should be a correlation of two directions: information - BEM-technology and engineering - in this case, by the example of solar heating systems.

These criteria have been defined by means of an inductive method of knowledge, in the course of complex evaluation of data, with the accompanying structuring and systematisation of information and the main semantic features defined in the course of the study, taking into account the generalised nature of the information presented in the normative and practical knowledge base, by introducing factor analysis of data into the study methodology, and by synthesizing separate data. Non-compartmentalised axiomatic statements based on pre-determined indicators of the objects under analysis based on the results of a field inspection compared to information provided in similar articles by other authors and normative and technical documentation, accompanied by semantic analysis of the concepts, combined study of data and comprehensive interpretation of definitions relating to the aspects under consideration.

This solution will, among other things, also enable the achievement of growth in performance based on criteria other than those previously determined (reliability, economic, environmental and energy efficiency). The reduction in the amount of effort and time spent on project and theoretical work largely determines the development of the level of comfort and quality of this type of production. First of all, the improvement of any indicators is achieved not through the introduction of a new method of performing certain works, which has not been tested before, but directly through the possibility of introducing and implementing these new methods.

In other words, there are many ways of performing certain production tasks. These methods are more efficient than traditional methods, but not used because of the extreme complexity of implementation. This aspect leads to the important concept of profitability (expediency), which is less relevant to the technical sphere and therefore not considered by the authors of the article in the list of previously mentioned criteria, but is nevertheless an equally important indicator that should be considered before implementation in this or that sphere.

In addition, this value is itself a complex concept to interpret and evaluate and includes such equally important details (factors) as the level of comfort, the level of correlation, economic components, safety, including the technosphere, and much more, in particular, public acceptance and political aspects, which undoubtedly makes this criterion not a technical one, but an extremely important one, as it allows not only for comparative analysis with other variants of the same idea and
directly with analogues on the basis of available expressed numerical data, but also for displaying some statistical database.

The symbiosis of BEM technology and the use of active solar systems for installation on facade structures of buildings undoubtedly has such a criterion as profitability (feasibility), which in this case gives a high performance compared to the design of solar systems without BEM technology. However, it should be remembered that the theoretical assessment of a given object or process is much less accurate than a practical study that uses strictly natural data through observation methods. An empirical study of the cost-effectiveness of the symbiosis of BEM technology and the use of active solar systems for devices on facade structures can therefore show results different from those presented by the authors of the article, but certainly positive, in many ways, perhaps even better than those highlighted in this thesis.

5. Practical significance

It proposed to consider the implementation of such a concept using the example of a comparative analysis of two roofing system options presented above: the first is a traditional gable roof system, and the second is one that fills one of the two slopes with solar collectors for the helium plant. As established earlier (see Table 1), the variant with the introduction of solar system elements allows for higher actual heat transfer resistance of the roof structure. This, in turn, has an impact on improving the thermal protection of the building and, consequently, on the indicators that determine the energy saving class of the entire building. This information reflected directly in the building’s energy model, which being developed using BEM technology.

The above principle defines a list of specific measures and processes required to achieve the highest possible efficiency. The outcome of this approach, while adhering to earlier recommendations, is to ensure reliability, energy, economic and environmental efficiency, which directly form a benchmark for the overall technical progress. First of all, it should be noted that the introduction of solar heating systems helps to ensure technosphere and environmental safety by reducing emissions and discharges of pollutants generated by the use of various traditional fuels (solid, liquid and gas), and secondly, the efficiency and low operating costs of engineering systems using solar energy [16-17].

The above information characterizes the expediency of applying BEM technologies in the implementation of solar heating systems, as well as by analogy, which suggests that other variants of systems, processes and methods have similar indicators, the combination of which with a high degree of probability can ensure the growth of efficiency and reliability criteria.

6. Conclusion

The application of BEM technologies in the design and implementation of active solar systems is an important, integral factor in the development of the construction industry, ensuring technosphere and environmental safety and economic component.

Within the framework of the topic discussed in this article, the authors plan to carry out a more detailed study focused on the definition of practical indicators of the structural and engineering component separately for two energy models of buildings with solar heat supply systems, with the accompanying consideration of the correlation of the results obtained.

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