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Future of Architecture: Buildings as Power Plants

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Abstract: After the energy crisis in 1970s, buildings began to be used as a platform for the elements which produce energy from renewable energies to return them into energy producing power plants. This is a safe, clean and economic way to produce energy since the energy is produced where it is needed and they use renewable energy resources. So, it promises hope for the future energy production. Therefore, the aim of this study is to examine buildings which produce electricity by using renewable energy resources and to show that this is one of the safest, cleanest and most economic ways to be used to produce energy in the future. This is done by describing power plants and how buildings are used as power producing stations by the use of renewable energy resources or other energy producing materials, then by examining case studies which are constructed and already being used, case studies which are just a design that have not yet been constructed, and by making projections to the future energy producing techniques that are just a proposal in 2021. In the conclusion, buildings are proposed as the future power plants, either here on earth or on another planet like Mars.

Key words: Energy efficiency, sustainable architecture, power plants, renewable energy resources, alternative energy resources, building envelope.

1. Introduction

"Learn from yesterday, live for today, hope for tomorrow. The important thing is not to stop questioning" is said by Einstein [1].

"A power station or power plant is a facility for the generation of electric power" [2]. Power plants are essential for the industrialization in our civilized world. Since the industrial revolution, electricity production became an essential necessity for our everyday life. Power plants mostly burn fossil fuels to generate power, but this results in a great amount of greenhouse gas release and this release leads to global warming and climate change .

Nuclear power plants do not release greenhouse gases, but they are extremely dangerous because they give more harm to the environment than fossil fuel power plants if an explosion or meltdown occurs as has happened in Chernobyl Nuclear Power Plant in 1986, or in Fukushima Nuclear Power Plant accident after a tsunami in March 2011. Nowadays some power plants use renewable energy resources which are environment friendly. Moreover, there is a new phenomenon which is to produce energy with the use of renewable energy resources as integrated on the buildings. In this use, buildings in which we live turn into power plants, where there is no need to carry the energy produced. Energy is produced where it is needed. This is very efficient since settling on Mars is being designed today and competitions for producing building projects on Mars are being held by (National Aeronautics and Space Administration) NASA. Lately a competition was opened in February 2019 for the design of a greenhouse to be constructed on Mars [3]. Building integrated renewable energy resources would be very useful in buildings on Mars.

As Einstein quoted, it is necessary that we learn from yesterday—from the accidents we had in the past, live according to that—not use power plants that are harmful and dangerous to the environment to today, and in this way hope for tomorrow to have a better life

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here on earth, or even on Mars or another planet in the universe. Therefore, the aim of this study is to examine buildings which produce electricity by using renewable energy resources and to show that this is one of the safest ways that could be used to produce energy in the future. This is done by describing power plants and how buildings are used as power producing stations by the use of renewable energy resources or other energy producing materials, then by examining case studies which are constructed and already being used, case studies which have not yet been constructed and making projections to the future energy producing techniques that are just a proposal in 2021. In the conclusion, buildings are proposed as the future power plants, either here on earth or on another planet like Mars.

2. Use of Renewable Energy in Architecture

With the oil crisis in the 1970s, it has been clear that fossil fuels are limited. It was like a rehearsal of what would happen when fossil fuel reserves end up. This was also the beginning of the search for new and renewable energy resources because of the fact that environmental problems were recognized at nearly the same time with the energy crisis.

Beginning with the industrial revolution, humans use fossil fuels heavily. Fossil fuels emit a lot of greenhouse gases. Greenhouse gases lead to global warming and environmental pollution. Before the industrial revolution, resources were being used slowly and therefore wastes were returned into resources again by the ecosphere in this time period. But after the revolution, use of resources became incredibly fast, but the speed of returning the wastes into resources was just the same as before. Therefore, resources became to come to an end and wastes began to pile up in the ecosphere. This especially applies to energy resources. Therefore, new and renewable energy resources which are environment-friendly began to be searched and used especially in architecture and on the buildings.

There are many renewable energy resources that are being used in the world. These are:

- solar energy;
- wind energy;
- bioenergy: biomass, biogas (trees, methane from wastes);
- geothermal energy;
- environmental heat resources (earth, underground water, surface water, air);
- hydro energy;
- wave energy;
- tidal energy.

Most of these resources are being used as the resource of power plants while some of them are suitable to be used in architecture. Renewable energy resources which can be used in architecture are:

- solar energy;
- wind energy;
- bioenergy: biomass, biogas;
- geothermal energy;
- environmental heat resources.

Among these energy resources, geothermal energy and environmental heat resources are very difficult to integrate with the buildings. Therefore, the first three of these energy resources are examined in this study. Additionally, there are some other energy resources which could be used in the design of the buildings like piezoelectric materials, pyroelectric materials and thermoelectric materials. They could also be used to help buildings produce energy. They are also examined in this study as different energy resources. They are materials, but they can produce electricity under certain circumstances.

3. Examination of Buildings as Power Plants

Power plants are facilities that turn energy in different forms into electricity or heat which could be used in industry or buildings. Each power plant is designed according to different resources used in energy conversion. But the content of this study is the buildings as power plants in which people live. If all the buildings in the world could produce the energy they required with the use of renewable energy resources, there would be no need for dangerous or non-environment-friendly power plants. Therefore, buildings as power plants whose main function is not producing energy (but do as a side-function) are examined in this study. These buildings generally use renewable energy resources.

3.1 Buildings That Produce Energy from Solar Energy

Buildings can produce energy from solar energy in two ways: passive and active. Passive use of solar energy includes only design principles; therefore energy conversion is not much as in active systems, because there is no technology in passive use. Therefore, active use of solar energy and in particular photovoltaic (PV) component use (electricity production from solar energy) is examined in this study in order to show that buildings can (and they do) produce energy they demand (and in some cases more than their demand) from solar energy themselves. So they are actual power plants. This kind of applications is called Building Integrated Photovoltaics (BIPV). This type of buildings already exists today.

3.1.1 Solar-Fabrik Administration Hall

Table 1 Information of Solar-Fabrik Administration Hall.

Building's name	Solar-Fabrik/Manufacture Hall for Solar Panels
Location	Freiburg, Germany
Architect	Rolf + Hotz, Freiburg Fred Rolf, Matthias Hotz
Construction date	1999
PV manufacturer	Solar-Fabrik GmbH
PV type	Mono-crystalline silicon
PV system power	56.5 kWp
Electricity production	40 MWh/year
Total PV area	450 m^2

This building is the administration part of the manufacture factory of solar panels of the firm. It is used to demonstrate the use of PV panels which they manufacture. PV components are used at different parts of the building as seen in Figs. 1 and 2; on the roof, in the façade as integrated, as shading devices and on an advertisement screen on which the firm's name is written.

Solar-Fabrik building is a zero-emission building that produces PV components with the use of 56.5 kWp installed PV capacity and a rapeseed oil CHP (combined heat and power) capacity. It has the capacity to produce 40 MWh/year with 450 m^2 PV area. Installed PV system produces nearly 25% of the building's energy requirement. Moreover, rapeseed oil CHP produces required thermal and electrical energy with 130 MWh electricity and 180 MWh thermal powers. In this way, Solar-Fabrik is a production hall which is driven by only renewable energy [4].

Fig. 1 View of the Solar-Fabrik Administration Hall (Müjde Altın, August 2006).

Fig. 2 Detail of PV components (Müjde Altın, August 2006).

3.1.2 Fraunhofer Institute Building

Table 2 Information of Fraunhofer Institute Building.

Building's name	Fraunhofer Institute Building
Location	Freiburg, Germany
Architect	Dissing+Weitling Arkitektfirm, Soren Andersen, Kopenhag
Construction date	2001
PV type	Poly-crystalline silicon
PV system power	20 kWp
Electricity production	15 MWh/year
Total PV area	200 m^2

Fraunhofer Institute is an institute in Freiburg, Germany where research is going on about solar architecture and PV components while PV components are being used on the building itself. PV components are being tested on the building. The building has 3 storeys and 3 wings. PV components

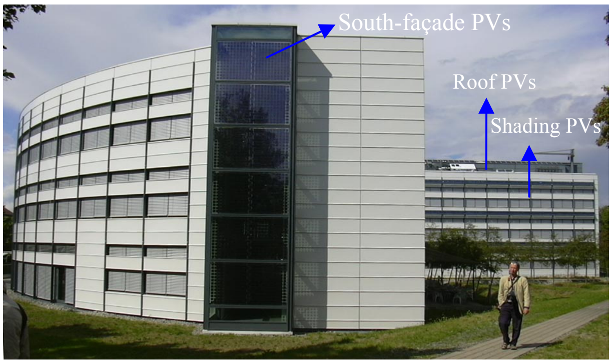


Fig. 3 View of Fraunhofer Institute building with PV components (Müjde Altın, August 2006).

Fig. 4 View of Fraunhofer Institute building with PV components over the windows and on the roof of southern wing (Müjde Altın, August 2006).

Table 3 Information of Fraunhofer Institute building's PV system [5].

PV system location	Power (kWp)
South façade (Magistrale)	2.4
Roof of atrium	5.0
Shading devices on southern wing	3.9
Roof on southern wing	4.5
Roof on central wing	4.8

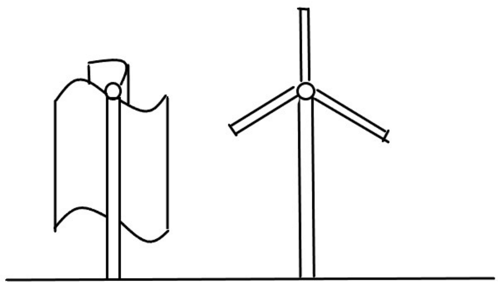
are used on the roof, on the southern façade (called as Magistrale) and as shading devices over the windows as seen in Figs. 3 and 4. The construction completed in 2001 [6].

A total area of 200 m^2 PV components is used on the building in different parts of it. Some of them are used on the roof, some on the staircase on the south façade and the rest as shading devices over the south facing windows. System power is seen in details in Table 3. A total of 15 MWh electricity production of the PV components would supply nearly whole energy demand of office lighting requirement [5].

The energy requirement of the building should be decreased in such applications since the PV component efficiency is a little low. Therefore, other passive design principles are also used in the design of the building in order to lower the energy demand [7, 8].

3.2 Buildings That Produce Energy from Wind Energy

Buildings that produce energy from wind energy use turbines to generate electricity. They are called Building Integrated Wind Turbines (BIWT). They can be either Vertical Axis Wind Turbines (VAWT) or Horizontal Axis Wind Turbines (HAWT) as seen in Fig. 5.



Vertical Axis Wind Turbine Horizontal Axis Wind Turbine

Fig. 5 Different types of BIWTs.

3.2.1 Bahrain World Trade Center

Table 4 Information of Bahrain World Trade Center.

Building's name	Bahrain World Trade Center
Location	Manama, Bahreyn
Architect	WS Atkins & Partners
Construction date	2004-2008
Height	240 m
Wind trubines	3 × 225 kW 29 m diameter horizontal axis wind turbines
Electricity production	1,100-1,300 MWh/year

Bahrain World Trade Center is a good example for BIWTs. The building consists of two 50-storey towers connected with three bridges. On these bridges, the horizontal axis wind turbines are mounted, and they work there producing electricity as seen in Fig. 6. The towers are like sails of a ship. The aerodynamic structure of the towers helps catch the wind and increase its speed so that the energy produced increases. Wind tunnel testing has been done for the building [9].

The calculated production of the wind turbines is as in Table 5. This table shows that the building could produce 1,100-1,300 MWh/year. This equals to 11-15% of annual energy requirement of the building [10]. If considered from the viewpoint of carbon emissions, this energy equals to:

- 2,900 kg carbon emission (of a petroleum power plant) [9];
- 2,000 kg carbon emission (of a gas power plant) [9].

Table 5 Energy production of wind turbines (as calculated) [9].

Turbine 1	340-400 MWh/year
Turbine 2	360-430 MWh/year
Turbine 3	400-470 MWh/year

3.2.2 Pearl River Tower

This tower building is an example of vertical BIWTs. They are placed [11] on the two mechanical floors of the tower where the aerodynamic structure of the building directs the winds towards. As a result of this, energy production increases [11].

Table 6 Information of Pearl River Tower.

Building's name	Pearl River Tower
Location	Guangzhou, China
Architect	SOM, Adrian D. Smith & Gordon Gill
Construction date	2013
Height	309.6 m (71 floors)

Technologies used in the building for energy generation are:

- wind turbines;
- solar collectors;
- PV components;
- microturbines (which could not be realized).

There are 4 big openings for the wind turbines on the 2 mechanical floors of the tower as seen in Fig. 7. Through these openings, the air flows letting turbines produce energy.

Building design included vertical axis turbines in order to catch wind coming from any direction. But before this, it was tried to lower the energy requirement of the buildings with passive design principles. The tower is intended to help lower carbon emissions as of China's target to lower carbon emissions 40-45% of 2005 levels by 2020 [12].

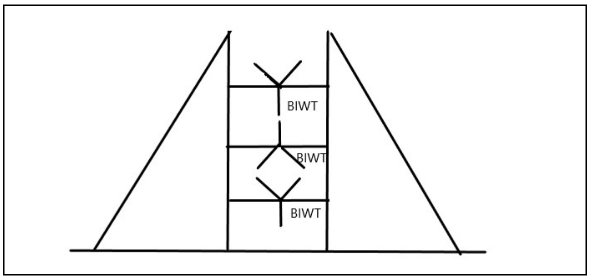


Fig. 6 The schematic drawing of Bahrain World Trade Center showing the three wind turbines.

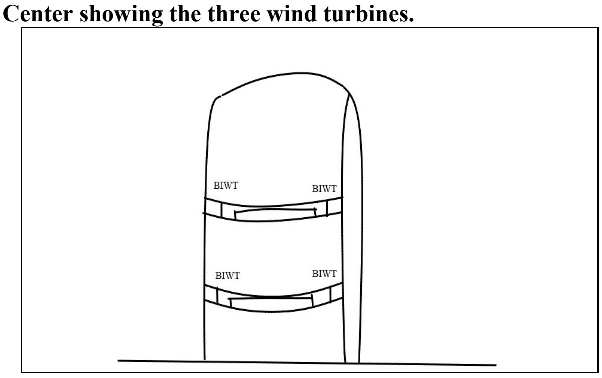


Fig. 7 The schematic drawing of Pearl River Tower showing the BIWTs.

Fig. 8 **View of BIQ building [©Arup].**

3.3 Buildings That Produce Energy from Bioenergy: Biomass, Biogas

Buildings can produce energy from bioenergy, meaning biomass or biogas. This is a new design principle which has only one constructed example as integrated. There are several projects that have not been constructed yet, but this also promises a probable use in the future.

3.3.1 Bio Intelligent Quotient (BIQ)—Bioreactor Façade Building

This building's facade is the first of its kind. Panels containing living algae are used at the sun facing façade of the building as seen in Figs. 8 and 9. These panels are called as Solar Leaf [13]. Total area of these panels is 200 m^2 and they are used both as shading devices and as space heating elements with the heat produced by photosynthesis [14, 15].

When algae grow big enough, they are taken from the panels and are used as biomass and energy is produced as heat and electricity. This energy is 5 times of the energy that could be produced from any other plant. Algae changes its color as photosynthesis goes on (it gets darker green as it reproduces), showing that they are producing heat and food of themselves [15]. Panels of algae produce all energy demand of the building while they decrease 6 tonnes of carbon emission in a year [14].

Fig. 9 **Detail of Solar Leaf panels with algae [©Arup].**

This is the only constructed example of algae buildings. There are several projects using algae as well but not yet constructed. There are several projects using algae. In the future many buildings with algae would be seen. Therefore, algae or in general bioenergy is a promising building component to convert buildings into power plants.

3.3.2 Solar-Fabrik Administration Hall, Freiburg, Germany

This building was examined in Section 3.1.1 as an example of solar energy use in buildings. It also is an example of biomass use in buildings. Even though the biomass is not used as a building element as integrated, it produces significant amount of energy (130 MWh electricity and 180 MWh thermal power annually) with the use of rapeseed.

3.4 Buildings That Produce Energy in Different Ways

Buildings can produce energy by using renewable energies as integrated on themselves. In addition to renewable energies, they can use different ways to produce energy. Generally these ways are use of materials which produce electricity under certain circumstances. Three types of the materials are examined here in this section:

- piezoelectric materials;
- pyroelectric materials;
- thermoelectric materials.

These materials have not yet been used in the construction of any building, but they promise a hope for the future energy production of buildings to convert them into power plants.

3.4.1 Buildings That Produce Energy with the Use of Piezoelectric Materials

Piezoelectric property is the ability of a material (especially crystals and some ceramics, bones) to change electric field or electrical potential as a result of mechanical pressure applied to the material. It has been discovered by French physicists Jacques and Pierre Currie in 1880. The word "Piezo" is derived from Greek meaning "to compress, to apply pressure". It is reversible, meaning a piezoelectric material produces electricity when pressure is applied while it produces pressure when electricity is applied. It is being used as striker at lighters and barbeques today [16].

The pressure necessary for a piezoelectric material to produce electricity can be produced from different resources like:

- people's movements;
- low frequency seismic vibrations;
- voice;
- wind.

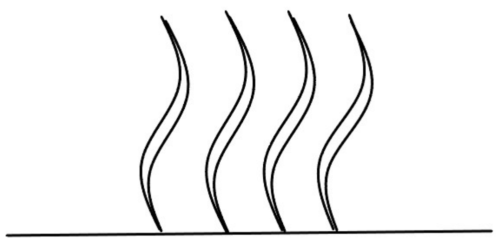


Fig. 10 Detail of the piezoelectric materials used on the façades in MATscape Project designed by Mitchell Joachim[17].

(1) MATscape Project by Mitchell Joachim

Piezoelectric leaves on the façade of the buildings produce electricity when they move with the air movements as seen in Fig. 10. When they move with the wind, this movement produces a pressure and this pressure produces electricity. Therefore, this kind of use of piezoelectric material is also promising building component to convert buildings into power plants [17].

3.4.2 Buildings That Produce Energy with the Use of Pyroelectric Materials

Pyroelectric materials are materials that convert any temperature change into electricity. If they could be used in the design of facades of buildings which heat up and cool down everyday naturally, they could produce electricity. However, the whole crystal should be heated up or cooled down to produce electricity and they need to be designed carefully [18].

3.4.3 Buildings That Produce Energy with the Use of Thermoelectric Materials

In 1821 Thomas Johann Seebeck discovered that a thermal difference between two different conductive materials produces a voltage. Thermoelectric materials produce electrical potential when there is a temperature difference between its both surfaces. Since there is temperature difference between inner and outer spaces in building shells most of the time, building facades could produce energy if they are constructed with thermoelectric materials. But when the temperature is in balance, the current would stop [18].

4. Evaluation

There are several energy resources and several materials that could be used to convert buildings into power plants from energy consumers. Solar energy, wind energy and bioenergy renewable energy sources have already been integrated into architecture. So, this kind of buildings is already working as power plants. Other renewable energy resources and other materials need to be studied a lot, but they promise to be successful in the future.

Nowadays piezoelectric materials are used on watches that run with very little energy. There are studies to produce electricity with the use of piezoelectric material on dance floors, TV remote controls, doorbells. It can be said that piezoelectric materials would take the place of batteries in the future, as well as power source in buildings maybe for charging batteries, or even electric cars with their use on building facades. As Pablo Picasso said, "Everything you can imagine is real", anything you can imagine, or dream can be made real one day in the future. As has happened with Jules Verne's stories, when he wrote "twenty thousand leagues under the sea", it was a dream, but afterwards submarines were developed and still being used today. So, yesterday's dreams are today's reality. So it is necessary to dream today, to make them real in the future.

It is not known today what it will be like to live in the future, or where. People may have moved to Mars or another planet in the future. But it is obvious that they will need energy in their life. Therefore, providing energy within the design of the building will be a very efficient and necessary criterion for the architects of the future.

5. Conclusion

Beginning with the energy crisis in 1970s first solar energy has entered building designs. In time, wind energy began to enter building designs and in the last decade its use began to take place in buildings. In the last years, biomass-biogas began to take place in the design of buildings. It can be said that renewable energy resources are being tried to be integrated into buildings one by one. Moreover, other materials can also be integrated into buildings to produce energy. All of these have one thing in common: converting buildings into power generating mechanisms from power consuming elements. In other words, it can be said that designing and constructing buildings as power plants has become one of the design criteria of architects today. Maybe one day in the future it will be possible to see power plants as buildings, not nuclear power plants or any other power plants which are giving harm to the environment. First step of this is already taken by the buildings examined in this study. It is necessary to search and develop new materials and technologies to be used rapidly. For a cleaner future, for sustainable architecture … why not?

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