

ОСНОВИ ПРИРОДОКОРИСТУВАННЯ NATURAL RESOURCES

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PROSPECTS OF DESIGNING SMALL ARCHITECTURAL FORMS USING ALTERNATIVE ENERGY SOURCES

Abstract. *The energy efficiency of the transport system is one of the key issues in the concept of sustainable development of modern cities. Increasing energy efficiency in the transport sector implies increasing the efficiency of the entire transport sector: from modernizing vehicles to introducing energy-efficient comfortable stops for public transport into the city system. One of the problems of modern architecture of large cities is the creation of a unified architecture of small architectural forms (SAF), namely, stops of urban public transport. They should not only have a modern design, but also be comfortable, functional, safe and energy efficient. In the article, the authors propose a unified urban archetype for an energy-efficient public transport stop for the city of Kyiv. Energy efficiency is achieved by installing solar panels on the roofs of the SAF. During the placement of the bus stop, it is imperative to take into account the shading from nearest buildings located on the south, south-east and south-west sides. Depending on the orientation of the roof of the stop to the cardinal points and the type of solar panels, it can generate about 2030 kW·h/year (west orientation) – 2269.9 kW·h/year (south orientation) of electricity. The maximum deviation from the averaged equal-percentage value (2143.16 kW·h/year) related to the actual data between the maximum and minimum of generation is only 5.55%. This is explained by the angle of photovoltaic panels, which is optimized for universal use. The proposed archetype is energy efficient, functional, and therefore can be taken as a basis for mass placement in the city.*

Key words: *public transport stop; energy efficiency; solar panels; archetype*

Introduction

Today, energy is the most important driving force of world economic progress. In the middle of the 20th century, energy consumption was growing in all countries of the world. If we look at the structural components of the world energy, we can see that most needs are provided by the use of minerals: coal, oil, natural gas, uranium. This leads to depletion of natural resources. Today environmentalists note that humanity requires 1.75 of planet Earth to provide all needs [1]. This means that people consume so quickly that the planet does not have time to replenish its resources. The UN report "Climate-neutral cities" [2] emphasizes the paramount role of urbocenoses in mitigating the problems associated with climate change. According to experts, 75% of global energy consumption and 80% of greenhouse gas emissions fall on cities [2]. The main contribution to the greenhouse effect is made by CO₂, which is an indicator of the ecological footprint of urbocenoses. The main contribution to the greenhouse effect is made by CO₂, which is an indicator of the ecological footprint of urbocenoses. Despite sharp fluctuations in the concentration of CO₂ in the Earth's atmosphere over the past geological period, the natural cycle of CO₂ over the past few millennia has not changed.

Anthropogenic activity disturbs this balance due to the release of CO₂ bound in such natural carbon storage as fossil fuels and green biomass. With the beginning of the industrial era in the XVIII century, the concentration of CO₂ in the atmosphere has increased by almost a third. As a result of these actions over the past century, there has been a global increase in average temperature, followed by global warming.

Reducing CO₂ emissions is the main mechanism for slowing down climate changes. In solving this problem, technologies with alternative energy sources are proposed.

In August 2018, the Government of Ukraine adopted the "Strategy for Low Carbon Development until 2050" [2], which provides a gradual reduction in fossil fuel use and the start of investment in renewable energy sources. Therefore, the search and implementation of energy efficient technologies is a priority task.

One method of the reduction CO₂ emissions is the use of solar radiation to generate electricity [3–7; 8–12; 13–14].

The energy efficiency of the transport system is one of the key problems in the concept of sustainable development of modern cities [15]. Increasing energy efficiency in the field of transport implies increasing the efficiency of the entire transport sector: from modernizing vehicles to introducing energy-efficient comfortable stops for public urban transport into the urban system [16–18].

Ukraine has developed the "Strategy for Sustainable Development of Ukraine until 2030". One of the operational purposes of the "Strategy" is to create a viable infrastructure, to promote inclusive energy efficient and innovative industrial development [19].

Within the framework of the "Strategy" in the city of Kyiv, the project of the solution of Kyiv "About the consolidated concept of the development of transport stops in the city of Kyiv" [20] was broken up. The project envisages the definition of archetypes of transport stops and the improvement of a single procedure for their placement, arrangement and maintenance. At the same time, city public transport stops should have a modern design; should be compact and functional; should be suitable for all age groups of passengers, taking into account people with disabilities; should be safe; environmentally friendly and energy efficient.

The idea of creating SAFs using solar panels is not new. For example, London was the first city in the world where TfL (Transport for London) in 2002–2005 tried bus stops with photovoltaic. Later this example was followed by cities in Canada and the USA [21]. Several autonomous stops have even been installed in Kyiv [21–23]. However, there has been no experience of mass construction of such stops.

Materials and Methods

The purpose of the work is to create a project of municipal transport stop using a renewable energy source (solar photoelectric modules with double glass).

Tasks:

- to calculate the amount of electricity required to provide a stop lightning during the year;
- to create a project of a stop for further mass installation in Kyiv.

Currently, there are more than 2,570 public transport stops in Kyiv. There are for about 1,190 equipped with waiting pavilions, 664 – with stop complexes [24]. Most of them are aesthetically and technically outdated.

It should be noticed that almost all existing stops consume electricity from the electricity grid for lighting at night and heating during winter period. According to the following formula, we calculate the amount of electricity required to illuminate one stop during the year:

$$W = N \cdot P \cdot \tau \cdot z, \quad (1)$$

where W – amount of electricity required to illuminate one stop during the year (kW/year); N – the number of luminaires at one stop (pcs.); P – the power of one luminaire (W); τ – the time during that the luminaire consume energy (hours); z – number of working days.

According to calculations, we have approximately 1051 kW/year for one stop (we take 8 lamps, the power of each of which is 36 kW, 8 hours of operation during 365 days).

According to formula (2) we find the amount of energy consumed by all stops in Kyiv during the year:

$$W_{general} = W + a, \quad (2)$$

where $W_{general}$ – the amount of electricity consumed by all stops during the year (kW/year); W – the amount of electricity consumed by one stop during the year (kW/year); a – the number of stops in the city of Kyiv (pcs.).

$$W_{general} = 1051 \cdot 2570 = 2701070 \text{ Kw/year}$$

For comparison, according to the method of electricity audit [25] it is established that an apartment of 100 m² will consume 10–15 kW of energy per day, which will be 3650–5475 kW per year. All the energy spent on lighting all the capital's bus stops could be provided from 500 to 700 apartments with an area of 100 m².

To solve the problem of energy consumption of existing stops, a project of the bus stop with photoelectric modules was developed.

To fully provide an illumination of a stop, the solar module must generate a certain amount of electricity. This number is not constant and depends on a number of factors:

- period of the year and number of sunny days;
- longitude and latitude of the area (in our case we take the city of Kyiv);
- shading from nearest buildings located on the south, southeast, southwest sides;
- location of the object relative to the north-south direction;
- number of luminaires and their power (calculations were performed for LED luminaires with a power of 36 W).

Kyiv is located at 50° 27' 16" north latitude and 30° 31' 25" east longitude.

The time of sunrise and sunset during the year for the city of Kyiv (Fig. 1) varies in such a way that the greatest duration falls on the summer period (16–18 hours per day), and the smallest – respectively on the winter (11–13 hours per day).

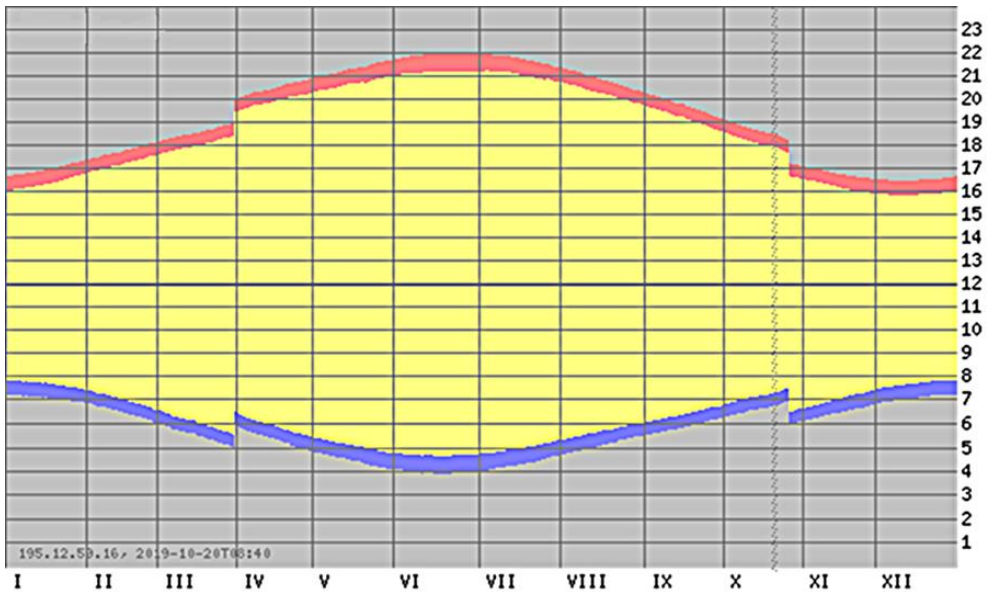


Figure 1 – Day and night duration schedule for Kyiv [26]

■ – day time; ■ – night time; ■ – sunrise; ■ – sunset

Data about the amount of sunlight that falls per unit area of the surface for the city of Kyiv (Table 1) is accepted according to the current norms in Ukraine [27]. We see that the largest amount of sunlight falls during the period from June to August, the smallest – from December to February. The largest amount of electricity will be produced in the period from May to September in the southern, southeastern and southwestern orientation of the roof (Table 2). Excess electricity can be collected for further use or for recharging gadgets and electric scooters (at the stop there is a parking space for bicycles and scooters).

Table 1 – Solar radiation gains on a horizontal surface, averaged by month

Month		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Days number <i>n</i>		31	28	31	30	31	30	31	31	30	31	30	31	
Solar radiation gains on a horizontal surface, averaged by month	Direct	MJ/(m ² ·mon)	25	46	100	170	285	300	300	265	170	80	23	15
		MJ/(m ² ·day)	0.81	1.64	3.23	5.67	9.19	10.0	9.68	8.55	5.67	2.58	0.77	0.48
		kW·h/(m ² ·day)	0.22	0.46	0.90	1.57	2.55	2.78	2.69	2.37	1.57	0.72	0.21	0.13
	Diffuse	MJ/(m ² ·mon)	60	96	170	215	280	290	288	230	168	110	58	44
		MJ/(m ² ·day)	1.94	3.43	5.48	7.17	9.03	9.67	9.29	7.42	5.60	3.55	1.93	1.42
		kW·h/(m ² ·day)	0.54	0.95	1.52	1.99	2.51	2.69	2.58	2.06	1.56	0.99	0.54	0.39
	Total	MJ/(m ² ·mon)	85	142	270	385	565	590	588	495	338	190	81	59
		MJ/(m ² ·day)	2.74	5.07	8.71	12.8	18.2	19.7	19.0	16.0	11.3	6.13	2.70	1.90
		kW·h/(m ² ·day)	0.76	1.41	2.42	3.56	5.06	5.46	5.27	4.44	3.13	1.70	0.75	0.53

Table 2 – Annual amount of produced energy at orientations that cause high effectiveness of energy production

Roof orientation	Produced electric energy, kW·h/year
West	2030,4
South West	2171,2
South	2269,6
South East	2266,2
East	2163,7

It is convenient to determine the amount of electricity produced by solar panels in specialized software.

This work uses the Power Calculator program, developed by IBC Solar [28]. It uses standard calculation techniques.

The program requires you to enter the location address of the object, length, width, angle and orientation of the roof. Another possibility is to draw the contours of the roof on the map with the task of the lowest edge and angle of inclination.

Results and Discussion

Civilization moves from consumer society to sustainable development. The first estimates a man by the amount of consumption, which leads to overconsumption of energy resources, excessive environmental pollution by carbon dioxide and other combustion products, heat, waste etc.

The sustainable development estimates by the amount of resource economy. This causes decrease of environmental pollution sometimes, to the detriment of economic effect. In this case, architecture should be not only aesthetical, but also pragmatic, energy-efficient, environment-friendly, and, if possible, combined with renewable energy generation.

Small architectural forms are especially perspective in this regard. There are too lot of them in modern cities. Municipal transport stops are especially important for people. Unlike the rest of SAFs, there is no possibility to avoid them. In many old cities, a lot of them are decrepit and need reconstruction. It is important to create an architype of functional and energy-efficient stops of municipal transport.

The authors have developed an archetype of autonomous municipal transport stop. The bus stop has an area of 20 m². There is a kiosk, a waiting area, an area for bicycles and scooters. The project also provides sockets for charging gadgets.

The stop has a v-shaped roof, each part of which is inclined at an angle of 15 degrees to the horizon (Fig. 2, 3). The autonomy of the stop is achieved by installing solar photovoltaic modules with double glazing and a battery pack for energy storage. It is also possible to install a specialized controller to control the charging process and energy consumption.

The amount of electricity that solar panels will produce depending on the orientation of the roof is given. According to calculations using the Power Calculator program, the largest amount of electricity will be generated in the period from May to September in the south (2269.6 kW·h/year), southeast (2266.26 kW·h/year) and southwest (2171.2 kW·h/year) roof orientation.

The averaged equal-percentage value related to the actual data between the maximum and minimum of generation (Table 2) is

$$2 \cdot 2030.4 \cdot 2269.6 / (2030.4 + 2269.6) = 2143.16 \text{ kW} \cdot \text{h} / \text{year}$$

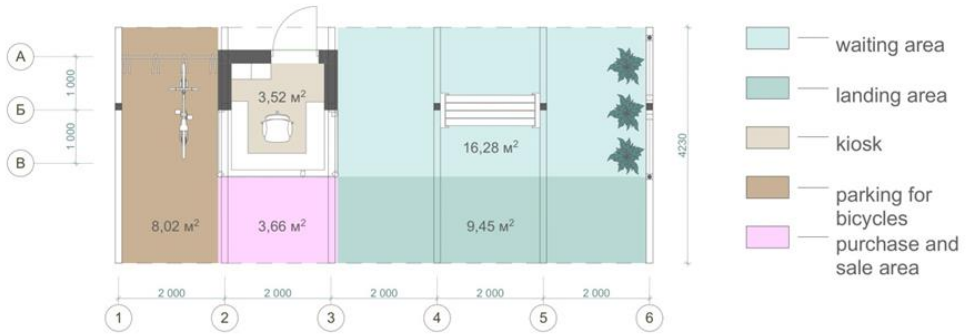
The maximum deviation is only 5.55%. This is explained by the angle of photovoltaic panels, which is optimized for universal use.

The archetype is recommended for wide introduction in modern cities and towns to rise energy efficiency and provide sustainable development of urbocenoses.

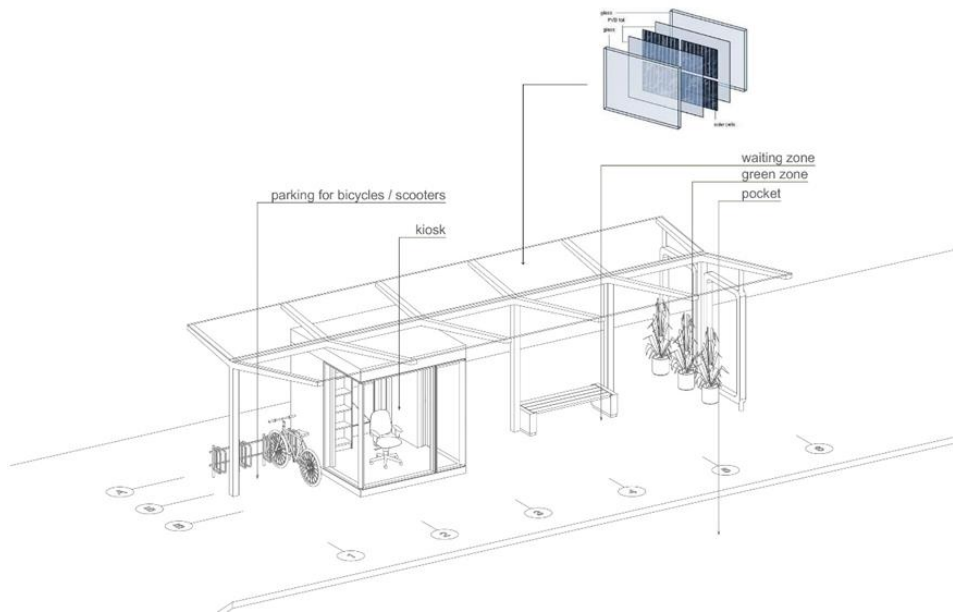
Conclusion

The completed stop project contributes to the sustainable development of cities, including the following benefits:

- aesthetic appeal due to modern design and new technologies;
- autonomy and energy independence (due to the installation of solar photovoltaic modules with double glazing and a battery pack for energy storage);
- environmental friendliness. Solar panels use alternative sources (sunlight) as a source of heat. Due to this, they are environmentally friendly and safe;
- security. The lighted stop in the evening is a safe place to wait for public transport, storage of bicycles and scooters;
- comfort. The project of stopping public transport with the use of alternative energy sources makes it possible to create more comfortable living conditions for people of different ages and different physical abilities at this facility;
- due to the listed advantages, the proposed project can be taken as a basis for creating a common architecture for public transport stops for the Kyiv city.



a



b

Figure 2 – drawings of the stop:
a – stop plan with location of functional areas;
b – general view of the stop
with functional areas and solar panels



a



b

Figure 3 – Visualization of the bus stop: a – autumn-winter period;
b – spring-summer period



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ПЕРСПЕКТИВНІСТЬ ПРОЕКТУВАННЯ МАЛИХ АРХІТЕКТУРНИХ ФОРМ
З ВИКОРИСТАННЯМ АЛЬТЕРНАТИВНИХ ДЖЕРЕЛ ЕНЕРГІЇ

Анотація. Енергоефективність транспортної системи є одним із ключових питань концепції сталого розвитку сучасних міст. Підвищення енергоефективності у транспортному секторі передбачає підвищення ефективності всього транспортного сектору: від модернізації транспортних засобів до впровадження енергоефективних комфортабельних зупинок для громадського транспорту в міську систему. Однією з проблем сучасної архітектури великих міст є створення єдиної архітектури малих архітектурних форм (МАФ), а саме, – зупинок міського громадського транспорту. Вони повинні мати не тільки сучасний дизайн, але й бути зручними, функціональними, безпечними та енергоефективними. У статті автори пропонують уніфікований міський архітип для енергоефективної зупинки громадського транспорту для міста Києва. Енергоефективність досягається встановленням сонячних панелей на дахах МАФ. Під час розміщення зупинки обов'язково враховувати затінення від найближчих будівель, розташованих на південній, південно-східній та південно-західній сторонах. Залежно від орієнтації даху зупинки на основні точки та типу сонячних панелей, вона може виробляти близько 2030 кВт·год/рік (орієнтація на захід) – 2269,9 кВт·год/рік (орієнтація на південь) електроенергії. Максимальне відхилення від усередненого рівнопроцентного значення (2143,16 кВт·год/рік), що стосується фактичних даних між

максимумом та мінімумом генерації, становить лише 5,55%. Це пояснюється кутом нахилу фотоелектричних панелей, який оптимізований для універсального використання. Запропонований архітип є енергоефективним, функціональним, а отже, його можна взяти за основу для масового розміщення в місті.

Ключові слова: зупинка громадського транспорту; енергоефективність; сонячні панелі; архітип

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