Hindawi
International Journal of Photoenergy
Volume 2019, Article ID 9592746, 11 pages
https://doi.org/10.1155/2019/9592746

Research Article

Assessment of the Use of PV Panels with Energy Accumulation Option for Riga City Office Building

Kristina Berzina, Inga Zicmane, and Konstantins Kasperuks

Faculty of Power and Electrical Engineering, Riga Technical University, Azenes Street 12/1, Riga, Latvia

Correspondence should be addressed to Inga Zicmane; inga.zicmane@rtu.lv

Received 21 March 2019; Revised 10 July 2019; Accepted 18 July 2019; Published 8 October 2019

Guest Editor: Daniel T. Cotfas

Currently, demand-side management (DSM) covers a whole range of technological and policy measures aimed at reducing electricity consumption connected with economic activities. Thus, the development of wind PV and other renewable energy technologies, combined with microgrid technology, offers the remote consumers and prosumers ample opportunities to stabilize long-term costs and increase local energy system security. Apart from that, DSM from microgrid based on renewable sources also has certain social benefits, such as protection of the environment and conservation of natural resources. Due to the advances in photovoltaic material research and solar panel price reduction over the last years, the usage of this alternative energy source in Baltic region countries seems more attractive. The usage of energy storage devices can help use the solar power more efficiently and smarter. This paper deals with the optimization of a proposed solar panel array of a renovated office building's communal lighting in Riga, using storage devices and demand-side management of the produced power, looking into a way to calculate the needed storage capacity on the basis of potential PV system and existing power consumption for communal space lighting system. The proposed approach will become one of the first basic steps in applying DSM to help reduce the communal space's illumination power consumption, in turn helping to reduce the needed PV generating power and energy storage.

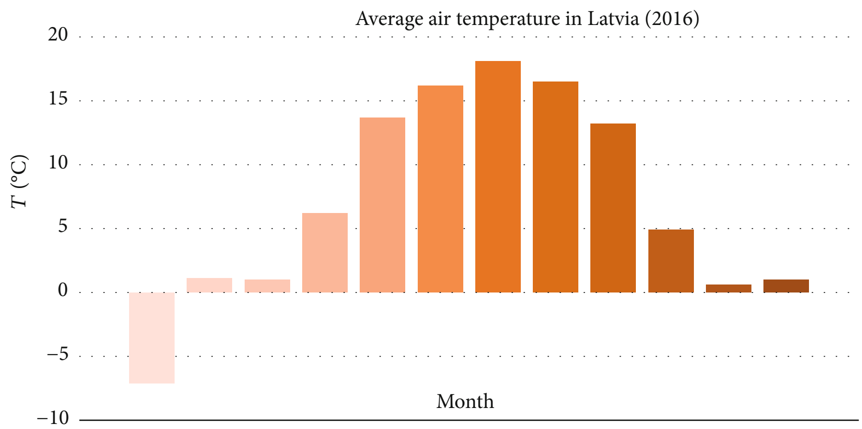
1. Introduction

Today, the use of renewable energy is one of the most promising forms of electricity consumption that can be considered as a virtually inexhaustible source of energy. This future perspective is determined by the ecological aspects, low operating costs, and projected deficit of nonrenewable natural resources. According to the forecasts of the European Commission, the renewable energy industry will account for 1.1% of the total product in 2020.

Many large corporations contribute to the use of renewable energy. For example, Apple Inc., as the leading solar power station owner, provided the operation of two data centres with alternative energy [1]. Tesla, for its part, is investing in solar power plants with the aim to reduce CO_2 emissions in regions with high levels of atmospheric pollution [1].

In northern countries, where the sun's radiance is not that high throughout the year, the introduction of solar energy as a viable renewable energy source has been hard. But in recent years, the efficiency of the photovoltaic (PV) panels has been improved greatly [2] and this has caused the prices to drop [3] significantly. These advances should be considered, when thinking of ways to reduce on-grid power consumption and solving the problem of demand-side management.

The air temperature affects the work ratio of the solar panels. The majority of solar cells demonstrate a drop of work ratio (up to 30%) as the temperature rises, but while it is exceeding the operating temperature value, the equipment can be damaged. For almost all types of solar cells, the operating temperature is in the range of -40°C to +85°C. Taking into account the average air temperature in Latvia (-5.9°C) (LEGMC data, Figure 1) [4], the operating temperature of the cells would not be exceeded and there would not be an additional need for the installation of cooling equipment. But during hot summer days, the air temperature can exceed +30°C, when the panel surface is heated to 60°C-70°C, reducing its work ratio. This problem can be solved



	Average temperature (°C)
January	−7.1
February	1.1
March	1
April	6.2
May	13.7
June	16.2
July	18.1
August	16.5
September	13.2
October	4.9
November	0.6
December	1

Figure 1: Average air temperature in Latvia (in 2016).

by installing solar panels on the metal structures of a roof, thus creating a gap of few centimetres in order to ensure air flow between the roof and solar panels.

Germany is the EU's leading country in the extraction of electric energy by means of solar cells. In 2015, nearly 40 GWh of solar energy was generated in Germany [5]. As shown in the map (Figure 1), in Latvia, there is approximately the same solar activity as in Germany (1000 kWh/m^2 and 1200 kWh/m^2, respectively), which suggests that the production of electric energy from solar cells would be as successful as in neighbouring countries.

The map (Figure 2) visually shows that greater solar activity is in coastal areas, in the vicinity of Riga and in Zemgale. So, the installation of solar panels for Riga buildings (including the office ones) shall be considered useful. The average annual solar activity is 1000 kWh/m^2. According to the data of the Latvian Environment, Geology and Meteorology Centre (LEGMC) [6] collected since 1950, the longest duration of sunshine per year is observed on the Baltic Sea coast (Kolka, Ventspils, and Liepaja): 1840-1940 hours per year. The sun shines in Zemgale about 1850 hours a year. In the eastern regions, the duration of sunshine is less: 1670-1720 hours per year; but in the Vidzeme Highland, it is only 1580 hours per year. In general, in coastal areas in summer, there are the biggest number of clear days and fewer fall-outs than in region areas, located further away from the sea. The duration of sunshine is also largely determined by the amount of clouds, not only by astronomical factors. The sun is shining slightly less than half the probable duration of sunshine in the territory of Latvia as a result of great cloudiness. During the winter months in the territory of Latvia, the sun shines only 10-25% of the possible shining time. In the summer months, in general, the average the sun shines is only 50-60% of the possible duration of sunshine. In the territory of Latvia, without the sun, there is an average of 90-110 days per year; in the Vidzeme and Latgale Highlands, 110-120 days. In the winter months, on average, more than half of the days of the month the sun does not shine. As can be seen from the above data, the maximum sunny hours in Riga are 2110 hours per year, but the minimum is -1519 hours per year. When installing solar cells in Riga, their average working time will be about 22% of the total time.

This paper considers ways to ensure the illumination of a renovated office building's staircase and communal space, using solar power as much as possible.

Due to the increase in the tariff for electricity, there is interest in switching office loads to renewable energy sources.

This article considers the possibility of switching the load of communal lighting to renewable sources; in particular, the use of solar batteries (PV) is planned. The choice was made based on the aspects and limitations of the urban environment.

The consumption of communal lighting has partly probabilistic nature. When considered in detail, like any other load curve, the load curve of the lighting system can be divided into a stationary and probabilistic component.

The office building itself is newly renovated. Its common space is equipped with LED lights. Nevertheless, the total

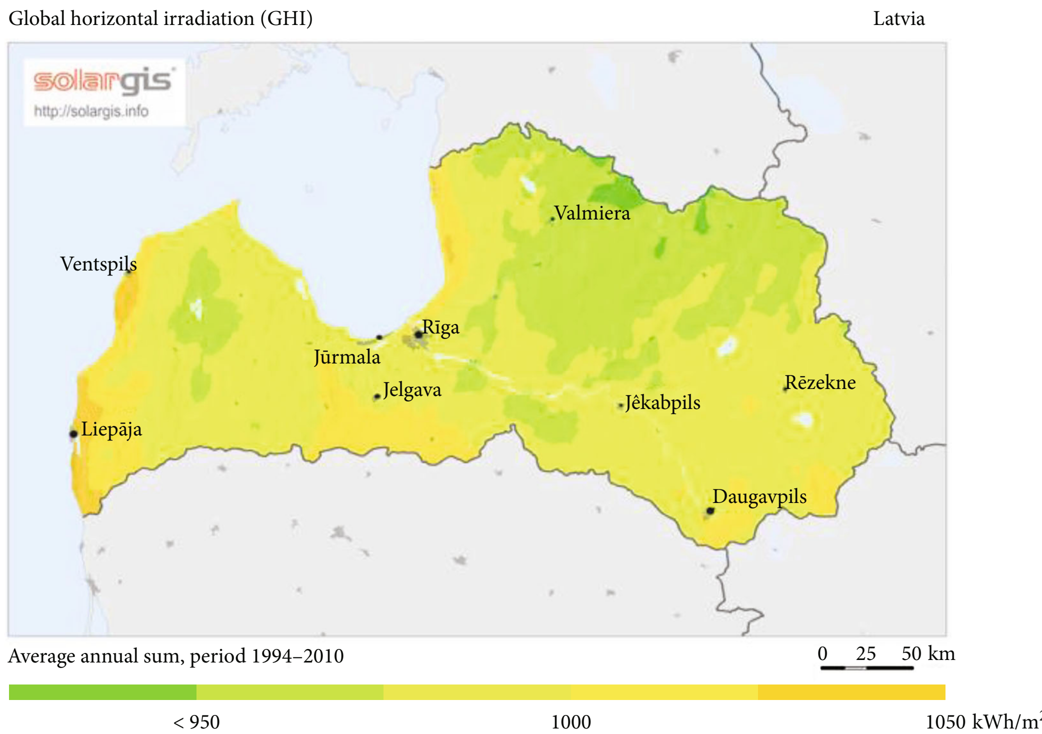


Figure 2: Solar activity in Latvia [6].

daily energy consumption for the communal space lighting system is more than

$$E_{cl} = 380\,\text{kWh}, \quad (1)$$

where E_{cl} is the communal space light system energy consumption.

2. The PV Generation and Sun Insulation Analysis

2.1. Types of the Solar Panel

(i) Monocrystalline solar panels

(ii) Polycrystalline solar panels

Thin film solar panels:

(i) Amorphous silicon solar panels

(ii) Cadmium telluride solar panels (CdTe)

(iii) Copper indium gallium solar panels (CIGS or CIS), (Table 1) [7]

2.2. Optimal Position of the Solar Panel. The efficiency of solar panels is determined not only by the intensity of the received solar radiation but also from the angle at which the panel is directed towards the direction of the solar radiation. Therefore, for the panel to get maximum solar radiation, this angle should be 90°. In order to find out the angle of a stream of the sun and the sun's height in solstice, you need to know the geographic latitude and geographic longitude of the particular place (Figures 2 and 3); Riga: latitude $56°56'56''$N, longitude $24°6'23''$E (56.948889, 24.106389) (Figures 4 and 5) [4].

Using the Photovoltaic Geographic Information System, it is possible to determine the optimal angle of inclination of the position of the solar panels (Figure 5) [8], where H_h is the solar radiation on a horizontal surface (Wh/m^2/per day), H_{opt} is the radiation to the optimal angle of inclination (Wh/m^2/per day), $H(39)$ is the radiation at the inclination of 39° (Wh/m^2/per day), I_{opt} is the optimal angle of inclination (°); PP is the repayment factor of the investment project, I_0 is the amount of initial investment, and CF is the cash flow from project implementation.

Based on the results (Table 2) obtained, the optimal angle of inclination of the installation of solar panels for the mapping point is 38°. Positioning solar panels at this angle will reduce reflected solar energy and thus increase the efficiency of the solar plant.

3. The Load Analysis in Office Building's Staircases and Communal Space

Five recorders "Circutor CIR-e3" were installed to record the overall energy consumption and load character of the office building, as well as to carry out audit and further analysis of the data obtained. Two analyzers were connected to the input cable for fixing the data of the total electricity consumed in the building (Figure 6) [9].

Table 1: Types of solar panel.

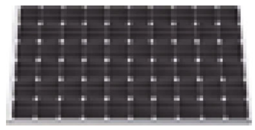
Name			
Type	Monocrystalline	Polycrystalline	Thin film (CIS)
Product name	Sharp NU-RD280	Trina Solar TSM-270 PD05	Solar Frontier SF170S
Nominal power P_{max} (W)	280	270	170
No-load voltage U_{oc} (V)	39.2	38.4	112
Short-circuit current I_{sc} (A)	9.67	9.18	2.2
Voltage at maximum power U_{mpp} (V)	31.2	30.9	87.5
Current at maximum power I_{mpp} (A)	8.97	8.73	1.95
η (%)	17	16.5	13.8
Panel area S (m^2)	1.643	1.553	1.228
Occupied area of solar panels per 1 kWp S_{kWp}	5.87	5.75	7.22
The cost of solar panels per 1 kWp C_{kWp}	996.4	959.3	923.5
Temperature factor k_t (%/°C)	-0.31	-0.41	-0.30
Power losses P_{zud}, % at $T = 70$°C	13.95	18.45	13.5
Price per piece (EUR)	279	259	157

Figure 3: Visualization of solar panel design.

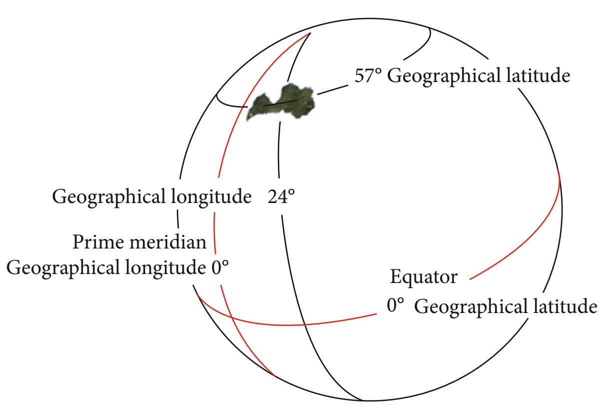


Figure 4: Geographic latitude and longitude in Latvia [4].

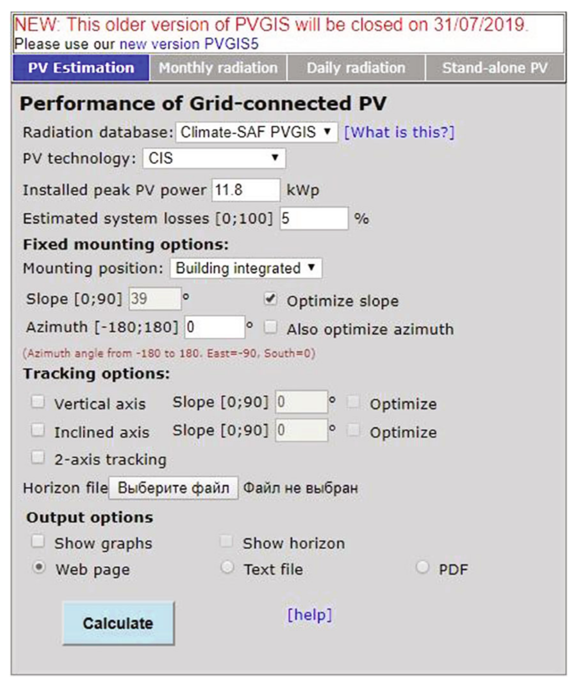


Figure 5: Calculation of the optimal angle of inclination [8].

The solar panels are intended to be used only for utility lighting; internal installation was reorganized, and the lift equipment (the peaks indicated by the arrows at Figure 6) was connected to another entry. After the pump was disconnected, measurements were made again and graphs were obtained (Figure 7).

As a basic model of the lighting load, the load schedule of communal lighting of office space was adopted. The schedule is presented in 10x relative units, because the typical lighting load is minor than the typical whole office building load curve.

Table 2: Monthly solar activity on the roof of an office building.

Month	H_h	H_{opt}	H (39)	I_{opt}	T_{24h}
January	450	847	847	71	-5.5
February	1060	1730	1730	64	-4.3
March	2570	3730	3730	55	0.1
April	4210	5150	5150	41	6.2
May	5540	5870	5870	27	12.5
June	5860	5810	5810	18	16.1
July	5550	5630	5630	22	19.6
August	4400	5010	5010	35	17.9
September	2860	3770	3770	48	13
October	1380	2110	2110	60	6.8
November	513	895	895	68	3.8
December	297	558	558	72	-1.1
Per year	2900	3430	3430	39	7.1

On the basis of lighting schedule data for mathematical model, the common consumed power of building's communal space lighting (Figure 8) is built.

4. The Mathematical Model of Sun Insulation and PV Generation

A load analysis was performed, using a mathematical model [10]. The result data are represented in Figure 8. The communal space lighting system's consumption in our case is constant through the season in summer and winter months, because the communal space is without windows and there is no daylight component.

To model the electrical load of the lighting system, we use the probability and statistical model:

$$P_{pi} = \bar{P}_l + \beta\sigma \cdot (P_i), \tag{2}$$

where P_i is the wattage rating on the ith hour of the daily schedule; $\bar{P}_l$ is the mathematical expectation on the ith hour of the daily schedule; β is the reliability factor of the calculation, which determines the probability with which the random load values will remain lower than the assumed estimated value P_{pi}, and $\sigma(P_i)$ is the average square deviation for the ith stage of the daily schedule.

Under the normal probability distribution law of the load values under $\beta = 2$, $\sigma(P_i) = 0.025$.

$$P_{pi} = \bar{P}_i P_{\max} \cdot (1 \pm \beta\sigma(P_i)) K_s, \tag{3}$$

where K_S is the seasonal factor, the value of which in our case is equal to1 [11].

The intensity of solar radiation depends on a variety of factors, geographical latitude, the angle of inclination of the receiving surface towards the sun, climate, air pollution, sea level elevation, and season. The study assumes the installation of PV on a roof of the existing building in Riga. Arising from these, all the above-mentioned parameters were taken into account.

The direct solar radiation Q_1 is found by Kostrov's formula:

$$Q_1 = \frac{Q_0 \sin\alpha}{\sin\alpha + c}, \tag{4}$$

where Q_0 is the solar constant of 1370 W/m^2 and c is the value characterized by the degree of transparency of the atmosphere (in our case $c = 0.81$).

Calculation of the sun's altitude α, geographical latitude, and inclination towards the horizon is calculated using the Kupar approximation formula.

Diffuse solar radiation is calculated by the formula

$$Q_2 = Q_{2h}\left[0.55 + 0.434\cos\theta + 0.313(\cos\theta)^2\right], \tag{5}$$

where Q_{2h} is the flow of diffuse solar energy falling on the horizontal plane (according to Berlage's expression) [12].

Thus, the orientation angles of the site were set using the above-mentioned expressions to determine the given energy falling on the inclined platform (at an angle of 38°). After the data analysis, it was decided to place 72 photovoltaic panels on the building's roof; the generation is represented in Figure 9 [11].

5. Calculation of Power Balance and Optimal Battery Storage

Assuming the transfer of the power of communal lighting to alternative sources of generation, potential balance of capacities is shown in Figure 10.

The main condition for the working capacity of the planned closed-loop system is the ability to provide the consumer with sufficient power.

$$P_{\mathrm{GPV}} + P_a \geq P_c K_s, \tag{6}$$

where P_{GPV} is the generated PV power, P_a is the accumulated power, P_c is the consumed power, and K_s is the safety factor.

The amount of energy possible to save at the current time (t) is determined by two parameters of "free" capacity of the accumulation system (D_a) and the maximal charge current value (I_c).

If the battery capacity is equal to C_a, then

$$0.8 \cdot C_a \geq D_a. \tag{7}$$

Coefficient 0.8 is taken from the equation $(1 - K_p)$, where K_p is the coefficient of allowable battery charge (K_p~0.8) [10].

Thus, the mathematical expression for the required accumulation when calculating the power balances of the system of communal lighting in the charging mode of accumulating devices will be equal to

$$P_a = P_{\mathrm{GPV}} - \frac{P_c}{E_i} \geq 0, \tag{8}$$

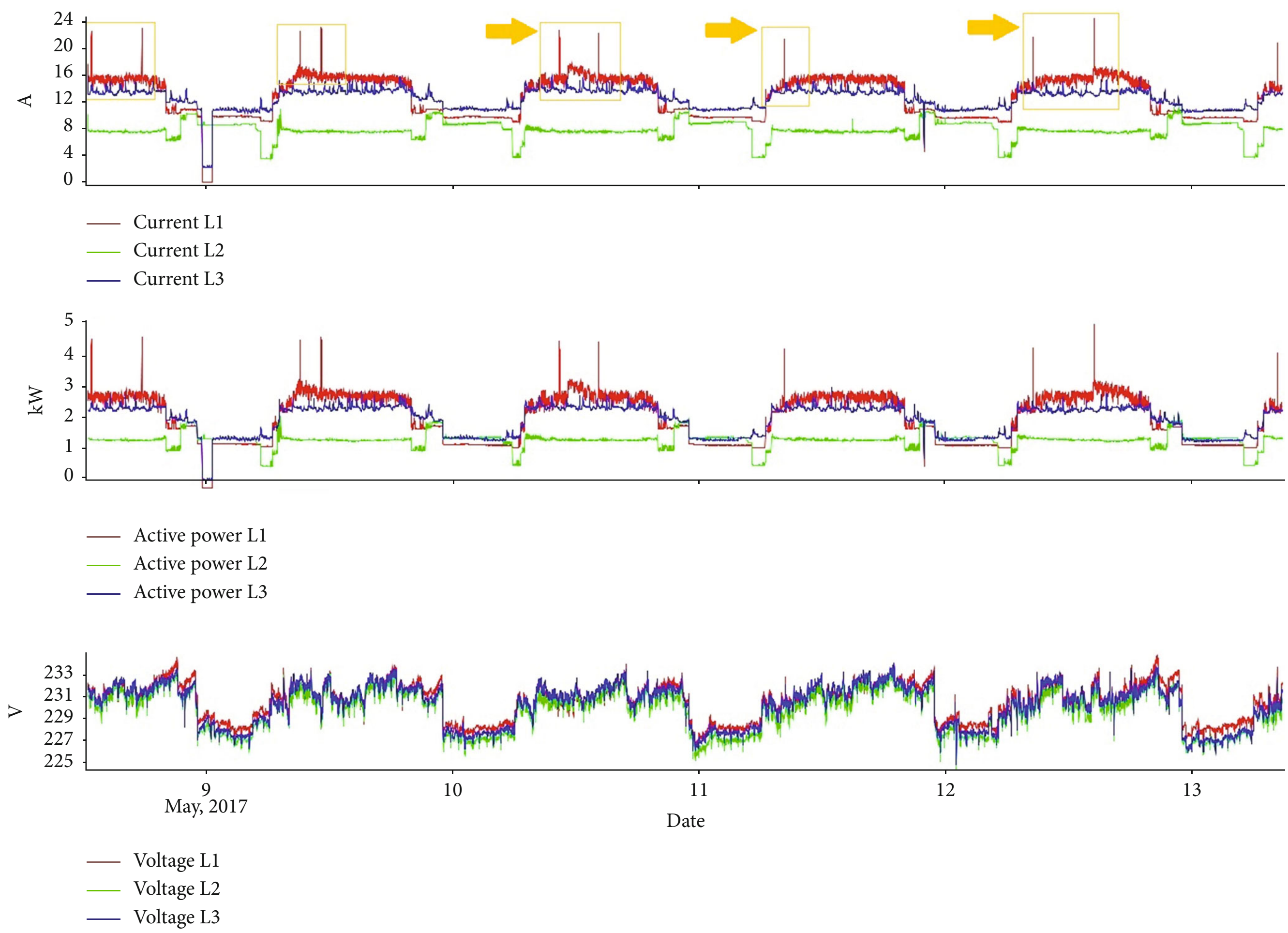


Figure 6: Utility schedule before adjustment.

where P_{GPV} is the generated PV power, P_{c} is the power consumed by the system, and E_{i} is the efficiency of the inverter.

Correspondingly, in the battery discharge mode

$$P_a = P_{\mathrm{GPV}} - \frac{P_{\mathrm{c}}}{E_{\mathrm{i}}} < 0. \quad (9)$$

The mathematical expression for calculating the power balance in the charging mode of the accumulating unit will be equal to

$$\begin{cases} P_a t \le D_a U_a K_a, \\ I_a = \dfrac{P_a}{n_a U_a} \le I_{\mathrm{C}}, \end{cases} \qquad \begin{cases} P_a t > D_a U_a K_a, \\ I_a = \dfrac{P_a}{n_a U_a} \le I_{\mathrm{C}}, \end{cases} \quad (10)$$

where n_a is the number of battery units, U_{a} and I_{a} are the voltage and the charge current of one battery, and $K_{\mathrm{a}} < 1$ is the efficiency of the battery [10].

Optimizing the expression will look like

$$\begin{cases} \bar{D}_a = D_a - I_a t K_a, \\ P_{\mathrm{C}} = P_a - I_a U_a, \end{cases} \qquad \begin{cases} \bar{D}_a = D_a - I_a t K_a, \\ P_{\mathrm{C}} = [(P)]_a - I_a U_a. \end{cases} \quad (11)$$

Mathematical expressions for calculating the power balance in the discharge mode of the accumulating unit will be equal to [10]

$$\begin{cases} |P_a| t \le \left[\left(1 - K_{\mathrm{p}}\right) C_a - D_a\right] U_a, \\ I_a = \dfrac{|P_a|}{n_a U_a} \le I_{\mathrm{p}}. \end{cases} \quad (12)$$

The C_{a} and I_{a} values determine the working capacity of an autonomous electrical power supply system using renewable energy sources.

By adding battery storage, it is possible to use the solar power more efficiently, but there is the unknown variable, how much exactly has to be stored.

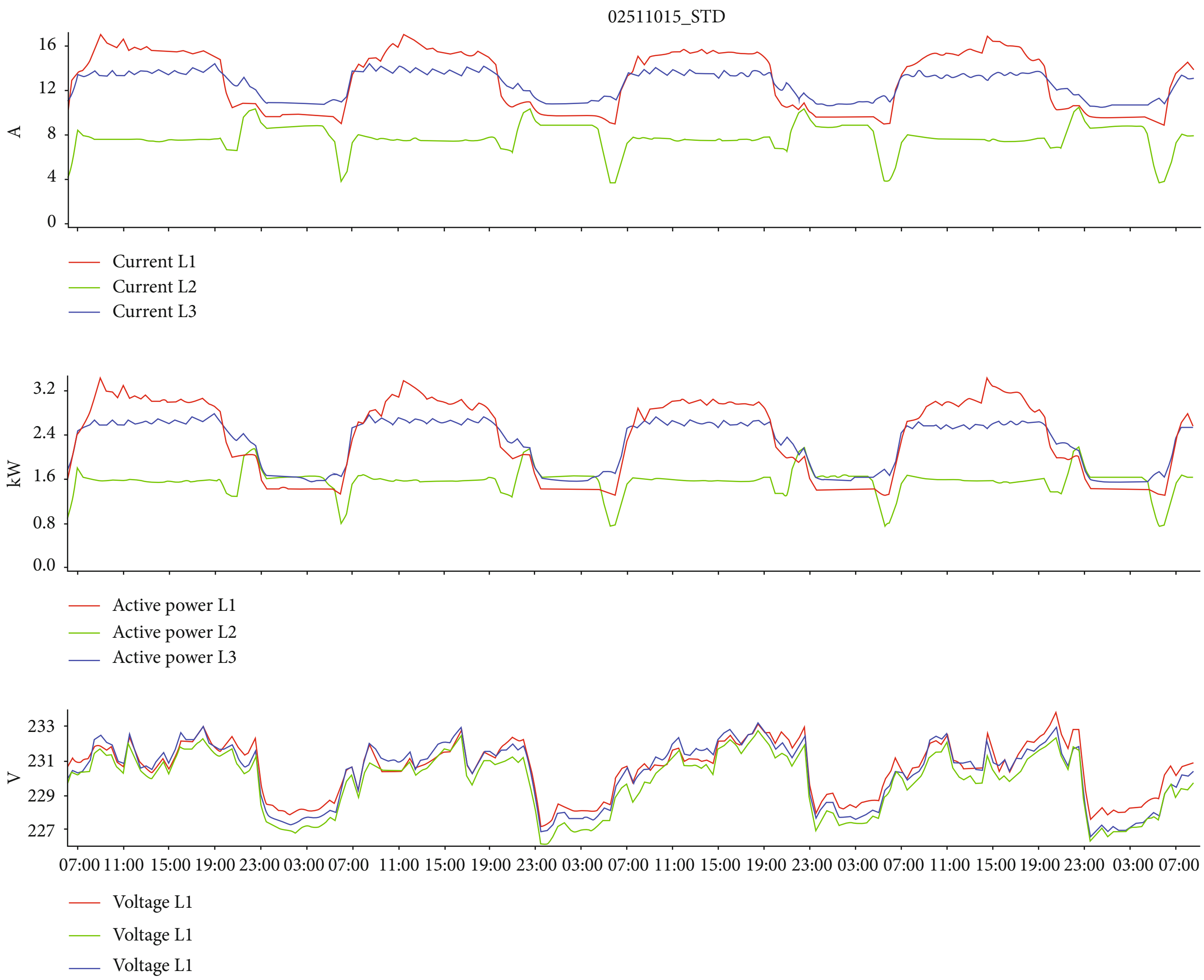


Figure 7: Utility lighting schedule after adjustment.

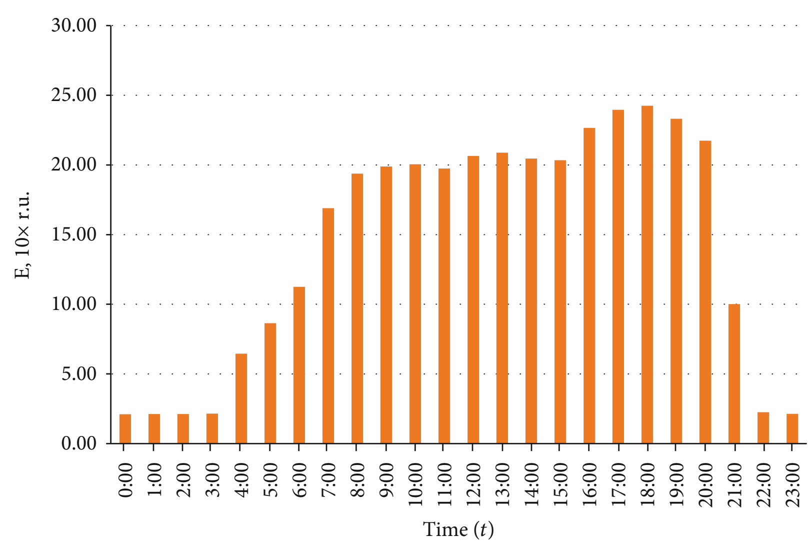


Figure 8: Consumed power of building's communal space lighting.

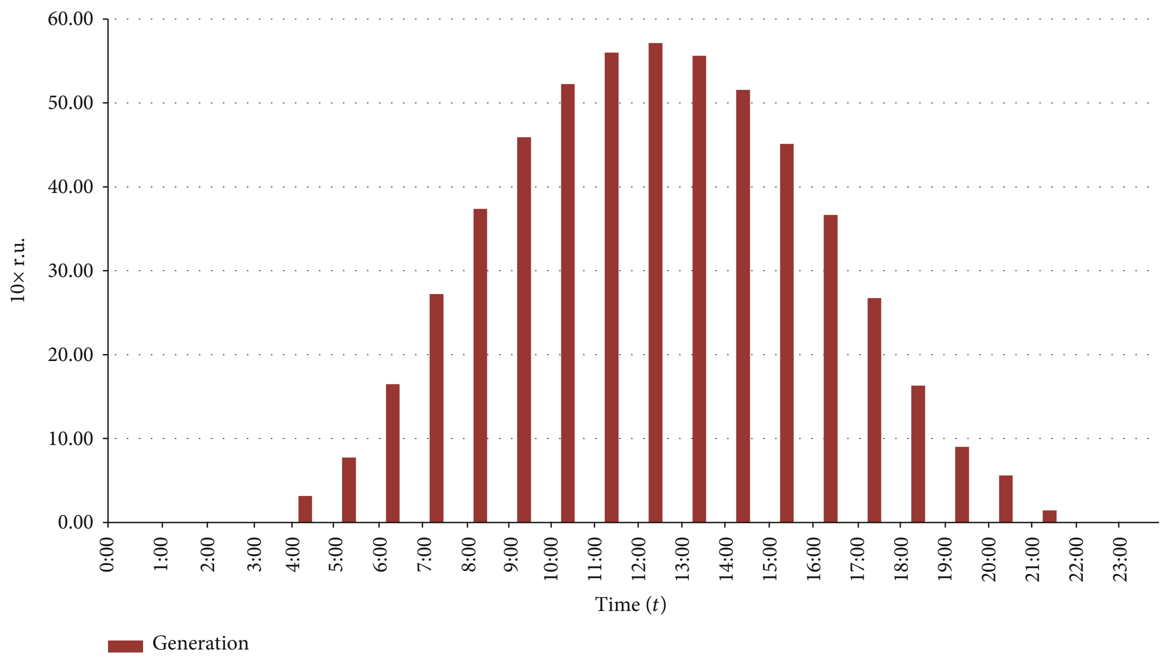


Figure 9: Generated power of PV at the building's roof.

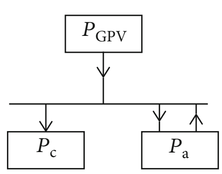


Figure 10: Power balance.

By looking back to Figure 9 and adding the energy produced by photovoltaic elements, it can be seen that in summer months there is potentially a lot of wasted energy, which can be stored. And for the time of the year when there is not enough solar energy to cover the whole daily consumption, it can be used to shave off the demand peaks.

The minimum storage capacity can be calculated, using the following procedures:

(i) For consumption and generation graph, both producing functions $P_{PV} = f(t)$ and $P_c = f(t)$ can be found, see Figure 11

(ii) Two intersections can be found

(iii) Three regions P_{st1}, P_{st2}, and P_{st3} can be separated for integration operations

(iv) The sum of these areas (13) is the minimum storage capacity of the needed battery storage

$$P_{st.sum} = P_{st1} + P_{st2} + P_{st3}. \tag{13}$$

Individual areas of the graph can be found using equations (13) to (14).

$$P_{st1} = \int_a^b P_C(t)dt - \int_a^b P_{pV}(t)dt, \tag{14}$$

$$P_{st2} = \int_c^d P_C(t)dt - \int_c^d P_{pV}(t)dt, \tag{15}$$

$$P_{st3} = \int_d^a P(t)dt, \tag{16}$$

where a is the sunrise time $t = t_{sunrise}$, b is the first intersection of functions P_C and P_{pV}, c is the second intersection of functions P_C and P_{pV}, and d is the sunset time $t = t_{sunrise}$ (Figure 12).

The calculation should be done for summer months to fully consider the maximum generating potential of the solar panels. At the same time, equation (17) must be considered:

$$P_{st.summ} \cdot k_{loses} \leq P_{OG}, \tag{17}$$

where

$$P_{OG} = \int_b^c P_{pV}(t)dt - \int_b^c P_C(t)dt \tag{18}$$

is denoted as the maximum overgenerated power.

The k_{loses} coefficient considers conversion and other loses.

The building in question has already taken steps to decrease the usage of electrical energy for communal space lighting, but further improvements are possible. The usage of direct current (DC) and wireless dimming sensors can bring great benefits.

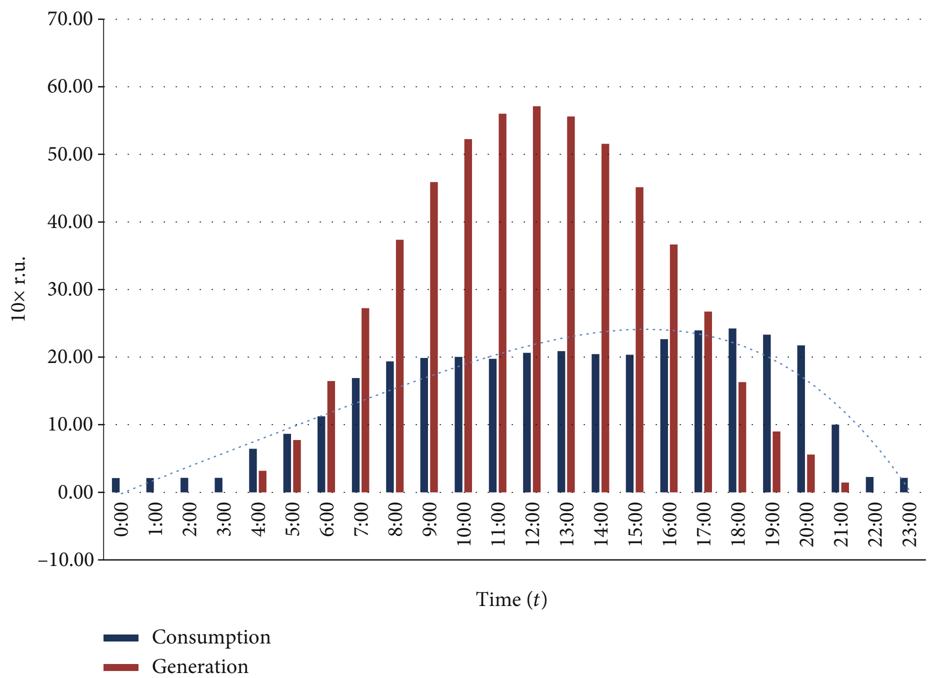


FIGURE 11: Consumption and average square value of power generated in summer months.

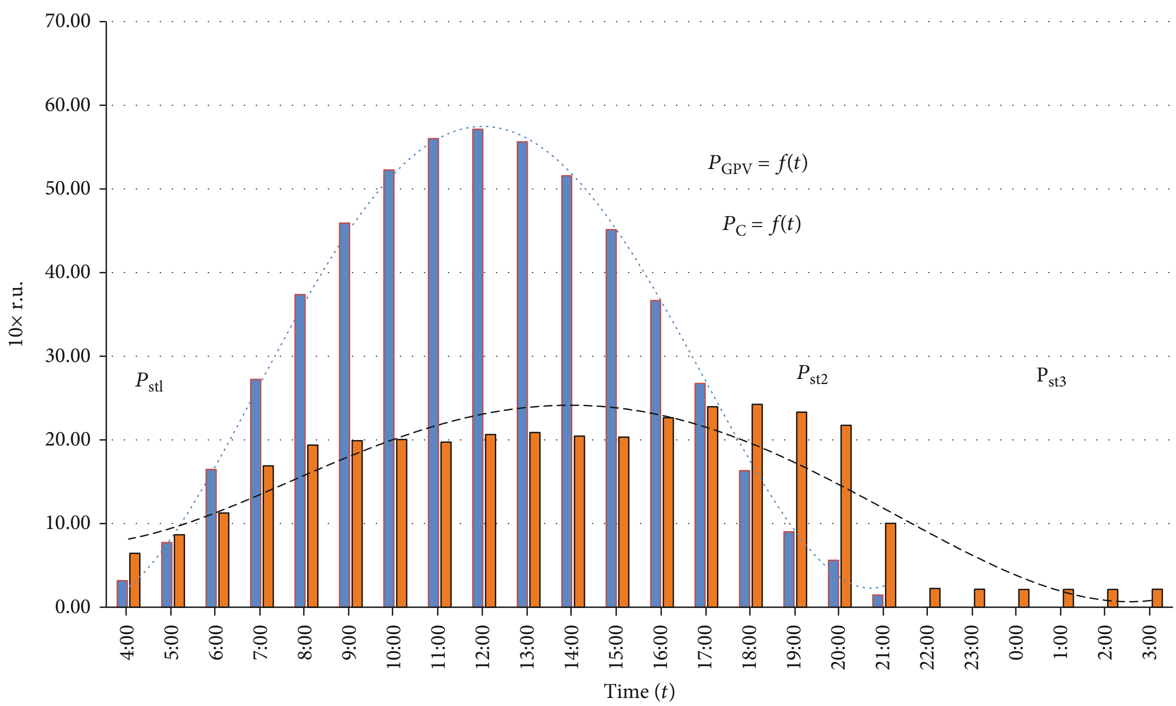


FIGURE 12: Representation of areas to be calculated.

6. Repayment Calculation

Such a repayment calculation is not permissible, as the annual profit will be different, because the amount of electricity produced will vary from year to year, as well as the price of electricity will be different. At the same time, the manufacturer of solar panels indicates a decrease in the panel's work ratio over time (no more than 10% after 10 years of operation and no more than 20% after 25 years of operation).

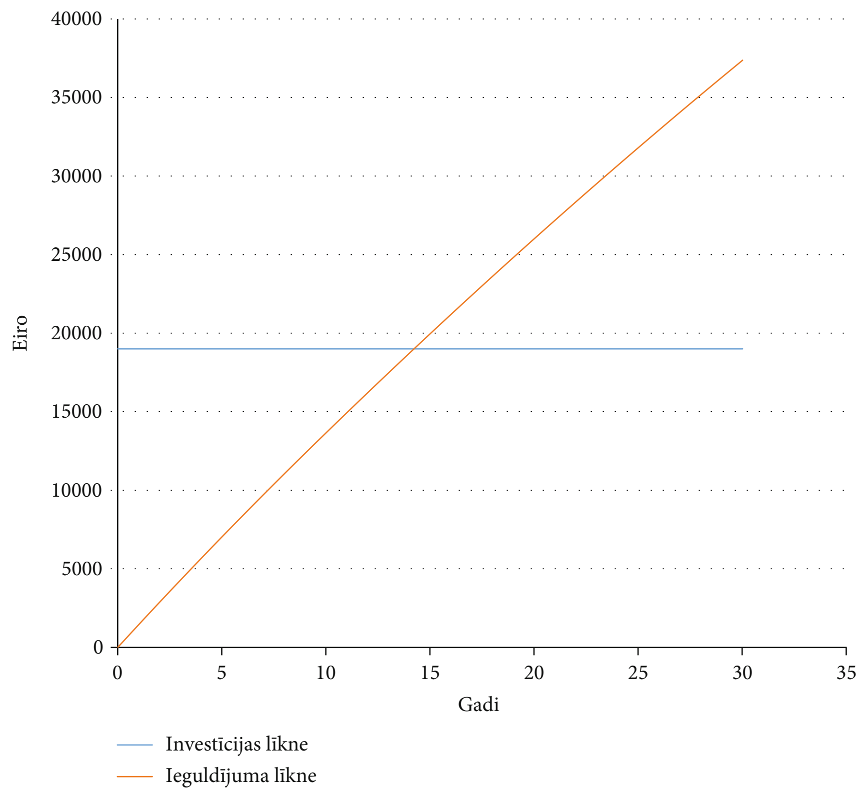


Figure 13: Repayment schedule.

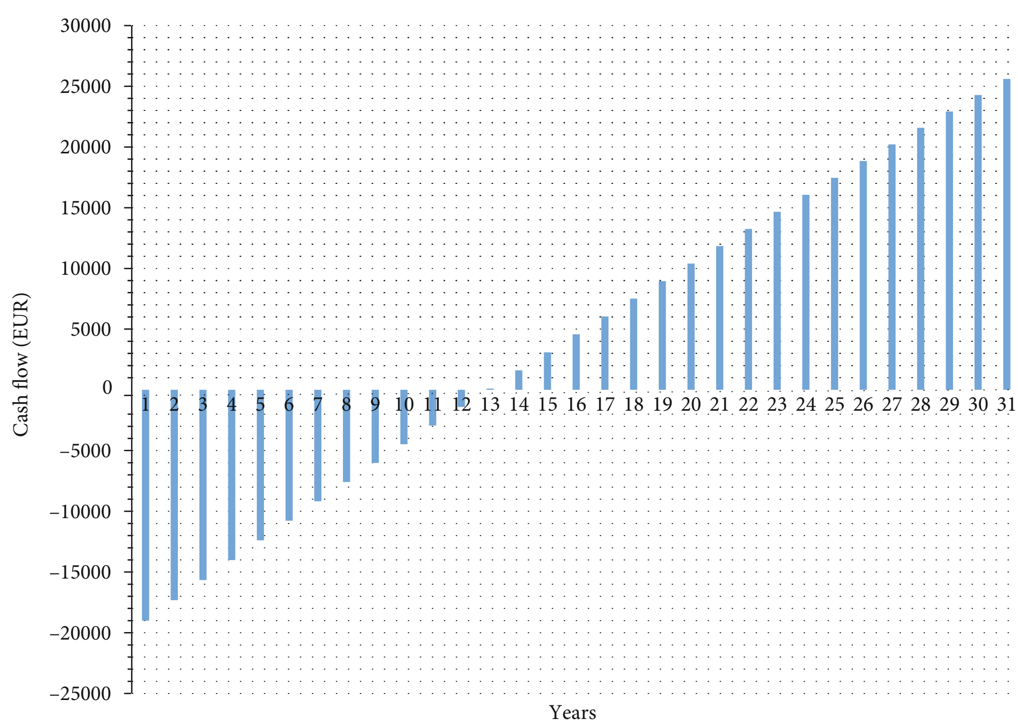


Figure 14: Cash flow schedule.

Therefore, a formula that takes into account discount rates will be applied:

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{\mathrm{CF}t}{(1+i)^{t}}, \tag{19}$$

where NPV is the current net value, i is the discount rate, CFt is the incoming cash flow during the period t, n is the repayment deadline, and t is the period of time [10].

During the year, the solar panel produces a maximum of 11970 kWh at a constant electricity tariff (€ 0.14/kWh), which means annual profits will be approximately € 1600 with a decrease every year thereafter. In light of this, we will construct the investment repayment schedule (Figure 13).

As the schedule shows, the investments will be paid back in 12-13 years, which is to be considered an acceptable indicator. Given the constant rise in electricity prices, investments can be paid even more quickly (Figure 14).

The calculation of the total payment amount is based on the following formula [13]:

$$Y = \frac{D(i/m)}{1 - 1/((1+(i/m))n \cdot m)}, \tag{20}$$

where Y is the monthly payment amount, D is the amount of a loan, i is the interest rate, m is the number of interest accruals during the year, and n is the loan maturity in years.

7. Conclusion

Choosing the right size for PV panel quality, quantity, angle, and energy storage in the photovoltaic system can prove itself to be difficult, especially in Baltic region countries, where the initial investment can be expensive and should be considered.

In this paper, the authors have looked into a way to calculate the needed storage capacity on the basis of potential PV system and existing power consumption for communal space lighting system.

Future work will incorporate other factors, such as the usage of DC power supply to help reduce the communal space's illumination power consumption, in turn helping to reduce the needed PV generating power and energy storage.

The usage of direct current (DC) and wireless dimming sensors can bring great benefits. The next optimization step is the possibility to combine local DC lighting distribution, avoiding the voltage conversion loses in LED luminaires.

Data Availability

Unfortunately, the PV measurement data used to support the findings of this study will not ever be made available because all those are confidential information which we have no right to disclose. We can present only a link to the site https://www.csb.gov.lv/en from which the statistical data was obtained.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] http://www.datacenterdynamics.com/content-tracks/design-build/apple-reaches-100-renewable-energy-across-all-data-centers/74708.fullarticle.

[2] A. Polman, M. Knight, E. C. Garnett, B. Ehrler, and W. C. Sinke, "Photovoltaic materials: present efficiencies and future challenges," *Science*, vol. 352, no. 6283, article aad4424, 2016.

[3] R. Fares, *The price of solar is declining to unprecedented lows*, Scientific America, 2017, https://blogs.scientificamerican.com/plugged-in/the-price-of-solar-is-declining-to-unprecedented-lows/.

[4] http://www.ingdep.lv/lv/Saules-lenkis-virs-horizonta-Latvija.

[5] https://www.energy-charts.de/energy_pie.htm.

[6] http://solargis.com/products/maps-and-gis-data/free/download/europe.

[7] O. Yehezkeli, R. Tel-Vered, J. Wasserman et al., "Integrated photosystem II-based photo-bioelectrochemical cells," *Nature Communications*, vol. 3, no. 1, 2012.

[8] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php.

[9] http://circutor.com/docs/FT_CIR-e3_EN.pdf.

[10] B. V. Lukutin, S. G. Obukhov, and E. B. Shandarova, *Autonomous Power Supply from the Micro Hydro Power Station*, STT, Tomsk, Russia, 2001, http://window.edu.ru/catalog/pdf2txt/252/75252/55909.

[11] T. Huld and E. D. Dunlop, *PVGIS*, European Commission, Joint Research Centre Institute for Energy and Transport, Renewable Energy Unit, 2012.

[12] I. O. Muravlev, M. A. Surkov, E. V. Tarasov, and N. F. Uvarov, "Fuse selection for the two-stage explosive type switches," *IOP Conference Series: Materials Science and Engineering*, vol. 189, article 12004, 2017.

[13] https://www.citadele.lv/.