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ENERGY OPTIMISATION OF RESEARCH BUILDINGS IN VIENNA WITH A PHOTOVOLTAIC FAÇADE.

THE IMPORTANCE OF PV FAÇADES IN THE ARCHITECTURAL CONCEPT OF AN ENERGY-EFFICIENT BUILDING

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Abstract

Research consisting in the analysis, definition of parameters of a high degree of energy efficiency with a guaranteed share of renewable energy is of particular importance in the implementation of the concept of sustainable development. In Vienna, there have been built buildings whose construction and operation inscribe into an extensive research programme that includes an energy management strategy according to the latest standards developed for energy-efficient construction. These buildings, which are represented by research and educational institutions, are a kind of research field for new technologies and solutions to optimise energy consumption. In architectural terms, the implementation of photovoltaic façades signals the high technological level of prototype solutions. The Author's research methodology was based on the analysis of data characterizing new and modernized buildings, carried out on the basis of current internet sources, literature data and local visions during her study trip to Vienna. The aim of the paper is to present the energy concept of buildings, used to optimize energy acquisition and consumption, as a signpost for the application of guidelines and standards in possible Polish solutions.

Keywords: **Energy-efficient architecture; Energy efficiency; Photovoltaic façade; Renewable energy sources.**

1. INTRODUCTION

It is already clear today that better overall efficiency of future energy systems can be significant if the use of renewable energy sources increases. The introduction of photovoltaic elements into modern architecture is the result of an understanding of the need to use renewable energy sources, in this case solar energy, in order to implement sustainable development principles. In terms of architecture, it is this technology, which marks its presence in the façade or on the roof, that at first glance defines a building as modern and energy-efficient.

2. SITUATION OF THE CITY OF VIENNA – BACKGROUND TO PROJECTS

For years, Vienna has been at the top of various rankings. The first is the "Quality of Living" ranking of the international consulting company Mercer, in which, along with several German (Munich, Düsseldorf, Frankfurt) and Swiss (Zurich, Geneva, Basel) cities, Vienna was ranked first for the tenth time among the cities in the world assessed in terms of quality of life. This assessment is consistent with a fashionable urban strategist Charles Montgomery's theory of the future cities and his bible on urban organisms, *A Happy City*. The Austrian capital was appreciated, among other things, for the "Smart City Vienna" strategy, which has been implemented since 2011. The main points of the Smart City framework strategy to be implemented in many different thematic areas are: resource conservation, a holistic integrated approach to sustainability, high quality of life and resource efficiency through the productive use of innovation and new technologies. The "Smart City Vienna" strategy aims to successfully meet the challenges of the 21st century: by 2025, 2030 and even 2050, a total of 38 specific tasks have been defined [6].

2.1. Smart City Vienna 2050 objectives

- Reducing energy consumption, using renewable energy
- Low energy building standards and necessary renovation of existing buildings
- Reduction of environmental pollution by CO_2 reduction
- Development of innovative energy technologies
- High level of education system as a basis for Smart City Vienna
- Vienna as a favourable preferred economic area
- Vienna as a model city of environmental benefit
- Health care
- Public participation

The policies pursued in the strategy to include significant energy savings, green solutions as well as access and promotion of new technologies.

Safe and inexpensive energy supply is and remains one of the most important requirements for the quality of life and economic development of the city. The Viennese energy system is to be radically restructured to reduce CO_2 emissions. Huge investments have been made to increase energy efficiency throughout the entire energy system from generation to distribution and consumption of energy. The supply of urban energy is constantly being switched from fossil fuels to renewable energy sources.

2.1.1. Energy supply targets:

- A high level of security of energy supply
- Smart grids will ensure decentralised energy supply based on renewable sources.
- Doubling renewable energy in urban areas in the period 2005–2030
- Vienna's final energy consumption will be covered by an increase of 30 percent in 2030 and 70 percent in 2050 from renewable sources.

In times of scarce resources, the use of local renewable energy sources is becoming increasingly important. In order to give citizens, building contractors, city authorities, companies and all interested parties a quick overview of local energy potentials, the City's Energy Planning Department has developed the "Energy" thematic city map. This provides, among other things, information on the potential of solar, geothermal, wind and waste heat.

Figure 1.
Thematic city map "Energy" available for everyone. Source: https://smartcity.wien.gv.at/site/en/thematic-city-map-energy

In order to be able to quickly find information about the potential of Vienna's roof areas to use solar energy, a practical tool has been created – a cadastre of solar potential. This map shows both heat generation potential (solar thermal energy) and electricity generation potential (photovoltaic).

2.1.2. Scientific and research objectives:

The "Smart City Vienna" strategy sets out a new form of innovation promotion in which burning issues are jointly identified between the city administration, universities and research institutions, companies and users, considered in an interdisciplinary way and tested in local city laboratories. In line with this, Vienna will be one of Europe's five leading cities for research and innovation in 2030. It already brings together and attracts many of the best research units from multinational corporations and initiates a strong focus on innovative research projects as a contribution to social and environmental transformation [7].

3. RESEARCH BUILDINGS – ENERGY OPTIMISATION

The analysis was carried out for 3 buildings built as much as possible on the basis of the most recent experimental research carried out in scientific and research facilities in Vienna. Research tasks were defined as an effect of applied technological solutions in buildings of high energy standard. The analysis of technological and construction possibilities aiming at saving energy in a building is closely related to the dimension of architectural conditions.

One of the important and prospective methods of using solar energy, as a renewable energy, reducing the energy consumption of the building and fitting into the idea of sustainable development, is to convert it into electricity using photovoltaic (PV) cells. It is estimated that covering only the southern façades of buildings and their roofs in European countries with PV cells would result in meeting over 30% of the continent's energy needs. [1]. The use of a PV façade contributes to the optimization of the building's energy concept. The selection of examples results from emphasizing the combination of energy gain with the architectural effect of the adopted facade solutions. At the same time, PV modules in the casing have an informative function: they serve to articulate energy content and expose the technological advancement of the building, they are a visual way for investors to express their pro-ecological commitment.

3.1. The ENERGYbase office building

3.1.1. Research tasks

The ENERGYbase office building was built in 2008 in Vienna as part of the "House of the Future" initiative. It is a demonstration building, indicating important technological possibilities for future office and

Figure 2., Figure 3.
The façade of the ENERGYbase office building equipped with a PV panel. Source: Author

industrial buildings in terms of energy, climate comfort and room quality. The building with a usable area of 9,200 m^2 has been developed together with many innovative solutions in passive house standard. The concept uses a balanced approach based on three pillars: energy efficiency, renewable energy and maximum user comfort.

The planning and design of the ENERGYbase building was scientifically supported by the Austrian Institute of Technology (AIT). As a result, the necessary data on the energy management of the building could be documented at an earlier stage of the planning and concept. This data formed the basis for the development of an energy-optimised office building. As a research centre, AIT presented an important contribution to the detailed planning of innovative building technology. The results of extensive analyses generated by means of expert tools, such as dynamic building and system simulations as well as flow simulations, were presented and discussed during many regular discussions and specialist meetings in the design and implementation process.

3.1.2. Architectural and energy context

According to the principle of "form follows function", the projection and external appearance of this pioneering building takes full account of the sun as an energy source.

The southern façade has been specially angled to make the best use of the sun (passive and active): in winter, when the sun is low, its heat is captured and transferred indirectly to the building's rooms through customized channels. A sunscreen made of perforated louvres is located just behind the curved façade; waste air from the entire storey is extracted at the ceiling level. As a result, the heated air is extracted upwards behind the façade into the ventilation openings instead of spreading through the interior space. On sunny winter days, this air passes through a heat exchanger where fresh air from outside is heated.

The whole of the southern façade is an interesting geometry in terms of architecture and at the same time it fulfils the role of an energetically active façade (Fig. 2., Fig. 3.). The PV modules are embedded on a structural grid, which extends in front of the external wall of the building in the form of unconventional shading shelves, integrated into the façade. The lower planes of the repetitive breakages are inclined in the opposite direction and constitute a glazing strip. The geometry of the façade is such that the windows are in the shade in the summer, when 100% insolation is used by photovoltaic modules mounted in the façade shaped in such a way that they are inclined at an angle of 30 degrees towards the rays of the southern sun, in this case only indirect radiation (daylight) enters the building. The active photovoltaic components and solar collectors are specially arranged on the top shelf in order to maximise the energy output of the sun and at the same time provide a sunshade for the interior. 400 m^2 of photovoltaic panels produce 37,000 kWh of electricity per year. Compared to panels positioned vertically on a façade, the photovoltaic modules inclined at an angle of 30 degrees achieve a much higher energy yield (38% increase in power generation compared to a traditional vertical façade), especially during the summer months [8].

3.2. The Aspern IQ Technology Centre building

Developing an ambitious project for the Aspern IQ Technology Centre, Vienna Business Agency was able to draw on the experience gained in the 2008 ENERGYbase office building.

3.2.1. Research tasks

Since October 2013 the research company Aspern Smart City Research (ASCR) has been based in the IQ building, which also serves as a business incubator. The company took care of configuring the technical infrastructure for the research programme, and in the current state of investment it has started research with real data on the exploration of the Vienna district – Seestadt Aspern [2]. The main aim of the exploration is to create an overall technical concept for the selected test field in Seestadt Aspern and then implement it in real conditions. There are researched ways to increase the energy efficiency of the building infrastructure and electricity networks, the use of renewable energy sources and storage technologies. The data is analysed by ASCR and the aim is to optimise the energy consumption of the building and thus reduce energy costs with innovative technologies. When defining consumption cases, requirements are derived for an overall technical concept that includes the basic structure of the ICT architecture (hardware and software) and the technical infrastructure (heat pumps, photovoltaic systems, etc.).

3.2.2. Architectural and energy context

The construction of a modern IQ centre required the implementation of state-of-the-art construction solu-

Figure 4., Figure 5.
IQ Centre building with PV installation on the façade. Source: Author

tions to meet the highest requirements in terms of sustainability and comfort of use. The technology centre was built to minimize energy consumption to meet passive house standards. An important role in the planning process was played by: simulation of thermal behaviour of buildings according to the principles of building physics, simulation of daylight and ecological conditions of the building. The primary energy demand of the centre was reduced to 51 kWh/m^2/year. As a plus energy building, it produces 15% more energy than it consumes over a 12-month period. This is achieved through integrated photovoltaic components and small wind turbines. The photovoltaic panels integrated in the façade and additional photovoltaic panels mounted on a flat roof have a total surface area of 1,300 m^2 and produce up to 140 kWp of electricity [9].

The façade of the IQ building is equipped with added bands of BAPV (Building Applied Photovoltaics) photovoltaic modules on a horizontal support structure (Fig.4., Fig.5.). The panels, inclined at an angle of 30º, provide a sun screen for the window bands beneath them on the side of the building with the highest insolation. The façade shaped in this way becomes an element of the architecture system, a generator of electricity and an important element of creating the aesthetic function of the building.

3.3. TU Wien Plus-Energy office building

3.3.1. Research tasks

The TU Wien Plus-Energy office building is a unique research and construction project by Schöberl & Pöll GmbH, the Institute of Construction and Technology of the Vienna University of Technology and ARGE Architects Kratochwil-Waldbauer-Zeinitzer, which won the state prize in the category "Research and Innovation". The office building of the Vienna University of Technology is a skyscraper that produces more energy than is needed to operate and use the building with the largest photovoltaic system integrated into the façade.

This 1970s building was modernised and converted into a modern positive energy skyscraper as one of eight buildings on the Getreidemarkt TU Wien campus. In addition to the integration of the photovoltaic installation, the so-called "Plus-Energy Office High-Rise Building" is based on the extreme minimisation of energy consumption. For research purposes, an extensive energy monitoring system has been installed to assess whether the actual energy consumption and energy supply corresponds to the planned, expected values after commissioning and before optimisation. The results of the monitoring system for 2016 are presented and analysed. Deviations between planned and measured values are discussed at the level of the annual primary energy balance. Currently known problems responsible for increased consumption are categorised according to cause and analysed paying special attention to using them as the input for the optimisation process [10].

3.3.2. Architectural and energy context

The architecture of the Vienna skyscraper presents façade solutions in the Building Integrated Photovoltaics (BIPV) system, making full use of all this vertical space and generating maximum solar energy (Fig. 6). The design of the façade determined the use of different solar modules of different shapes and sizes, and therefore required energy electronics solutions that would go beyond the typical photovoltaic design. A total of 2,199 m^2 of roof and façade space was allocated to the photovoltaic installation. The photovoltaic system provided a total output of 328.4 kWp, 97.8 kWp from the roof, and 230.6 kWp from the façade. The building is not self-sufficient but is an example of extreme energy efficiency.

The installation of photovoltaic cells integrated into the casing in the BIPV system creates a so-called energy façade. This makes up the expression of the building's architecture. The PV modules in the casing have an informative function: they serve to articulate the energy content and expose the technological advancement of the building of the Technical University of Vienna.

It is worth noting that the building does not only use the energy from the sun through photovoltaic installation to achieve the "Energy-plus" effect. In addition, solutions based on the latest energy-saving technologies were used in the process of optimizing the energy consumption of the building:

- waste heat from the server room was used for heating in the winter months
- during the summer months, the heat from the server room is dissipated into the surrounding air and used in hybrid cooling towers to cool the server room and building
- a system of night ventilation was implemented, the internal temperature control controlled by intelligent systems according to needs and adopted algorithms to control these systems.

Figure 6.

Figure 7.

The façade of the TU Wien Plus-Energy office building with a BIPV casing. Source: Author

In a positive energy building, the amount of energy needed for the general use of the building (heating, cooling, lighting, etc.) and the actual energy consumption resulting from the use (computers, telephones, equipment in the communal areas, etc.) has been extremely minimized.

Plus-Energy Office High-Rise Building consumes only one eighth of the energy normally used by an office building – and only one fourteenth of the energy used before renovation. In total, around 9,300 components have been optimised to minimise energy consumption: from 803 kWh/m^2 gross area per year to 56 kWh/m^2. With a conventional renovation (which corresponds to a typical new office building) it would be 458 kWh/m^2.

4. SUMMARY

The described buildings have the character of research, scientific and didactic institutions. They are created here to collect data, to pay particular attention to the development of appropriate management strategies for special energy systems of the building. The use of PV systems on the building's façade is of particular importance here. The role of a photovoltaic façade is to generate electricity, but as an integral part of the architecture, it remains in mutual relation not only with the aesthetic function but also with the utility function and the whole process of building use.

The optimisation of the energy concept of buildings (Tab. 1) is complemented by the possibility of installing PV on the roof, however, the main architectural component is the energy active façade.

The energy aspect is emphasized in the world and in Poland in a noticeable way and is more and more strongly connected with the field of architecture. In the near future, designers will be faced with the requirements of expanding their knowledge and multidisciplinary cooperation in the area constituting the interface between architecture and technical knowledge including PV technology. Globalisation and increasing access to global scientific knowledge increase the exchange of ideas with the world's leading scientific centres, it results in an increased interest of investors and other decision-makers in environmental issues in the construction sector and, in a narrower spectrum, in energy respect. Therefore,

Table 1.
Optimisation of the energy concept in research and development buildings with PV installations

Building name	Year of construction	Type of PV covering	Surface of PV installations	Installation power
ENERGYbase office building	2008	façade	400 m^2	53 kWp
Aspern Technology Centre building	2013	façade+ roof	1,300 m^2	140 kWp
TU Wien Plus-Energy office building	The1970s Modernisation 2016	façade+ roof	2,199 m^2	328.4 kWp

these changes encourage to update the knowledge on the relationship between architecture and energy efficiency issues and to relate it to practical and experimental research, including design and implementation experience on the examples of western cities, including Vienna, in order to be able to benefit from their experience and implementation and transfer to Poland.

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