Photovoltaic electricity production in a two-floor house in Serbia

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Abstract: An attractive solution for a sustainable present and future is to integrate photovoltaic (PV) panels into building envelopes. For these PV panels applied in a two-storey house in Belgrade-Serbia, we use software *EnergyPlus* to investigate its electricity generation and maximum power and determine the house orientation for which the panels produce maximum amount of electricity in a year. In addition, we determine that in order for these panels economically to produce electricity, the necessary government subsidies for PV panels located at the south roof are around 50%.

Keywords: Photovoltaic (PV); electricity; building; power; energy; subsides.

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Mirko Blagojević finished BSc in Mechanical Engineering at Kragujevac University in 1993 and in 2004, MSc at Kragujevac University, Yugoslavia. Mr. Blagojević worked in industry where he gained valuable experience in design of power engines from 1993 to 2000. He has been Teaching Assistant at Kragujevac University, Faculty of Mechanical Engineering, Serbia and Montenegro where he is actively involved in research on solar energy and building energy simulations since 2000. From 2004, he has been active research officer on research project titled 'Development and investigation of hybrid plane collector of solar energy for heat and electricity conversion' financed by Ministry for Science, Technology and Development of Republic of Serbia.

1 Introduction

As combustion during electricity production from non-renewable resources presents one of the main reasons for global and local pollution, sustainable electricity production by PVs provokes great attention worldwide (Haas, 2003; Muneer *et al*., 2003; 2004; Li *et al*., 2004; Nomura and Akai, 2004). An attractive solution for future is to integrate PVs into the building envelope especially as it is expected that in future great shortages of electricity may exist and the price of PV panels may drop because of their massive forthcoming production (Yoo and Lee, 2002; Bahaj, 2003; Compagnon, 2004; Yang *et al*., 2004).

For a house in Belgrade-Serbia, we investigated electricity generation by PV panels integrated in all its walls and roofs. We assumed that this building might consume electricity either from PV panels or from the electricity grid. We answered several research questions of interest:

- What is the maximum amount of power of PV panels during electricity generation in this house?
- What is the amount of electricity that can be generated yearly?
- What is the best orientation of the house for the highest electricity generation?
- What is the degree of economic viability of PVs integrated into building architecture in Serbia (Belgrade region) today?
- What is the level of state subventions needed to produce electricity economically?

2 Building with integrated-photovoltaic panels

Table 1 lists characteristics of the investigated building, and Figures 1 to 3 shows the appearance of its envelope from north and south. The building is located in Belgrade region in Serbia with latitude of 48.82 degrees. It has two storeys with one flat in each storey. It has seven envelope surfaces with distinct orientation designated as the north wall, east wall, south wall, west wall, north roof, south roof, and upper roof. These surfaces are entirely covered by PV panels, while surfaces of windows and doors are not. Figures 1 to 3 also shows the location of the north of the house relative to the building walls. The location is defined by angle θ as an angle between the true north and the house north. The angle is useful to express the orientation of the house when the house is rotated for simulation purposes.

The size of each PV surface (wall or roof) of the building is shown in Figure 2. The greatest size have PV surfaces located at the south and north walls. The characteristics of used PV panels (and cells) used in PV surfaces are given in Table 2. The PV cells are of mono-crystalline type. The yearly maximum power of each PV surface per square metre when $\theta = 0°$ is also given in Figure 2 showing that the PV surface with the highest power per square metre (of 160 W/m^2) is placed at the south roof and the PV surface with the lowest power per square metre (of 30 W/m^2) at the north wall.

Table 1 Building characteristics

Properties	*Characteristics*
Located in	Belgrade, Serbia
Latitude	44.82°
Longitude	20.28°
Time zone	+1 h
Elevation	99 m
Typical building	House in Serbia
Number of flats	Two
Number of stories	Two stories
Roof slope	44.82°

Figure 1 Appearance of southern part of building

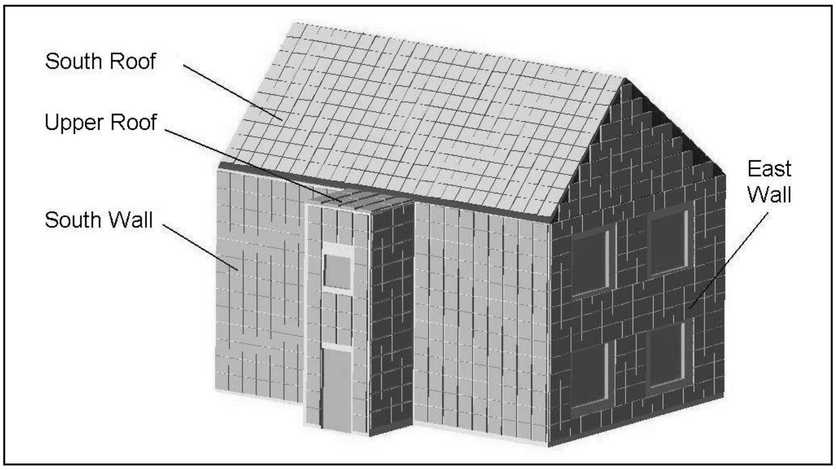


Figure 2 Appearance of northern part of building

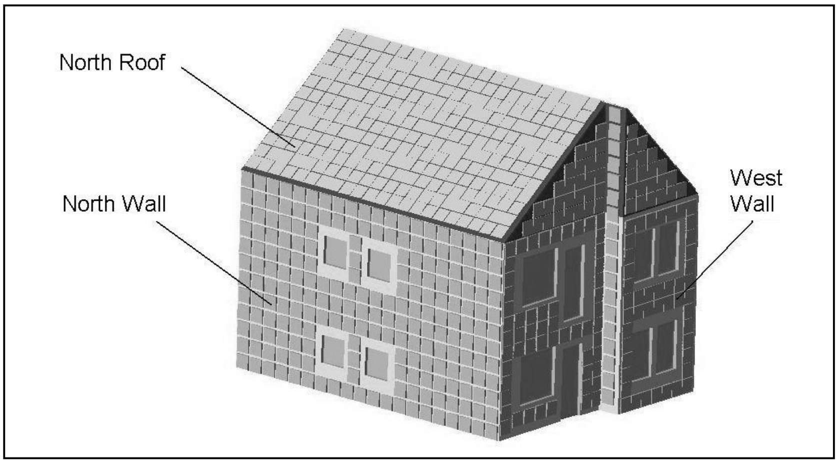


Figure 3 Plan of building

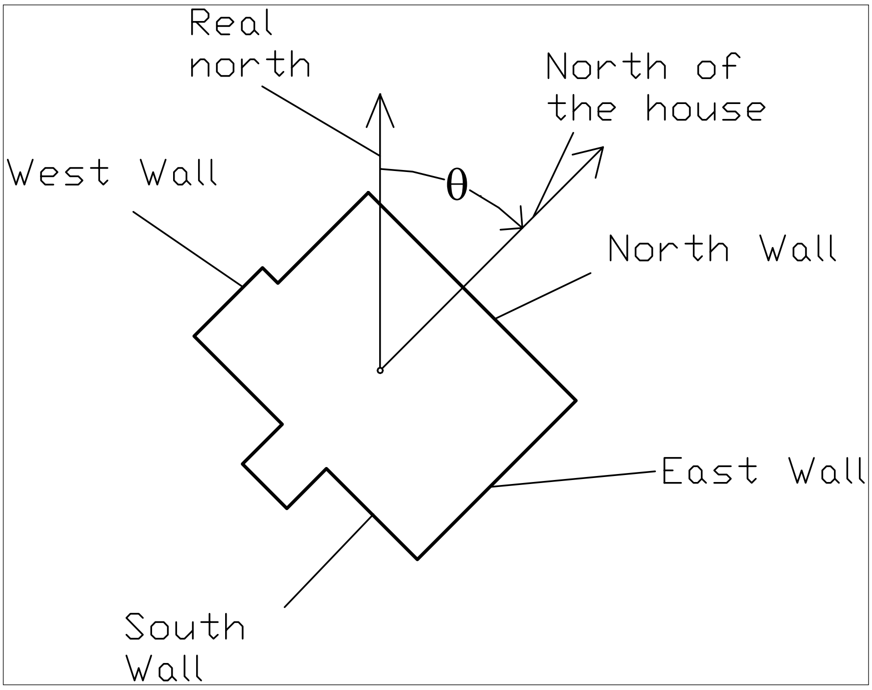


Figure 4 Size and maximum power of PV surfaces of the PV building

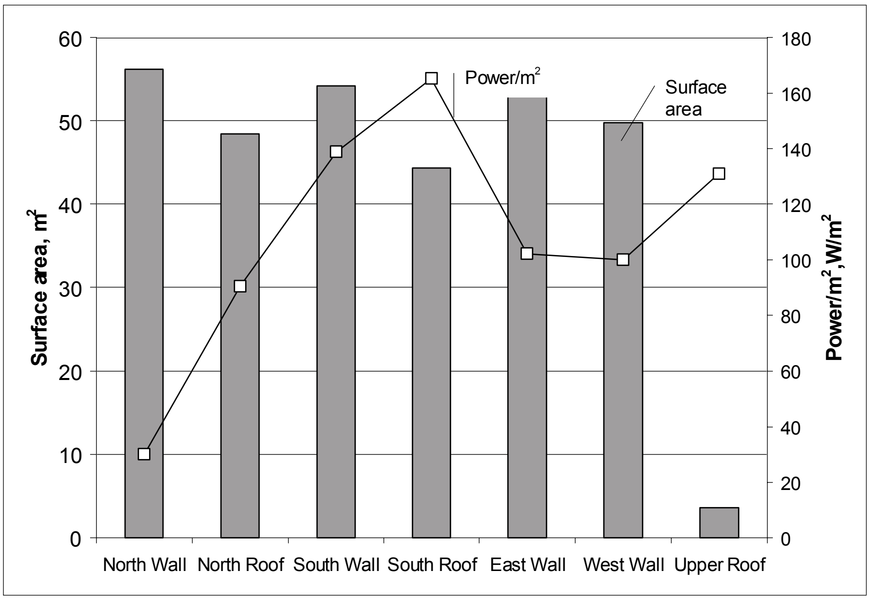


Table 2 PV characteristics

Properties	*Characteristics*
Array type	Mono-crystalline
Number of cells in series	36
Shunt resistance	1 000 000[ohms]
Short circuit current at reference conditions	6.5 [A/K]
Open circuit voltage at reference conditions	21.6 [V/K]
Temperature at reference conditions	25° [C]
Radiation at reference conditions	1000 [W/m2]
Current at maximum power	5.9 [A]
Voltage at maximum power	17 [V]
Temperature coefficient of short circuit current	0.002 [A/K]
Temperature coefficient of open circuit voltage	–0.079 [V/K]
Ambient temperature at NOCT	20° [C]
Cell temperature at NOCT	40° [C]
Radiation at NOCT	800 [W/m2]

3 Energy plus and photovoltaic building

To model the PV-house as well as to calculate its produced electricity and developed power, we used software *EnergyPlus* produced by Lawrence Barkley National Laboratory in USA (Crawley *et al*., 2001).

In this software, a photovoltaic panel is modelled as electricity circuit with one diode.

The programme enables integration of single panels in wall and roof surfaces of the house to describe their orientation and use results of solar-radiation calculation (Ernest Orlando Lawrence Barkley National Laboratory, 2004).

Currently, EnergyPlus does not include separate models for supplementary equipment for a PV array such as batteries, charge controllers, power-point trackers, and inverters. It is assumed that electricity produced by the PV arrays is always put to good use, as in an ideal, grid-tied system. Modules are generally assumed to be actually operating at maximum power point. For a variety of reasons, actual installations of PVs are often observed to exhibit system-level problems that significantly reduce electricity production. Therefore this modelling should be considered a method of bracketing the upper end of electricity production rather than an accurate prediction of what the panels will produce. Furthermore, the model predictions are closely related to the solar radiation data of TMY2 origin in the EnergyPlus weather file. These solar data are usually from a model rather than direct measurements. These data encountered by a real installation in a given year are likely to differ from the TMY2 data.

4 Mathematical model

The model of photovoltaic panel (the equivalent electricity circuit with one diode) predicts its electrical performance. The model is also known as the 'TRNSYS PV' model. The model was developed by Duffie and Beckman (1991) and first incorporated into a component for the TRNSYS simulation package by Eckstein (1990). This model employs the Eckstein model for crystalline PV modules, using it whenever the short-circuit IV slope is set to zero or a positive value as modified by Ulleberg (2002). Mathematically speaking, the EnergyPlus PV model employs equations for an empirical equivalent circuit model to predict the current-voltage characteristics of a single module. This circuit consists of a DC current source, diode, and either one or two resistors. The strength of the current source depends on solar radiation and the IV characteristics of the diode depend on temperature. The results for a single module equivalent circuit are extrapolated to predict the performance of a multi-module array.

5 Electricity power and production

To describe electricity generation by the PV house, we calculate its maximum electricity power (*D*) and its produced amount of electricity (*Q*) on a yearly basis. Higher value of *D* of the PV house would mean higher production of electricity in unit time. Then, the environmental performance of the PV house should be regarded as better since higher production of electricity may globally reduce CO_2 production.

We evaluate *D* as a yearly maximum of the sum of the values of the predicted hourly powers of all PV surfaces as:

$$D = \sum_{J=1}^{N} Q_{\max, J}. \tag{1}$$

Here, $Q_{max,J} = \max (Q_{I,J})$ where $Q_{I,J}$ stands for the electrical energy (an output of EnergyPlus) produced by PV surface *J* during hourly time interval *I* where $I = 1,\ldots, 8760$ and $J = 1,\ldots N$. Next, *N* stands for the total number of distinct PV-surfaces. Figure 3 shows *D* for different orientations of the PV house. When θ = 225°, the PV house has the maximum value of *D* at 21.7 kW. This value is 12% greater than the minimum value of *D* obtained when θ = 90°.

We calculate *Q* as:

$$Q = \sum_{I=1}^{8640} \sum_{J=1}^{N} Q_{I,J}. \tag{2}$$

Figure 6 shows *Q* for different orientations of the PV house. When θ = 270°, the value of *Q* has its maximum value of 0.142 TJ (this is the best orientation of the PV house). This value is 8% higher than the minimum value of *Q* obtained when θ = 90°.

Figure 5 Yearly power at integrated PVs vs. the building orientation

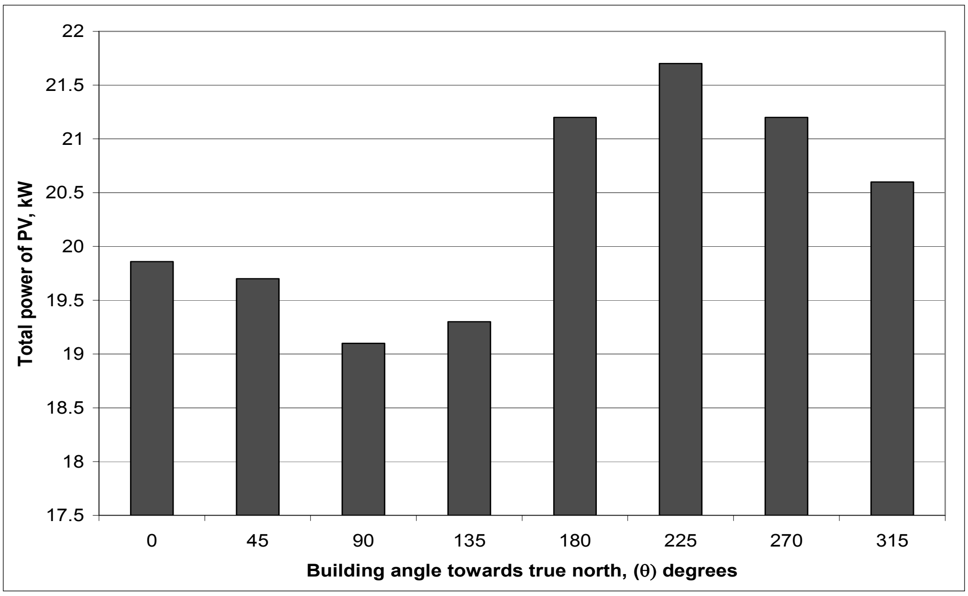
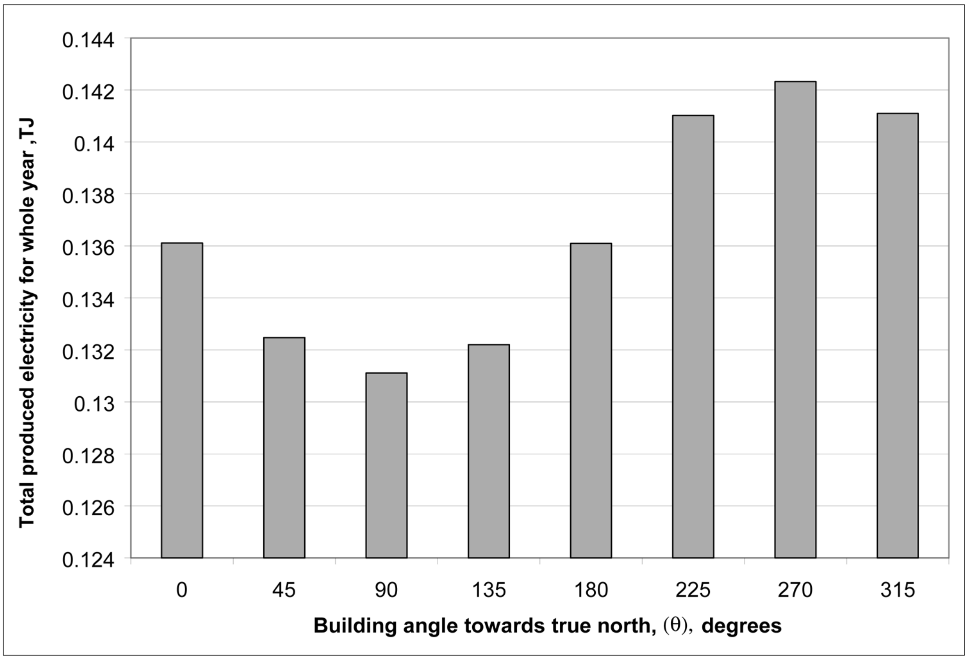


Figure 6 Yearly electricity produced by integrated PVs vs. the building orientation



6 Economics

To find the degree of economic viability of PVs integrated into building architectures in Serbia (Belgrade region) today and the level of state subventions needed in order to make electricity production economically feasible, we performed some economic calculations. We calculated each PV surface (designated by *J*) of the PV house its investment cost (IP_J) and electricity revenue (CQ_J).

We calculate IP_J as:

$$IP_J = A_j \; TP_J \tag{3}$$

where A_J represents size of PV surface of the PV house designated by *J* and TP_J represents cost of m^2 of PV surface '*J*' in present value €. In this analysis of investment in PVs, we took into consideration only the price of PV surfaces but not the price of additional electro equipment (battery, battery controller, and inverter). For all PV surfaces, value for TP_J would be the same. The value for TP_J would be different for present and future scenarios.

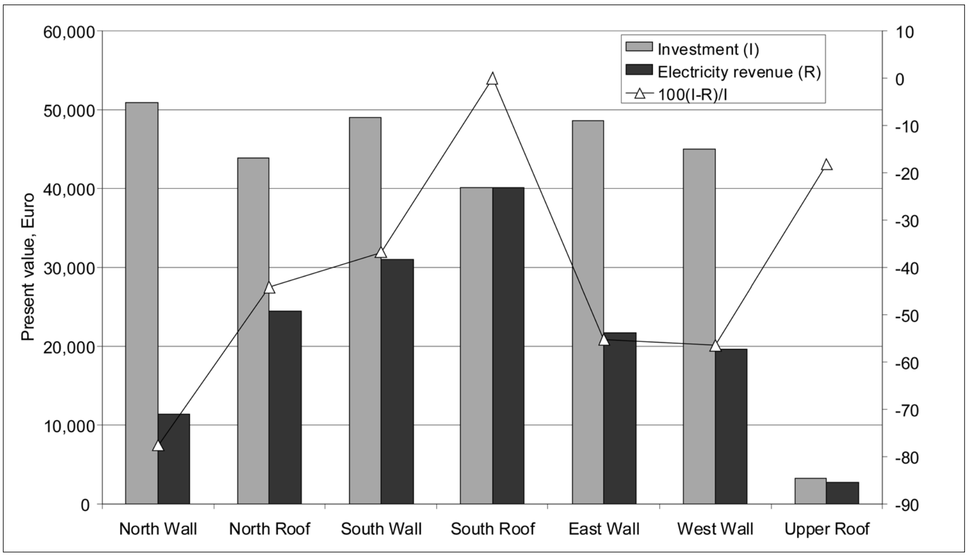
We calculated CQ_J during the entire house life (*n* years) in money units of the first investment year (present value €) using the following equation:

$$CQ_J = Q_J \; TQ \frac{(1+e)}{(d-e)}\left[1-\left(\frac{(1+e)}{1+d}\right)^n\right]. \tag{4}$$

Here, $Q_J = \sum_{I=1}^{8640}\sum_{J=1}^{N} Q_{I,J}$ represents electricity produced by PV surface '*J*', *TQ* represents electricity price of kWh of electricity in present value €, *d* stands for the discount rate, *e* stands for the escalation rate of electricity price, and *n* stands for the expected life of PV surface. In addition for these analyses, we took current values of $d = 0.1226$, $e = 0.1$, and $n = 50$ years. Values of *d* and *e* were taken here to be constant during the entire useful life of a house, however, due to current fluent economic situation in Serbia, these values may be variable. The value for *TQ* would be different for present and future scenarios.

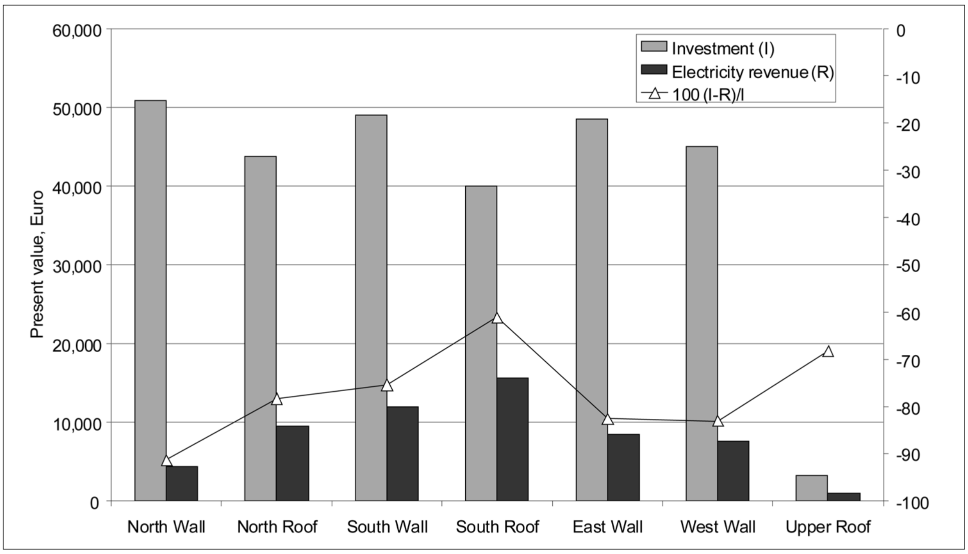
Figure 7 shows the present situation in Serbia. It also shows the electricity revenue and investment in PVs for each PV surface when $\theta = 0°$ when $TP = 588$ present value €/m^2 and $TQ = 0.05$ present value €/kW-h. As can be seen in Figure 7, the highest investment costs are for PVs installed on the north wall of around 51 000 Present Value Euros and the lowest are for the south roof of around 40 000 Present Value Euros (if the upper roof is not taken into account). However, the highest electricity revenue is obtained from the south roof PVs of order of 16 000 Present Value Euros and the significantly lower electricity revenue is obtained from the north wall. The electricity revenue from the south roof is around 49% lower than the value of investment. It can be concluded that when the main electricity is available at power grid, generation of electrical energy by PVs is currently not economically viable for Serbia (Belgrade). To spread use of solar energy for generation of electricity in Serbia, it would be necessary to subsidise this kind of energy production and devise new state-level policies to support solar renewable energy use.

Figure 7 Electricity revenue and investment in PVs when θ = 0° for the curent situation



To answer what is the level of state subventions needed in order for the electricity production to be economically feasible, we constructed Figure 8 for two subsidised scenarios showing the calculated electricity revenue and investment in PVs when θ = 0°. In the first scenario, it is taken TP = 588 present value €/m^2 and TQ = 0.13 present value €/kW-h. This means that the price of PVs is the same as that of the current Serbian PV-panel market, but the price of electricity is higher by 157% than that of the current Serbian electricity market. In the second subsidised scenario, it is taken TP = 299 present value €/m^2 and TQ = 0.05 present value €/kW-h. This means that the price of electricity is the same as that of today's electricity Serbian market and the price of PV panels is lower than that of today's PV-panel Serbian market by 49%. For these two subsidised scenarios, we obtain the same as Figure 8 where IP_J and CQ_J have the same value for the south roof meaning that the electricity production by PVs at the south roof will be economically viable. For other PV-surfaces, these subsidises should be lot higher. In the first subsidised scenario, government would subsidise the price of the generated PV electricity by the south roof by 157%, and in the second subsidised scenario, government would subsidise procurement of PV panels at the south roof by 49%. In future, the price of PV panels can drop because of the expected massive production of PV panels. To conclude, for PV panels located at the south roof, the necessary subsidies should currently be either about 50% for purchase of PV panels or around 160% for sold PV-electricity to grid in order these panels to produce electricity economically.

Figure 8 Electricity revenue and investment in PVs when θ = 0° for two subsidised scenarios



7 Conclusion

Although PV production may become a necessity in the future, it still requires huge financial support from the government by adequate policies. The policies should enable either:

- higher price for produced PV electricity (if this electricity is sold to the grid)
- subsidies for procurement of PV panels.

For future research, we may ask the following questions. What is the situation in Balkan region? What are the maximum possibilities of producing heat by incorporating solar water heaters into the building envelope? What are the maximum possibilities of producing heat and electricity simultaneously by incorporating hybrid solar collectors into the building envelope?

References

Bahaj, A. (2003) 'Photovoltaic roofing: issues of design and integration into buildings', *Renewable Energy*, November, Vol. 28, Iss. No. 14, pp.2195–2204.

Compagnon, R. (2004) 'Solar and daylight availability in the urban fabric', *Energy and Buildings*, April, Vol. 36, Iss. No. 4, pp.321–328.

Crawley, D.B., Lawrie, L.K., Winkelmann, F.C., Buhl, W.F., Huang, Y.J., Pedersen, C.O., Strand, R.K., Liesen, R.J., Fisher, D.E., Witte, M.J. and Glazer, J. (2001) 'EnergyPlus: creating a new-generation building energy simulation program', *Energy and Buildings*, April, Vol. 33, Iss. No. 4, pp.319–331.

Duffie, J. and Beckman, W. (1991) *Solar Engineering of Thermal Processes*, New York: John Wiley and Sons, Inc.

Eckstein, J. (1990) 'Detailed modeling of photovoltaic components', *MS Thesis – Solar Energy Laboratory*, University of Wisconsin, Madison.

Haas, R. (2003) 'Market deployment strategies for photovoltaics: an international review', *Renewable and Sustainable Energy Reviews*, August, Vol. 7, Iss. No. 4, pp.271–315.

Ernest Orlando Lawrence Barkley National Laboratory (2004) 'EnergyPlus Engineering Document', *The Reference to EnergyPlus Calculations (incaseyouwantorneedtoknow)*, 29 March.

Li, D.H.W., Cheung, G.H.W. and Lam, J.C. (2004) 'Analysis of the operational performance and efficiency characteristic for photovoltaic system in Hong Kong', *Energy Conversion and Management*, Corrected Proof, Available online 26 August, in Press.

Muneer, T., Asif, M. and Kubie, J. (2003) 'Generation and transmission prospects for solar electricity: UK and global markets', *Energy Conversion and Management*, January, Vol. 44, Iss. No. 1, pp.35–52.

Muneer, T., Asif, M. and Munawwar, S. (2004) 'Sustainable production of solar electricity with particular reference to the Indian economy', *Renewable and Sustainable Energy Reviews*, Uncorrected Proof, Available online 2 September, in press.

Nomura, N. and Akai, M. (2004) 'Willingness to pay for green electricity in Japan as estimated through contingent valuation method', *Applied Energy*, August, Vol. 78, Iss. No. 4, pp.453–463.

Ulleberg, Ø. (2002) *HYDROGEMS Component Library for TRNSYS 15 User Manual*, Institute for Energy Technology, Kjeller, Norway.

Yang, H., Zheng, G., Lou, C., An, D. and Burnett, J. (2004) 'Grid-connected building-integrated photovoltaics: a Hong Kong case study', *Solar Energy*, January–March, Vol. 76, Iss. Nos. 1–3, pp.55–59.

Yoo, S-H. and Lee, E-T. (2002) 'Efficiency characteristic of building integrated photovoltaics as a shading device', *Building and Environment*, June, Vol. 37, Iss. No. 6, pp.615–623.