ASSESSMENT OF POTENTIAL FOR ON-SITE ELECTRICITY PRODUCTION FOR COOLING AND FREEZING FACILITIES BY APPLICATION OF PHOTOVOLTAICS

M. Mančić[*,1], D. Živković[1], M. Laković-Paunović[1], M. Rajić[1], M. Đorđević[2] and M. Jovčevski[1]

Faculty of Mechanical Engineering, University of Nis, Nis, Serbia [1]

Faculty of Technical Sciences in Kosovska Mitrovica, University of Priština[2]

Abstract: Application of photovoltaics can be identified as a measure for lowering electricity costs and reduction of CO_2 emissions. The cooling and freezing facilities predominately use electricity for their operation processes. Furthermore, the fruit and vegetable purchase season correspond to the period with the greatest solar insulation periods in Serbia. Electric peak loads in the fruit and vegetable freezing and cooling sector are a consequence of keeping the cooling chamber temperatures at a given temperature below zero, keeping the production treatment rooms at near zero temperatures, and freezing processes in the freezing tunnels typically at -40 °C. In this paper, an assessment of potentials to use photovoltaics to reduce electricity dependency from the electricity supplier was analyzed using Trnsys software. The available area for mounting photovoltaics is determined by the available rooftop area of the cooling and freezing facility. Simulation for a typical meteorological year is conducted to determine the average available electricity gain for a cooling chamber. A scenario with panels mounted directly on the rooftop construction with 10° slope and a scenario with angled mounted systems resulting in photovoltaic panel slope of 35° were analyzed. Technical specifications photovoltaic system elements available at the local market were used for the simulation.

Key words: photovoltaics, electricity production; solar; Trnsys software

1. INTRODUCTION

With the "liberalized" electricity market in Serbia and rising energy prices, decentralized electricity production (DE) and renewable power generation have a record of increased market interest [1]. Evaluation of advantages and disadvantages of mitigation to decentralized electricity production against the general sustainability criteria indicates that DE can contribute to CO2 emission reduction and lower consumption of primary energy carriers [2]. Models and approaches for decentralized energy planning can differ worldwide, since development strategies are area-based, shaped to meet energy needs and develop renewable energy potentials with least cost to the economy and environment [3]. Labels promoting higher energy performance standards in housing have been promoted in many European countries as market mechanisms, while for less advanced countries this can be an opportunity to learn and develop such labels to suit market demand and implementation of European Energy Performance of Buildings Directive recast [4]. Application for membership in European Union imposes the issue of compliance with European objectives in the terms of energy efficiency, renewable energy and reduced CO_2 emissions.

Photovoltaic (PV) technologies are recognized as one of the most suitable for decentralized electricity production in urban areas [5, 6]. Adequate technical approach implies economical PV production for maximum electricity generation by mounting the panels only on the south roof surface of a building [6]. Nevertheless, in this paper potential of electricity production using photovoltaic

[*]Corresponding author e-mail: marko.mancic@masfak.ni.ac.rs

collectors is estimated for roof mounted panels as a retrofit solution with the rooftop façade orientation predetermined for an existing cooling and freezing facility. The model assumes production of electricity predominately to meet on-site electricity loads of the cooling and freezing facility, whereas it is assumed that the excess electricity, if any, is transferred to the grid. The production operates in 3 shifts, processing approximately 8,000 tons of fruit annually. The fruit freezing and storage and hot processing operate throughout a year. The aim of the paper is to research the potential for decentralized electricity production using roof mounted PV and determine the difference between energy demand and local energy production. An annual balance of locally produced and consumed energy is performed using TRNSYS software and historic electricity billing data of the freezing and cooling facility installation.

2.LEGAL BARRIERS OF APPLICATION OF PV SYSTEMS

Construction of plants and performing the activity of energy generation from such plants are regulated by a number of laws and by-laws in the Republic of Serbia [7]. The group of regulations governing the field of planning and construction of facilities includes: Law on Planning and Construction [8], Law on the Spatial Plan of the Republic of Serbia [9], their pertaining by-laws and other regulations. Planning documents include spatial plans (regional spatial plans, spatial plans of units of local self-government, and spatial plans of areas for special use) and urban development plans (urban master plan, general regulating plan, detailed regulating plan). The Law on Planning and Construction with the relevant by-laws regulating the area of construction of facilities prescribes the procedures for receiving information on locations and location requirements, the construction permit, and the operation permit, while planning documents define the objectives of spatial planning and development, i.e. spatial development, such as whether it is planned in a certain time period to construct a certain facility in a certain location in the Republic of Serbia. In order to obtain the above permits it is necessary to obtain the technical requirements for connection to the power grid, and other requirements.

In the course of obtaining the construction permit for solar plants there is no requirement to obtain the Environmental Impact Assessment, except when the facility is constructed in protected natural areas or other areas of special purpose, when the Environmental Impact Assessment may be required [7].

For plants of capacity up to 1 MW it is not necessary to obtain the energy permit, meaning that for these plants the construction permit shall be issue without the procedure for obtaining of the energy permit. The Energy Law, the Decree on Conditions of Supply of Electricity, the Rules on the Operation of the Distribution System and the Rules on Operation of the Transmission System set out a procedure for the connection of generating facilities to the power grid [7].

The special type of structures or works for which it is not necessary to obtain acts of competent authorities for construction or acts for the performance of works are simple structures. Simple structures are structures which are built on the same cadastre plot at which the main structure is constructed, and which are performed in a manner which does not interfere with the regular functioning of surrounding structures. The law states explicitly the solar connectors which are not connected to the energy distribution network as such structures. Construction of auxiliary structures and economic structures including the construction of plants utilizing renewable energy sources of installed capacity up to 50 kW, where construction is carried out on the basis of a decision approving the performance of such works and which is issued by the authority in charge of issuing construction permits, is also a case of constructing structures without the issuance of construction permit [8].

As light weight panels not connected to the national electricity supply grid should not require a construction permit, as per article 144 of the Construction and planning Law [8]. However, any such activities must be reported and a plea should be made to the local government in the governing municipality, which should allow the installation activities without the construction permit. However, the local authority could act according to the article 145 of the Construction and planning law and require a construction permit, especially if the PV system has a significant size or power rating.

In addition, the applicant should request technical conditions for the PV system from the national electricity supply company, due to theoretical possibility of interference of locally produced electricity with the grid, despite the fact that the company is not interested in selling electricity and exporting it to the grid. Furthermore, the electricity supply company has the authority to inspect whether these conditions were met after the construction.

3.ANNUAL ELECTRICITY DEMANDS AND PV PRODUCTION POTENTIALS

The available technical documentation of the production site buildings of the facility was reviewed in detail to gather information about the location, rooftop areas and construction. The area where the production buildings are located, can be considered open without any shading on the rooftop areas from external objects, which could interfere with the PV system operation. There are 2 production buildings which could be considered adequate for installation of the PV system. Apart from this, there is a small security building, and an open construction building for covering stored firewood biomass, thus protecting it from rain and similar weather conditions.

The main freezing and frozen fruit storage building is the largest building at the premises (1). This building consists of several functional parts: offices, compressor and machinery chambers, preproduction hall with the freezing tunnels, old frozen fruit storage chambers. The building rooftop has dual 10-degree slope, one half of which is oriented mostly towards south. Part of the rooftop, above the compressor and machinery chambers is occupied by condensers. Based on the available technical documentation, the construction of the building is concrete steel, properly designed to withstand static weight loads, as well as wind loads. The rooftop is constructed from a corrugated steel plate. Based on the on-site inspection, the construction of the building is in good shape, and able to support the weight of the PV panels mounted on the rooftop plane. The freezing department and the preproduction hall are 81.6m long, and 25 m wide, while the office part is 25 m wide and 15 m wide.The annex frozen good storage chamber is located next to the main freezing production building (3). The height of the building and the rooftop slopes lie in the same planes with the main freezing building. The construction of the building is steel concrete, with the insulation panels mounted to the support construction. The rooftop is made from corrugated steel sheet plates. The building is new, made according to technical design documentation, and can support mounting of PV panels in both roof planes. Since this is the new building, the company has expressed that they would prefer covering this rooftop with PV panels first, as part of the phase 1- construction of the small-scale pilot PV plant.

The third building is used for hot processing. It has a steel and concrete steel support construction, with masonry. The rooftop is made, with surface areas of 373 m2 made of steel sheet plates with a slope of 8 degrees, 600 m2 made of “salonit” with a slope of 8 degrees and 150 m2 made of masonry plates, with a slope of 35 degrees. The orientation of the sloped surfaces are predominately towards east and west.

The following assumptions were made to asses nominal power of the PV systems for each of the rooftops: Typical panel size is 1 x 1.7 m, Typical panel power is 250 W. The potential for installation of PV systems is summarized in the table 1.

Table 1. Estimated rooftop potential for mounting PV systems

No.	Surface (m^2)	Power (kW)	No. Of panels.
P1	2410	340	1360
P2	1600	228	914
P3	540	77	308
P4	400	57	228
Σ	4950	702	2810

Based on the architectural documentation (1,3) of the building with rooftop P4, the construction of the building is designed for stress up to 1,247 N/m2, whereas the two types of support construction built under the steel plates is sized can withstand stress of 12,800 N/cm2 and 12,800 N/cm^2. With the typical building stress calculated at 350 N/m2, the construction should have no troubles supporting the typical weight of 20 kg/ panel, or 11.7 kg/m2 of array.

Additional data was gathered during the on-site visits, about the electricity consumption of the company. The greatest energy consumers at the company are the compressors of the freezing facility. The electric motor power ranges from 55 to 200 kW (table 5). Hence, the company has a large enough demands side power rating to consume complete locally produced electricity, especially for the system of up to 50 kW.

Table 2 Main electricity consumers on-site

Consumer	**Type of compressor**	**Cooling capacity (kW)**	**Working regime (t_e/t_c)**	**Electric motor power (kW)**	**COP**
Tunnel freezer	„Mayekawa“ N160VLD-HE	112.6	-40/+35°C	110	1.47
	„Stal“ SVB-73 booster	590	-40/-10°C	200	N/A
Batch blast freezer	"POLAR 6" booster	180	-40/-10°C	55	N/A
Cold storage (6 cold rooms)	„Mayekawa“ N200VLD-HE	346.8	-32/+35°C	200	N/A
Cold storage or product manipulation and alternative regime of 2 cold rooms	„Mayekawa“ N160VLD-ME	169.5 / 409.7	-32/+35°C -10/+35°C	132	2.04 /3.63
Product manipulation and alternative regime of 2 cold rooms	„Mayekawa“ FM160L-M	409.7	-10/+35°C	132	N/A
	„Mayekawa“ N200MUD-M.	682.8	-10/+35°C	200	N/A

Note: Compressor No 5.** *is intended to work on* ***-10/+35°C or -32/+35°C working regime, *depending on the cooling needs. All compressors are* ***rotary screw type compressors, except No.3 which is reciprocating type compressor.***

Electricity consumption is measured at one point in the company. The greatest consumption of electricity is in the summer season, when most of the fruit is frozen and when solar insulation reaches peak values. Annual electricity consumption is presented in Fig. 1.

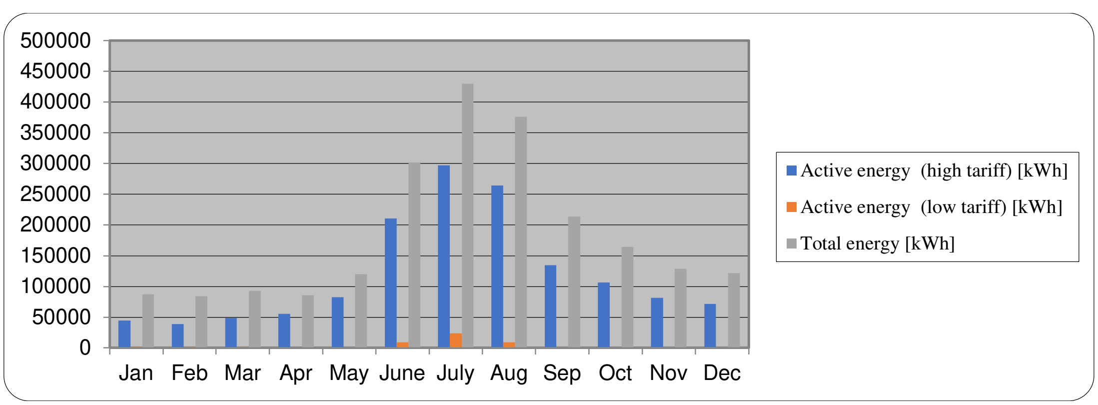

Fig. 1. Annual electricity consumption

The annual performance of the PV system is simulated using TRNSYS software with the following assumptions:

- The PV panels are mounted on the rooftop plane, without the change of slope, i.e., 10 deg slope,
- The PV panels are mounted on the rooftop with additional mounting construction and the slope is changed to 35 deg, while at the same time the power of the PV system which could be accommodated to the rooftop is reduced (as explained in the rooftop analysis).
- It is assumed that mounting systems which change the slope of the panels to a more optimal increase wind stress on the construction, and reduce available rooftop area to 50%. The reduced surface area should not be a problem for the small-scale installation, but could significantly reduce on-site production potential for the large-scale system.
- The simulation results for the same type offered PV arrays are presented 4, but for the installed power of approx. 170kW, 140 kW with the south and north orientations (-22 deg and 158 deg azimuth angle), and 10 deg slope, as well as approx 81 kW of installed power with a 10 degree slope and south orientation (-22 deg azimuth).
- The results of the annual performance simulations with increase of the installed PV surface area are given in table 2.
- The simulation is based on Luxor LX280 PV panels and Fronis 30kW inverters.

Table 3 Simulated PV system production during a typical meteorological year with respect to installed system power (Annex 4).

Installed power (kW)	Slope (deg)	Orientation	Production (kWh)	Solar electricity ratio (%)
30.00	10.00	S	13666.89	0.58
20.00	35.00	S	9599.16	0.41
50.00	10.00	S+N	21448.52	0.91
60.00	10.00	S+N	25339.34	1.07
81.00	35.00	S	38876.60	1.64
96.00	35.00	S	46075.98	1.95
140.00	10.00	S	63778.83	2.69
170.00	10.00	S	77445.72	3.27
177.00	35.00	S	84952.58	3.59
310.00	10.00	S+N	131917.13	5.57
340.00	10.00	S	154891.44	6.54
480.00	10.00	S+N	209362.85	8.84
620.00	10.00	S+N	263834.26	11.14
680.00	10.00	S+N	289173.60	12.21

The table 4 shows increase of locally produced electricity using the simulated PV system which corresponds to the roof top areas, their orientations and PV module slope with and without panel support. It can be observed from the table, that, due to low efficiency of the current PV systems the annual ratio of total electricity demand of the company that could be met by the small-scale system is 1.07%, and the maximum ratio that could be met by the large-scale system is up to 12.2%. The option of building only south oriented system with 10 degree slope could cover 6.54% of the annual electricity demands, which is the first option with the lower power rating (340kW).

Simulation results are given in the figures 2, 3 and 4.

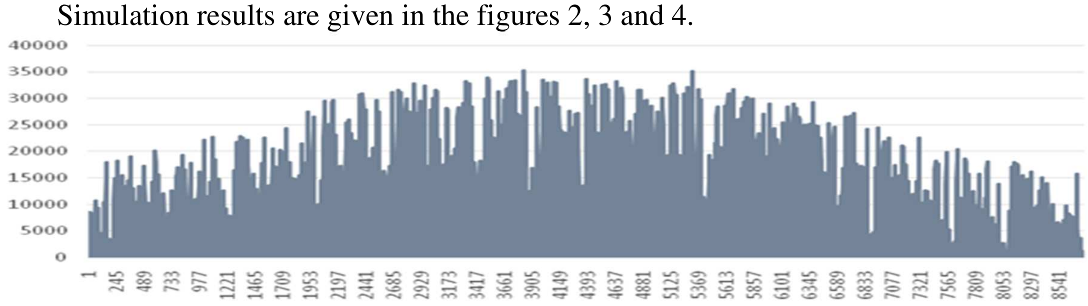

Fig. 2. Simulated performance of Luxor LX-280P, ~30 kW with FRONIS inverter, slope 10 deg, azimuth -22 deg

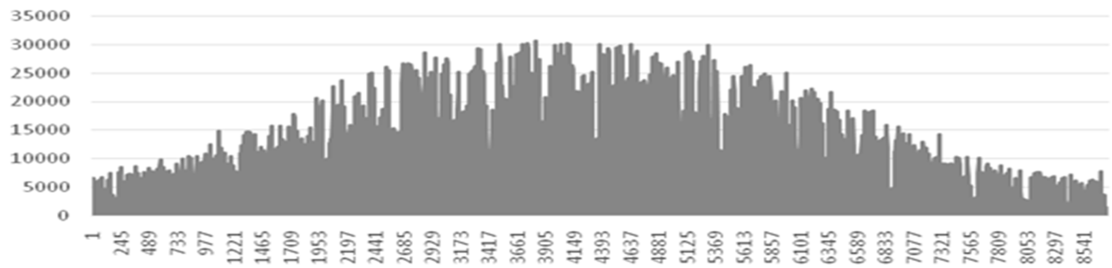

Fig. 3. Simulated performan□e of Luxor LX-280P, ~30 kW with FRONIS inverter, slope 10 deg, azimuth 158 deg

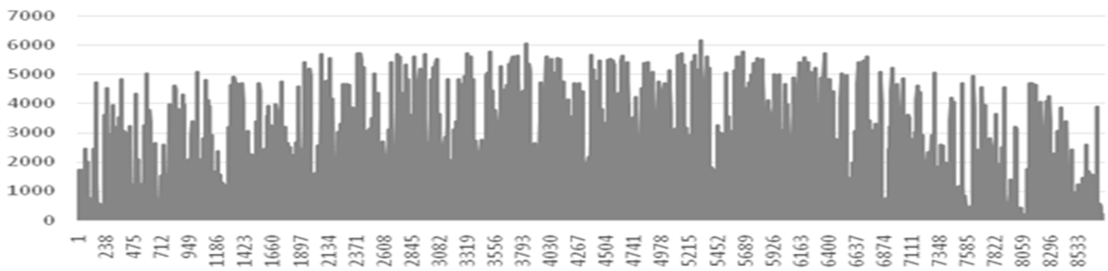

Fig.4. Simulated performan□e of Luxor LX-280P, ~30 kW with FRONIS inverter, slope 35 deg, azimuth -22 deg

4.CONCLUSION

In this paper, an analysis of the potential of a cooling and freezing facility to meet its electricity demands by on-site electricity production using roof mounted PV systems was analyzed. A retrofit for an existing facility was analyzed, where the existing roof layout determined both solar panel orientation and slope, which significantly affect PV performance. Some possible legal issues of implementation of the analyzed project were analyzed in the paper. It was determined that a maximum possible installed power of the PV system is close to 700 kW, whereas the installed power of the most significant electricity consumers (i.e., compressors of the cooling and freezing system) have a power rating of 1029 kW. With the slopes and orientation of the rooftops of the analyzed facility not laid out in an optimal position for solar system implementation, the local electricity production cannot meet local electricity consumption. The investment in solar panels with predominately North orientation is not financially reasonable. Therefore, the installed power of the PV system should be limited to approximately 340kW. The analyzed system can meet approximately 12% of the on-site electricity production. Application of PV panels with panel support which creates panel slope of 35 degrees increases specific annual performance of a unit surface of PV system, however, it decreases installed power and therefore potential for electricity production by approximately 40%.

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