DE GRUYTER Open Phys. 2019; 17:307–312

Research Article

Paweł Węgierek and Justyna Pietraszek*

Analysis of electricity generation efficiency in photovoltaic building systems made of HIT-IBC cells for multi-family residential buildings

https://doi.org/10.1515/phys-2019-0032
Received Feb 24, 2019; accepted Apr 26, 2019

Abstract: The purpose of this article is to analyze the efficiency of electricity generation in photovoltaic systems located on the building made on the basis of HIT-IBC cells for multi-family residential buildings. The comparative analysis of the efficiency of electricity generation by photovoltaic (PV) installations made of two cell types - Heterojunction with Intrinsic Thin-layer-Interdigitated Back Contact (HIT-IBC) and classical mono-crystalline silicon (mono-Si) - showed that the efficiency of HIT-IBC cells is 60% higher. These cells were selected for use as photovoltaic systems located on the building to cover the demand for electricity through an exemplary multi-family residential building, consisting of 35 apartments divided into two, three and four-person households. Considering the previous calculations, in which it was shown that a PV installation made of HIT-IBC cells (PV1) is able to generate 192,75 kWh/(m^2·y), annual electricity production was calculated by the indicated photovoltaic installation. It was found that the photovoltaic installation located on the roof of the building, based on HIT-IBC cells, will allow to cover the total electricity demand by a selected multi-family building. In addition, the installation's payback period of 9 years was calculated, which takes a high place in the lifespan of photovoltaic installations of 20-25 years and thus ensuring the economic efficiency of the adopted technical solutions.

***Corresponding Author: Justyna Pietraszek:** Lublin University of Technology, Department of Electrical Devices and High Voltage Technology, ul. Nadbystrzycka 38A, 20-618 Lublin, Poland; Association for Innovative Solutions in Power Engineering, ul. Stefczyka 32, 20-151 Lublin, Poland; Email: j.pietraszek@pollub.pl
Paweł Węgierek: Lublin University of Technology, Department of Electrical Devices and High Voltage Technology, ul. Nadbystrzycka 38A, 20-618 Lublin, Poland; Association for Innovative Solutions in Power Engineering, ul. Stefczyka 32, 20-151 Lublin, Poland; Email: p.wegierek@pollub.pl

Keywords: photovoltaic systems efficiency; energy saving buildings; HIT-IBC solar cell; electricity generation; electricity demand

PACS: 88.40.mr, 88.40.H-, 88.05.-b, 88.40.hj, 88.05.Bc

1 Introduction

Increasing electricity prices mean that the cost of using electricity receivers is the largest percentage of household budget spending in modern households. In order to pre-estimate electricity consumption in households, reference quantities should be used given in the study by the Baltic Energy Conservation Agency SA as part of the European Commission's program called "Electricity Efficiency (EL-EFF) Region - Improving Electricity Efficiency in 8 European Regions" [1]. The most important parameters needed to carry out the analysis of electricity demand include: the area of the flat, the number of people living in the household, the basic features of the building and the furnishing of rooms with electrical equipment. The analysis of the demand for electricity, for the analyzed multi-family residential building with calculations, was made taking into account the number of people living, divided into two-, three- and four-person households. The presented methodology is in line with the method proposed by the Central Statistical Office, which systematically conducts surveys of household budgets in Poland [2].

The analysis was made on the basis of the laboratory results presented in the previous article [3]. The aim was to present a comparative analysis, taking into account operational conditions, ensuring maximum efficiency of photovoltaic systems located on the buildingbased on two photovoltaic cell technologies: PV1 – HIT-IBC cells based on monocrystalline silicon and PV2 – classic mono-Si cells [4]. In order to carry out the analysis, measurements were made taking into account the influence of the working temperature and the tilt angle of the cells and the intensity of solar radiation [5].

2 Experimental procedures

A comparative analysis of the efficiency of electricity generation by building photovoltaic installations made of two types of cells - HIT-IBC (PV1) and classic cells of monocrystalline silicon (PV2) was carried out. The analysis was based on the results of measurements of both types of cells in laboratory conditions (Figure 1) [6]. Then, it was related to the actual environmental conditions corresponding to the location of the installation in Lublin, assuming that the installation area of both installations is the same. The first tested sample was a HIT-IBC cell, labeled as PV1, produced by the SunPower, with a surface of 0.0153 m^2, dimensions 125×125 mm and with efficiency level of 22,5%. The second examined sample included in comparative analysis was a silicon-based solar cell, labeled as PV2, manufactured by EverbrightSolar Company, with a surface of 0.0239 m^2, dimensions 156×156 mm and efficiency level of 18,5% [3]. The main feature of the laboratory stand was the Discovery DY600C climatic chamber, cooperating with auxiliary equipment such as a pyranometer, solar simulation system and a computer with software specially created for testing. These cells were tested at temperatures in the range of -20°C to 100°C in increments of 5°C for various angles of inclination of solar cells from 0° to 60° with a graduation of 5°, in each case for nine intensity of radiation from 200 W/m^2 up to 1000 W/m^2 [7]. Further analysis of energy generated by installations located in Lublin with solar cells located at an angle of 30° was carried out, which corresponds to the value used in the design of solar systems in Lublin. The data used for calculations included average values of sun intensity and the number of hours of sunshine per day, corresponding to particular months of the year and the maximum cell power for system operation temperature, according to data from the Lublin-Radawiec meteorological station [8]. The analysis showed that the efficiency of installations with PV1 cells is 60% greater than that of installations with PV2 cells. The calculations showed that the PV installation made of HIT-IBC cells is capable of producing 192,75 $kWh/(m^2 \cdot y)$, while the installation made of traditional monocrystalline cells generates only 120,02 $kWh/(m^2 \cdot y)$.

It follows clearly that the use of the PV systems, made of HIT-IBC cells, fits right in with the idea of energy efficient building while ensuring economic efficiency of the adopted technical solutions [9]. These cells have been selected for use as photovoltaic systems located on the building to cover the demand for electricity through an exemplary multi-family residential building, consisting of two, three and four-person households. The total number of

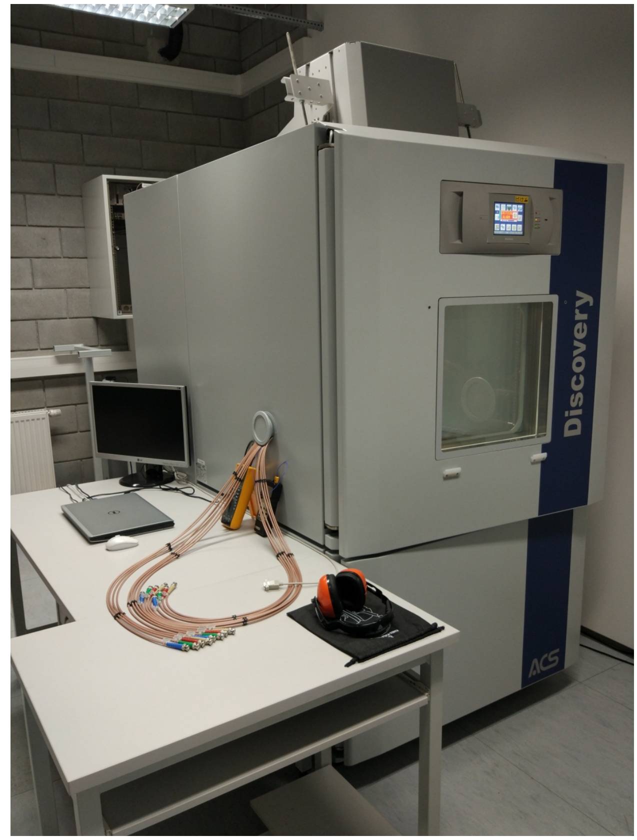

Figure 1: Discovery DY600C climate chamber

apartments is 35, which will be inhabited by a total of 90 people. The place for the photovoltaic installation consisting of modules made of HIT-IBC cells will be the roof of the building with a total area of 508,2 m^2 [10].

In order to best estimate electricity consumption in households depending on the number of people, it is necessary to know the electrical equipment used in home use and their parameters. Information on electricity consumption by individual electrical equipment is placed on the energy label specified by the manufacturer, which contains the data on the name and model of the device, as well as energy efficiency classes [11].

The higher the class, the more energy-efficient and economical the device is. There are seven main groups from A to F, which classify devices in terms of their consumption of electricity. The letter A corresponds to the lowest electricity consumption, so that the device is more energy-efficient, while the letter F is the least economical equipment in operation. Devices that allow a high degree of energy savings are classified as "A +" or even "A +++" classes [12].

Table 1: The division of selected devices existing in households depending on the energy classes and type of consumption

The type of device [-]	Energy class [-]	Electric energy usage [kWh/y]			Type of consumption [-]
The type of apartment		*4-person*	*3-person*	*2-person*	
Fridge	Class A		*320*		High
	Class A++		*200*		Average
	Class A+++		*170*		Low
Dishwasher	Class A+	*260*	*195*	*65*	High
	Class A++	*234*	*175*	*58,5*	Average
	Class A+++	*182*	*136*	*45*	Low
Washing machine	Class A+	*156*	*104*	*52*	High
	Class A++	*140,4*	*93,6*	*46,8*	Average
	Class A+++	*109,2*	*72,8*	*36,4*	Low
Vacuum cleaner	Class A		*52*		High
	Class A+++		*25*		Average
	Class A+++		*25*		Low

3 Results

Analysis of residential divided on two, three and four-person households, was carried out for three levels of electricity consumption: high, medium and low. For each of these stages, 20 household appliances and radio/television (RTV) equipment with variable energy classes were specified. High consumption is characterized by equipment with the lowest energy efficiency classes, medium equipment used for average consumption, while low energy consumption uses the most energy-efficient equipment.

As a device with a changing energy class, a fridge, a dishwasher, a washing machine and a vacuum cleaner were specified. The number of people in the apartment determines the time of use of these devices, which translates into the electricity they consume and generated annual usage time. The smaller the number of people, the lower the use of equipment, and thus the greater savings from the electricity consumed. For other devices, the service life does not depend on the number of people, and the differences between energy classes in the consumption of electricity are so small that they have not been taken into account. Detailed information on the selected household appliances can be found in the following Table 1.

Comparing three types of flats, one can notice a correlation between the number of people in the household and the demand for electricity. The fewer people are in a given apartment, the lower the electricity they consume. In the case of high consumption, the demand for electricity in relation to a four-person household falls by 12% in three-person flats and by as much as 30% for double-family households.

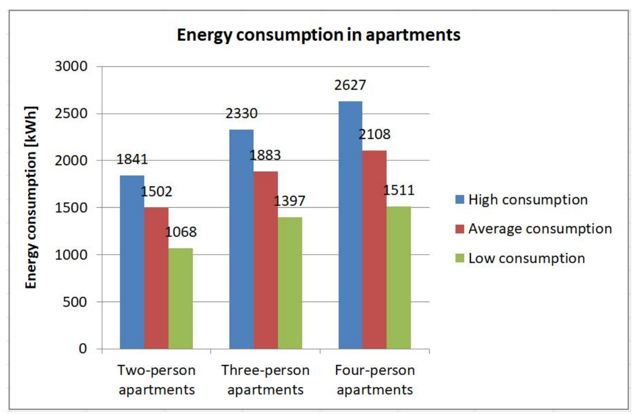

Figure 2: Demand for electricity for three types of apartments [1, 2]

The same applies to medium and low consumption. For average consumption, the percentage decrease is 11% and 29%, respectively for 2-people flat. However, for low power consumption, these values are 9% for apartments for 3 people and 31% for two-person households. These results are presented in Figure 2 [1, 2].

According to the assumptions regarding the number of apartments in the building, an analysis of electricity consumption in four, three and two-person flats was prepared in a multi-family residential building consisting of 35 apartments: 18 apartments × 2 people, 12 apartments × 3 people and 5 apartments × 4 people. Double flats constitute 49% of all flats in a multi-family building, three-person flats constitute 36%, while four-person flats constitute 15%.

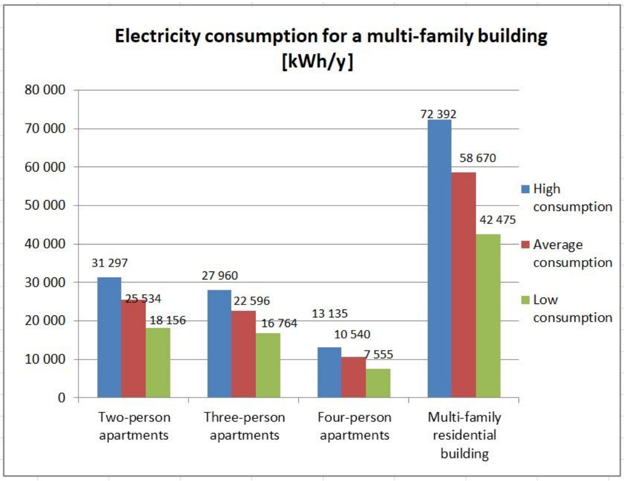

Figure 3: Electricity consumption for a multi-family building divided into two, three and four-person flats

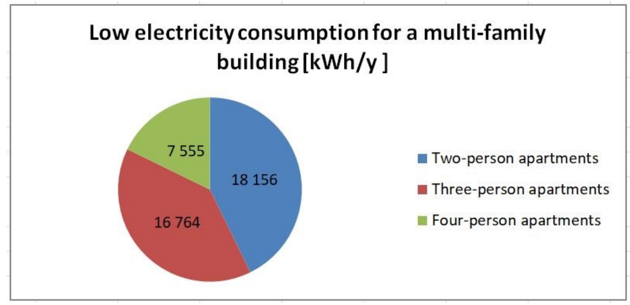

Figure 4: Low electricity consumption for a multi-family building [kWh/y]

Based on the calculations and simulations carried out, total annual electric energy consumption was obtained, which is respectively for double apartments for high consumption, 31 297 kWh/y (for 18 apartments), for average consumption it is 25 534 kWh/y, while for low consumption it is 25 534 kWh/y, whereas consumption is 18 156 kWh/y. This represents 43% of the total electricity consumption of all apartments in a multi-family building. The presented data has been placed in Figure 3.

In the case of three-person apartments for high consumption, this value is 27 960 kWh/y (in the case of 12 apartments), for average consumption it is 22 596 kWh/y, while the low consumption is 16 764 kWh/y. This represents 38% of the total electricity consumption of all apartments in a multi-family building. In quadruple apartments for high consumption, this value is 13 135 kWh/y (for 5 apartments), for average consumption it is 10 540 kWh/y, while low consumption is 7 555 kWh/y. This represents 19% of the total electricity consumption of all apartments in a multi-family building.

Double flats consume the most electricity in the total balance for a multi-family building, despite the smallest unit consumption. This is due to the largest number of such flats in the building. Regardless of the type of consumption, double flats constitute 43% of total electricity consumption, three-person ones - 38%, and four-person apartments - 19%. Detailed results for low electricity consumption are presented in Figure 4 below.

Considering the previous calculations, in which it was shown that a PV building installation with modules made of HIT-IBC cells (PV1) is able to generate 192,75 kWh/(m^2·y), annual electricity production was calculated by the indicated solar installation. A roof for a multi-family building with a total area of 508,2 m^2 has been selected as the site for a photovoltaic installation composed of HIT-IBC cells. The amount of energy that a photovoltaic installation composed of modules with HIT-IBC cells placed on the roof is able to produce is 97 955,55 kWh/y.

To compare the results, the calculations were repeated for installations of modules made of traditional monocrystalline cells (PV2), able to generate 120,02 kWh/(m^2·y). While maintaining the same assembly conditions (roof of a residential building), it was calculated that the amount of energy that a solar installation composed of mono-Si cells placed on the roof is able to produce is 60 994,16 kWh/y. It is clear from this that the efficiency of installations with PV1 cells is 62% greater than the efficiency of installations with PV2 cells, assuming that in both cases the area occupied by the installations is the same.

Assuming the least favorable case, which is the high energy consumption in households amounting to 72 392 kWh/y, the installation based on HIT-IBC technology is able to cover the total energy demand for a multi-family housing building divided into two, three and four-person flats, providing surplus electricity produced equal to 25 563,55 kWh/y. Regarding to the solar installation, which consists of mono-Si cells, the amount of electricity produced during the year is not able to cover the demand in case of high consumption, it would fulfill its role only for low or medium energy consumption in households. The coverage of electricity consumption for a multi-family building is shown in Figure 5 below.

For further considerations, a solar photovoltaic system built using modules of HIT-IBC cells was chosen because it covers the electricity demand in all three variants for the shown multi-family building. A photovoltaic system generating 97 955,55 kWh per year would have to have a power of about 97,9 kWp, so a power value of 100 kW was assumed for the calculation. It was assumed that the cost of 1 kW on grid PV installation is 5 000 PLN/kW, and this cost is affected by the type of construction (flat roof), type

Table 2: Reimbursement of costs for the purchase of a photovoltaic installation based on HIT-IBC cells

Ordinal number [-]	Year [-]	The energy produced [kWh]	The cost of energy saved [PLN]	Cost of purchase [PLN]
1	2018	97955,55	58773,33	500 000,00
2	2019	195911,1	117546,66	500 000,00
3	2020	293866,7	176319,99	500 000,00
4	2021	391822,2	235093,32	500 000,00
5	2022	489777,8	293866,65	500 000,00
6	2023	587733,3	352639,98	500 000,00
7	2024	685688,9	411413,31	500 000,00
8	2025	783644,4	470186,64	500 000,00
9	2026	881600	528959,97	500 000,00
10	2027	979555,5	587733,3	500 000,00
11	2028	1077511	646506,63	500 000,00
12	2029	1175467	705279,96	500 000,00
13	2030	1273422	764053,29	500 000,00
14	2031	1371378	822826,62	500 000,00
15	2032	1469333	881599,95	500 000,00
16	2033	1567289	940373,28	500 000,00
17	2034	1665244	999146,61	500 000,00
18	2035	1763200	1057919,9	500 000,00
19	2036	1861155	1116693,3	500 000,00
20	2037	1959111	1175466,6	500 000,00

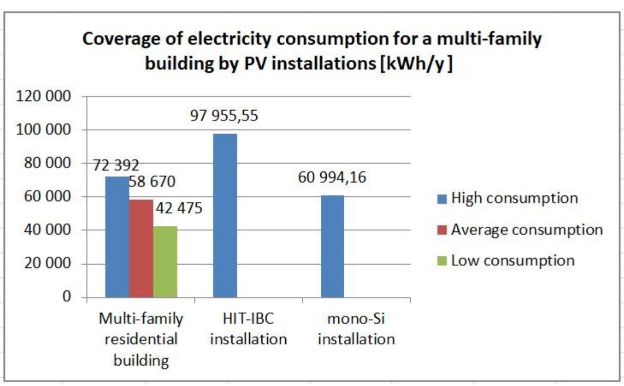

Figure 5: Coverage of electricity consumption for a multi-family building by PV installations [kWh/y]

of roofing, length and thickness of cabling, components used and size of the installation. The cost of a 100 kW photovoltaic installation composed of modules with HIT-IBC cells is therefore 500 000 PLN. To calculate the payback time of the installation, an electricity price of 0,60 PLN/1 kWh and an installation lifetime equal to 20 years was assumed.

The analysis carried out above shows that the return time of a photovoltaic installation based on modules of HIT-IBC cells is 9 years, assuming an annual electricity production of 97 955,55kWh/y (Table 2).

4 Conclusions

The analysis was based on the results of measurements of both types of cells under laboratory conditions, and then referred corresponding to the real environmental conditions for the location of photovoltaic systems (Lublin), assuming that the total area of both installations is the same. The analysis showed that the efficiency of the system with PV1 cells was 60% higher than the installation of PV2 cells. When comparing two types of photovoltaic cells intended for the installation placed on the roof of the building, it clearly follows that the use of photovoltaic systems built of HIT-IBC cells fits into the idea of an energy-efficient building by fully covering the electricity demand of the multi-occupied residential building consisting of two, three - and four-person households. At the same time, it may allow the use of surplus electricity produced for other purposes, including to power streetlights around the facility, or electric heating of nearby pavements or entrance of the building.

In addition, the installation's payback period of 9 years was calculated, which takes a high place in the lifespan of photovoltaic installations of 20-25 years and thus ensuring the economic efficiency of the adopted technical solutions.

Acknowledgement: Publication of this article was funded by Lublin University of Technology, Department of Electrical Equipment and High Voltage Technology.

References

[1] The Baltic Energy Conservation Agency S.A., Save the environment by saving money! - Guide on how to save electricity at home, the EL-EFF Region Project – Raising Electricity Efficiency in 8 European Regions, 2007, 1-13, (in Polish).

[2] Central Statistical Office, Production Department, Energy consumption in households in 2015 – information and statistical study, Statistical Publishing Establishment, 2017, 1-166, (in Polish).

[3] Wegierek P., Billewicz P., Pietraszek J., Analysis of the Influence of Ambient Conditions on Efficiency of HIT-IBC-Based Photovoltaic System Dedicated for Energy Efficient Buildings, in 2017 International Conference on Electromagnetic Devices and Processes in Environment Protection With Seminar Applications of Superconductors (Elmeco & Aos), 2017, 1-4.

[4] Zinchuk O., Drozdov N., Fedotov A., et al., Effect of the hydrogen and argon ion-beam treatments on the structural and electrical properties of Cz Si wafers: Comparative study, Vacuum, Supplement 1, 2009, 83, S99-S102.

[5] Partyka J., Żukowski P., Węgierek P., et al., Temperature dependence ofthe width of the deep-level band in silicon with a high-concentraction of defects, Semiconductors, , 2002, 36 N.12, 1326-1331.

[6] Billewicz P., Węgierek P., Laboratory Stand for Examining the Influence of Environmental Conditions on Electrical Parameters of Photovoltaic Cells, Electrotechnical Review, 2016, 8/2016, 176-179.

[7] Ghani F., Rosengarten G., Duke M., Carson J.K., On the influence of temperature on crystalline silicon solar cell characterisation parameters, Solar Energy, 2015, 112, 437-445.

[8] Madessa H.B., Performance analysis of roof-mounted photovoltaic systems – The case of a Norwegian residential building, Energy Procedia, 2015, 83, 474-483.

[9] Rohatgi A., Meier D.L., McPherson B., Ok Y.W., Upadhyaya A.D., Lai J.H., Zimbardi F., High-throughput ion-implantation for low-cost high-efficiency silicon solar cells, Energy Procedia, 2012, 15, 10-19.

[10] Schmela M. (red.), Global market outlook for solar power 2017-2021, 2017, Brussels, SolarPower Europe.

[11] Brown A.S., Green M.A., Impurity photovoltaic effect: Fundamental energy conversion efficiency limits, Journal of Applied Physics, 2002, 92, 1329-1336.

[12] Cristobal A.B., Marti A., Luque A., Next generation of photovoltaics: New concepts, 2012, Berlin, Heidelberg, Springer-Verlag,.

Abbreviations

PV – Photovoltaic; HIT-IBC – Heterojunction with Intrinsic Thin-layer-Interdigitated Back Contact; mono-Si – Monocrystalline silicon; EL-EFF – Electricity Efficiency; RTV – Radio/ TeleVision;