Methodology for selecting energy efficient and environmentally safe technologies and materials used in construction

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Abstract. The paper gains relevance by discussing the energy efficiency of buildings and facilities and its key aspects using the example of facade systems. Based on the analysis of scientific publications, the authors note that energy efficiency should be considered during construction engineering, because the energy conservation factors assumed at this stage directly influence the energy performance during construction and operation. The point is made that a comprehensive scientific approach is required to select energy efficient materials and technologies, as materials meeting the energy efficiency and environmental safety requirements at the engineering stage may turn out carcinogenic at the operation stage due to failure to observe the work technology. At the construction stage, energy efficiency should be accomplished by using high-technology work methods. The scientific novelty of the research consists in offering a methodology for selecting energy efficient and environmentally safe construction materials and technologies, in particular, with the use of a computer program. A summary of the methodology is provided including the initial and resulting screen forms of the computer program. The practical relevance consists in adapting the new computer program for selecting energy efficient materials and technologies to make other structural systems of buildings and facilities.

1. Introduction
The analysis of scientific publications [1-9] discussing the energy efficiency of buildings and facilities shows that the essential part of the research is focused on the correct choice of a thermal insulant for making facade systems and determining its optimal thickness. This approach is explained by the fact that major heat losses occur through outer walls [10-13]. Although the contemporary market of insulation materials for construction is enormous, the selection of suitable materials ensuring energy efficient facade systems in modern buildings and facilities is no ordinary task [14]. The existing thermal insulation materials differ from each other not only by the level of thermal conductivity, fire resistance, moisture resistance, or vapor permeability, as well as service life, pricing policy, but also, which is no less important, in terms of the level of technological integration and environmental safety [14]. Certain thermal insulants, showing obvious advantages, also have certain deficiencies, among which is a lack of consumer awareness. Failure to follow the work technology in performing thermal insulation works deteriorates the performance characteristics of a construction system.
It follows from the above that the assurance of energy efficiency is a problem calling for a comprehensive scientific approach which stipulates that the energy efficiency factor requires consideration at all stages of the lifecycle of construction systems [15]. This need is also explained by the fact that the energy efficiency issues correlate with the resource conservation issues in the housing and utilities sector and by the understanding that the design of existing buildings and facilities focuses solely on the performance factors [16]. At best, building construction involves certain developments associated with water, heat and electric power saving. However, as emphasized in [16], "the energy resource conservation factors assumed at the construction stage directly influence the same factors at the operation stage". A comprehensive study and assurance of energy efficiency only proves valid as a reword of the statement given in [16] as: "the energy conservation factors assumed at the engineering stage directly influence the energy performance during construction and operation".

There are scientific publications [17-19] viewing energy efficient construction technologies and materials as those only that also meet the environmental requirements. However, this approach is not always correct, as certain energy efficient materials tend to lose their initial properties over a specific period of operation and may start to emit carcinogenic substances. Still, it would be reasonable to underline that the concepts of energy efficiency, resource conservation and environmental safety of construction systems are closely interconnected. Where a construction product meets at least some of the above requirements, there appears a pronounced synergy effect. Some papers [20] consider, among others, as resource conservation technology an opportunity to recycle construction and production waste to produce new materials. They also can be considered environmentally safe if no environmentally hazardous substances are emitted during their recycling and use. For example, these requirements are met by such composite materials as Penocom [21], Vinisol etc.

2. Problem setting, purpose of research

Setting the problem underlying this research involves the identification of possible ways to assure energy efficiency of construction systems at all stages of their life cycle, because a holistic view of energy efficiency will guarantee a comfortable everyday life for people, in particular, by way of reducing heat losses through outer enclosing structures.

The purpose of this research is to develop a methodology for selecting construction materials and technologies ensuring energy efficiency of buildings and facilities by the example of facade systems, in particular based on the use of a computer program.

3. Summary of methodology for selecting energy efficient and environmentally safe materials and technologies

The key aspects of the methodology suggested are:

1. Mandatory consideration of the parameters under review at the three lifecycle stages characteristic of a construction system: engineering (during the development of both detailed documentation and work method statements for individual process cycles), construction (performance of works on the construction site in accordance with the designs, namely: implementing solutions aimed to save water, electric power, heat, compressed air and other resources when drafting the construction site layout plans; using prefabricated transformable container units accommodating two and more floors for temporary construction camps etc., carrying out quality control), and operation (performance of works ensuring energy efficiency and environmental safety of a construction system during its operation, for example, timely repairs, replacement of necessary metering instruments etc.).

2. Identification of the key factors affecting the energy efficiency of a construction system at various lifecycle stages.

3. Identification of energy efficient materials and technologies and their further substantiation based on the environmental criteria.

Because the selection of energy efficient materials and technologies based on a multitude of criteria is a fairly labor-intensive activity, the authors (S.G. Abramyan, N.M. Mikhailova) have developed a computer program to select thermal insulants for energy efficient facade systems assuming such
critical characteristics of these materials as thermal conductivity, vapor permeability, water absorption, service life etc. Each characteristic is rated according to its relevance. The program is versatile as it allows, in the first place, considering an unlimited number of thermal insulation materials and characteristics by incorporating specific commands, and, second, as it allows adapting the performance of construction works to certain energy efficient technologies by incorporating the editing command and including the technology parameters in the construction works.

The program was tested in selecting the most energy efficient thermal insulant out of eight possible options based on the four critical characteristics. Below are given the initial form of the database (figure 1) and the resulting form for identifying optimal construction materials (figure 2).

As shown by the newly developed program, the highest rating was gained by liquid thermal insulants with code "7". On the other hand, according to the authors [22, 23], producers of liquid ceramic thermal insulants often overstate the characteristics of this material for advertising purposes, and as such, they do not correlate with the true facts. When applying this material, it is essential to strictly observe the work technology, for example, the nozzle direction and the minimum distance between the nozzle and the surface to be insulated (painted). Failure to observe the material
application technology causes straight freezing of slopes in panel housing during severe cold weather etc. Therefore, it is very important to use a holistic approach in selecting energy efficient materials, which also must conform to the environmental safety and enhanced technology integration requirements. In its turn, enhanced technology integration (with low labor cost and reduced work time) is known to improve the overall economic efficiency. Considering the above, a comparative analysis was carried out for the five thermal insulation materials as shown in figure 2, where PENOCOM having the fourth rating in terms of its thermal conductivity, vapor permeability, water absorption and service life gained the first place. For illustration purposes, figure 3 gives the emission rates for volatile compounds in the process of material preparation and use.

**Figure 3.** Emission of volatile compounds during the preparation and use of the PENOCOM thermal insulation material, mg/m³

The principal difference of PENOCOM as a thermal insulant from other insulating materials is that it is made of industrial waste, i.e. its production simultaneously resolves the waste disposal issues.

**Summary**

Because the cost of utilities used by humankind is consistently growing, it is reasonable to assume that the market of construction technologies will see more advanced materials and technologies ensuring the energy efficiency of facade systems in buildings and facilities.

The methodology suggested for selecting energy efficient and environmentally safe materials and technologies provides for a comprehensive solution of issues at all stages of the life cycle of a construction system. However, the new program, as used at this stage, is only able to solve certain local tasks, such as the identification of energy efficient materials by their thermal performance and energy efficient technologies by the share of technology integrated in the work process. Thereby, energy efficient technologies are understood as the performance of works with minimum labor costs, energy consumption, production waste, transport expenses etc. As a result, the new program is set for future improvement along with the methodology suggested. A separate database is planned to be created for both materials and application technologies. Where necessary, using the appropriate transfer command, the materials and application technologies under review will be uploaded to the computer program to further select the most energy efficient and environmentally safe materials based on a multitude of criteria. Such program will allow making optimal decisions at the engineering stage and as part of further implementation of engineering solutions for the erection and operation of construction systems.

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