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ARTICLE

Bioelectricity production in an indoor plant-microbial biotechnological system with *Alisma plantago-aquatica*

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ABSTRACT The paper descibes the development of a biotechnological system for generating bioelectricity on closed balconies of buildings from living plants *Alisma plantago-aquatica* and soil microorganisms grown in containers with natural wetland substrate, provided with a graphite and Zn-galvanized steel electrode system. This biotechnology worked efficiently from the first days after installation and was practically at full capacity 2 weeks later. Electric power output was highest in the spring-summer and the early autumn period (at the time of the highest photosynthetic activity of plants). The highest current output was 58.6 mA at 10 Ω load. Bioelectricity generation by the biosystem was stable with slight fluctuations throughout the year in well-lighted and heated premises at a temperature of 21-26 °C, and the seasonal reduction of the bioelectricity level was 8.71%. On not-heated closed terraces and glazed balconies, with temperature fluctuations from 5 to 26 °C, the electricity production decreased in the winter period by 19.98% and 39.91% with and without adding of sulfate-reducing bacteria, respectively. The proposed system of electrodes for collection of bioelectric power is new, easy to manufacture and economical. It is resistant to waterlogged environment, and has good prospects for further improvements for more effective collection of plant-microbial bioelectricity. Maintainance of the biosystem is simple and accessible to everyone without special skills.
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Introduction

Getting electricity from living plants and microorganisms directly from their place of living, i.e. from the soil, is an innovative method of alternative energy production, which has been actively investigated by scientists in the last 10 years (Strik et al. 2008; De Schamphelair et al. 2008; Kaku et al. 2008; Helder et al. 2010; Picot et al. 2011; Rothballer et al. 2011; Kuijken et al. 2011; Timmers et al. 2012; Liu et al. 2013; Lu et al. 2015, Koen et al. 2015; Rahimnejad et al. 2015; Moqsud et al. 2017; Nitisoravut et al. 2017).

The project "Starry Sky" of Plant-e Company (Wageningen, Netherlands) is the first real example of implementation of the plant-microbial power generation with 300 roadside LED bulbs lighted by electricity produced by the plant-microbial groups of the surrounding soil near Amsterdam in the Netherlands (Schultz 2014).

The energy of the electrons emitted by soil bacteria during the decomposition of the root excretions of plants is the source of electricity in this biotechnology (Strik et al. 2008; Nitisoravut and Regmi 2017). Thus, the green cover on the roof of a building (or around) solves the problem of its energy supply and at the same time provides ecological coverage of the building or landscaping of its surroundings. With the improving technology, 100 m^2 of vegetation of a green roof will be able to provide energy for a house that consumes 2800 kWh per year (Strik et al. 2011). The technology of producing electricity from living plants and microorganisms is prospective for a widespread application of energy supply to buildings, street lighting, WiFi access points, mobile phone charging, and various energy demands of ecotourism (Helder et al. 2012; Wetser et al. 2015).

Bioelectricity from root excretions of living plants and soil microorganisms is renewable and environment friendly. Its exploitation does not cause emission of greenhouse gases or toxic substances because the technology is aimed only at collection of the electrons circulating in the substrate through introducing a system of electron collection into it (Strik et al. 2008). In addition, green roofs contribute to preservation of the environment since they significantly reduce energy consumption by the building (Castleton et al. 2010).

Nowadays, the main problems of plant-microbial bioelectric technology are the low power and high cost of materials used to collect the electrons and protons (Helder et al. 2013a; Behera and Varma 2016). However, there are

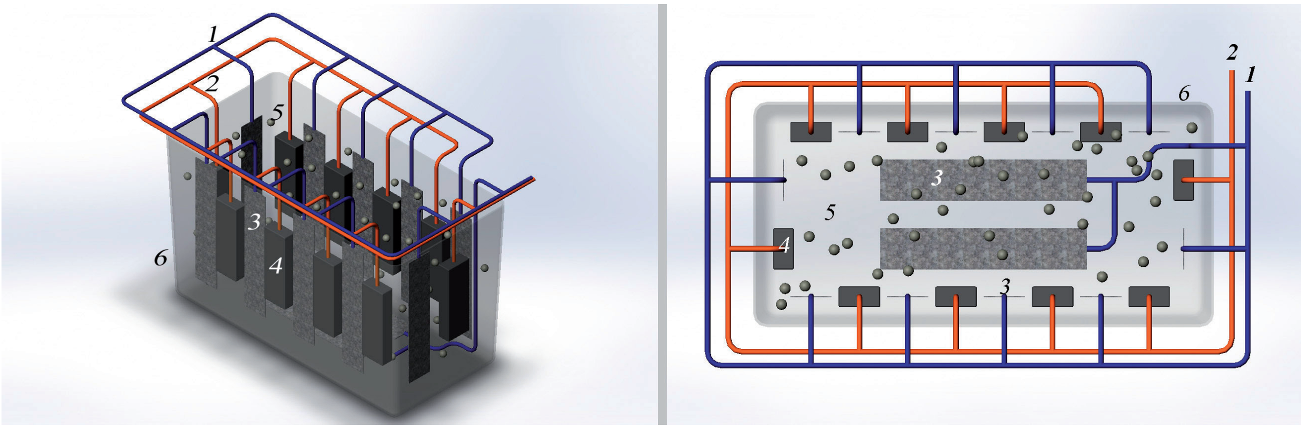

Figure 1. Schematic arrangement of the system of electrodes in container with the plants. A: front side view of the container. B: top view of the container. 1 - output wire, connecting the system of 12 anodes; 2 - output wire, connecting the system of 10 cathodes; 3 - anode; 4 - cathode; 5 - substrate; 6 - container; 7 - plants.

many ways to increase the capacity of plant-microbial electrosystems, e.g., improvement of the cathodes and anodes (Picot et al. 2011; Chen et al. 2012; Helder et al. 2012; Nitisoravut et al. 2017; Wetser et al. 2017), experiments with new environments (Timmers et al. 2010; Helder et al. 2011; Lu et al. 2015; Moqsud et al. 2015) and with new plants (De Schamphelaire et al. 2008; Kaku et al. 2008; Helder et al. 2010; Timmers et al. 2010; Timmers et al. 2012; Hubenova and Mitov 2012; Yadav et al. 2012; Liu et al. 2013; Lu et al. 2015; Oon et al. 2015; Wetser et al. 2015; Regmi 2016) have been published. In this study, our aim was the improvement of this technology by developing and testing a new biosystem, with new cheap electrodes, a non-standard environment, and new species of plant.

Seasonal reduction of power energy produced on green roofs is another problem of using the energy of living plants and microorganisms (Helder et al. 2013b). The decline of power output in the winter-spring period under outdoor conditions has been well documented (Helder et al. 2013b; Daj et al. 2015); power received from green roofs and marsh areas was significantly lower than that obtained in the laboratory. We decided to test the possibility of using indoor premises: closed and glazed terraces, balconies or winter gardens, as an alternative to green roofs in countries with extremely cold or arid climate to prevent seasonal losses of power energy for year-round production of plant-microbial energy.

To implement the above-written aims, we set up the following tasks:

- select plants that could be grown inside buildings (in glazed terraces or balconies or near the windows of the apartments) while producing electricity;
- explore the possibility of their long-term cultivation in enclosed conditions of buildings;
- assess the prolonged functionality of the electrode system in aquatic environment;
- determine the current and voltage output that can be obtained from our bioelectric system and assess its suitability for the production of bioelectricity inside buildings for a long time;
- estimate the effect of external factors on the generation of bioelectricity on green indoor balconies and terraces.

Materials and Methods

Biocomponents of the electro-biotechnological system

Spring is the optimal time for replanting of *Alisma* (Grigoriev et al. 2006), the plant chosen by us as a biocomponent for the electro-biotechnological system. Plant specimens were taken from various city reservoirs, ponds and lakes, in the city of Lviv (Ukraine). Young specimens with 2-3 small leaves that have not yet blossomed were taken and planted into swampy soil substrate in plastic containers of 0.0525 m^2 area with a system of electrodes to collect electricity. The substrate for plant cultivation consisted of silt from a natural reservoir and water in a proportion of 2:1. Each box contained two bushes of plants. The plants were not disinfected, not to break the original relationship of microorganisms and plant roots, crucial for generating electricity.

The 100 ml suspension of *Desulfovibrio* sp. Yav-6 (Moroz and Rusyn 2012) with cell density of 2.7 mg/ml was added to some containers two times during the plant development (in the 1st and 2nd month) to test the hypothesis of favorable influence of sulfate-reducing bacteria on the level of bioelectricity.

Plant growth was measured by counting and summing the lengths of leaves and stems to obtain total length

(Helder et al. 2010); average values were calculated per container.

Electrical components of the system

Our bioelectricity collecting and measuring system (Rusyn and Medvediev 2018) consisted of electrodes placed in the plastic container with plants, directly in the zone of association of plant roots and microorganisms, where electrons and protons are released. For anodes, galvanized steel plates of 292(h) x 30(w) x 0,8(t) mm size were used. For cathodes, graphite plates of 90(h) x 30(w) x 15(t) mm size (Rusyn and Medvediev 2015) were prepared. Multi-conductor copper wires of 1.5 mm diameter were used for connection of cathodes and anodes (Rusyn and Medvediev 2016).

The anode system of one container consisted of 12 plates, connected by wires and located in the container at a distance of 0.5 cm from its walls as follows: 2 plates were put to the bottom of the container and 10 plates, which bent on third part to the form of a one entire plane, were placed vertically along the walls (Fig. 1A, B).

The system of cathodes consisted of 11 graphite plates connected by wires and located in the container vertically between the anodes (Fig. 1A, B) at a depth of 10 cm and at a distance of 0.5 cm from the vertical walls of the container.

Experiment design

The containers with plants and electrodes were kept inside the buildings in different conditions:

1. on unheated glazed terraces and balconies, where temperatures ranged from 5 °C in winter to 26 °C in summer;

2. on glazed balconies and terraces heated in winter, at average temperature from 21 °C to 26 °C for the duration of the experiment, and under identical conditions, directly in apartments with temperature of 21 °C to 26 °C throughout the time.

The experiment was conducted in realistic conditions that can be created in private appartments, and in two different temperature regimes as the the housing stock consists of two types of enclosed balconies and terraces: heated and without heating. Variable mixed lighting, including natural illumination by daylight through the window and artificial light sources, was applied. The plants were watered every 2-3 days.

The experiment with repetitions continued for 40 weeks for a few years from the spring planting to the early spring of next year, when it was possible again to renew the vegetation by planting new plants, to reveal the peculiarities of the development of plants and of the generation of bioelectricity in enclosed living quarters.

Measurements and calculations

The values of voltage (bioelectric potential; U, mV) and current (I, mA) were measured with a digital multimeter, with the probes connected to the wires coming from the cathodes and anodes. Measurements were performed daily.

Open circuit voltage (open bioelectric potential) was monitored over time in open-circuit state of the plant-microbial biosystem.

In order to determine at which external resistance one can obtain maximum power density, measurements were carried out using different loads from 10 Ω to 12 kΩ. Resistors of 10, 50, 250, 500, 1000, 3000, 5000, 12000 Ω were used, and the voltage through the external resistor, connected in the circuit periodically for 15 min, was recorded. During a laboratory experiment, the voltage was also measured when an external resistor was permanently connected for several days. Current strength was calculated theoretically using practically measured voltage and resistance, but was also in fact measured, with resistors.

Current was calculated as the voltage output divided by external resistance according to equation

$$I\ (A) = U\ (V) / R\ (\Omega)\ \text{(Ohm's law)}$$

and the current density was calculated as

$$J\ (A/m^2) = I\ (A) / S\ (m^2),$$

where U is the measured voltage; R, the external resistance; and S, the active area of the electrodes. Power density was calculated as

$$P\ (W/m^2) = J\ (A/m^2) * U\ (V)$$

Power density was normalized to the $1m^2$ experimental planting surface of the plants covered by the electrodes. The average bioelectric potential and current strength were calculated two-weekly and for the total 40 weeks of the experiment.

Results and Discussion

Selection of plants for electric biotechnology in enclosed indoors areas

The use of *Oryza sativa* (Kaku et al. 2008; De Schamphelaire et al. 2008), *Arundinella anomala*, *Arundo donax* (Helder et al. 2010), *Spartina anglica* (Timmers et al. 2010; Helder et al. 2010; Wetser et al. 2015), *Glyceria maxima* (Timmers et al. 2012), *Ipomea aquatica* (Liu et al. 2013) and *Phragmites australis* (Wetser et al. 2015) in the technology of bioelectricity production from living plants has been described in literature. The choice of plant for electric biotechnology is very important and determines how effective it will work. When applying the same systems of collecting electricity, but using different plants, energy output differed tenfold: the power obtained from *Spartina anglica* and *Arundinella anomala* was 0.222 W/m^2 and 0.022

Table 1. The development of *A. plantago*-aquatica plants in the biosystems on unheated and heated terraces and balconies without or with the addition of sulfate-reducing bacteria *Desulfovibrio* sp. ($p < 0.05$).

Time of plant growth (week)	Conditions					
	5 - 26 °C / unheated premises / without sulfate-reducing bacteria	5 - 26 °C / unheated premises / with sulfate-reducing bacteria	21 - 26 °C / heated premises / without sulfate-reducing bacteria	5 - 26 °C / unheated premises / without sulfate-reducing bacteria	5 - 26 °C / unheated premises /with sulfate-reducing bacteria	21 - 26 °C / heated premises / without sulfate-reducing bacteria
	The average number of leaves in one biosystem			Quality of plants		
0	6.1	5.3	6.0	***	***	***
2	11.7	10.2	11.2	***	***	***
4	14.9	15.6	16.3	***	***	***
6	16.7	16.8	17.6	***	***	***
8	16.6	17.5	17.8	***	***	***
10	15.9	17.4	18.4	***	***	***
12	16.7	19.8	19.5	***	***	***
14	14.5	18.5	18.3	**+	***	***
16	9.3	17.1	17.4	**+	***	***
18	6.2	16.7	17.2	*++	**+	***
20	4.1	10.6	17.7	*++	*++	**+
22	2.3	5.5	16.6	+++	+++	***
24	1.1	1.3	16.8	+++	+++	***
26	0	0	17.8	-	-	***
28	0	0	17.3	-	-	***
30	0	0	17.6	-	-	***
32	0	0	16.7	-	-	***
34	0	0	17.1	-	-	***
36	0	0	17.0	-	-	***
38	0	0	16.5	-	-	***
40	0	0	16.9	-	-	***

*** Green leaves. +++ Yellow and drying leaves. - Death of all plants

W/m^2, respectively (Helder et al. 2010).

The plants mentioned above are plants of wet habitats. We also focused our attention on the wetland plants when choosing plants for bioelectric power generation and, simultaneously, landscaping of buildings. It is precisely in waterlogged conditions of wetlands where bioelectricity, produced by plants and microorganisms, can be most fully exploited, because penetration of oxygen to the electrodes and the consequent loss of circulating electrons and protons is reduced to a minimum (Helder et al. 2012), and as wetlands are also ideal for the development of electricity producing microorganisms (Lovley et al. 2011).

The plants for bioelectric technology were selected among not demanding plants that do not require special care, are cosmopolitan and decorative, and at the same time perennial. Perennials, compared to annual plants, have a more active secretion of organic substances in the soil (Lynch and Whipps 1990; Kuzyakov and Domanski 2000), which leads to the accumulation of the so-called rhizodeposit in the root zone of the soil (Dennis et al. 2010), and production of bioelectricity depends on splitting of rhizodeposit by the microorganisms.

Alisma plantago-aquatica, also known as European water-plantain or common water-plantain (Crocker and Wilmer 1914; Tsvelev 1979) was chosen as a plant that possesses all above-mentioned necessary characteristics for bioelectricity generation technology. It is a perennial grassy plant, up to 0.6 - 1 m high (Gubanov et al. 2002; Grigoriev et al. 2006), which suggests the presence of ample rhizodeposit. The plant is used in landscape design; it is planted along ponds or in marshy areas of gardens and parks (Grigoriev et al. 2006). In spring and early summer, the plant is attractive by its rosettes of leaves, and in summer, with its small white, sometimes pink or lilac flowers that appear on long stems (Darbyshire et al. 2014). Water plantain practically needs no care. It is widespread in all continents, both in the northern and southern regions, including Africa and Australia (Grigoriev et al. 2006). Thus, *A. plantago-aquatica* was selected as a plant for bioelectricity generation.

Cultivation of A. plantago-aquatica in bioelectric power generation systems in buildings on closed balconies and terraces

Our next task was to find out if it is possible to cultivate *A. plantago-aquatica* indoors in containers with systems of electrodes. The plant was found to be able to grow in typical conditions on unheated enclosed balconies and

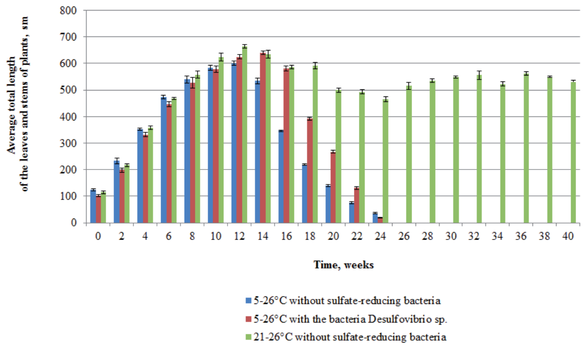

Figure 2. Growth of *Alisma plantago-aquatica* in bioelectricity systems indoors under different conditions during 40 weeks of the experiment: the average total length of leaves and stems of the biosystem plants during sudden temperature fluctuations from 5 to 26 °C with and without addition of bacteria *Desulfovibrio* sp., and at stable temperature range of 21 - 26 °C.

terraces in a marshy substrate in containers with systems of anodes and cathodes from early spring to mid-autumn, and all year round on the heated terraces and balconies or directly in the flats (Fig. 2).

The results of monitoring the plant growth during the spring-summer period under conditions of closed premises showed that such an environment was favorable for development of plants: new leaves grew actively, the number of leaves in the containers nearly doubled during the first two weeks, in the next two weeks the quantity of leaves yet increased by 41.9% on the average (Table 1). Leaf biomass increased during summer, and the plants bloomed (Fig. 3A-D).

In the autumn period, temperature decrease and reduction in daylight on unheated terraces caused the leaves to turn yellow and wilt and, despite the appearance of young shoots, the plants died (Fig. 3E, F and Table 1). In systems with added sulfur-reducing bacteria, the plants retailed the leaves for a longer period, and the yellowing and wilt of leaves took place 4 weeks later than in the containers without bacteria (Table 1). At that time, the plants in containers without added bacteria lost about half of foliage mass, and the leaves turned yellow and dried up.

Displacement of containers with plants to warm and well-lit areas of the flats from early autumn to early spring prevented the decay of plants and they continued to develop the whole winter (Table 1). Year-round cultivation of water plantain is possible on enclosed heated balconies and terraces, and near windows in the apartments, where the temperature does not fall (Fig. 2). *A. plantago-aquatica* reproduces by seeds and division of rhizomes (Gubanov et al. 2002). Strong self-seeding throughout the summer and germination of young bushes from rhizomes provide year-round green cover of containers. System maintenance

Figure 3. The development of plants *A. plantago-aquatica*, transferred from the natural reservoirs in May in the containers with muddy substrate and a system of electrodes, kept in typical conditions of unheated enclosed balconies and terrases: (A) May, the 1st month of the experiment. The plants are still young and have a few small leaves; the average height of the plants is 21.2 cm. (B) June, the 2nd month of the experiment. Bushes of water plantain are well formed and have 7-8 leaves, the height of the ground part is 36.1 cm on the average. (C) July, the 3rd month of the experiment. Beginning of flowering. (D) September, the 5th month of the experiment. Flowering ends, leaves begin to turn yellow. (E) October, the 6th month of the experiment. The leaves turn yellow and dry. (F) November, the 7th month of the experiment. Despite on the presence of young leaves, the plants died.

is simple and consists in watering 2-3 times per week.

So, glazed balconies and terraces – which are usually used to increase the size of the apartment by arranging rest area or workplace there, or if they are not heated, are used as a buffer zone between the apartment and the outside world to reduce the cost of heating – can perform another important, energy supply function. Glazed balcony or terrace can be seen as a greenhouse where

Table 2. The cost of components bioelectric-producing system

Elements of the biotechno-system	Materials	Cost (EUR)
Container	Polypropylene	3.27
Cathodes	Graphite plates	15.30
Anodes	Plates of galvanized steel	4.14
Conductors for connecting the cathodes	Copper multiple wires	1.19
Conductors for connecting the anodes	Copper multiple wires	1.19
Plants A. plantago-aquatica		4.70 (0.0)
Soil universal substrate		1.91 (0.0)
Water		-
Mud		-
Total		31.70 (25.09)

there is sufficient natural light, stable temperature can be maintained by underfloor or radiator heating. These areas can be used for growing *A. plantago-aquatica* with the aim of obtaining plant-microbial energy in the flats.

System cost

Our proposed electrode system for collecting bioelectricity (Fig. 1) functioned properly in wetland substrate during the 40-week experiment, and did not require replacement. The newly designed graphite-galvanized steel system of electrodes (Rusyn and Medvediev 2018) is easy in manufacture and of low cost. On average, the cost of materials for one biosystem an area of 0.0525 m^2 is 31.7 EUR as shown in Table 2.

The plants for bioelectricity generating systems can be bought in plant nurseries, as well as taken from natural reservoirs. Similarly, the soil for the system may be purchased or obtained from the natural environment. This leads to a further reduction of the cost of the system, in this case to 25.09 EUR (Table 2).

The price of materials for 1 m^2 of the system goes from 501.8 EUR (without the cost of plants and soil substrate) to 634.0 EUR (with cost of with these elements plants and soil substrate).

The cost of collecting and installing the bioelectric-system are also insignificant. The price of collecting the biotechnological system, based on the cost of the hardware for connecting the technical components of the system, at a scale 10 000 biosystems, will be inconsiderable. The installing the biological system, which is quite simple and fast.

Production of bioelectricity under different conditions

The average output voltage of the bioelectric systems

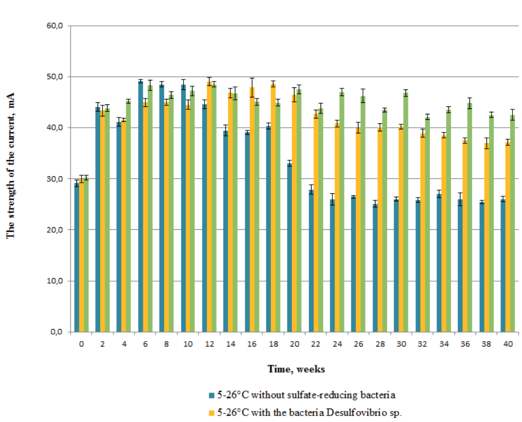

Figure 4. The average current strength of the biosystems with *A. plantago-aquatica* under 10 Ω load during 40 weeks of experiment in different conditions: at temperature fluctuations from 5 °C to 26 °C on the unheated terraces and balconies with and without sulfate-reducing bacteria and at 21 °C to 26 °C on the heated balconies and terraces without the bacteria.

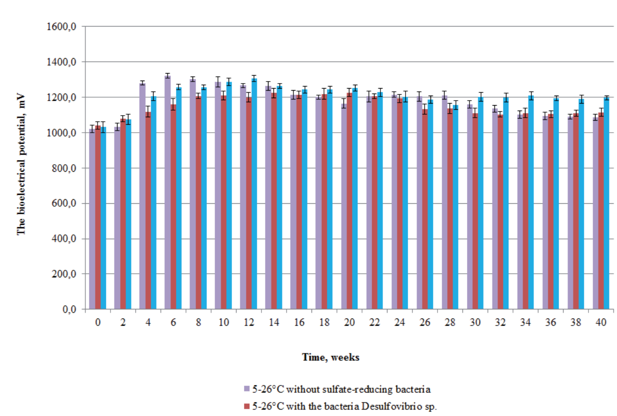

Figure 5. The average open circuit bioelectrical potential of the biosystems with *A. plantago-aquatica* during 40 weeks of experiment in different conditions: at temperature fluctuations from 5 °C to 26 °C on the unheated terraces and balconies with and without sulfate-reducing bacteria and at 21 °C to 26 °C on the heated balconies and terraces without the bacteria.

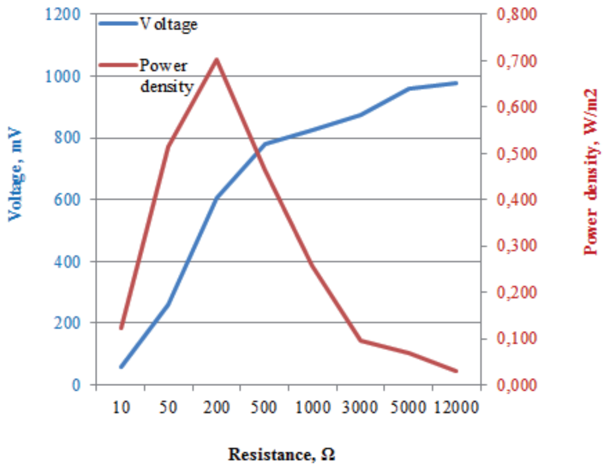

Figure 6. Output voltage and power density of bioelectrical systems with A. plantago-aquatica under the action of external resistors 10 Ω - 12 kΩ. The bioelectric potential of the electro-biosystems is close to 975 mV when using a resistor of 12 000 Ω.

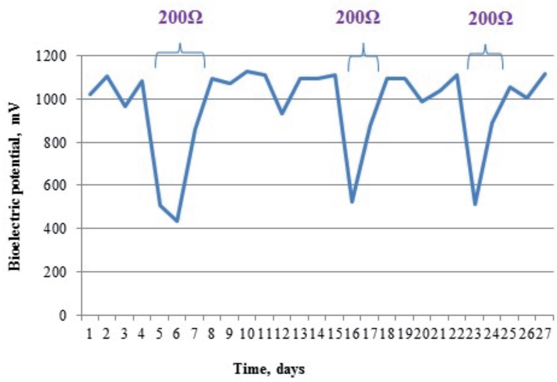

Figure 7. One-day and two-days effects of an external resistor of 200 Ω on the generation of bioelectric potential by an bioelectrical system with *A. plantago-aquatica*.

with the *Alisma plantago-aquatica* in indoor conditions of buildings during the 40-weeks of experiment ranged from 1.15 V to 1.21 V, and the average current strength was from 34.2 to 44.6 mA, depending on the conditions of cultivation (Fig. 4, 5). The maximum registered voltage was 1.34 V and current strength at an external resistance of 10 Ω was 58.6 mA.

The work of the bioelectric system under short-term action of external resistance is shown in Fig. 6. The highest power density was found at 50-500 Ω loads, in agreement with the data of Cheng et al. (2006). The maximum power density was 0.702 W/m^2 using an external resistor of 200 Ω, but long-term use of 200 Ω external load resulted decrease of output voltage by ca. 51.48% during one day and 58.27% over two or more days (Fig. 7). After to open of circuit voltage was restored during the day and returned to the initial level after 2 days (Fig. 7).

The set-up time of average annual bioelectric values in the biosystems

We propose to set up the bioelectricity generating system with seedlings of young plants (instead of growing them from seeds), so power generation starts from the first days after installation. During the first two days of our experiment, current strength increased by 67.7% and 65.3%, and amounted to 50.3mA and 48.1mA with and without addition of a suspension of sulfate reducing bacteria, respectively. The average current with 10Ω load for the second week of cultivation was 43.3 - 44.1 mA (Fig. 4). Two weeks after starting the bioelectricity generating system, the output voltage reached the annual average level (Fig. 5) and, up to that point, increased by 14.05%. So, finally, in two weeks the system operated at almost full capacity.

Dependence of bioelectric performance on the plants' development

Significant increase of power output with the development of aerial parts of plants in the system was observed. On unheated terraces and balconies, where plants undergo cyclical development,. the maximum electric output was recorded in summer and early autumn, when the bushes of plants were the most developed, contained the maximum number of developed green leaves and were photosynthetically the most active (Table. 1; Fig. 2). The highest recorded current, above 50 mA, and open circuit voltage above 1.3 V, was observed on unheated terraces and balconies in the 6th-20th weeks of experiment, in summer and early autumn. Output dropped almost to the initial level after the death of plants in systems without sulfur bacteria on unheated terraces.

Influence of external factors on the function of the system

One of the main external factors that influence on the development of plants inside buildings is temperature. In the housing stock, there are both heated glazed balconies or terraces, and closed balconies and terraces without heating where temperature drops sharply in the autumn-winter period. The biosystems are electrically productive around the year inside buildings, but the output depends on the temperature regime in which biosystems are kept. On heated terraces, where temperature is always favorable for the plants, current strength did not fall below 40 mA (Fig. 4), and was only slightly lower, by 3.88%, in the autumn-winter period. Bioelectricity generating systems on unheated balconies and terraces without the addition of sulfur bacteria were most effective only in the spring-summer period, and from the 20th week on, with decreasing temperature and loss of plants, output was falling. Current dropped to the baseline level already in the 22th week (Fig. 4), and output voltage decreased almost to the baseline level by the 40th week (Fig. 5).

On unheated balconies and terraces, but with addition of sulfate-reducing bacteria, the time course of bioelectric power output was completely different, in spite of unfavourable temperatures. On the 26th week of the experiment, when the system with sulfate-reducing bacteria was already without living plants, average strength of the current was still 40.11 mA. Wetland substrate by itself, with the organic residues of leaf fall and with added sulfate-reducing bacteria, was obviously the source of electricity generation in these conditions. Current was maintained above 40 mA during 30 weeks of cultivation, and its subsequent decrease was insignificant (Fig. 4).

Electric power obtained from the containers with plants is the result of activity of electricity-producing microorganisms that grow by utilizing the plant root secretions (Helder et al. 2013a). Nitrogen-fixation (Beijerinck 1901) and reduction of sulfate by *Desulfovibrio* (Pfennig 1989; Moroz and Rusyn 2012) can play a key role in maximizing bioelectric output. Nitrogen supply promotes photosynthetic activity of plants, which consequently will increase the amount of nutrients excreted by the roots and utilized by the electricity producing microorganisms. Sulfate, which may be present in wetland environment in low concentration, is undesirable for the collection of bioelectricity, as it acts as an alternative electron acceptor (Ivanov et al. 2017; Morris and Jin 2009). Therefore, reduction of sulfate by *Desulfovibrio* sp., sulfate-reducing bacteria, is a positive factor in the biotechnology of bioelectricity production. And also, perhaps, sulfur-bacteria can promote the development of the power-generating bacteria by their metabolites that they secrete into the subtrate and that may directly participate in the process of producing of bioelectricity.

Although the theoretical calculated power of 3.2 W/m^2 (Strik et al. 2011) potentially available in this technology has not been achieved yet, we are still one step closer to achieving this goal using the new electrodes systems, environment and plants *A. plantago-aquatica*.

Using bioelectro-technology proposed by us, the generation of current strength is stable throughout the year at a temperature of 21 - 26 °C in well-lighted premises, glazed, heated terraces and balconies. Seasonal reduction of the bioelectricity level is equal to 8.71%. On closed balconies and terraces that are not heated, at a temperature fluctuations 5 - 26 °C, the production of bioelectricity decreases in the winter period compared with average values of the spring-summer-autumn period by 39,91% without sulfur-bacteria and by 19.98% with addition sulfur-bacteria. Such a decrease in the generation of bioelectricity in the winter period on closed terraces and balconies is insignificant compared with the same one fixed decrease of bioelectricity in green roofs in outdoor conditions of almost 5 times (Helder et al. 2013b) or with the fully termination of generation of the current of strength in wetland forests (Dai et al. 2015). This fact reveals the great potential of glazed green terraces and balconies as a source of bioelectricity in the winter period. The glazed loggias of houses, after the improvement of biotechnology, can be used to grow marsh plants *A. plantago-aquatica* in order to obtain plant-microbial energy in apartments.

Conclusions

Green gardens, located on glazed balconies or closed terraces, are an alternative to green roofs as sources of bioelectricity in countries with cold or arid climate and solve the problem of bioelectricity losses *in situ* during the cold seasons of the year. Although the power, theoretically possible in this technology, is still not achieved, the proposed bioelectro-technology with wetland plant *A. plantago-aquatica* has progress in thrift, efficiency and round-the-year collection of bioelectricity, and contains new approaches that have good prospects for further improving of the collection of plant-microbial bioelectricity.

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