The Use of Photovoltaic Conversion in Innovative Solutions

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Abstract. The year 2021 is inevitably coming, in which all newly built buildings should meet the standard of almost zero-energy all newly build constructions (nZEB). This means that buildings should have almost zero or low energy consumption. The energy demand should be covered to a very high degree from renewable sources, including renewable energy produced on-site or nearby. One of the renewable that can be used is solar energy, which for the 9th time in a row has achieved the largest share (42.5%) of new investments utilising renewable energy sources. Currently, solar energy is most often used by photovoltaic cells, which converts it into electricity. Over the past 15 years, the accumulated annual growth rate of photovoltaic production has been over 40%, which means that the photovoltaic industry is the fastest growing in the world. The annual capacity of new solar installations installed has increased from 29.5 GWp in 2012 to 107 GWp in 2018. The development of solar technology is huge. Previously known technologies are improving and refined, which stands for that the efficiency of electricity conversion is increasing. New innovative technologies using photovoltaic cells are also emerging. These include cells dedicated to the building facade BIPV, used in louvres of curtain blinds, filling mullion-transom facades, roof skylights or balustrades. NanoPV windows are a new product appearing on the market. This is a product that uses innovative material - quantum dots, i.e. small semiconductors with the sizes of several or several dozens of nanometers, having the ability to absorb and emit electromagnetic radiation. In this work, the authors present the development of photovoltaic technology and the most interesting solutions according to the authors regarding the use of solar technologies.

1. Introduction
From January 1, 2021, in all European Union countries, newly designed and thermomodernized buildings must meet the standard of "almost zero energy consumption" nZEB buildings. Only historic buildings are exempted from the requirements, but in this case, it is worth improving energy efficiency if possible [1-3]. The introduction of this standard is in line with the sustainable development policy, which assumes minimizing the consumption of natural resources, improving the energy efficiency of buildings and the transition from fossil fuels to renewable energy sources. The nZEB standard is set by each member state, adapting it to the economic possibilities [4]. Designing and implementing nZEB buildings with stringent energy efficiency requirements while ensuring comfort will certainly be very difficult at the beginning [5-7]. However, given the gravity of the problem, the introduction of such exacerbations is inevitable.

In the countries of the European Union, 2017 had 215 million residential buildings. In the same year, the housing sector accounted for 27.2% of final energy consumption. The main share in energy consumption is heating (64.1%), followed by the preparation of domestic hot water (14.8%), electricity used for lighting and to power most electrical equipment (14.4%) [8,9]. Over the past 15 years, however, a decrease in the consumption of energy for heating needs and an increase in energy for domestic hot water production has been observed. and lighting and equipment powered by electricity [10]. Natural gas (36%), followed by electricity (24.1%) and renewable energy sources (17.5%) are mainly used to meet final energy consumption for housing needs in member countries. In Poland, the
structure of the share in energy consumption is as follows: heating 65.8%, domestic hot water preparation 16.3%, lighting and eclectic devices 9.6%.

The introduction of the nZEB standard in construction will certainly contribute to a sharp decline in energy needs in this sector. The problem is the huge resources of existing buildings, which still consume a lot of energy. Certainly the systems of financing thermal modernization of buildings introduced by the countries. However, many changes in the sector are needed to build new or upgrade existing buildings to the nZEB standard. The introduction of new products and technologies on the market of building materials can be observed that will help in obtaining appropriate parameters of nZEB buildings [11-14]. However, these technologies must be economically viable for investors. In addition to the need to reduce the energy consumption of buildings, the second very important task is the transition from fossil fuels to renewable energy sources.

The use of renewable energy sources in the last decade has increased by over 20% from 1 140 GW in 2009 to 2 369 GW in 2018. Currently, the most renewable energy comes from wind and sun. In 2018, 42.5% of new investments in renewable energy sources were associated with solar energy. In the same year, the production of the photovoltaic industry increased by 5% and reached a global government production of about 113 GW of solar modules. The price of 1 MWh of electricity generated by the solar installation has dropped from USD 371 to around USD 57 over the years [15]. This trend is caused by the constant development of photovoltaic technologies, which in turn is the reason for the decline in module prices in most markets. Rising electricity prices and falling installation prices mean that solar farms are becoming more and more popular every year. Currently, the payback time of a photovoltaic installation in Poland is 5.5 years, which compared to 2018 when the prices of solar panels in Poland ranged from 6 to 7.5 thousand gross and there was no financial support and electricity was cheaper, it is almost a threefold decrease. The return time for the installation 2 years ago was around 14 years.

2. Photovoltaic technologies and their application
The first solar modules were built in 1954. Their efficiency was very low and reached 4%. Only 4 years later, the technology was refined enough to increase efficiency by 9%. Constant R&D activities within this area allowed for reaching over 20% in present (current year) applies to modules larger than 1.4 m². [16]

The conversion of electricity in photovoltaic cells occurs as a result of the photovoltaic effect. This phenomenon consists in the formation of electromotive force caused by physical phenomena in a heterogeneous environment and consequently, it is a lighting. Centre, in which such an environment can occur is, for example, a joint of two semiconductors, an electrolyte and a semiconductor or also a semiconductor and a metal. The photovoltaic effect occurs in all semiconductors. However, depending on the type, its course has different intensity and depends on different wavelengths of the incident light. Semiconductors are elements whose potential barrier is less than 5 eV [17]. Because energy conversion can take place with the help of various materials and devices of various designs, this technology is widely used. This causes the possibility of continuous development of photovoltaic systems and a decrease in their prices over the years. Currently, the highest efficiency (47.3%) in laboratory conditions are hybrid cells four-junction or more (concentrator). However, their area is between 200-800 cm² [18].

2.1 solar technologies
There are various divisions of photovoltaic cell technology, and the scheme developed by the PVthin Scientific Council was used to present them [19]. Depending on the technology, the cells are divided into wafer-based, silicon thin-film hybrid and thin-film cells.
2.1.1 Wafer-based cell. Wafer-based cells are the first photovoltaic technology created. They are so-called 1st generation cells that rely on crystalline silicon and the use of p-n joints. There are two groups here: monocrystalline and polycrystalline cells. The former is the oldest and most common technology. They consist of a pure silicon crystal characterized by a single continuous structure. The main advantage of this type of cells is efficiency reaching 15-20%. However, it is associated with a complicated production process that generates high financial outlays. The second group are cells using polycrystalline silicon, which was formed from many single crystals. The production process involves melting silicon into a suitable mould and cutting it into thin plates assembled into one whole. The simplified production process makes this type of cells cheaper compared to the previously discussed. However, because one single crystal is not used for production, the efficiency of this type of cells is lower and amounts to 9-14%. [20-23]

2.1.2 Thin-film cell. Along with the development of photovoltaic technologies, thin-film cell technology has been developed whose semiconductor material is applied in the form of a thin layer and often it is not silicon, but e.g. cadmium telluride (CdTe) or a mixture of copper, indium, gallium and selenium (CIGS). The thin-film cell group consists of conventional thin-film cells of the second generation and "emerging thin film of the third generation". These cells consist of thin layers of semiconductor material with a thickness of 1 to 4 \( \mu \)m, which are deposited on a glass, polymer or metal substrate. Thanks to this it is possible to produce flexible and lightweight constructions used e.g. as building elements. Despite better absorption of solar radiation, these generations have an efficiency of 5-7%. The production costs of this type of cells are lower than in the previously described cases.

Among the cells belonging to the second generation, we can distinguish, among others cadmium telluride (CdTe) and copper, indium, gallium and selenium (CIGS) alloys. CdTe cells are produced on a glass substrate. These cells form one compact structure of black colour. This type of cell works well at high temperatures. CIGS film acts as a direct bandgap semiconductor and forms a heterojunction, as the bandgaps of the two different materials are unequal. Thin-film CIGS cells are deposited on a substrate, such as soda-lime glass, metal or polyimide film, to make contact with the back surface. The entire PV module is made of one cell. [22-25]

The creation of the third generation cells was aimed at developing devices with high efficiency while maintaining low production costs. Unlike conventional thin-film technologies, separate synthesis and deposition steps are often used in this case. This group includes Dyed photosensitive DSC or Dye-Sensitized Solar Cells (DSSC). DSC solar cells are technically and an economically reliable alternative concept for current photovoltaic devices with a p-n connection. Cells of this type are often called photoelectrochemical cells. Energy conversion occurs similar to photosynthesis in plants.

Organic cells (OPV) use materials of organic origin to absorb solar radiation. They can be made in a flexible form, so they can be used in construction.

Perovskite, a naturally occurring mineral made of calcium titanium (CaTiO3), absorbs solar radiation with a wavelength of 300 to 800 nm in a way that allows electricity to be produced. Unlike other materials used in photovoltaics, perovskites can be produced with much less financial expenditure, which is associated with the technological process. The performance of perovskite cells under laboratory conditions reaches 15-20%.

Quantum Dot PV - Cells based on quantum dots is a relatively discovery in solar photovoltaics. QDPV uses small semiconductors, several dozen nanometers in size, capable of absorbing and emitting electromagnetic radiation. At the moment, they are characterized by the relatively low efficiency of
9%, but due to the low costs and the full range of applications, they have great development potential. [26-30].

2.1.3 Silicon thin-film hybrid cell. Thin-layer hybrid cells: tandem or hetero- and Multi-junction are an intermediate group between wafer-based and thin-film cells. They combine silicon technology with a thin film layer with a wide slit band. Hetero and Multi-junction technology refers to cells that use one (hetero) or two and more (multi) stacks of cells with different bandwidths to capture a wider range of light waves. Thanks to this it is possible to achieve higher efficiency. Unfortunately, the technological process is complicated and its costs are relatively high. This group includes CPV concentrators, gal arsenide cells (GaAs), tandem perovskite-silicon and Micromorphous (a-Si/μc-Si). In CPV concentrators, solar energy conversion is the same as in conventional technology. The only difference is the use of the lens and mirror to focus solar radiation on a small area, obtaining a concentration of 2 to 1000 sun (1 sun means 1000 W/m² solar radiation). Systems of this type use non-imaging systems, i.e. they do not reflect the image reflected from their surface, but leave them distorted, which translates into increased efficiency.

Gallium arsenic cells are characterized by high efficiency and a wide range of functionality, have strong absorption properties and a direct spectrum band. GaAs is a complex semiconductor that is great for converting solar energy. These cells use thin absorbing films, but require plates as a matrix for crystal growth.

Micromorphous (a-Si/μc-Si) is a combination of silicon in the form of hydrogenated, amorphous and microcrystalline, which allows the absorption of most of the light spectrum. Most importantly, μc-Si solar cells are less subject to light-induced degradation and show better-stabilized efficiencies as compared to that attainable from a-Si:H devices.

The perovskite/silicon tandems utilize the printing of the perovskite stack on the top layer of silicon cells, which allows for higher efficiencies by absorbing different parts of the light by different layers of the cell. The development of this type of cells is to ensure high efficiency while ensuring low production costs. [29,31-33].

3. The use of innovative solutions in photovoltaic technologies

In the search for new solutions in the field of PV, scientists have developed various methods of obtaining electricity. One such solution is the conversion of thermal energy into electricity using quantum dots. About the use of quantum dots, among others, wrote: Jianqiang Liu et al. Vaishali Sharma Prafulla K. Jha, Suwit Kiravittaya, Fahad Mateen, M. Marandi, Shengzhong (Frank) Liu and Joseph M. Luther. Scientists from the research and development centre of one of the Polish companies presented an interesting application that developed the energy-saving nanoPV window. This product has a transparent solar panel using quantum dots. This glass, apart from generating power, will also be able to emit light in any colour. [34-41]

Other of the innovative solutions are CPV concentrators on which you can find many scientific materials. Tieliu Jiang et al. in his work he describes CPV using a linear concentrator with Fresnel lenses. In the publication of K.S. Reddy finds information on the newly designed two-stage square parabolic CPV panel, whose efficiency is 32, 03%. In the scientific material presented by Shoukat Ali Khan we read about the analysis of a multi-generation system with a CTV/T concentrator and hydrogen storage. The CPV temperature management solution proposed here uses the NBHT nuclear pool. Part of the energy generated by CPV is used to power the electrolyser, which produces hydrogen and oxygen. This solution allows both the production of electricity and heat.

A promising solution was presented by Philipp at al. the highly efficient LCPV concentrator proposed by the authors using both Fresnel lens technology and mirror. A new "biFresnel" ADG
(achromatic doublet on glass) achromatic lens has been developed that has almost the same performance compared to standard SOG modules (silicone on glass). The advantage of the newly developed lens lies in its lower temperature dependence. At present, 3j cells have been used and the obtained performance values have reached 33.3% for mono and 30% for large modules. This technology is very promising. It is estimated that replacing 3j cells with 4j cells will increase yield by 40%. [42-47]

The authors have already written about solar tiles in 1990 and 1997 [48-60]. Therefore, this technology has been known for over 30 years and is constantly being improved at various angles. Photovoltaic panels are subjected to "standard test condition" type tests, which conditions apply to 1000 [W/m²] sunlight and 25°C temperature. Studies carried out on photovoltaic cells have shown that each increase in temperature by 1°C causes a decrease in efficiency by 0.45%. Therefore, scientists are constantly looking for solutions on how it is possible to reduce the temperature of the panels to increase efficiency. Many different ways of cooling PV panels are known in the literature: liquids, air or phase-change materials [50-63]. However, the cooling of solar tiles is new. Research on this solution is carried out by J. Wajs et. al. [56] The solar tile has been equipped with an air cooling system located at the rear of the system. Various depths of cooling channels and various volumetric flow rates were analyzed. The system was subjected to radiation of 900 [W/m²]. It was shown that the best efficiency is achieved with an airflow of 4 m³/h and a channel depth of 25 mm. Under such conditions, the average surface temperature decreased by 6.3 K. The total system efficiency measured as the sum of electricity and heat was 32%. The cooling system proposed by the authors is shown in Figure 1.

![Figure 1. experimental prototype of cooling PV roof tiles](image)

Another interesting solution when it comes to photovoltaic plates are plates that are resistant to high dynamic loads. To date, many solutions of this type have already been described, which have been tested in both laboratory tests and on a real object [57-62]. The latest research in this field was presented by scientists from China. The authors propose the creation of pavements and bicycle paths in Hong Kong from PV tiles. To this end, a prototype of PV plates was developed, which was subjected to both laboratory tests and in real conditions. Research overlapped with simulations of a previously developed mathematical model. An important fact presented by scientists is that the glass material that was used as a protective barrier of cells has mechanical strength and durability similar to concrete. Studies have shown that even after damage, glass is one compact element and does not break down into smaller parts, moreover, damage to the glass does not affect the work of cells that still generate electricity. The tiles can be made of non-slip and heat-resistant materials, which is important in the case of roads or pavements. [63]

Another solution applies to tandem cells. These cells arise from the assembly of several layers absorbing light. Each of them works effectively in different ranges of light wavelength, thanks to which they can generate electric current much more efficiently than traditional photovoltaics. Tandem devices that combine perovskite and silicon cells have great potential to achieve efficiency above 30% while
maintaining costs at an optimal level. F. Sahli et al. have developed a new way of stacking cells that achieves the conformal growth of many compounds with controlled optoelectronic properties directly on the microns of textured monocrystalline silicon. The development of this method allowed achieving steady-state efficiency of 25.2%. [64]

Another branch of photovoltaics is BIPV technology, which is becoming increasingly common, new and improved solutions are emerging. BIPV technology in his articles mentions, among others Hameed Alrashidi, which proposes a new hybrid BIPV/T solution. In winter, this system will adopt the BIPV/Air mode to provide space heating and electricity generation. For the rest of the year, the system works in a BIPV/water system, producing hot water and electricity at the same time. Experimental studies have shown that in summer the daily electrical power and efficiency are 0.12 kWh and 7.6%, respectively, while in winter 0.65 kWh and 12.5%. In addition, in summer the water tank heats up to over 40 °C, which allows it to be used for utility purposes. whereas in winter this solution allows obtaining an average experimental room temperature of 18.6 °C. [65-68]

4. Conclusions

Striving for buildings to achieve an almost zero-energy standard, which means almost zero or low energy consumption, is a huge challenge for the whole world. Ensuring the use of energy from renewable sources is inevitable. To this end, scientists around the world are improving existing ones and creating new solutions that make the most of the energy from the sun, wind or earth. A very wide range of research is carried out in the field of photovoltaics, which means that this technology is the fastest-growing among solar technologies. Recent research has achieved record efficiency of hybrid cells of 47.3%. At the moment, this efficiency applies only to laboratory conditions, but it shows that photovoltaics has a very large potential for development and achieving high efficiency. Experiments are being carried out in every corner of the world to develop new materials or technologies that have a high potential for future use.

New solutions with high efficiency mean that older technologies, not necessarily worse, are becoming cheaper and thus more willingly bought. We are heading towards a new era where conventionally energy sources are replaced by "green" technologies.

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