Journal of Energy Resources and Conversion
Volume 4 | Issue 1

Research Article Open Access

One Year Monitoring of Energy Performance of Innovative Demonstrational Pavilion with Water Flow Glazing Windows

Krasimir G Georgiev[1,*], **Miglena Nikolaeva-Dimitrova**[2]

[1]Institute of Mechanics, Acad. G. Bontchev St., bl. 4,1113 Sofia, Bulgaria
[2]Central Laboratory of Solar Energy and New Energy Sources, Bulgarian Academy of Sciences, Tzarigradsko chaussee, Blvd. 72, 1784 Sofia, Bulgaria

[*]**Corresponding Author:** Krasimir G Georgiev, Institute of Mechanics, Acad. G. Bontchev St., bl. 4,1113 Sofia, Bulgaria, Tel.: +359898695548, E-mail: krasimir.georgiev@imbm.bas.bg

Citation: Krasimir G Georgiev, Miglena Nikolaeva-Dimitrova (2025) One Year Monitoring of Energy Performance of Innova tive Demonstrational Pavilion with Water Flow Glazing Windows, J Energ Res Convers 4(1): 103

Received Date: July 22, 2025 **Accepted Date:** August 22, 2025 **Published Date:** August 25, 2025

Abstract

The innovative demonstrational Pavilion is built according to the European project under the program Horizon 2020. It is the first building with three façades constructed with Water Flow Glazing (WFG) windows. The circulating fluid inside the glass panes provides the energy used for indoor conditioning of the Pavilion. Air-to-air heat pump ensures that the temperature of the fluid inside the WFG modules is kept within the predefined comfort levels. On its roof, there is 5.04 kWp. photovoltaic systems. In this paper is investigated one year monitoring of the energy performance of the Pavilion. Four case studies are analysed - one month per each season: in Spring - month March, when the energy production is similar to consumption, in Summer – July, when production is greater than consumption, in Autumn – October, when production is similar to consumption and in Winter – December, when production is less than consumption. The results show that on a yearly basis the Pavilion covers the national criteria for nearly Zero Energy Building /nZEB /.

Keywords: Renewable sources; solar energy; PV systems; nZEB; Water Flow Glazing (WFG)

Introduction

Improving energy efficiency in buildings has a key role in achieving the ambitious goal of carbon-neutrality by 2050; set out by the European Green Deal [1] where the main objectives are Reduction of greenhouse gas emissions by 55% by 2030; Zero net emissions by 2050; economic growth should not depend on the use of natural resources. These intentions require large-scale of actions in all economic sectors: investment in new environmentally friendly technologies; innovations in industry; cleaner and cheaper transport; decarbonisation of the energy sector; renovation of the building stock. Improving existing buildings and striving for smart solutions and energy efficient materials can reduce energy losses. In 2020; roughly 75% of the EU building stock is energy inefficient. All buildings in the EU are responsible for 40% of our energy consumption and 36% of greenhouse gas emissions; which mainly stem from construction; usage; renovation and demolition [2].

The construction sector is one of the main consumers of energy and is responsible for about 30% of greenhouse gas emissions. Final energy consumption in residential buildings made up more than 70% of the global total in 2018; with growth resulting primary from floor area and population increase; while floor area alone remains the main driver of higher consumption in non-residential buildings [3]. Incorporating energy efficient strategies into the design; construction and operation of buildings leads to reduction in energy use. Ensuring the quality of the microclimate and living conditions in a building is a result of an integrated dynamic system and the demand for economic-effective solutions to reduce energy costs. The concept of nearly Zero Energy Buildings (nZEB); renewable energy systems and academic research; makes nZEB more and more feasible. Directive 2010/31/EU on the energy performance of buildings – EPBD [4]; together with the Energy Efficiency Directive (EED) and the Renewable Energy Directive (RED) [4]; has developed a package of measures that create the conditions for significant and long-term improvements in the energy performance of European building stock. The EU legislative framework for buildings has led Member States to adopt nZEB definitions and national policies for their implementation.

The Bulgarian definition of nearly zero-energy building (nZEB) came into force with the new legislative changes in the Energy Efficiency Act (EEA) from May 2015. According to EEA § 1; point 28 there are two main requirements set in this definition. The first one is concerning the energy consumption of the building; which directly applies to the building envelope characteristics and consumption patterns; while the other one focuses on the source of the energy supply. According to the national action plan for nZEB the renewable energy has to cover no less than 55% of all the energy needs excluding appliances and should be generated by the building itself or by a renewable energy source that is located on site at building level or near the building [5].

Energy is needed for the daily functioning of a building. The European directives on the energy performance of buildings have emphasized the need to reduce the energy consumption of buildings.

Ensuring the quality of the microclimate and living conditions in a building is a result of an integrated dynamic system and the demand for economic-effective solutions to reduce energy costs. The main parameters of a building as a whole are its orientation; layout and location. All of them could influence the amount of sun a building receives and therefore its year-round temperature and comfort levels.

In assessing the measures that can be taken to improve the energy efficiency of buildings; we distinguish several main categories [6]:

- Improving the building envelope (improving insulation; thermal insulation windows; building design; super insulated construction envelopes; etc.);
  • Reduction of heating and cooling loads (bioclimatic design; techniques for passive heating and cooling; control of solar revenues; etc.);
  • Use of renewable energy sources (solar collectors; photovoltaic systems; etc.);

- Energy management and monitoring systems;
- Conditions for internal comfort;
- Energy efficient lighting fixtures.

In modern buildings; especially offices; the glazing surface makes up most of the façade; which increases the impact of windows on the overall energy efficiency. The optimization of the glazing façades by transforming them into renewable energy sources can significantly improve the building energy profile and its cost. Historically; there have been developments in the use of solar energy in buildings and later ideas for integrating glazed façades with water flow (WFG). The first step of using sunlight and an absorbent building façade is a development called the Thrombus Wall. It has functions for cooling; heating or as an architectural element. Another type of thrombus wall is the water wall; which performs the same functions; but has better performance because the water temperature does not rise as much as the masonry [7]. The integration of the Thrombus Wall as architectural element has not received enough attention. Nowadays; when looking for energy efficient solutions; the use of solar panels as façades of buildings can prove its advantages. Building envelopes are crucial to reduce energy used for heating and cooling. Building codes must remain a policy priority along with technology efficiency improvements. The Heating; Ventilation and Air-conditioning (HVAC) system that provides heating; cooling and ventilation is the largest single end-user in both commercial buildings and residential buildings and is responsible for 33% and 48% of electricity consumption; respectively [8].

The building envelope has energy saving potential in case of good construction design. The subject of consideration is the application of innovative façade technology in the construction of a demonstrational Pavilion and the use of a renewable energy source through a PV system. Application of WFG (Water Flow Glazing) façade is an innovative solution; which combines heating and cooling systems and renewable energy technology in one technical solution to achieve nZEB. WFG can fully substitute regular façades with their mechanical and thermal characteristics. WFG façade elements are working as transparent low temperature solar collectors. Façade characteristics (g-factor; U-value) may be actively manipulated to achieve the best energy performance of the façade. WFG elements can be used as vertical walls; partition walls / ceiling elements or exterior elements. WFG is important part in building and HVAC system with a radiant heating/cooling element. Because of the high absorption of IR spectra of the façade elements; the peak loads of the conventional cooling system may be significantly reduced. The amount of energy absorbed (renewable solar summer excess) may be used directly for Domestic Hot Water (DHW) and for improved performance of the heat pump.

In this paper; we present the energy performance for year 2020 of an innovative demonstrational Pavilion that implements Water Flow Glazing technology. The WFG elements in the Pavilion are connected to a heat pump; which regulates the temperature inside and ensures that the inner space is properly conditioned. Electricity covering the needs of the equipment inside the Pavilion is supplied by a PV system mounted on the rooftop.

The Water flow glazing elements of the Pavilion bear (are equipped with) monitoring equipment; recording their performance and energy utilization. Weather station is mounted on the rooftop and constantly monitors the outdoor climate conditions. The data from the weather station provides information about the outdoor environment in which the WFG elements and the PV system operate.

In this paper; our goals are first to achieve by controlling and transferring the solar energy using WFG windows less environmental impact for heating; cooling and lighting and second that the Pavilion covers the national criteria for nZEB.

Demonstrational Pavilion with the innovative design built in the Scientific Campus II of the Bulgarian Academy of Science

Integration of Water Flow Glazing (WFG) façade

The demonstrational Pavilion with an innovative façade system was built in Sofia; Bulgaria; according to the European project Horizon 2020 (Figure 1.). The building is oriented in clear geographic directions east-west; north-south. The east; west and south façades are transparent and built with the WFG modules. In addition; there is an internal partition wall. North façade is opaque and there are the entrance door and technical equipment and installation block.

The interior of the Pavilion is single volume space with a partition wall; built with WFG technology. The use of such a WFG façade system allows maximum utilization of daylight; high transparency and optimal indoor comfort. It consists of triple glazing with two chambers (fluid chamber and argon chamber) and a modular aluminium frame. The main advantage is that the fluid in the transparent glazing transforms the passive façades into active solar collectors. The heat from the fluid in the glazing is used for heating and cooling. WFG increases natural interior lighting. It is a vertical-shaped module with dimensions of 1.3m x 3m; suitable for the façade element of office buildings. Each module includes its own circulation pump and heat exchanger; which make the individual elements of the module independent. The circulation pump provides flow rates in the glazing up to 8.0 l/min. These modules are composed of standardized building elements and are fully replaceable and easy to connect to each other.

Figure 1: Innovative demonstrative Pavilion in Sofia; Bulgaria

In the Pavilion; the eastern and western façades are built with CoolGlass water flow glazing modules. The aim is to prevent heat from entering the indoor area; especially in summer with a high reflective front and low infrared absorption. The south; the façade is built with HeatGlass; while the north façade is opaque. (Figure 2). The structure and the main working principles of the two types of WFG modules is well described in paper [9].

The difference between HeatGlass and CoolGlass is the position and the type of the coating layer. In the HeatGlass modular prototype the coating is after the Argon chamber [9]. This is a low-emissivity coating which very effectively reflects long-wave heat radiation back into the water and so the heat loss from the water is minimized. At the same time; this coating maximizes natural light transmission. In the CoolGlass module; the coating is before the Argon chamber [9]. The CoolGlass module has a coating; which is very transparent with very high light transmission; it has low solar factor and blocks energy at the surface. The highest average Water Heat Gain and lowest Internal Heat Flux are obtained for HeatGlass; which makes this module type a good choice for the local climate conditions.

Examination of annual thermal behaviour of WFG shows that in CoolGlass the monthly mean water heat gain parameter on a yearly base is stable. Only for HeatGlass this mean parameter is positive which means that we are harvesting energy through the whole year. The yearly variations of the internal heat flux are strongly related to the annual changes of the solar irradiation. The internal heat flux is an indicator for the energy consumption to ensure indoor comfort. The internal heat flux should be at minimum during the winter and this is when HeatGlass performs better. At the same time; HeatGlass underperforms the other units during the summer with lowest internal heat flux; but this performance could be improved through controlling the water flow rate and T inlet.[9]

A heat pump is included in the construction of the HVAC system; control the set-up temperature of the WFG module by reducing/heating its temperature.

The demonstrational Pavilion uses WFG as heating and cooling devices. The water circulating in the glazing provides energy for the air conditioning of the building. The installed air-to-air heat pump ensures that the water temperature is maintained within pre-set limits to achieve comfort in the Pavilion. In summer; the water captures excess heat and the heat pump provides cooling through the internal partition walls. The façade system during the summer months works as a radiant cooling device.

One major objective of the Pavilion is to show the integration of the WFG technology into heating; ventilation and air conditioning (HVAC) systems in winter and summer modes. The complete HVAC system for the demonstrator is shown in Figure 2.

The system consists of a primary circulation circuit between the heat pump and the façade and a secondary circuit inside each WFG module. The primary circuit transports energy from the Heat pump to each WFG window. According to the current demands; the heat pump is responsible for both – heating and cooling purposes. The heat pump is mounted on the north façade. Each façade consists of five WFG windows and forms the secondary circulation circuit. Using the heat exchangers under each window the energy is transferred and controlled. In the demonstrational Pavilion; there are two modes for controlling the temperature and maintaining the indoor temperature. The first mode is by controlling the temperature of the fluid in the WFG. During this mode; the heat pump controls the set temperature of the fluid. In this mode during the winter season; the heat pump heats the fluid at the set temperature and turns off. There is no danger for the windows to be overheated. The inconvenience here is that when the temperature of the room is not comfortable enough you have to raise it manually. The same process occurs with the cooling mode. Once again; there is no possibility of overcooling the windows. The second way is to control room temperature. During this mode; the heat pump controls the set temperature of air inside the Pavilion. In this mode during the winter season; it tries to reach the set temperature. There is a (Proportional-Integral-Derivative) PID controller and a temperature controller mounted in the control unit of the heat pump. The PID controller looks at the set temperature and compares it with the actual value. As the temperature is lowered and is distanced from the set temperature; the heat pump tries to reach it; delivering more and more heat inside the WFG. There is a danger for the windows to be overheated. The convenience here is that it is all automated. The same process occurs with the cooling mode. There is danger for WFG to be overcooled and condensation occurs on the outside part of the glass. During this mode; the internal temperature is controlled by a temperature sensor mounted on 1.5 m. above the ground on the radial wall. Good working conditions are due to the proper work of the Heat pump system of the demonstrational Pavilion. This is the device responsible for the main part of the energy consumption.

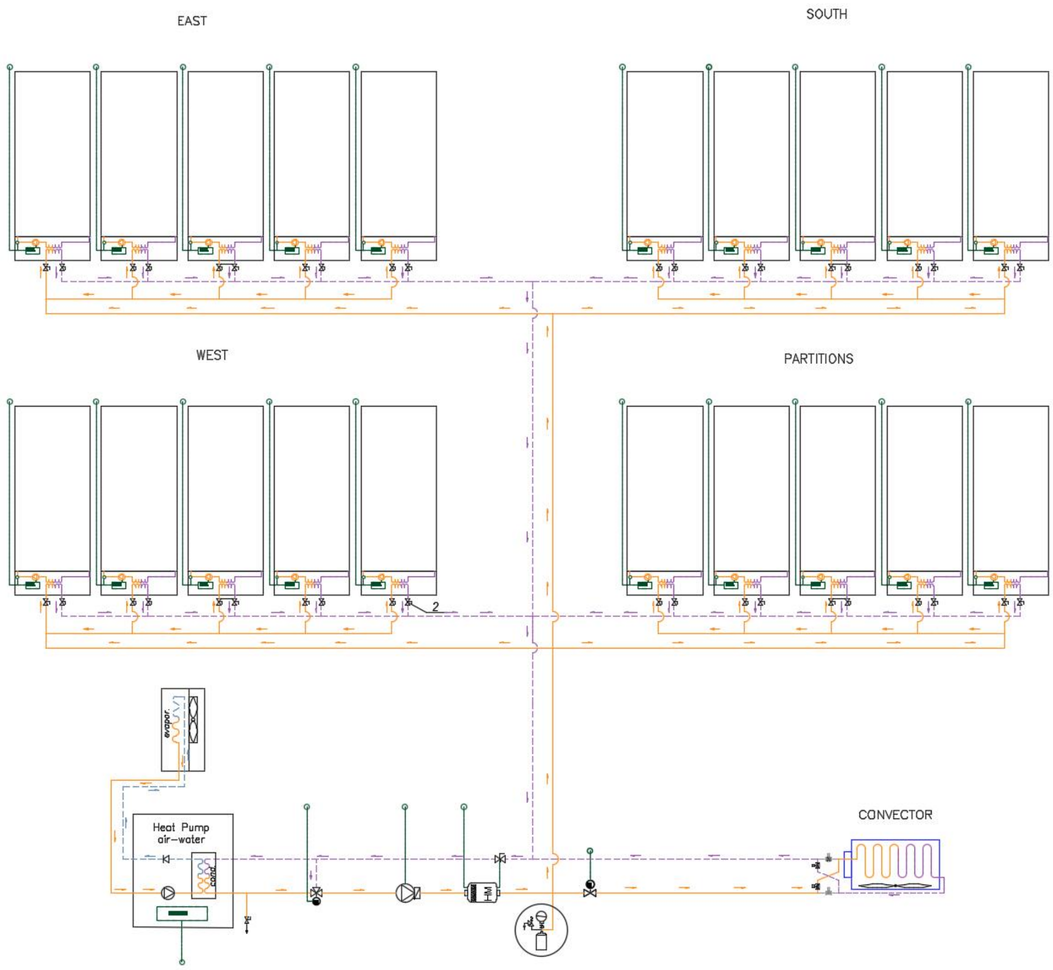

Figure 2: Integration of Water Flow Glazing façade into the HVAC system of the Demonstrational Pavilion

The pump is usually set up to keep indoor conditions comfortable in working hours with temperatures between 21-25°C. After that; the pump is set up regarding the weather season and eliminates damages and problems in the demonstrational Pavilion like condensed water on the walls; freezing; etc. Other consumers are lighting; measurement and technical equipment; computers etc. but they are with significantly less consumption than the heat pump.

Photovoltaic modules on innovative demonstrational Pavilion in Sofia

To meet the requirements for nearly zero energy building on the roof of the Pavilion; are installed 18 photovoltaic (PV) modules URECO F6E280H3A connected to solar inverter Huawei sun-2000 ktl. Power output of the solar generator is 5.04 kWp with an area of 29.3 m^2. PV modules are mounted with a tilt angle of 10 degrees facing south. (Figure 3.). The Pavilion is connected to the grid and the excess energy from the solar generator is exported to the local electric grid. When electricity from PV panels is more than the consumption of the Pavilion; this amount of energy is delivered to the electric grid and when the Pavilion needs more electricity; it is taken from the electric grid. In order to monitor power consumption of the Pavilion smart meters have been mounted in the main electrical box. This gives us a chance to collect and analyse data for all electrical consummators. All data is stored in a cloud and can be accessed via web browser and mobile application.

Figure 3: PV system on the roof of the innovative demonstrational Pavilion in Sofia with installed capacity 5.04 kWp.

Monitoring of innovative demonstrational Pavilion in Sofia

The monitoring of the Pavilion is in real time – records the measured value every 5 minutes and ensures the accurate operation of the installations. The control functions of the monitoring system enhance the management of the WFG installation; lightning and other consumers of electricity. The goals are to ensure high-energy efficiency and maintain living comfort. The monitoring system collects information and records data from the mounted devices. (Figure 4)

On each façade - internal and external are mounted the pyranometers to measure the total incoming irradiance of the façade. A pyranometer installed on the southwest façade measures the global solar irradiance. The temperature sensors over a distance of 0.7 m in height (Pt 1000; class A) are installed on a single WFG module on every façade. All temperature and irradiance data are collected by data acquisition system Keysight Technologies 34980A. Meteorological station is mounted on the roof for monitoring Relative Pressure; Outdoor Humidity; Temperature; Wind; Dewpoint Gust; Rain; etc. (Figure 5.). The data acquisition is done through the AtenTTo monitoring and control platform.

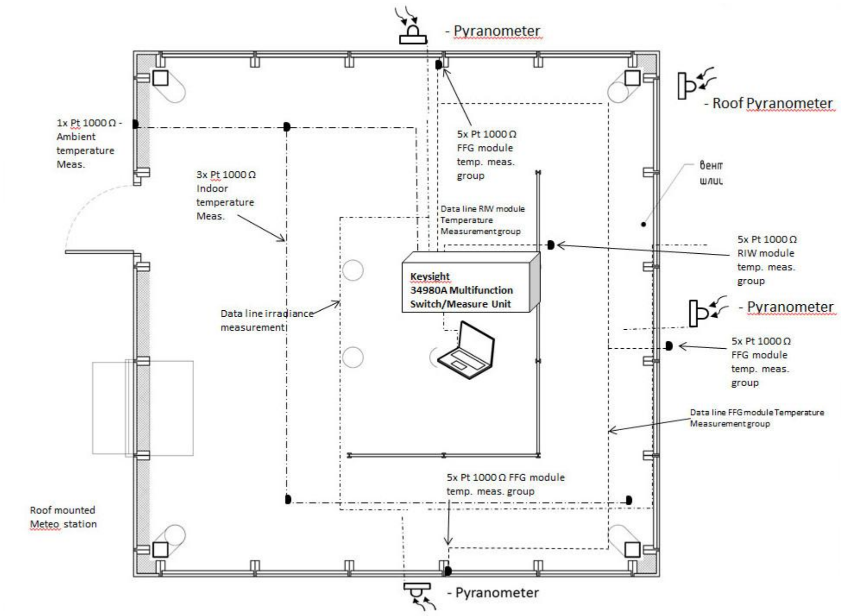

Figure 4: Scheme of the system for monitoring of incident/transmitted solar irradiation; WFG module and room temperature of the innovative demonstrative Pavilion

Figure 5: Equipment Data meters of the monitoring system: a) pyranometer for global solar irradiance; b) pyranometer mounted inside the Pavilion and part of the mounting tape of the PT1000 on WFG module; c) meteorological station; d) visual demonstration of the data obtained now.

Energy Performance of Innovative Demonstrational Pavilion in Sofia for 2020

One of the basic parameters that defines the energy performance of the Pavilion is the weather. In this paper one whole year – 2020 of monitoring is presented. City of Sofia; Bulgaria is with typical moderate continental climate. Winters are relatively cold and snowy. In the coldest days temperatures can drop below −10°C (-11.7°C in December 2020 [10; 11]). Fog usually occurs in the mornings in winter. Summers are warm and sunny. In summer; Sofia generally remains slightly cooler than other parts of Bulgaria; due to its higher altitude. The hottest month for 2020 was August with an average temperature of 21.5°C [12]. However; sometimes in summer in the city appear heat waves with high temperatures exceeding 35°C. The hottest days usually are in July and August. The highest temperature was 34.1°C in May 2020 [10]. In the spring and autumn in Sofia; the weather is variable and dynamic. Average annual temperature was 11.6°C in 2020 [10].

In this paper; four case studies are going to be analysed one per each season: March; July; October; and December 2020.

Case 1 Spring – month March

March is chosen because it represents the typical; dynamic spring weather in Bulgaria; Sofia. On the Figure 6 the outdoor temperature; indoor temperature in the Pavilion and outdoor solar irradiation are presented. As it can be seen; the maximum outdoor temperature is 21.9°C and minimum is - 4.2°C. Average outdoor temperature is 6.4°C. Mean indoor temperature is 21.1°C in the Pavilion. Highest indoor temperature in March is 32.9°C; while the lowest is 13.1°C. The temperature control of the pump in March is set up to 23°C on the fluid in the WFG during working hours. Night hours it is set to 20°C. The indoor temperature is following the outdoor temperature but it is warmer (Figure 6). The heating mode of the pump is on.

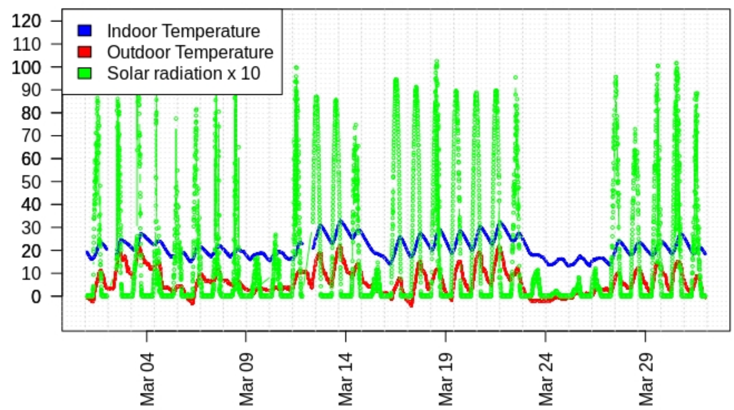

Figure 6: Indoor and outdoor temperature in °C; and solar irradiation in W/m^2; (the irradiation has to be multiplied by 10 on Y scale) of the Pavilion during March 2020

This dynamic weather influences the PV production. In sunny days PV production is a bit more than 20 kWh per day and the sensor of the roof shows solar irradiation with max values approx. 1000 W/m^2; which is presented on the Figure 6. There are four days with almost no PV production and significant consumption on 24-th; 25-th; and 26-th March 2020. (Fig 7) This is due to the snowy days where the PV system was covered by snow. The total energy production during March was 426 kWh; while the consumption was 515 kWh. There is no significant difference between the energy production and the consumption of the Pavilion during this month.

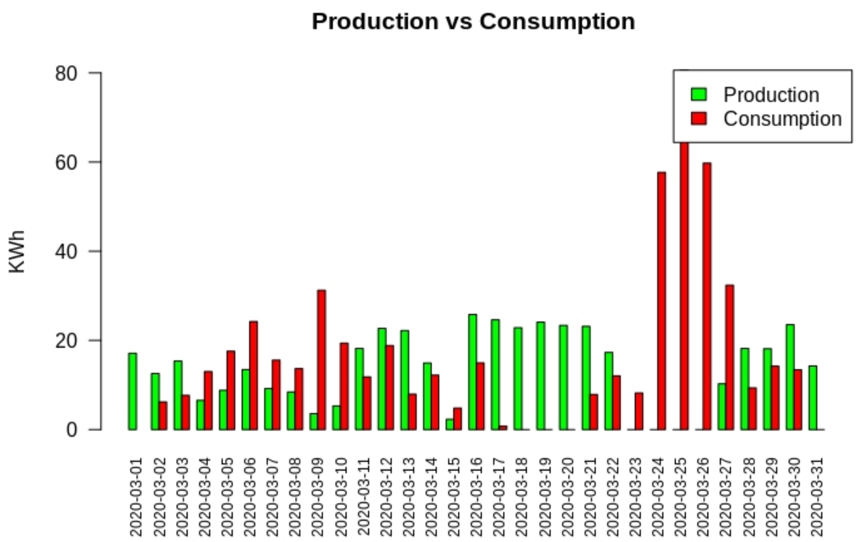

Figure 7: Energy production from PV panels and the consumption of the Pavilion in Sofia during March 2020

Case 2 summers – month July

July is usually warm; sunny month with a maximum temperature of 32°C and minimum temperature of 11.3°C that is presented on the Figure 8. Mean outdoor temperature is 20.9°C measured from meteorological station on the Pavilion. Average indoor temperature is 25.2°C in the Pavilion. Indoor highest temperature is 32.3°C; lowest 21.0°C in July.

The temperature control of the heat pump is set up to 21°C on the fluid temperature control. Usually the pump works continuously because of the impossibility of cooling the Pavilion to the set up temperature. The cooling mode of the pump is on. There is one day with missing data but this is not significant for presenting the energy consumption and production during July 2020.The pyranometer shows solar irradiation with max. Value approx. 1200 – 1300 W/m^2. On sunny days; the PV production is more than 30 kWh per day. On cloudy days; the energy production is less than 10 kWh. (Figure 9). In July; only 3 days are cloudy.

The total energy production during July 2020 is 853 kWh; while the consumption - 613 kWh Main part of the energy consumption is used for cooling the demonstrator.

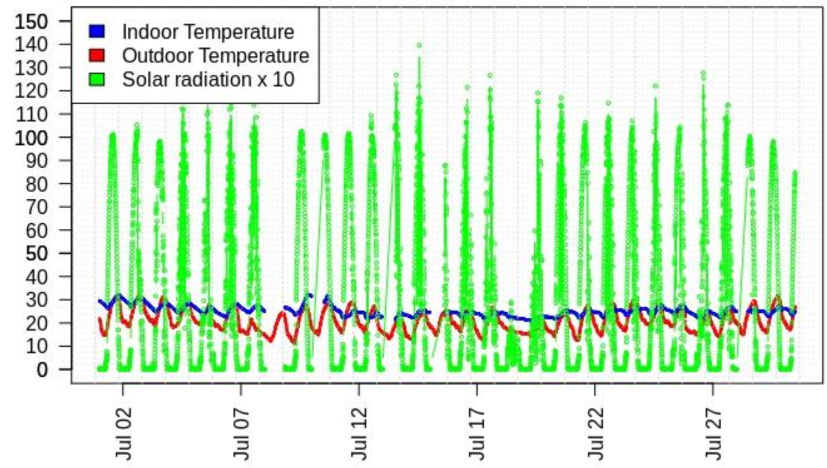

Figure 8: Indoor and outdoor temperature in °C; and solar irradiation in W/m^2; (the radiation has to be multiplied by 10 on Y scale); of the Pavilion in Sofia during July 2020

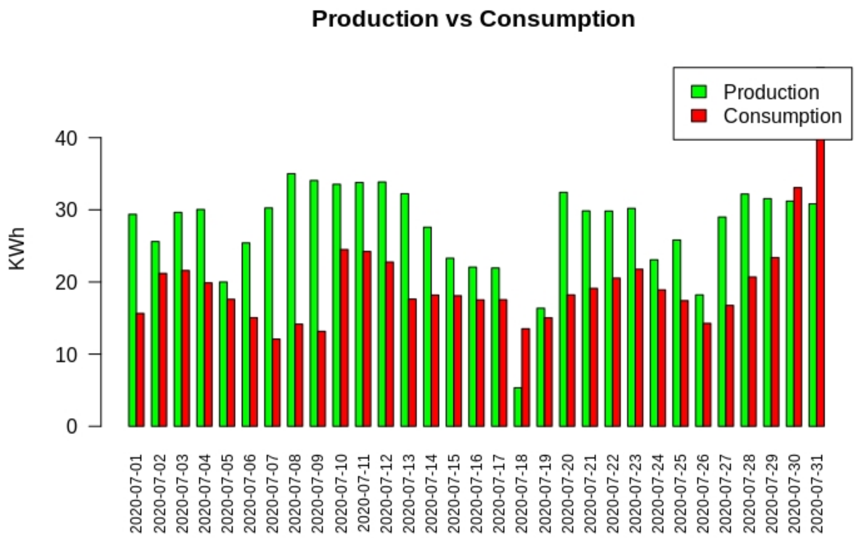

Figure 9: Energy production from PV panels and the consumption of the Pavilion in Sofia during July 2020

Case 3 Autumn – month October

October in 2020 is chosen because it is relatively warm and sunny. Highest temperature is 31.6°C and lowest temperature is 0.4°C. Mean outdoor temperature is 12.9°C. Mean indoor temperature is 22.0°C in the Pavilion. The maximum indoor temperature is 29.3°C; minimum is 15.9°C. More than the half month was with sunny days. The pyranometer on the roof shows solar irradiation with maximum values approximately 900-1000 W/m^2. (Fig 10)

The temperature control of the pump in October is set up to 21°C on the indoor temperature control during working hours. Night hours it is set to 19°C. The heating mode of the pump is on. When the indoor temperature hits the set up temperature; the pump stops. There are two days with missing data from the monitoring parameters; but this not significant for the energy performance of the Pavilion. The monthly energy production is shown on the Figure 11 Energy production was approximately 20 kWh per day on sunny days. On cloudy days; it is less than 5 kWh per day.

The total energy production during October is 444 kWh; while the consumption is 368 kWh. This month the energy consumption of the Pavilion is less than the PV production

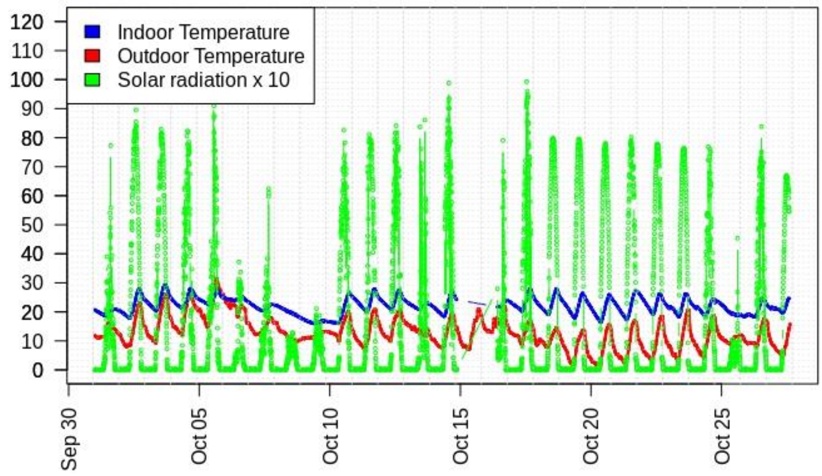

Figure 10: Indoor and outdoor temperature in °C; and solar irradiation in W/m2 (the radiation has to be multiplied by 10 on Y scale); of the Pavilion during October 2020

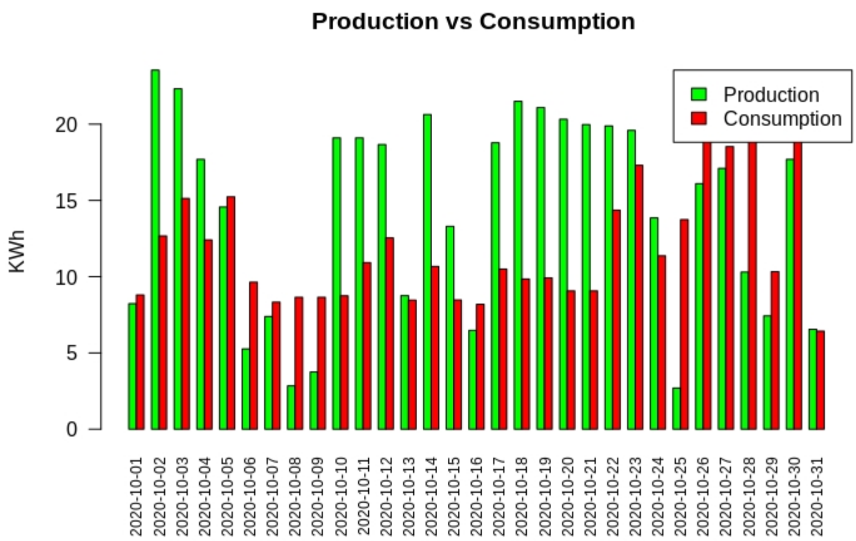

Figure 11: Energy production from PV panels and the consumption of the innovative demonstrative Pavilion in Sofia during October 2020

Case 4 Winter – month December

December is a relatively cloudy; with foggy mornings and few sunny days. The highest temperature in December is 12.6°C and the lowest at the beginning of the month is -11°C. Average outdoor temperature is 3.2°C. Average indoor temperature is 19.4°C in the Pavilion. Maximum indoor temperature; is 27.6°C; minimum is 16.6°C. As it is shown on Figure 12; there are three days with missing data of monitoring parameters.

The temperature control of the heat pump is set up to 21°C on the indoor temperature control during working hours in December. Night hours are set to 18°C. The heating mode of the pump is on. When the indoor temperature hits the set up temperature; the pump stops.

The pyranometer shows solar irradiation with maximum values approximately 600-700 W/m^2 (Figure 12.). The main part of the energy consumption is to keep the indoor temperature of the Pavilion warm and comfortable. This is the reason for significant energy consumption more than 40 kWh (Figure 13) per day; especially in the beginning of the month when outdoor temperatures are very low.

The total energy production during December 2020 is 111 kWh; while the consumption is 614 kWh.

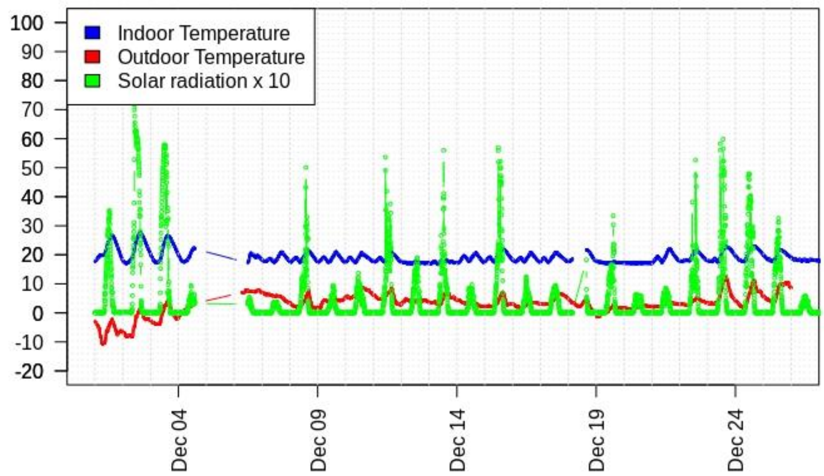

Figure 12: Indoor and outdoor temperature in °C; and solar irradiation in W/m^2 (the radiation has to be multiplied by 10 on Y scale) of the Pavilion during December 2020

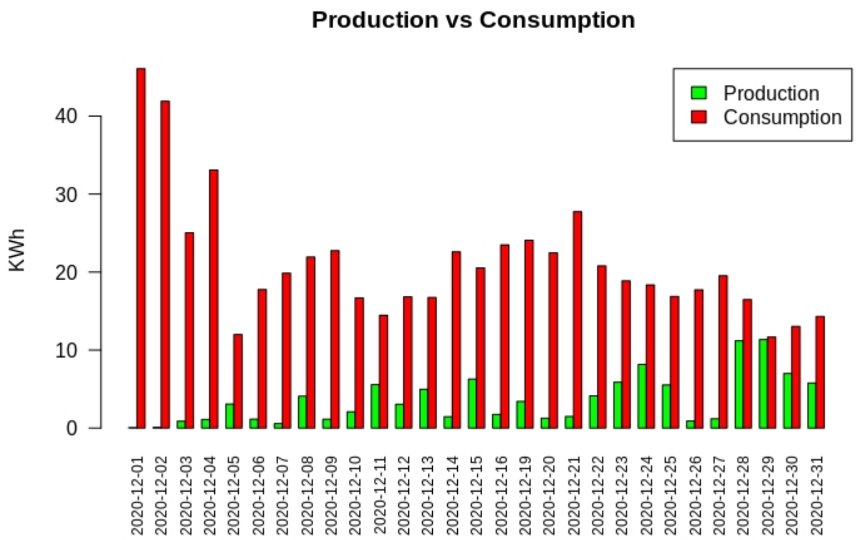

Figure 13: Energy Production from PV panels and the consumption of the Pavilion in Sofia during December 2020

Production and consumption for annual 2020

As it is stated upwards it is accepted that the WFG system integrated in a building serves as solar thermal collector and it also serves as a heat-exchanger between the external and internal space. This WFG uses the solar energy to increase the temperature of the fluid inside. In this case it is assumed that the energy performance of this glazing can be calculated using the following simple equation:

$$Q_{wfg} = m\,C_p\,(T_{wfg,out} - T_{wfg,in})$$

where:

- m - mass flow rate; kg/s;
- Cp - specific heat of fluid (in our case it is a mixture); kJ/kgK;
- Tout; wfg - temperature outlet; ^{0}C;
- Tin; wfg – temperature inlet; ^{0}C

As it is familiar the specific heat of a body is the amount of heat per unit mass required to raise the temperature by one degree Celsius. Since the WFG unit is filled with a mixture including water and ethylene glycol – the specific heat is calculated using the following equation [14]:

$$C_{p,mix} = \left(\frac{m_1}{m_{mix}}\right) C_{p,1} + \left(\frac{m_2}{m_{mix}}\right) C_{p,2}$$

where:

- m - mass; kg;
- Cp - specific heat of fluid (in our case it is a mixture); kJ/kgK. Specific heat capacity (for fresh water – 4;16 kJ/kgK and Ethylene glycol - – 2;36 kJ/kgK.

This new heat capacity depends on the proportion of each component; which can be calculated from mass or volume. In our case the specific heat capacity is 4;016 kJ/kgK.

Table 1 shows the results from the calculations. It is accepted the following conditions while calculating the energy performance of the WFG: the energy income is calculated for the time when there is sunlight available during the day; the difference between $T_{out;\,wfg}$ and $T_{in;\,wfg}$ must be positive in order to have energy ingested by the glazing; these calculations cover the period while it is cold in Bulgaria (October 19 2019 – May; 20 2020).

Table 1: Energy Production from WFG façade for (October 19 2019 – May; 20 2020)

WGF	East	East 1	76;46	; kWh
		East 2	68;31	; kWh
		East 3	75;40	; kWh
		East 4	325;20	; kWh
		East 5	196;86	; kWh
	South	South 1	1038;14	; kWh
		South 2	747;77	; kWh
		South 3	858;36	; kWh
		South 4	681;05	; kWh

		South 5	636;87	; kWh
	West	West 1	74;99	; kWh
		West 2	70;36	; kWh
		West 3	75;68	; kWh
		West 4	304;67	; kWh
		West 5	122;77	; kWh
Total (2019-2020)		5352;88		; kWh

Energy production and consumption of the demonstrational Pavilion by months are presented on (Figure 14.). The annual energy production from the PV system is 5840 kWh and consumption is 6470 kWh. In winter months the consumption is greater that the production significantly; while in spring and summer the production is more than consumption of the Pavilion. In autumn; the production is relatively similar to the consumption. The coldest month is January with average temperature close to 0°C. The production in January is 150 kWh; and consumption is 770 kWh; used mainly to keep indoor temperature comfortable. The hottest month is August with a mean temperature of 21.5°C. The energy production in August is 800 kWh and the consumption is 790 kWh. Figure 15 shows in details the production by months for 2020.

It should be noted that the consumption; self-sufficiency and imported energy have different values shown in the Figure 15. The values are lower than the actual one shown in Fig.14 and does not include consumption 773 kWh in January and 610 kWh in February 2020.

The analysis of the energy management on an annual basis shows that in the production of electricity from the solar generator is 5839.28 kWh; the own consumption is 2086.87 kWh; which is 35.74% of the total yield. The remaining yield of 3752.41 kWh or 64.26% is exported to the national electrical grid. The results for energy consumption from the Pavilion show 6468.81 kWh (on Fig.15 is 5085.81kWh). Self-sufficiency is 2086.87 kWh (on Figure 15 is 1788.58 kWh); which is 32.26% (on Fig 15 is 35.17%) of the total consumption and imported energy from national electrical grid is 4382 kWh (on Figure 15 is 3297.10kWh) which is 67.74% (on Figure 15 is 64.83%) of the total consumption. To meet local requirements for nZEB at least 55% of the energy used for heating; cooling; ventilation; domestic hot water and lighting should be energy from renewable sources; produced in the building or in its close surroundings. This can be achieved by installing batteries to store energy that was exported to national network or 3752.41 kWh. In that case; more than 55% of energy will come by renewable sources produced in the building or in its close surroundings. The Pavilion can be classified as nZEB.

On an annual basis; as it shows Figure 14; is seen that the energy loads for heating; cooling; artificial lighting and power supply for technical equipment may be covered on 90% by energy produced from the PV system. Power required for artificial lighting and power supply for technical equipment have relatively constant value.

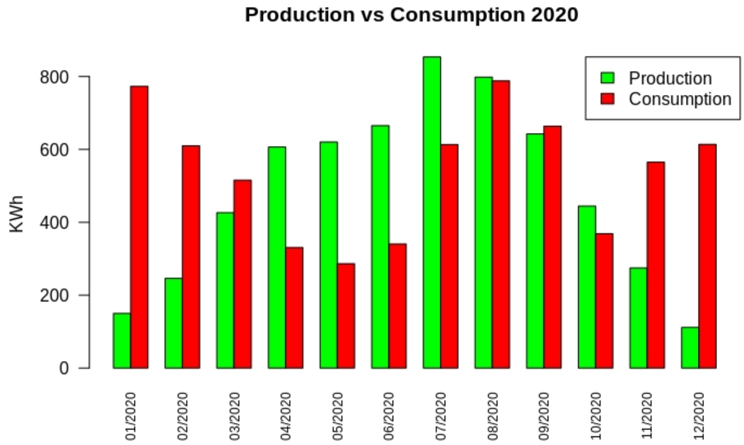

Figure 14: Monthly energy production from PV panels and the energy consumption of the Pavilion during 2020 year

Figure 15: Energy management of Pavilion for year 2020 without production data from January and February 2020 (773 kWh in January and 610 kWh in February)

Conclusion

The global interest in nearly zero-energy buildings (NZEBs) has led to their establishment as mandatory building objectives in Europe for all new constructions starting in 2021. The principles outlined in the Energy Performance of Building Directive (EPBD) emphasize the significance of reducing energy demand through various energy efficiency measures to achieve NZEB status [13].

This work presents results and evaluation of the energy produced and consumed by the innovative Pavilion in Sofia; Bulgaria. The obtained results show the first year of operation of the Pavilion. The aim is to accumulate data; analysis and conclusions; in order to improve the energy performance of the Pavilion. The demonstrational Pavilion has WFG façade and PV system; which provide the necessary energy for heating and cooling. The heat pump balances the cooling and heating requirements for indoor comfort. WFG panels work as integrated solar collectors. The energy system of the Pavilion includes a PV system; which is connected to the national electrical grid and provides electricity for heating; cooling; lighting and power supply. Combining WFG with an integrated PV system in the Pavilion definitely reduces energy consumption.

Monitoring and research of the Pavilion during its operation helps to improve the work of the systems and to assess the indoor comfort of the building. WFG systems can control temperatures and provide comfortable indoor environment. The proposed solutions with the use of various technologies implemented in the Pavilion are optimal for the design of an office building with nearly zero energy consumption. Ongoing monitoring will show different problems and solutions; which will provide more information about the operation of the Pavilion and its systems. The present study proved that on an annual basis the innovative demonstrational Pavilion meets the national criteria for nearly zero energy building / nZEB /.

Acknowledgments

This work was supported by the Horizon 2020 Program - 'Secure; clean and efficient energy'. The Program has three focus areas: Energy-efficiency; Low carbon technologies; and Smart Cities & Communities. Project ref. 680441 InDeWaG: Industrialized Development of Water Flow Glazing Systems. (http://www.indewag.eu/)

References

1. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0169&from=EN

2. https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-feb-17_en

3. https://www.iea.org/reports/global-status-report-for-buildings-aind-construction-2019

4. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN

5. https://seea.government.bg/documents/BG_National_nZEB_Plan_EN.pdf

6. Danny H.W. Li; Liu Yang; Joseph C (2013) Lam Zero energy buildings and sustainable development implications – A review Energy, 54: 1-10

7. O Saadatiann, K Sopian, CH Lim, N Asim, MY Sulaiman (2012) Trombe walls: A review of opportunities and challenges in researchand development Renewable and Sustainable Energy Reviews; 16: 6340–51.

8. Y Chen, L Norford, H Samuelson, A Malkawi (2018) Optimal control of HVAC and window systems for natural ventilation through reinforcement learning Energy Build.; 168: 195-205.

9. M Nikolaeva-Dimitrova, M Stoyanova; Pl. Ivanov; K. Tchonkova; R. Stoykov; Investigation of thermal behaviour of innovative Water Flow Glazing modular unit; Bulgarian Chemical Communications, 50: 21-7.

10. http://www.meteo.bg/meteo7/sites/storm.cfd.meteo.bg.meteo7/files/godishen_buletin_NIMH_2020.pdf

11. https://bulletins.cfd.meteo.bg/bull/Buletin_NIMH_202012.pdf

12. https://bulletins.cfd.meteo.bg/bull/Buletin_NIMH_202008.pdf

13. Abolghasemi Moghaddam, Saman & Serra, Catarina & Gameiro da Silva, Manuel & Simões N (2023) Comprehensive Review and Analysis of Glazing Systems towards Nearly Zero-Energy Buildings: Energy Performance; Thermal Comfort; Cost-Effectiveness; and Environmental Impact Perspectives. Energies.

14. Amyn S, Teja (1983) Simple method for the calculation of heat capacities of liquid mixtures. Journal of Chemical & Engineering Data, 28: 83-5.