Building Integrated Photovoltaics in the overall building energy balance: Lithuanian Case

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Abstract: The integration of PV systems into buildings becomes more and more significant in the context of increasing energy consumption and rising energy costs. The paper presents analysis of roof and walls integrated PV system performance on the overall building energy balance, based on simulations and experimental data.The renovation of residential building, in Kaunas town, Lithuania, was chosen for the analysis. The purpose of renovation was to reduce the energy costs and the environmental impact from energy production. Energy production and efficiency of roof integrated PV system were simulated and economical assessment of the renovation was performed. An alternative case - PV integrated in the facade was analyzed by different software.

1. Introduction

The European Union has adopted Directive EPBD (European Commission 2013), which indicates that all public buildings from 2018 and the rest from – 2020 must comply with the close to zero category energy building standards. Currently, Lithuania implemented buildings modernization program only partly complies with the EU directive. Analyzing various building renovation scenario, solutions are often made based on the predicted amount of energy consumption savings. Currently, the most energy efficient residential buildings in Lithuania, on average, consume around 49 kWh/m^2 per year, around 19 kWh/m^2 of which is used for heating. Meanwhile, non-renovated multi-apartment buildings consume almost six and a half times more, i.e. 318 kWh/m^2 per year (275 kWh/m^2 per year for heating) (Lithuanian Ministry).

Retrofitting building energy consumption depends not only on the level of insulation of the building partitions but also on the ability to produce and use energy from renewable sources. In order to achieve high energy efficiency, it is necessary to integrate renewable energy sources using tools (renewable energy systems - RES) in retrofitting buildings (Energy consumption 2014). Lithuania has ambitious quantitative targets for renewable. The energy strategy has set up a target for 2010, with RES generating 12% of the energy supply of which electricity produced by RES should amount to 7% (Streimikiene et al. 2005). In many articles the possible integration of PV systems into the roofs and facades options are provided and also their advantages and disadvantages (Kalogirou 2013, Chae et al. 2014, Cerón et al. 2013, Peng et al. 2011, Vartiainen 2001, Vartiainen et al. 2000). According to some authors, for more precise assessment of renovation projects it is necessary to take into account the multiplicity of retrofitting by moving beyond to the energy efficiency (Biekša et al. 2011). A certain retrofitting scenarios choice should depend on the buildings themselves, orientation, environmental condition, retrofitting rates, quantify the energy savings, CO2 emissions, retrofitting measures during processing.

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2. Methodology

This article presents the modeling of solar systems integrated in the roof and walls. According to actual and modeling data, a systematic analysis of energy needs, determination of building energy class before and after modernization of the residential house was carried out.

2.1 Description of the object

3-storey residential house built in 1958 was chosen for the study (Fig.1). Residential house is in Kaunas (house area – 1108.64 m^2, number of floors – 3). Power consumption in 2015: the quantity of heat for heating – 146.08 MWh/per year, thermal water heating costs – 97.87 MWh/ per year. Total building heat consumption per year 243.95 MWh. Retrofitting building during 2015 consumed 25.82MWh the total electric power per year. Building CO_2 emission amount is 54.53 ($kgCO_2/m^2 \times year$). The measures applied to improve the energy performance of the building – walls and roof insulation, replacement of windows and alternative energy sources usage. Terms of use of solar energy are particularly suitable. House roof – sloping, one side – southern, so installed solar collectors should be particularly rational use of natural energy.

Fig. 1. Residential house before retrofitting

2.2 Computer simulation

In order to assess the production of electricity by means of integrated solar power plants for results obtaining Swiss photovoltaic solar system modeling program PVSYST V6.49 was applied. By applying program PVSYST V6.49, it was modeled retrofitting building's roof and wall data entering to the program climate parameter values indicated in Republican construction norms RSN 156-94 Construction Climatology and data collected by KTU Architecture and construction climate station (2009-2014 year) (Fig.2 and Fig.3).

<u>PVSYST V6.49 modeling results:</u>

Solar plant of 10 kW photovoltaic elements is integrated in the roof:

- During solar dominant period (April-September) 32% of the electricity demand is covered.
- the total yearly reimbursed 41% of the total electricity demand.

Wall-integrated 10 kW photovoltaic elements solar power plant:

- During solar dominant period (April-September) 20 % of the electricity demand is covered.
- the total yearly reimbursed 29 % of the total electricity demand.

<u>Modeling results according to RSN 156-94</u> Construction Climatology:

Solar plant of 10 kW photovoltaic elements is integrated in the roof:

- During solar dominant period (April-September) 32% of the electricity demand is covered.
- the total yearly reimbursed 44% of the total electricity demand.

Wall-integrated 10 kW photovoltaic elements solar power plant:

- During solar dominant period (April-September) 20 % of the electricity demand is covered.
- the total yearly reimbursed 32 % of the total electricity demand.

<u>Modeling results according to data collected by KTU Architecture and construction climate station:</u>

Solar plant of 10 kW photovoltaic elements is integrated in the roof:

- During solar dominant period (April-September) 36% of the electricity demand is covered.
- the total yearly reimbursed 46 % of the total electricity demand.

Wall-integrated 10 kW photovoltaic elements solar power plant:

- During solar dominant period (April-September) 24 % of the electricity demand is covered.
- the total yearly reimbursed 32 % of the total electricity demand.

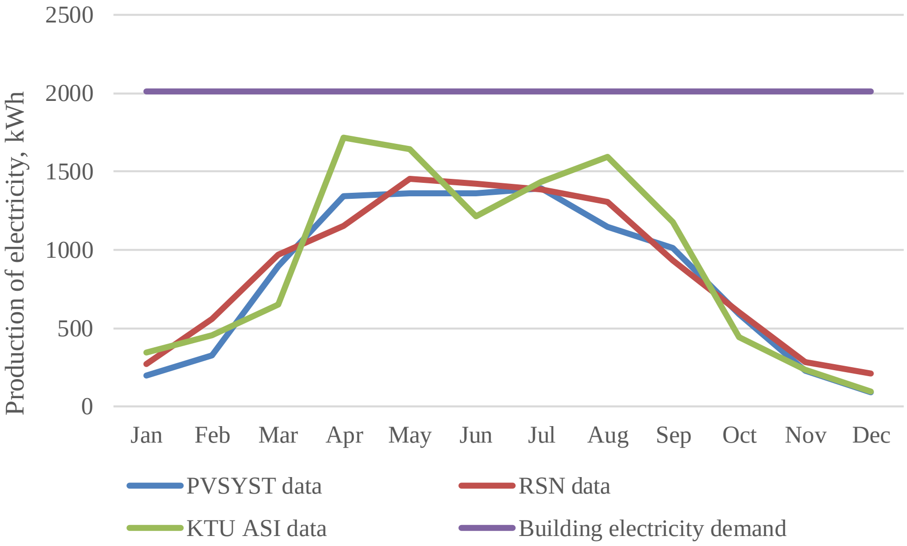

Fig. 2. BIPV electricity generation modeling under *different climate data* (roof case 36º)

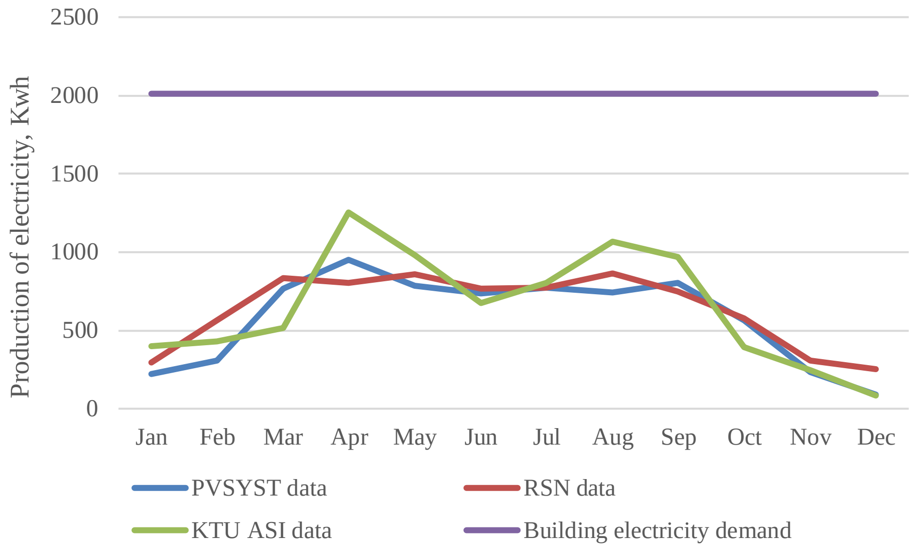

Fig. 3. BIPV electricity generation modeling under *different climate data* (wall case 90º)

2.3 Energy Performance Certification

Energy performance certification of buildings is a key policy instrument for reducing the energy consumption and improving the energy performance of new and existing buildings. For existing buildings, energy certification attests to the energy performance of the building, and provides information that may increase demand for more efficient buildings, thereby helping to improve the energy efficiency of the building stock in the country. Energy performance certification of retrofitting building was carried out according to STR 2.01.09:2012 Energy Performance of Buildings methodology. Calculation of non-renovated buildings energy efficiency results show that the building specific losses are 1762.99 W/K, which corresponds to the energy efficiency class E. The graph in Fig. 4 shows the variation in heat loss, depending on the insulation choice and BIPV integration.

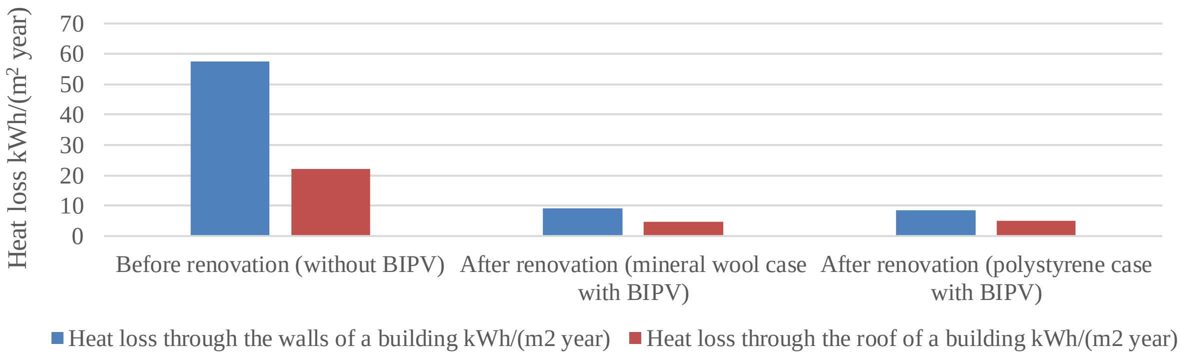

Fig. 4. Heat losses, calculated with NRG3 certification program

2.4 Experimental study

In line with EU requirements to reduce energy consumption and to use the minimum amount of energy from renewable energy sources in new buildings and retrofitting buildings the analyzed multistoried building was insulated with thermal insulation from the outside and 10 kW photovoltaic solar system (makes 18% of roof area) on the roof with the area of 66 m^2 (Fig.5). Energy consumption after insulation: the quantity of heat for heating – 61.22 MWh/per year, (reduced by 58.09%) thermal water heating costs – 28.71 MWh/ per year (reduced by 70.67%). Total building heat consumption per year is 89.93 MWh (reduced by 46.47%). After the retrofitting the house consumed 25.82MWh / year of the total electric power. Building‘s CO_2 emissions is 29.19 ($kgCO_2/m^2$×year). An experimental study was conducted in 2013 – 2015. During experimental study it was measured the electricity produced in the electric plant integrated on the roof and consumed electric energy demand in the building after retrofitting.

Fig. 5. Residential building after retrofitting

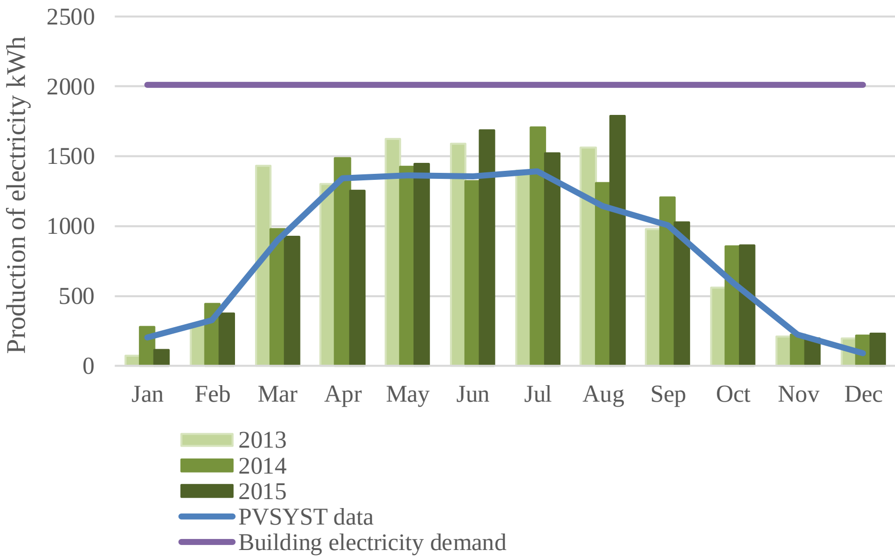

Fig. 6. BIPV electricity production comparison with the modeling and the building needs

3. Results

In Fig. 6 presented year 2015 graph shows the modeled electricity generation during all months. Blue curve denotes project 10 kW photovoltaic solar power electricity generation, according to data of PVSYST V6.49 meteorological data base, which shall guide the majority of modeling programs, when modeled in Kaunas. Purple curve shows the average of electric power demand in the building.

The green columns represent the actual (data collected during study) obtained production of electricity during the period of January - December in 2013-2015. During the study period, the integrated solar power plant produced electricity quantity which did not exceed the average monthly demand. During the summer period, the mentioned demand was covered by 77 %, winter period 10%. During the study, it was found that the installation of more powerful solar power plant is not appropriate because the building would generate more electric power than consumed.

Summarizing the roof integrated photovoltaic systems experimental study it may be indicated that over the past 2015 year it was generated 11426 kWh of electricity or 1496.7 kWh from installed kW, i.e., 15 % more than the theoretical predictions, which were followed during modeling programs.

Analyzing different insulation systems for insulated buildings, energy savings through the external borders cases, it can be concluded that very similar results achieved applying both wall insulation systems. Buildings, insulated with external thermal insulation composite systems with polystyrene foam through the external walls have saved an average of 65.92 kWh/ (m^2 per year).

Conclusions

The need for modernization provides the opportunity to implement a variety of strategies for renewable energy, including solar energy. The energy certification increases public awareness about energy consumption in buildings, allows energetically compare various buildings, motivates participants to building more energy efficient buildings. During the summer period, abovementioned demand was covered by 77 %, winter period 10%.

Using the area of the analyzed residential house roof area and installing 10 kW photovoltaic solar power plant, it will be covered 38 % electricity demand of the building during the year.

Implementation guidelines of buildings energy efficiency modernization the government should review the existing energy certification experience all over the world.

The paper produces recommendations and research findings that could be used for further improvement on the process.

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