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Energy Efficiency Issues in Buildings: Analysis of World Practice

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Abstract. At present, the volume of world energy consumption is continuously and rapidly increasing, which is a consequence of the industrialization process, population growth, increase in energy costs for the extraction of natural resources, etc. Therefore, the importance of solving the problem of energy efficiency is of paramount importance for modern civilization. In this work, there is an analysis of international experience of energy efficient construction. The main directions of energy-efficient development are highlighted. It's shown that the classical method of heat loss calculations wrongly takes into account the wind effect. The more correct one is required. At the same time, it is worth applying linguistic variables and fuzzy logic, which adequately describe states that are described by verbal statements, and not by numerical values. In conclusion, the most emerging tasks for our Republic are selected: optimal placement of the building on the general plan of the city, incl. maintaining the distance between buildings under the construction and urban-planning regulations; proper heat insulation of the building envelope by the orientation of facades and depending on the climatic parameters of the outside air; air-tightening of building avoiding in- and exfiltration; maximum possible automation of engineering systems up to integration from smart house to smart city level; modernization and optimization of the operation of engineering systems; maximum use of renewable and secondary (such as exhaust air) energy sources; rejection of the classical calculation method of heat loss estimation, which takes into account the effect of wind speed, and to develop a new methodology.

Keywords: energy efficiency, building envelope, heating, ventilation, air-conditioning, energy demand.

Introduction. Today, in almost all countries of the world, including our republic, the problem of saving thermal energy in the construction industry has led to the emergence of various energy-efficiency programs and technologies. In the development and implementation of two such programs "Energy Saving in Buildings and Social Systems" and "Solar Heat and Cooling", the leading role belongs to the International Energy Agency (IEA). In 1995, the IEA disseminated the best practices in the design, construction and monitoring of buildings with low thermal energy consumption in 13 countries. That activity was established under the Target XIII sub-program [1]. The average design value of thermal energy consumption in these buildings is below 50 kWh/m2, which is less than 1/3 of the average thermal energy consumption of traditional buildings. Figure 1 shows the annual consumption of thermal energy of the buildings of the subprogram "Task XIII".

These projects are pilot ones, and the technologies, and indicators proposed by them for the thermal energy consumption should be guidelines for the subsequent development of new building codes and programs for the thermal protection of external enclosing structures and the design of engineering systems, as well as for the construction of new buildings and the reconstruction of old ones.

Based on the above-mentioned pilot projects for our republic, it is necessary to create a unified design methodology for the thermal protection of building envelopes and modernization of engineering systems, to consider the possibility of using mechanical ventilation instead of natural ventilation for modern multi-story residential buildings with external enclosing structures with increased thermal efficiency. The methodology will be valid in the building codes and regulations of many European countries.

Relevance of research. At present, the volume of world energy consumption is continuously and rapidly increasing, which is a consequence of the industrialization process, population growth, increase in energy costs for the extraction of natural resources, etc., as a result, available oil and gas reserves around the world are rapidly depleting. The predicted reserves of oil and gas in the world are small, and the growth of their direct combustion in the future will be limited due to the pollution of the natural environment by emissions of gases and ash during their combustion. Therefore, the importance of solving the problem of energy conservation is of paramount importance for modern civilization

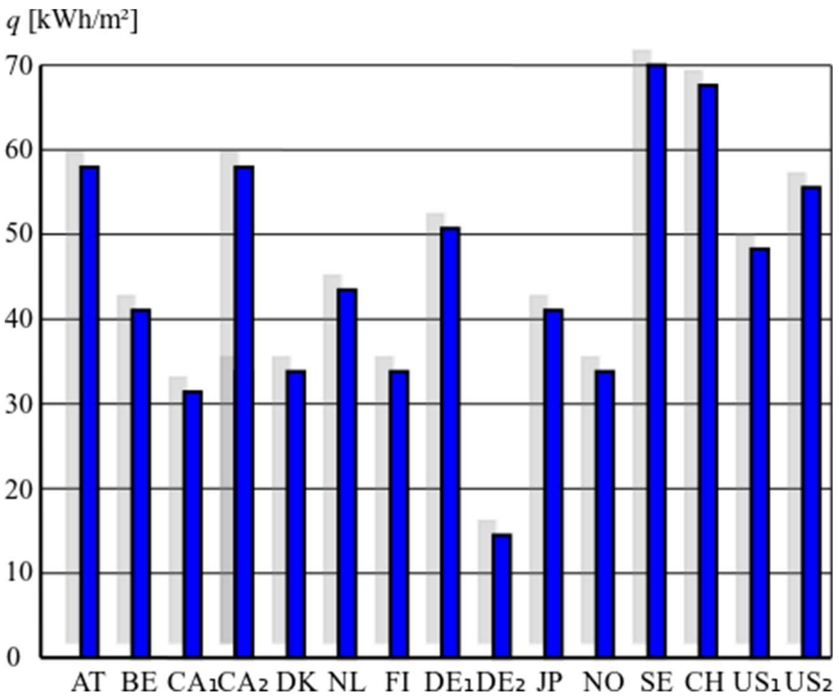

Figure 1. Annual heat energy consumption of buildings, built under the subprogram "Task XIII", kWh/m2: AT – Austria; BE – Belgium; CA1 – Canada-1; CA2 – Canada-2; DK – Denmark; NL – Netherland; FI – Finland; DE1 – Germany-1; DE2 – Germany-2; JP – Japan; SE – Sweden; CH – Switzerland; US1 – the United States of America-1; US2 – the United States of America-2

Recent studies and publications. The study and generalization of foreign experience in the field of energy efficiency in the construction industry show that the reduction of energy consumption for engineering systems of buildings for various purposes [2-14] is considered by the governments of many countries as the most important national economic issue and new legislative and regulatory documents, long-term programs are being developed, research and design projects are being carried out. work, programs of full or partial transition to renewable energy sources in the construction industry are being discussed.

When designing residential and administrative buildings, urban planners, architects, and energy and communication systems engineers should work together as a team, and the following main measures should be taken as energy-saving measures:

- the choice of the shape, size, and orientation [15-19] of the building and its rooms;
- the distance between buildings [20];
- the combination and placement of the building on the general urban plan [20];
- optimizing the wind effect on the buildings [20];
- increasing the overall thermal resistance to heat transfer of building envelopment [21-22] including heat insulation [13, 22-28], reducing the area and using energy-efficient glazing [28-30], decreasing thermal bridges [31] etc.;
- air-tightening of buildings to avoid uncontrolled air exchange and give full control to ventilation and air-conditioning systems [32-33]
- increasing the thermal capacity of opaque envelopment parts incl. using phase change materials to raise the thermal stability to outdoor temperature oscillations [34-35];
- optimising solar radiation gains [36-38];
- use of ventilated windows to reduce heat gain from solar radiation in summer and reduce heat loss in winter [39];
- using renewable energy [40-45] incl. absorption of solar radiation by the envelope and special indoor elements for heating [46];
- using green structures that connect building structures with living plants to increase the thermal resistance of the envelope, perform passive air-conditioning and control solar radiation gains and solar heating of the envelope [47-61];
- increasing the efficiency of engineering systems, inter alia:
    - correct selection of heating system type [62], heat transfer method [63-66], heat carrier temperature [66-67], proper balancing of all hydronic systems [68] etc.;
    - more efficient air distribution in ventilation and air conditioning [69-72];
    - energy-efficient air handling/make-up [73-77];

- proper automation of engineering systems up to centralised control of all of them at the level from the smart house to the smart city [68, 78-80].

In world design practice [60,61,81-87], two methods are used to determine the energy demands on heating, ventilation, and air conditioning systems. The first method is the calculation of stationary external and internal climatic parameters or stationary internal and unsteady external ones without simulation of the inertia. This method is approximate, which makes it quite easy to perform multivariate calculations and, as a rule, gives overestimated (sometimes underestimated) results for thermal loads. The second method is the calculation of non-stationary internal and external climatic parameters, taking into account the thermal engineering and heat storage characteristics of the external enclosing structures, usually using special software [81-87].

Purposes of the article. Based on the literature analysis, it's necessary to highlight the main tasks and directions to raise the energy efficiency in our Republic, which can be used for many other countries.

Main part. Our studies have shown that conventional methods for analysing and modelling the operation of heating, ventilation and air conditioning systems according to a special program and based on accurate processing of numerical data are essentially unable to cover the enormous complexity of real processes because it is practically impossible to take into account all the factors and parameters that affect the consumption of thermal energy. This corresponds to significant deviations between different building energy simulation software [82]. This circumstance leads to the fact that to obtain a real picture of the operation of indoor microclimate systems, it is necessary to abandon the traditional requirements for measurement accuracy, which were necessary for the mathematical analysis of well-defined heat consumption curves.

One of the problems in calculating heat losses is taking into account the wind effect. The "classical" method [88] requires using the indoor heat transfer coefficient 8.7 W/(m2·K) for internal wall surfaces (the air is close to still at the significant distance) and 23 W/(m2·K) for external ones (what average wind speed was accepted?). Most methods of post-soviet countries inherited the classical one. Is it suitable for each region – the question should be investigated. The second problem is correction factors β for winds. Nowadays, they are dependent on wind speed and repetitiveness at the facade orientation. But in urban areas, the wind changes speed and direction according to the alignment of buildings, which can be easily observed by difficult to calculate. Future development can fully change wind movement. The Building Norms provide design wind speed at a height of 10 meters from ground level. It's not acceptable for either modern high-rise buildings or one-two stories individual residential houses. Thus, the corrections β are wrong and cause invalid results. To correctly calculate and estimate heat losses, we need a new method corresponding to the regional climate peculiarities and wind protection of buildings.

It is assumed that to regulate the consumption of thermal energy and control the entire climate system, it is advisable to use the concept of a linguistic variable, introduced by L. Zadeh [89-91]. Such linguistic variables make it possible to more accurately determine and adequately reflect the approximate verbal description of these systems in the case when there is no exact mathematical deterministic description. At the same time, it should be taken into account that, according to the same author, many fuzzy modes described linguistically are often no less informative than an exact description.

Organized air exchange, heat recovery and recirculation in microclimate systems are the main factors to energy-efficiently ensure clean air and human comfort in the premises. The quality and reliability of the operation of these systems determine the living or working comfortable conditions for occupants, the safety and durability of the building envelope, ensuring social ecology and reducing the consumption of thermal energy. With the development of scientific and technological progress, a person has more and more opportunities to increase the level of comfort and safety in buildings. The advent of information technology has opened up vast horizons for this direction in the construction industry.

Now in modern construction, it is possible to automate all life support processes associated with microclimate systems. Automation and control of the operation of building engineering systems make it possible to significantly save thermal energy provided for engineering and communication systems. This is due to the optimization and synchronization of the operation of all these systems separately and their more efficient joint work. For example, synchronization of the operation of heating, ventilation and air conditioning systems can significantly reduce the consumption of thermal energy to maintain optimal indoor air parameters regardless of external climatic changes, increase the period of uninterrupted operation of engineering systems, and reduce the cost of maintenance and operation of equipment [92].

The task of microclimate systems is mainly that in the room for each person, taking into account his individual needs, it is necessary to create comfortable parameters of indoor air. In addition, when designing these systems, it is necessary to provide that, if necessary, the neutralization of permanent external climatic disturbances will be required.

One of the widely used measures to waste a large amount of heat energy is natural ventilation. Such systems are often present in new construction despite the results of calculations [93]. To achieve 4 % of efficiency (less than the last steam locomotives), it's necessary to build a 1 km skyscraper. The modernisation of such a system replacing exhaust grills with fans stabilises it but additionally squanders electricity. For newly built multi-story residential buildings, it is necessary to design mechanical supply and exhaust ventilation with heat recovery and individual control following the needs of each person. In many European countries (Norway, Germany, Finland, etc.), in new construction, it is mandatory to design mechanical exhaust ventilation with heat recovery from the exhaust air for heating or cooling the supply air. As an alternative, it's possible to modernise natural ventilation by installing a fan and a heat pump [94] at the top of the duct to redirect the heat energy for other purposes, for example, hot water and heating.

The design of a mechanical ventilation system and at the same time a combination of supply and exhaust mechanical systems with natural ventilation requires comparative calculations. It is necessary to improve the quality of the ventilation system and, accordingly, the internal air, to reduce the frequency of air exchange in residential premises to reduce the consumption of thermal energy.

The above requirements apply to all types of newly built or reconstructed residential and public buildings. It is known that internal heat generation in residential buildings usually does not exceed 10 W/m2. At the same time, our studies show that artificial cooling is practically not required for the climate of some regions of the Republic of Azerbaijan [95].

Numerical calculations show that with an average annual specific heat load on a heating system from 10 to 15 kW·h/m2, the difference in the total cost of heat energy for building heating systems without thermal protection and with thermal protection is minimal (the results of the studies refer only to newly built residential buildings).

Over the past decades, due to the changing requirements of investors, the increased needs of potential customers, as well as the relevance of energy-saving issues, the rising cost of thermal energy and the increasing costs required for the operation of buildings, as well as heating, ventilation and air conditioning systems used in modern multifunctional public and residential buildings have been significantly modified. The current state of the environment, indoor air quality and the growing need to create intelligent buildings have influenced the modernization and application of modern information technologies in microclimate systems.

In modern multifunctional buildings, the climatic parameters of the indoor air of certain rooms can be different, which is associated with the individual needs of people, production technology, etc. Therefore, the heat loads on the air-conditioning systems in individual rooms may not coincide either in time or in magnitude.

When designing ventilation and air conditioning systems, it is necessary to be guided by the fact that for the choice of technical solutions, the main criterion should be to ensure an environmentally friendly air regime within economically feasible limits with minimum consumption of thermal energy.

It is known that the growth of the population, respectively, will cause an increase in the consumption of thermal energy throughout the world, the consequence of which is an increase in harmful emissions into the atmosphere, since, until 2040, fossil fuels will be used up to 77 % according to US Energy Information Administration [96]. The pace of transition to alternative renewable energy sources is not very high.

It is known that a significant share of the produced thermal energy is spent on the needs of engineering systems of buildings and structures. According to our calculations, this share is about 50 % of all energy produced. The result corresponds to the European Union data [97]. This share must be reduced not by reducing the living standard of the people in these buildings, but, on the contrary, by increasing the comfort level not by increasing, but by rising the efficiency of thermal energy consumption.

Conclusions. Summarizing the above, it can conclude that to improve the energy efficiency of modern buildings, it is necessary to perform the following priority tasks:

- optimal placement of the building on the general plan of the city, incl. maintaining the distance between buildings under the construction and urban-planning regulations;
- proper heat insulation of the building envelope by the orientation of facades and

depending on the climatic parameters of the outside air;
- air-tightening of building avoiding in- and exfiltration;
- maximum possible automation of engineering systems up to integration from smart house to smart city level;
- modernization and optimization of the operation of engineering systems;
- maximum use of renewable and secondary (such as exhaust air) energy sources;
- rejection of the classical calculation method of heat loss estimation, which takes into account the effect of wind speed, and to develop a new methodology.

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Проблеми енергоефективності в будівлях: аналіз світового досвіду

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Анотація. На даний час обсяг світового енергоспоживання безперервно і стрімко зростає внаслідок процесу індустріалізації, зростання чисельності населення, підвищення енергетичних витрат на видобуток природних ресурсів тощо. Як наслідок, наявні запаси нафти та газу в усьому світі швидко виснажуються. Прогнозовані запаси нафти і газу у світі невеликі, і зростання їх прямого спалювання в майбутньому буде обмеженим через забруднення довкілля викидами газів і золи при їхньому спалюванні. Тому важливість вирішення проблеми енергоефективності має першочергове значення для сучасної цивілізації. У роботі проведено аналіз світового досвіду енергоефективного будівництва. Висвітлено основні напрямки енергоефективного розвитку. Показано, що класична методика розрахунку тепловтрат неправильно враховує дію вітру. Потрібна більш правильна методика виконання цього розрахунку. При цьому варто застосовувати лінгвістичні змінні та нечітку логіку, яка адекватно описує стани, які описуються вербальними висловлюваннями, а не числовими значеннями. На завершення виділено найбільш актуальні для нашої Республіки завдання: оптимальне розміщення забудови на генеральному плані міста, зокрема, дотримання відстані між будівлями за будівельними й містобудівними нормами; правильна теплоізоляція огороджувальних конструкцій за орієнтацією фасадів і залежно від кліматичних параметрів зовнішнього повітря; герметичність будівлі, що запобігає ін- та ексфільтрації; максимально можлива автоматизація інженерних систем до інтеграції від рівня розумного будинку до рівня розумного міста; модернізація та оптимізація роботи інженерних систем; максимальне використання відновлюваних і вторинних (наприклад, витяжного повітря) джерел енергії; відмова від класичного розрахункового методу оцінювання тепловтрат, що враховує вплив швидкості вітру, та розроблення нового методу.

Ключові слова: енергоефективність, огороджувальні конструкції, опалення, вентиляція, кондиціонування повітря, енергопотреба.

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