

# Energy efficiency and environmental friendliness, as important principles of sustainability for multifunctional complexes

## Los principios de eficiencia energética y respeto al medio ambiente para complejos multifuncionales

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Fecha de Recepción: 20/08/2020  
Fecha de Aceptación: 22/10/2020  
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### Abstract

*Originality/value: Energy efficiency and environmental friendliness, as important principles of sustainability for multifunctional complexes, are here considered in the context of the international experience, enabling an identification of the main aspects that are applicable when designing such buildings in Ukraine. Purpose: The purpose of this article is to study the principles of improving energy efficiency and environmental friendliness of multifunctional complexes in Ukraine and thereby enrich the national experience in designing sustainable architecture. Results: On the basis of the study, scientific principles and recommendations are developed that contribute to improving the energy efficiency and environmental friendliness of such complexes. Conclusion: It is concluded that the use of alternative energy sources can cover at least 15-20% of the total energy consumption, and by optimizing the plan it is possible to increase the energy efficiency of a building by up to 14%.*

*Keywords: Sustainability in architecture, energy efficiency, environmental friendliness, multifunctional complex, plan optimization*

### Resumen

*Originalidad/valor: La eficiencia energética y el respeto al medio ambiente, en su calidad de principios importantes de sostenibilidad para complejos multifuncionales, se revisan en el contexto de la experiencia internacional, permitiendo identificar los principales aspectos aplicables en el diseño de ese tipo de edificios en Ucrania. Propósito: El propósito de este artículo consiste en estudiar los principios para mejorar los complejos multifuncionales en Ucrania en cuanto a eficiencia energética y respeto al medio ambiente y, por tanto, enriquecer la experiencia nacional en el diseño arquitectónico sostenible. Resultados: En base al estudio, se desarrollan principios científicos y recomendaciones que contribuyen a mejorar la eficiencia energética y el respeto al medio ambiente por parte de dichos complejos. Conclusión: Se concluye que el uso de energías alternativas puede cubrir al menos un 15-20% del consumo total de energía y que – con optimizaciones – es posible aumentar la eficiencia energética de un edificio en hasta un 14%.*

*Palabras clave: Sostenibilidad en arquitectura, eficiencia energética, respeto al medio ambiente, complejo multifuncional, optimización de planes*

## 1. Introduction

*According to the Sustainable Development Goals formulated by the United Nations (UN), in 2019, the development of sustainable energy and infrastructure is one of the priority areas in the implementation of the principles of sustainable development. One of the targets in achieving Goal 11 “Sustainable Cities and Human Settlements” is reducing the negative environmental impact of cities by 2030, while Goal 7 “Inexpensive and Clean Energy” can be achieved, inter alia, by doubling the global energy efficiency indicators by 2030. Energy is the basis of modern society (Amasyali and El-Gohary, 2018); therefore, measures aimed at achieving these Sustainable Development Goals should cover various areas of activity, including the architectural design of buildings as these, when designed in accordance with the principles of energy efficiency and environmental friendliness, can contribute to sustainable urban development and reduce the environmental impact.*

*At the same time, according to studies published by the transnational oil and gas company BP in the annual review of global energy trends for 2019, one of the main challenges of global energy is the growth of energy consumption. Meanwhile, the number of buildings and complex worldwide that have a negative impact on the environment is increasing (Krarti, 2018), while the global demand for energy –with commercial and residential buildings taking third place in terms of energy consumption (Proskuryakova, 2017) – will increase by a third by 2040 (BP, 2019), which can lead to environmental degradation on a global scale. In this regard, architects from different countries, including the USA, the UK, Germany, and Russia, are developing principles for the*

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sustainability of buildings and structures, whereby prominence is given to studying the possibility of using alternative energy sources to reduce energy consumption and increase the energy efficiency of buildings while exploring methods to reduce the negative impact of architectural objects on the environment.

Over the years, scientists such as (Tabunshchikov, 1998), (Desideri, 2018), (Karti, 2017), (Shukla, 2018), (Troj, 2014), (Gracia and Cabeza, 2015) as well as (Chel and Kaushik, 2018) contributed to the study of the principles of improving the energy efficiency of buildings. In 2017, Karti, an employee of the University of Colorado in the field of Energy-Efficient Electrical Systems for Buildings, published a general overview of the main energy systems of buildings and proposed a systematic and practical approach to the analysis and design of energy-efficient buildings, emphasising that special attention should be paid to the analysis of operating costs. In the monograph "Advanced Energy Efficient Building Envelope Systems", published in the same year, Karti presented the latest developments of innovative building envelope systems that respond to changes in environmental conditions, providing comfortable conditions inside the building. Karti also underlined the importance of the choice of materials for building envelopes according to their thermal characteristics, which have a direct impact on the degree of energy efficiency of buildings. In the book "Optimal Design and Retrofit of Energy Efficient Buildings, Communities, and Urban Centers", published a year later, the researcher presented an overview of the modern methods and technologies aimed at improving the energy efficiency of buildings, whereby an important role is given to the choice of insulation materials and the use of LED lighting and daylight controls. Iso, Karti highlighted the importance of the desire to design buildings with zero and positive energy, that is, buildings that generate energy from renewable sources and consume it in equal or lesser amounts, respectively (Karti, 2018). Meanwhile, Desideri, a professor at the University of Pisa, and Azdrubali, a professor at the Third University of Rome, in their "Handbook of Energy Efficiency in Buildings" published in 2018, examined issues related to assessing the life cycle of buildings with zero energy consumption, from construction to operation. However, it is important to note that to date (the research date is December 2019), not a single multifunctional complex with zero or tending to zero energy has been built in international practice. Researchers at Shukla and Sharma as well as at the Rajiv Gandhi Institute of Petroleum Technology investigated how to use passive heating and cooling in buildings in their 2018 book titled "Sustainability through Energy-Efficient Buildings". With such a heating system, the heat necessary for heating buildings is generated by non-traditional sources, such as the heat generated by users of the building, whereby warm air is later captured by the ventilation system and transferred to heat the fluid in the heating system. Ecology and architecture were addressed by (Bauer, 2007), (Wines, 2000), (Schmidt, 2016), (Ghosh, 2015), as well as the abovementioned (Karti, 2018). Bauer, Mosle, and Schwartz, authors of the book "Green building. Konzepte für nachhaltige Architektur", claim that the worldwide construction sector consumes up to 40% of primary energy (Bauer et al., 2007) and therefore call upon architects to adopt a responsible attitude towards nature. They also describe methods of transition to an environmentally friendly energy supply and a reduction of energy and water consumption without lowering the comfort level of architectural objects. The authors use the concept of green buildings, that is, buildings that combine a high level of comfort with the minimal consumption of resources, which positively affects the environment. Continuing the study of the principles of green architecture, Wines put forward the concept of "environmentally friendly architecture", which is an architecture that focuses not only on the application of energy-efficient technological solutions but also "tries to reconcile man and nature" by reducing the environmental impact of the construction and functioning of buildings (Wines, 2000). Schmidt, in his book "Green Building and Energy Efficiency", also investigated the relationship between energy efficiency and environmental friendliness, describing an important aspect that should be considered when designing green buildings, namely the use of renewable energy sources (Sterling et al., 1983). Almost 30 years after this, Ghosh (Dhaka) and Dhaka (Dhaka) contributed to the study of green energy, exploring how alternative energy sources can be realised by processing urban, municipal and industrial waste (Ghosh and Dhaka, 2015).

In addition, the research of Marcus and Morris aimed at reducing energy consumption by reducing heat loss through building envelopes, which can be achieved by increasing the compactness of the building (Markus and Morris, 1985). Page also conducted research on this topic, and in his scientific works, he calculated the ideal floor height to minimize heat loss and balance the consumption of resources needed to maintain the building.

In Ukraine, the issues of energy efficiency and the environmental friendliness of buildings have only recently begun to be studied but have already gained interest from the scientific community. This is evidenced by the presence of a large number of dissertation works aimed at architectural and engineering solutions that affect the increase in energy efficiency, thereby reducing the energy consumption of buildings and their impact on the ecology of cities. Hereby, Dymo (2007), (Kanygin, 2010), (Nemirovsky and Ovsyannikova, 2009), (Sergeychuk, 2008), and others have contributed to the study of these issues. Sergeychuk's thesis titled "Geometric Modelling of Physical Processes while Optimizing the Shape of Energy-Efficient Buildings" was aimed at studying the principles of optimizing the shape of buildings to help increase their energy performance as well as develop theoretical foundations for the geometric modelling of physical processes in the heat-insulating shell of buildings and the



*internal environment. The scientific contribution of this work lies in explaining the laws between the shape of the building and the distribution of insulation in the building envelope, which allows the shape of the building to be optimised, thereby reducing heat loss and, accordingly, reducing energy consumption. In the dissertation by Kanygin, "The Economics of the Development of Alternative Energy Sources (on the Example of the European Union)" (Kanygin, 2010), the place and role of alternative (renewable) energy sources in the modern fuel and energy complex were identified based on the example of European Union countries. The study also examined the prospects and boundaries of the development of alternative energy as well as the degree of influence of renewable energy sources on the general energy supply and energy efficiency. Another dissertation on energy efficiency was written by Beregov, as a result of which, architectural and construction principles were developed to minimize heat loss while the principles for creating comfortable conditions in the premises of designed and operated buildings in the central regions of Russia were formed (Beregovoi, 2005). The assumption is made that, based on the similarity of the climatic parameters of the central regions of Russia and Ukraine, the results of this research work may also be applicable in the context of Ukrainian cities.*

*In general, all of the above scientific works in the field of energy conservation, written by specialists in technical and architectural specialties, were aimed at developing measures to save energy and reduce the negative impact of architectural objects on the environment, forming a broad technical base laid down both in the context of Ukraine and on the international level. Meanwhile, the theoretical aspects of the design of energy-efficient and environmentally friendly multifunctional complexes, as well as the principles of the interactions between spatial solutions and energy-saving technologies, are still poorly understood in Ukraine. In this regard, multifunctional complexes, already built in accordance with these principles, should be studied in practice to analyse the realized buildings from the point of view of architectural-planning and engineering-technological solutions. Despite the fact that in Ukraine, in recent years, new engineering, constructive and architectural-planning solutions have also been developed that are aimed at optimizing the energy and environmental performance of buildings, it is necessary to analyse sustainable solutions used in international practice, which will help accelerate their adaptation at the national level and determine which solutions may be applicable in the context of Ukrainian cities.*

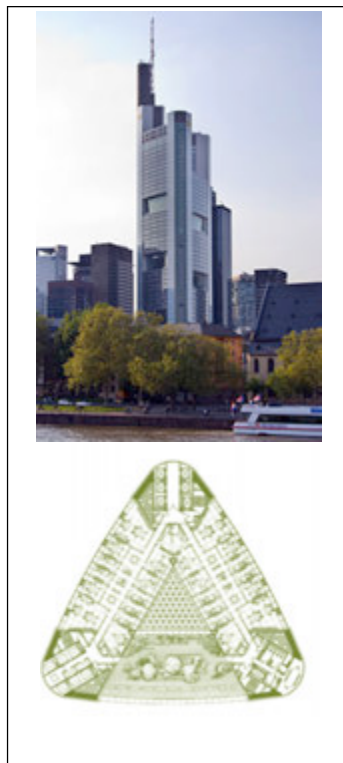
## **2. Methods**

*The object of this study is multifunctional complexes. As these are large agglomerates in cities and combine commercial and residential functions, they have significant indicators of energy consumption. In this regard, this study is aimed at exploring the international experience in designing sustainable multifunctional complexes, highlighting the main design principles aimed at achieving energy efficiency and environmental friendliness. Using a full-scale analysis, the study examined the complexes 30 St. Mary AXE see (Figure 1), Commerzbank Tower (Figure 2), Khan-Shatyr (Figure 3), Palais de Justice (Figure 4), Condé Nast Building (Figure 5) and Federation Tower (Figure 6) located, respectively, in London, Frankfurt, Nur-Sultan (Astana), Paris, New York and Moscow. We studied the planning in terms of the building forms chosen by the architects of these complexes as well as the engineering and technological solutions that were used in the design of building envelopes, facades, ventilation systems, etc. to improve the energy efficiency and environmental friendliness of these buildings.*

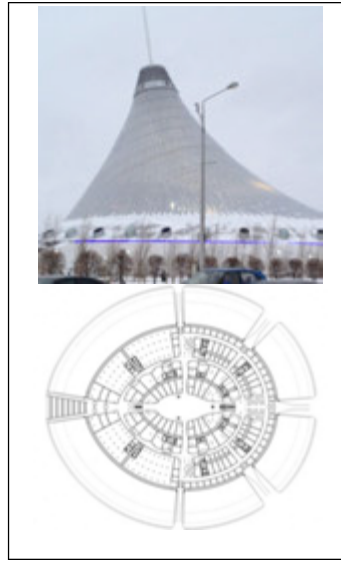




**Figure 1.** 30 St. Mary AXE, London, UK; top: photograph; below: plan



**Figure 2.** Commerzbank Tower, Frankfurt, Germany; top: photograph; below: plan

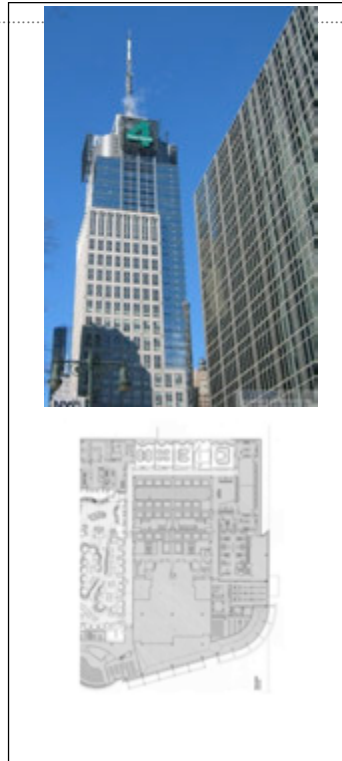


**Figure 3.** Khan-Shatyr, Nur-Sultan (Astana), Kazakhstan; top: photograph; below: plan

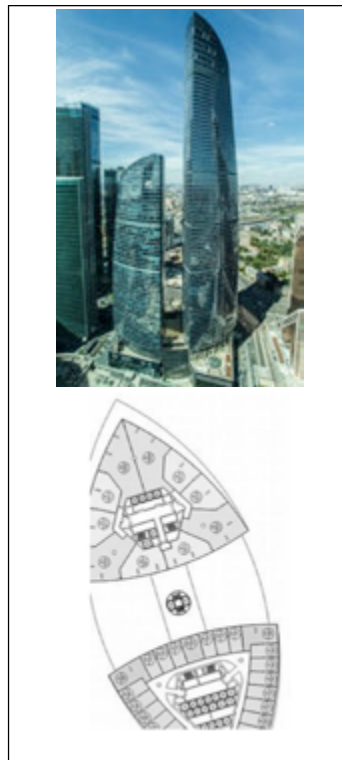


**Figure 4.** Palais de Justice, Paris, France; top: photograph; below: plan

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**Figure 5.** Condé Nast Building, New York, USA; top: photograph; below: plan



**Figure 6.** Federation Tower, Skyscraper Complex, Moscow, Russia; top: photograph; below: plan



A significant contribution to the development of energy-efficient architecture was made by British architect Norman Foster. Among other buildings, he designed 30 St. Mary AXE in London and the Commerzbank Tower in Frankfurt, whereby he actively used natural light and ventilation, which contributed to significant energy savings. Meanwhile, for the Khan-Shatry shopping and entertainment centre in Nur-Sultan (Astana), the architect used energy-efficient materials in the enclosing structures with thermo-technical characteristics to prevent heat loss. In addition, the use of landscaping inside the building, which is a heat-insulated dome, allows the centre to create its own microclimate. The issues of energy efficiency and environmental friendliness were also the focus of Italian architect Renzo Piano when designing the Palais de Justice court complex in Paris, where he designed a full glass facade for the building to provide a high level of natural lighting and ventilation and there by save energy. Furthermore, in the Condé Nast Building, which is an office building, American architects Robert Fox and Bruce Fowle used solar panels as sources of electricity. Meanwhile, in the multifunctional Federation Tower complex, which consists of two skyscrapers located in the city of Moscow, Russia, energy-efficient enclosing translucent structures comprising double-glazed windows were installed, allowing the optimum temperature to be maintained in the building. In the summer, the glass prevents the air inside from overheating, and in winter it reduces the outflow of heat to the outside, thereby maintaining the microclimate of the apartment or office. In general, almost all existing energy-efficient technologies are employed in these skyscrapers, including heat recovery systems, whereby the exhaust air is used to heat fresh air entering the building from the street.

In terms of architectural solutions, it is important to note that all of the above buildings, despite the complexity of the applied engineering and technological solutions aimed at improving indicators of energy efficiency and environmental friendliness, have a fairly simple form, both in plan and in height. As a result of the field analysis, it was concluded that the configuration of the plans tends towards simple geometric shapes, e.g., a circle, a triangle, a square and a rectangle, that is, shapes that best retain heat (Borodach, 1990). The plan of each of the six buildings is built around a central multi-luminous space, which performs the function of a natural ventilation duct, allowing warm air to circulate throughout the entire building. The building envelopes of the 30 St. Mary AXE, Commerzbank Tower, Khan-Shatyr and Conde Nast Building buildings have practically no acute angles in plan, which also reduces heat loss during the operation of the building. It is also noteworthy that the facades of all the studied complexes have a predominance of translucent structures, which increases the illumination of rooms through natural light, reducing the amount of time artificial light sources need to be used, thereby also reducing energy consumption during the operation of buildings.

It has been suggested that the shapes that best retain heat can achieve significant energy savings, which is why the energy efficiency of buildings with round, square, rectangular and triangular shapes was calculated. The calculation method is presented below.

The total heat loss of the building through the external building structure,  $Q_h$ , measured in MDzh, is determined by the formula:  $Q_h = 0,0864 * K_m * D_d * A_{1sum}$ , where  $K_m$  is the general heat transfer coefficient of the building;  $D_d$  is the degree-day of the heating period; and  $A_{1sum}$  is the total area of the external walling.  $A_{1sum}$  has the greatest effect on  $Q_h$ ; therefore, the smaller the total area of the outer walling, the less the heat loss. Based on the foregoing, we introduce a coefficient through which we can compare and evaluate buildings or choose their optimal dimensions depending on energy efficiency:  $E = S_{usable} / S_{walling}$ , where  $E$  is the energy efficiency of the building and this parameter is of the greatest interest for this study;  $S_{usable}$  is the usable area of the building; and  $S_{walling}$  is the area of walling. We transform this formula for various configurations of buildings in terms of:

1. Floor plan tends to a circle

$$E = S_{usable} / S_{walling} = \pi r^2 / (2\pi r h + 2\pi r^2) = 0,5r / h + r, \text{ where } r \text{ is the circle radius; } h \text{ is the floor height.}$$

2. Floor plan tends to a square

$$E = S_{usable} / S_{walling} = \pi r^2 / (4ah + 2a^2) = 0,5a / h + r, \text{ where } a \text{ is the side of the square; } h \text{ is the floor height.}$$

3. Floor plan tends to a rectangle

$$E = S_{usable} / S_{walling} = ab / (2h(a+b) + 2ab) = 0,5ab / (a+b) * h + ab, \text{ where } a \text{ and } b \text{ as the width and length of the rectangle, respectively; } h \text{ is the floor height.}$$

4. Floor plan tends to a triangle

$$E = S_{usable} / S_{walling} = (a^2/2) / (1.41ah + 2ah + a^2) = a / (6.82h + a), \text{ where } a \text{ is the leg of an isosceles right triangle equal to half the square; } h \text{ is the floor height.}$$



Regarding the principles of designing energy-efficient and environmentally friendly buildings, which have been studied in detail in theory and in practice, it should be noted that these principles are practically not applied in Ukraine at the moment, which is proved by the fact that the energy consumption of most buildings in Ukraine is on average 2-3 times higher than in Europe (Zubko, 2019). Today, the question of the influence of the building shape on energy efficiency, including the interactions of the forms and modern technologies aimed at increasing energy efficiency, such as the use of renewable energy in architecture, has been little studied in the scientific field and design practice. In addition, the issue of designing and building energy-efficient and environmentally friendly multifunctional buildings is not given enough attention at the national level, and there are practically no implemented examples of such objects. In this regard, using the experimental design method, in this study the model of an energy-efficient and environmentally friendly multifunctional complex is created with the aim of further developing proposals to reduce the negative impact of these buildings on the environment. In addition, in international practice, architectural and technological measures to ensure the sustainability of buildings are in most cases aimed at the application of engineering solutions and less often at architectural ones. Hence, this article also aims to develop scientific principles and recommendations regarding the determination of an optimal shape for building plans and their configurations based on the example of designing an energy-efficient and environmentally friendly multifunctional complex in Kiev. The design solution incorporates the idea of combining traditional and alternative energy sources (e.g. solar panels), which arose due to the overload of utilities in the region; therefore, this study presents design proposals for the maximum use of solar energy while taking into account the insolation regime of the island and examining the influence of shape-related energy performance indicators.

*The complex, the concept of which was proposed during the experimental design, is located on Rybalsky Island in Kiev, Ukraine, and combines functions distributed across blocks "A", "B", "C" and "G" (Figure 7), as listed below:*

*- Residential function: two 42-story towers with hotel-type apartments, blocks "B" and "C" (Figure 8), with a height of 167 m. These blocks have a plan in the form of a triangle with rounded corners.*

*- Public function:*

*- Shopping, cultural, entertainment and business centre with an increased number of storeys; block "G" (Figure 9) consists of trade and service areas (shops, boutiques and other trade enterprises). Block "G", like the aforementioned blocks "B" and "C", has the shape of a triangle with bevelled corners.*

*- Catering areas.*

*- Entertainment areas (e.g. bowling halls, billiard rooms).*

*- Cultural areas, including entertainment and club zones (with exhibition and exhibition halls, a cinema, a concert hall and club premises).*

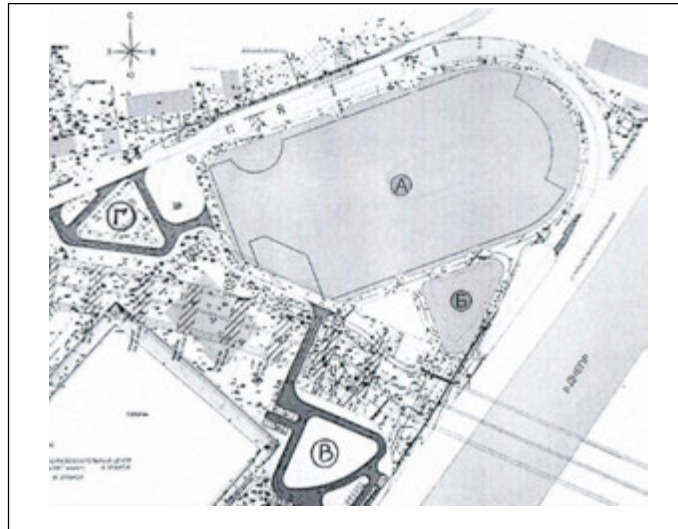
*- Office area.*

*- Auxiliary zones.*

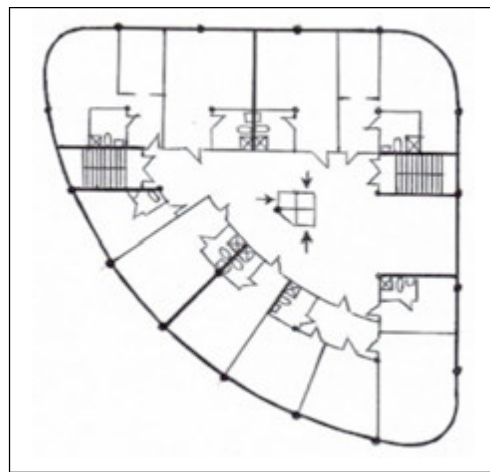
*- The technical function is a multi-tier ground parking lot with space for 7,500 cars and additional service and recreational functions; this is block "A" (Figure 10), which has an oval shape.*



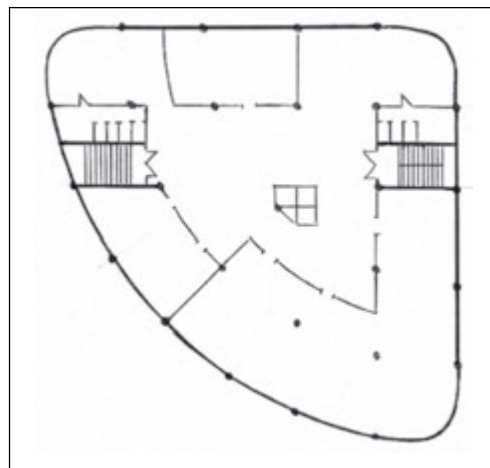




**Figure 7.** Space-planning scheme of a multifunctional complex on Rybalsky Island, Kiev

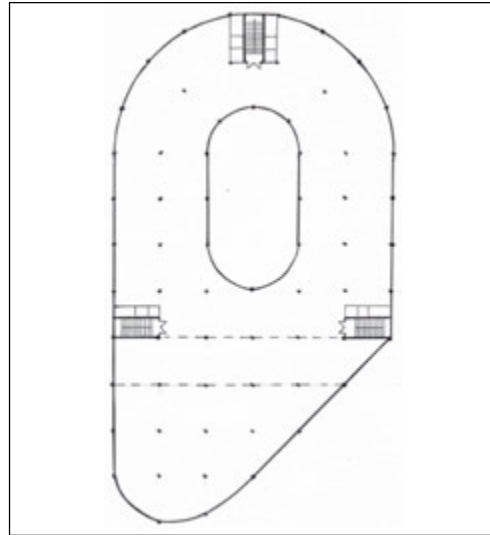


**Figure 8.** Blocks "B" and "C": hotel type apartments



**Figure 9.** Block "G": shopping, cultural, entertainment and business block





**Figure 10.** Block "A":ground multi-tier parking with additional service and recreational functions

*In this complex, the following technological principles have been laid down that ensure energy efficiency:*

- *Use of natural insolation and ventilation. The design of the high-rise blocks allows the use of natural ventilation in the rooms during the warm season, which will reduce the energy costs for air conditioning.*
- *Use of natural lighting. A high level of natural lighting is achieved through the transparency of the block's facades.*
- *Use of renewable independent clean energy sources such as solar panels and photovoltaic panels. The batteries can consist of several modules, while the power generated by each element directly depends on its area, position relative to the sun, and radiation intensity. Blocks "B", "C" and "G" are designed to use a partial passive solar power supply, with solar panels installed on the roofs of these buildings with an inclination angle of 30 ° and oriented to the south. Photovoltaic panels with a total area of 6,000 m<sup>2</sup> are also provided on the southern and western facades of the towers, glued to tempered glass and integrated into the facades of the towers in the form of strips 100-150 cm wide.*
- *Use of effective enclosing and building materials and facade systems. A three-layer polymer coating is recommended as this is an energy-efficient material that transmits sunlight well and protects the interior from sudden temperature changes.*
- *Use of new technologies for the automation of control, ("intelligent" control systems) to ensure the optimal mode of operation of ventilation, heating, and cooling systems. Thus, all the mechanical systems of the complex's windows are controlled by an "intelligent" system, ensuring the optimal operation of the ventilation, heating and cooling systems. For example, in adverse weather conditions, the windows automatically close and the mechanical ventilation and heating system are on; in sunny and warm weather, in contrast, the windows open automatically.*
- *Use of rational, compact, energy-saving, space-planning solutions through the optimization of parameters and architectural forms of the complex blocks.*
- *Use of rainwater and wastewater treatment systems in the basements of the blocks, reducing water consumption from the central water supply system by 20-30%. Purified wate can be use for the irrigation of winter gardens, whereby the principle of organization is described below.*



**Figure 11.** The greening of the roof of block "A" and the arrangement of winter gardens in the high-rise blocks "B", "C" and "G" of the multifunctional complex on Rybalsky Island, Kiev

*The principles of environmental friendliness are given special attention in this project, aiming to:*

- *Ensure the visual and functional relationship of the complex with nature, which is especially relevant in the context of growing urbanization and is achieved through the creation of gardens inside buildings. Hence, according to the design decision, the multifunctional complex on Rybalsky Island is a complex ecosystem that independently generates and maintains a microclimate that protects against excessive solar radiation and noise while maintaining the optimal level of humidity in the internal environment. A substantial role in creating the microclimate is played by the winter gardens, which the design solution places in the middle of the high-rise blocks of the complex (Figure 11). Winter gardens should also be organized on the flat roof of a multi-tier car park (block "A"). Gardening plays an important role: it serves as a sunscreen, reduces the effect of the "heat dome" ("heat island"), helps to reduce heat loss, helps maintain the required air humidity, regulates the composition of the air, lowers the air temperature in the room in the summer (it has been experimentally proved that in rooms with green spaces, the air temperature is lower than in rooms where there is no natural landscaping, ceteris paribus), and helps to reduce heat loss in winter.*

- *Sort garbage. In the economic zone of the complex, containers are provided for separate utilization of household waste, which will help reduce air and environmental pollution during further disposal.*

### 3. Results

*The study of international experience in the design of energy-efficient and environmentally friendly buildings has allowed us to divide all measures to reduce energy consumption and improve the environmental sustainability of multifunctional complexes into two types, namely engineering and technological measures and architectural and planning proposals. It is important that these measures are applied together to achieve the best results. In developing this project, it was shown that the basic principles of energy efficiency and environmental friendliness applied in international practice when designing buildings with various functional purposes can also be applied to the design of multifunctional complexes in Ukraine. The identified main measures to improve energy efficiency are the use of natural insolation and ventilation; the reduction of energy consumption through the use of renewable energy sources; and the use of energy-saving materials and architectural forms, taking into account function and energy efficiency. However, it is important to note that the principles of sustainable design should be adapted to the country's context; for example, the predominance of translucent structures on the facade is a general recommendation, whereby the choice of the glazing type should be made depending on the climatic and environmental conditions of the city in which the complex is to be built. Furthermore, the level of natural light should be determined based on the orientation of the building and the region in which it is to be built. In addition, the use of solar panels and other converters of natural energy requires the availability of specialists in the country to service them. Meanwhile, to ensure circulation and water purification the installation of appropriate equipment is*

required, and for the efficient sorting of garbage, it is necessary to have initiatives at the city level to process waste on a larger scale.

In our opinion, when designing multifunctional complexes in Ukraine, more attention needs to be paid to minimizing the heat loss from buildings, improving the comfort of staying in the complex through functional and visual interconnections in the environment, creating a special microclimate, integrating natural elements into the building and maximizing the architectural potential of natural resources. Energy efficiency in architecture should be realised through the use of compact building forms and the active use of alternative energy sources (solar panels) throughout the building. In the case study, the rated capacity of each of the 42-story apartment towers is 3,000 kW. As already mentioned, renewable independent sources of clean energy are intended for the upper floors of these towers, with solar panels 1,600 x 100 x 35 mm in size. These absorb and convert sunlight into direct electric current, which is subsequently converted by an inverter into alternating current for supply to the building. The design solution includes the use of an ECO TECH photovoltaic system with a capacity of 65 kW. Thus, the installation at the upper level of 7-8 panels with a capacity of 65 kW each makes it possible to obtain 450 kW of "additional" energy. This allows us to conclude that the use of these energy sources can cover 15-20% of the total energy load of the complex, meaning that the use of solar energy will significantly reduce the centralized electricity consumption from urban networks. However, it is important to note that the full solar power supply of the complex was not considered since the area of insulated surfaces is small compared to the total volume of the complex.

During the design, significant scientific research was carried out regarding the optimization of the parameters and architectural forms of the complex. In addition, experimental modelling was carried out under laboratory conditions at the Kiev National University of Construction and Architecture as well as at a public organization, Academy of Construction of Ukraine (Research Institute of Building Structures), by testing the reduced complex models and comparing the obtained indicators of from a thermal imager (Pulsar Quantum Lite 30) as well as the indicators obtained from an aerodynamic pipe. The heat loss of rooms and buildings measured using a thermal imager showed the heat loss dynamics, helping to determine their causes in different parts of the buildings, which was leased from the company Modern Business Security Systems SSBB, Ukraine, Kiev. The measurement results showed that 25% of the total amount of heat loss occurred through the walls, that is, through the enclosing structures, which made it possible to choose the optimal form of plans for the blocks of the complex. The relevant calculations of energy efficiency (E), according to the formulas presented in the methods section, are presented in (Table 1).

**Table 1.** The relationship of the shape of the building in plan and its energy efficiency, E

Plan form	$S_{usable}$ m <sup>2</sup>	Dimensions of the plan, m	h, m	$S_{walling}$ m <sup>2</sup>	E
Rectangle	100.	a=5, b=20	3.	350.	0.29
Square	100.	a=10	3.	320.	0.31
Circle	100.	r=5.64m	3.	306.26	0.33
Triangle	98.	a=14	3.	339.22	0.29

Based on these calculations, it was concluded that the use of compact layout schemes, such as a square and a circle, increases the energy efficiency of a building by 7% and 14%, respectively, compared with rectangular buildings. A building triangular in plan has the same E indicator as a rectangle, but this shape makes it possible to reduce the building envelope area, through which a significant amount of heat loss occurs. Given this fact, the design solution uses blocks with a small perimeter of the walls, whereby block "A" in the plan has the shape of a triangle adjacent to a square. Blocks "B", "C" and "G" in the plan have a triangular shape, which allows them to be entered into the master plan of the complex while enhancing energy efficiency. In the central part, there are elevator shafts and atriums that pass along the entire height of the towers; these, in addition to aesthetic functions, perform the function of natural ventilation ducts. In blocks "B" and "C", a lobby space is provided, including recreational areas with panoramic windows of the coastal scenery, which visually connects the interior of the complex with the environment, providing visual comfort and thereby reducing visual architecture of the city.

It is important to note that the best indicator of the difference between the calculated value of the specific heat loss and the maximum permissible value in the design solution was given by a triangular plan for the towers



and an oval plan for the ground parking area of block "A". Thus, a comparative assessment allows us to choose the most acceptable form of the building with optimal dimensions and characteristics to produce the least heat loss.

## 4. Discussion

In this study, proposals were made to optimize a building plan, thereby enabling the energy efficiency of the building to be increased by 14%. It should be noted that the studies of T.A. Markus and E.N. Morris (Markus & Morris, 1985) were already carried out in the direction of increasing the compactness of the building volume in order to reduce heat loss and, consequently, energy consumption; this aspect was also considered by D. Page (Page, 1974). Meanwhile, researchers such as A. De Gracia and A. Cabeza (De Gracia and Cabeza, 2015) considered the issues related to reducing the energy consumption of buildings through the optimization of building envelopes. In accordance with this, in this article it was shown that plan optimization may also be appropriate when designing buildings in Ukraine, facilitating significant savings in energy consumption. Optimization of the plan and building envelope, which can be applied in the climatic conditions of Ukraine, will undoubtedly allow higher energy efficiency indicators to be achieved, which, combined with engineering and technological solutions to ensure energy efficiency and environmental friendliness, will enable a significant reduction in energy consumption.

It was proved that the use of alternative energy sources can compensate for at least 15-20% of the total energy load on the complex. Research on the use of alternative energy sources has already been undertaken by (Chel and Kaushik, 2018), (Krtati, 2017), (Kashchenko, 2001), whereby it was shown that the use of these sources is possible in the context of Ukraine. However, it is important to note that the full solar power supply of the complex was not considered; this could be the next stage of research, based on the study of the international experience.

## 5. Conclusion

Based on the study exploring the scientific principles of energy-efficient and environmentally friendly design, a concept was proposed to increase the energy efficiency of a multifunctional complex. Recommendations are also formulated regarding the consistent use of various measures and methods in relation to the architecture of energy-efficient and environmentally friendly multi-functional buildings and complexes.

The scientific contribution lies in the proposed concept of improving the energy efficiency of buildings by optimizing the main characteristics of their forms, using alternative energy sources, such as solar panels, employing energy-saving technologies at the design stage, and using scientific principles of energy efficiency. Applying the principles presented in the article in design practice will reduce centralized energy consumption, thereby increasing energy efficiency, environmental friendliness and the comfort of the designed buildings. It will also make their further operation more economical, which confirms the hypothesis of this article in terms of the need for design under modern conditions in order to increase the comfort of visitors staying in the architectural object and to reduce its negative impact on the environment, guided by the principles of energy efficiency and environmental friendliness.

The methods for the architectural design of multifunctional energy-efficient buildings and complexes consist of the selection of architectural and planning parameters that will provide the lowest energy loss rate. As a result of the study, the optimal forms for multifunctional buildings were determined in the context of the influence of these forms and of the parameters of the building as well as the impact of engineering decisions on energy efficiency.

## 6. Acknowledgments

The study was carried out in the context of research plans of the Department of Architectural Design of Civil Buildings and Structures, the Faculty of Architecture, Kiev National University of Civil Engineering and Architecture in Ukraine as well as the Academy of Civil Engineering and the Union of Architects of Ukraine. The research materials have been repeatedly reported at international scientific and practical conferences.

Special thanks are expressed to the staff of the Mosproject-2 Design Institute. M. V. Posokhina (Moscow, Russia) as well as St. Petersburg State University of Architecture and Civil Engineering (St. Petersburg, Russia) for the design and technical support in the preparation of this study.



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