COST Action TU1205 (BISTS)
Building Integration of Solar Thermal Systems

Proceedings of COST Action TU1205 Symposium
Combined with EURO ELECS 2015 Conference, Guimarães, Portugal

Edited by: Soteris A. Kalogirou

This book may be cited as:

Proceedings of COST Action TU1205 Symposium

ISBN: 978-9963-697-17-5

Publication date: July 2015

Economic aspect of solar thermal collectors' integration into facade of multifamily housing

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ABSTRACT: The subject of this research is the Life cycle costs analysis of the building in order to evaluate the economic efficiency and cost-effectiveness of investments in various variants of application of active solar systems in aim to achieve the reduction of energy consumption and environmental pollution.

Different variants of solar thermal collector's application to the existing prefabricated residential building in the settlement Konjarnik in Belgrade, Serbia, are considered from the economic point of view. Cost-effectiveness and feasibility of various scenarios of energy optimization achieved by application of solar thermal collectors into the building envelope are evaluated on the basis of final energy consumption (within the EU-ISO standards).

The methodological approach involves the analysis of the costs of energy consumption for water heating, financial analysis of costs and savings over the life cycle of the existing building in case of solar thermal collectors' application to the building envelope as well as a comparative analysis of achieved results. Criteria for the economic analysis include the amount of investment, energy costs and life cycle costs of the building. According to the adopted criteria, the most suitable models are selected. This methodological approach is generally applicable in the analysis of investments in improvement of building energy performances, while possible technical solutions and the resulting economic benefits must be carefully considered.

Keywords: solar thermal collectors, investment projects, life cycle costs analyses, life cycle savings, greenhouse gases emissions.

1 INTRODUCTION

New energy-efficient buildings represent a small percentage in relation to the total building stock. Until the seventies, in Belgrade, buildings were designed without consideration of energy demands and consumption (Krstic-Furundzic & Djukic, 2009). According to the data collected by Serbia's Statistical Office, about 55 percent of the total of 583,908 existing housing units in Belgrade was built in this period (Krstic-Furundzic & Bogdanov, 2010). This figure reveals that Belgrade's building stock has a significant number of buildings whose energy performance has to be improved. It should not be disregarded because significant energy savings and reduction of fossil fuels consumption can be achieved.

In the paper, solutions for reducing energy consumption for water heating in existing housing are examined from economic point of view.

The methodological approach includes the analysis of the costs of energy consumption for water heating, financial analysis of costs and savings over the life cycle of the existing building in case of solar thermal collectors' application to the building envelope as well as a comparative analysis of achieved results. Criteria for the economic analysis include the amount of investment, energy costs and life cycle costs of the building. According to the adopted criteria, the most suitable models are selected. This approach could generally be applicable for building refurbishment, but generalization of technical solutions and possible benefits have to be carefully individually considered.

2 METHODOLOGY

During 1950's to 1970's, lot of suburban settlements had been built in Belgrade. The residential buildings in settlement Konjarnik, as the model on which different design variants and possibilities for improvements of energy performances by application of solar thermal collector systems are analysed and discussed from the aspect of energy benefits in a few papers by authors Krstic-Furundzic & Kosoric (2009a; b). Those scenarios are analysed from economic point of view in this paper.

Figure 1. Location of Konjarnik on the map of city of Belgrade.

Figure 2. Typical building with attic annex.

The analysis in the paper is hypothetical and it aims to show economic benefits of solar thermal collector system application on residential buildings in Belgrade climate. Methodological access includes description of the model for economic analysis, evaluation of economic efficiency, LCC analysis of variants of solar thermal collectors' application and comparative analysis of achieved results.

2.1 Description of the model for economic analysis

Settlement Konjarnik begins 4 km south-east of downtown Belgrade and stretches itself over 2 km (Fig. 1). It is selected for the analysis as settlement consisted mainly of typical buildings (Fig. 2) built in 1960's and 1970's. The settlement is characterized by large rectangular shaped residential buildings with typical south-north orientation, more exactly deviation of 10° to southwest is present (Fig. 3).

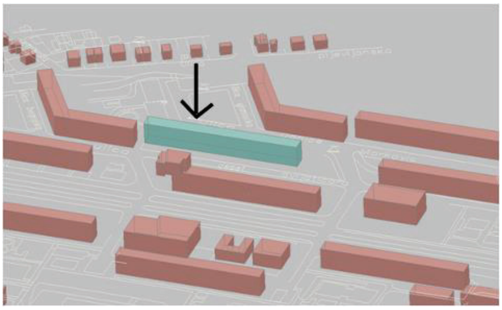

Figure 3. Buildings disposition in Konjarnik settlement

The selected multifamily housing, the 8-storey building, has rectangular and compact form and consists of 5 lamellas. It is located in a semi-closed block, on the south oriented hillside. The neighbouring buildings are sufficiently far to prevent overshading. One of the central lamellas, with four one-side oriented flats, is chosen for the analysis. As shown in Figure 2, facades oriented south and north consist rows of windows and parapets, which represent 70% and loggias, which represent 30% of facade surfaces (Krstic-Furundzic & Kosoric, 2009a). Existing refurbishment strategies applying on these residential buildings are transformations of flat roofs into slopping roofs by attic annex, which was action organized by municipality and glazing of loggias, which was illegal action usually realized by tenants (Krstic-Furundzic, 2010).

As the buildings in the analyzed settlement consisted number of lamellas, and as in the analysis of possibilities for solar thermal collectors application on south-west oriented facade and roof surfaces was selected central lamella (Krstic-Furundzic & Kosoric 2009a, b), in the paper evaluation of economic efficiency and feasibility were done for the same lamella. Authors of design variants calculated thermal energy for water heating (20-50˚C) according to number of apartments and occupants inside one lamella altogether which presents 251 kWh per day, i.e. 91,618.3 kWh per year for one lamella and the existing water heating system fully based on electricity was substituted with the new system – solar thermal collectors (AKS Doma –manufacturer), with the auxiliary system powered by electricity (Krstic-Furundzic & Kosoric 2009a, b). Solar thermal collectors with liquid working medium had been proposed. According to Polysun 4 Version 4.3.0.1., which was used for the analyses of energy contribution of solar thermal collectors, Belgrade is the city with global irradiance of 1341.8 kWh/m^2, and 2123.25 sunny hours per year (Krstic-Furundzic & Kosoric, 2009a; b).

Modern architectural concepts, which are based on rational energy consumption of buildings and the use of solar energy as a renewable energy source, give the new and significant role to the roofs (Krstic-Furundzic, 2006) and facades that become multifunctional structures. By application of solar thermal collectors, multifunctional roofs and facades could be created.

Four variants of position of solar thermal collectors on building envelope, designed by Krstic-Furundzic & Kosoric (2009a; b), are taken into consideration in the analysis of economic efficiency and cost-effectiveness of investments (Fig. 4).

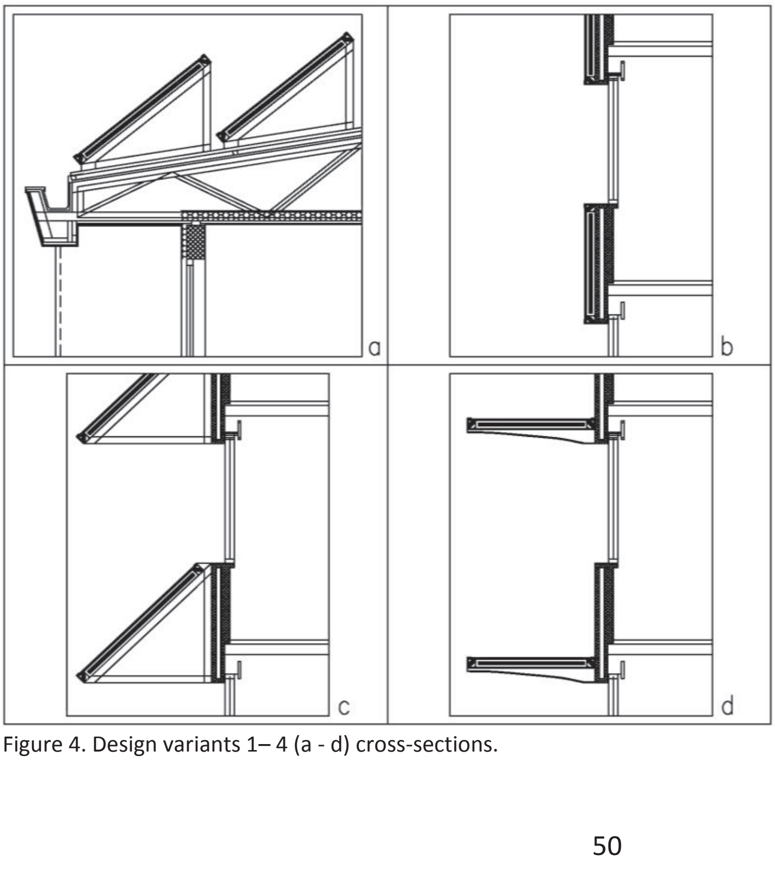

Figure 4. Design variants 1– 4 (a - d) cross-sections.

Variants of position of solar thermal collectors on building envelope are: 1) variant - solar panels mounted on the roof and tilted at 40˚, area of 100 m^2 (Fig. 4a); 2) variant - solar panels integrated in parapets (vertical position-90˚), area of 90 m^2 (Fig. 4b); 3) variant - solar panels integrated in parapets and tilted at 45˚, area of 120 m^2 (Fig. 4c); and 4) variant - solar panels integrated as sun shadings (horizontal position-0˚), area of 55 m^2 (Fig. 4d); which is described in detail in Krstic-Furundzic, & Kosoric (2009a; b).

2.2 Evaluation of economic efficiency

The goal of this LCC analysis is to evaluate economic efficiency and feasibility of different scenarios of solar thermal collectors' application into the envelope of existing multifamily housing in Belgrade and their impact on the environment.

The economic assessment includes LCC analysis of four scenarios that evaluates feasibility of solar thermal collectors' integration in the building facade and roof in order to reduce electricity demands from public electrical distribution network. Economic efficiency of accomplished energy optimization of presented variants is assessed according to final energy consumption (Krstic-Furundzic et al., 2013).

LCC analysis are carried out by Net Present Value methodology, which implies present value of investment plus discounting of all future costs to present value, and is suitable for comparative assessment of several different scenarios (different energy improvements of the same building). The LCC analysis which deals with application of solar thermal collectors for water heating is carried out as cost analysis through whole lifecycle of analysed components (WLC – Whole Life Cycle) (König et al., 2010). In addition to life cycle costs, this analysis includes also monetary benefits from electric energy feed-in tariff related to exploitation of solar energy.

Selected tool for LCC analysis in this study is BLCC (Building Life Cycle Cost) software, version 5.3-12 (EERE, 2012). BLCC software was developed by United State Department of Energy and it is used for calculation of buildings life-cycle energy savings. The LCC calculations are based on the FEMP (Federal Energy Management Program) discount rates and energy price escalation rates which are updated and published every year on April 1. With certain modifications, this software was used in several investment analyses in Serbia which required feasibility study for different models of optimization of facade, building structure, lighting and heating system (Plavsic & Grujic, 2005).

Evaluation criteria of the analyses results are divided into two groups (Plavsic, 2004):

1. Evaluation criteria for financial efficiency of each scenario include:
- Net Present Value (NPV);
- Adjusted Internal Rate of Return (AIRR);
- Simple Payback Period (in years).
2. Evaluation criteria for external effects include:
- protection and conservation of the environment;
- sustainability of energy resources.

Final efficiency assessment of the design and its scenarios (using computer software BLCC) is expressed in two areas:

- assessment of financial and market efficiency of the design, which determinates feasibility of the investment under real market conditions, measured by accumulation;
- assessment of social and economic efficiency of the design which evaluate the effects on social and economic development of the country.

Design scenarios are ranked by each criterion in final stage of the analysis. BLCC software provides choices such as:

1. design scenario which is most favourable in terms of lowest LCC.
2. design scenario with shortest Simple Payback Period.
3. design scenario with lowest emission of greenhouse gases.

With the assumption that lowest LCC and shortest SPP are of equivalent importance, final selection of the best scenario would be the one that best meets both criteria.

2.3 Criteria for efficiency evaluation

Criteria for efficiency evaluation include economic efficiency criteria and external effects.

Economic efficiency criteria involve:
Adjusted Internal Rate of Return (AIRR) - represents the discount rate which is investment value reduced to zero. This data indicates optimal ratio of income (savings) and expenses (costs) during economic life cycle of building.

Net Present Value (NPV) - is the sum of income during building life cycle which is reduced to its value of the first year of its life cycle (present value). Net Present Value presents an absolute indicator of profitability of the design taking into account the time preferences and, using discounting technique, it reduces all future design effects to their present value. For practical reasons, the initial investment period of building economic life cycle (beginning of investment study) is taken as base time for calculation of NPV. Discounting is performed according to previously established discount rate (usually the individual discount rate that makes the weighted arithmetic mean of real interest rates on funding sources). The discount rates of 10-12% are traditionally used by The World Bank for all funded projects. However, as the entire calculation in this study was done in euro currency, the average interest rate in Western Europe was taken into account. In this case, NPV is calculated for savings - as a specific design profit.

Simple Payback Period (SPP) - refers to necessary time (in years) for return of initial investment. Invested funds are returned in the year when the cumulative net effects of economic life cycle become positive. The aim is to reduce a simple payback period (value SPP), in order to be as short as possible. The acceptable payback time of the initial investment is considered to be before the end of last year of economic life cycle. Data such as initial investment, annual costs and balance saving during life cycle of the design are used to calculate SPP. Building Life Cycle Cost (BLCC) software operates with simple payback period, which is simple ratio of initial investment increased for all annual costs and savings (as the equivalent of income in one year).

External effects involve:
Different social and economic effects which do not need to be quantified. For improvement of energy efficiency these effects are of great social benefits such as conservation of the environment and non-renewable resources, influence on technical progress, quality of life of the population, increase of consumer surplus, etc.

2.4 LCC analysis of variants of solar thermal collectors‘ application

Comparative LCC analysis of the existing building model and different variants of solar thermal collectors’ integration in the building roof or facade takes into account: (a) capital costs, (b) energy costs - costs of electric energy consumption for water heating (electric boilers) from public network, (c) energy costs/incomes - feed-in tariff for renewable energy sources and (d) operating, maintenance and repair (OM&R) costs of installed solar system.

In this study, feasibility of investment in solar thermal collectors system, which would substitute certain percentage of production of hot water in the building, is estimated according to consumption of final electrical energy (from renewable and non-renewable sources).

2.5 Investment

A capital investment is considered as onetime cost in the first year of the economic life cycle of the project.

In the analysis of solar thermal collectors' integration into the building facade and roof, the value of complete installed system for each scenario is based on average value per 1m^2 of solar collector panel. According to manufacturer, the average price of solar collector system for hot water is 700€ per 1m^2 of solar panel. For four scenarios of solar thermal collectors' integration, total initial capital investments are shown in Tables 1 and 2.

2.5.1 Energy costs

Analysis of energy efficiency of solar collectors' integration assumes that there is constant electrical energy consumption for water heating within observed part of residential building. Four selected scenarios, with different solar collectors' positions, result in different capacity for production of electrical energy from renewable sources, and thus different consumption of electrical energy from public electricity network. In the analysis, public network electrical energy price was adopted according to current price list approved by "EPS - Elektroprivreda Srbije" in December 1, 2012, for consumers within the blue zone (351-1600 kWh per month), which represents zone of average household electricity consumption per month. This price is average price for households with two phase measurement of electricity consumption (1/3 of day – lower tariff). The price of 0.06 €/kWh was established as an input for electrical energy costs calculation. The price of 0.23 €/kWh was adopted for electricity from renewable sources (according to feed-in tariff of EPS and Regulation on Incentives for the production of electricity by using renewable energy sources and combined production of electricity and thermal energy).

3 RESULTS OF LIFE CYCLE COST ANALYSIS

Life cycle period for scenarios of solar collectors' integration in LCC analysis is 15 years. According to manufacturer, life cycle of proposed system for hot water is 20 to 25 years, while full capacity of the system is reduced by 20% after 15 years of use. Since energy efficiency analysis was carried out for system`s full capacity, period of full system capacity was adopted in this LCC analysis.

Majority of investments that have an impact on energy savings and environment conservation are long term investments and usually have very high capital costs. Since this investment analysis is limited to 15 years (period of full capacity of the system) and the system capacity cannot be determined precisely after this period, all future costs are discounted to present value using a real discount rate of 3.5%, so that the costs in very far future have as less as possible influence on analysis results.

Life cycle cost analysis is performed for each design variant of solar thermal collector' integration in the building envelope. Using BLCC software, the Net Present Value (NPV) is determined for each scenario, and the scenario that gives the best results during the life cycle was chosen. All future costs are discounted to present value using a discount rate of 3.5%.

Basic assumption is that inflation has a neutral effect on building life cycle if price relations (parity of prices) do not change in life cycle or if impact of inflation is identical on both income and costs of the building.

Results of LCC analysis, LC savings and greenhouse gases emissions for variants of solar collectors' integration are shown in Table 1, 2 and 3.

3.1 LCC Analysis results – application of solar thermal collectors

From the LCC analysis of variants of solar thermal collectors' integration, the following conclusions can be listed:

- Results of LCC analysis (Table 1) show that Variant 1, scenario with thermal collectors positioned on the roof in the area of 100m^2, is the most favourable variant, because it has the highest incomes from investment in renewable energy sources. Variant 3 also has incomes, but, although the area of solar collectors is bigger in comparison to Variant 1, energy production capacity is reduced as solar collectors are placed on the parapets of the facade. Also, Variant 3 has higher initial investments, so the overall incomes are smaller than in Variant 1.

Table 1. Results of LCC analyses of the four variants (design variants of integration of solar thermal collectors) compared to Reference model (Model of the existing building).

	Annual Costs			Present Value Costs			
Scenario	Annual Electricity Costs (base-year) (public) (€)	Annual Electricity Costs (base-year) (solar collect.) (€)	Annual OM&R* Costs (€)	Total Initial Capital Costs (€)	Discounted Total OM&R* Costs (€)	Discounted Total Energy Costs (€)	LCC (€)
Reference model	5,499.00					63,321.00	63,321.00
Variant 1	2,541.00	-11,332.00	100.00	70,000.00	1,152.00	-101,264.00	-30,112.00
Variant 2	3,570.00	-7,386.00	100.00	63,000.00	1,152.00	-43,959.00	20,193.00
Variant 3	2,653.00	-10,904.00	100.00	84,000.00	1,152.00	-95,051.00	-9,899.00
Variant 4	4,209.00	-4,939.00	100.00	38,500.00	1,152.00	-8,418.00	31,234.00

* Operating, Maintenance, and Repair

- Results of the analysis of LC savings (Table 2) also show that Variant 1 has better financial advantages compared to other variants. First of all, Simple Payback Period (SPP) is the shortest (8.05 years), Savings to Investment Ratio (SIR) is most favourable, as well as Adjusted Internal Rate of Return (AIRR). Shortest Simple Payback Period (SPP) shows that this variant has the highest savings.
- Variant 2 and Variant 4 certainly have positive influence on environment and reduction of energy consumption from non-renewable sources. But, from the investment standpoint, these variants are considered unacceptable, since the Simple Payback Period exceeds LC period of solar thermal collectors (15 years of full system capacity). Variant 2, with SPP of 16.95 years, might be acceptable if we take into account the fact that the real life cycle of solar collectors system is longer than 15 years.
- Variant 1, which has the highest savings in electrical energy consumption from public network, also has the lowest greenhouse gases emission (Table 3).
- From the aspect of LCC analysis the most favourable is Variant 1.
- Combination of Variant 1 and Variant 3 (solar collectors on the roof and facade) would certainly give much better results in the evaluation of the economic efficiency of investment in renewable energy.

Table 2. Results of Life cycle savings analysis of four scenarios (design variants of integration of solar thermal collectors)

	Annual Energy Consumption			Electrical energy Savings (+) or Cost (–)		Non–Energy Savings or Cost (–)						
Scenario	Electricity Consumption (public) (kWh)	Electricity Consumption (solar collec.) (kWh)	Total Investment (€)	Annual Electricity Savings (€)	Discounted Electricity Savings (€)	Annual OM&R* Costs (€)	Discounted OM&R* Costs (€)	First year savings (€)	Simple Payback Period (SPP) (year)	Adjusted Internal Rate of Return (AIRR) (%)	Total Discounted Operational Savings (€)	Savings to Investment Ratio (SIR)
Variant 1	-42,348.80	49,269.50	70,000.00	8,791.00	101,264.00	-100.00	-1,152.00	8,691.00	8.05	6.00	100,112.00	1.43
Variant 2	-59,503.50	32,114.80	63,000.00	3,816.00	43,959.00	-100.00	-1,152.00	3,716.00	16.95	0.87	42,807.00	0.68
Variant 3	-44,208.80	47,409.50	84,000.00	8,252.00	95,051.00	-100.00	-1,152.00	8,152.00	10.30	4.27	93,899.00	1.12
Variant 4	-70,142.80	21,475.50	38,500.00	731.00	8,418.00	-100.00	-1,152.00	631.00	61.03	-7.39	7,266.00	0.19

* Operating, Maintenance, and Repair

Table 3. Analysis of greenhouse gases emissions of four scenarios (design variants of integration of solar thermal collectors)

	Reference Model		Variant 1		Variant 2		Variant 3		Variant 4	
	Annual emissions (kg)	Life-Cycle emissions (kg)	Annual emissions (kg)	Life-Cycle emissions (kg)	Annual emissions (kg)	Life-Cycle emissions (kg)	Annual emissions (kg)	Life-Cycle emissions (kg)	Annual emissions (kg)	Life-Cycle emissions (kg)
CO_2	59,910.57	898,371.49	27,692.51	415,254.97	38,910.22	583,466.92	28,908.79	433,493.37	45,867.42	687,791.54
SO_2	301.89	4,526.86	139.54	2,092.45	196.07	2,940.07	145.67	2,184.36	231.12	3,465.76
NOx	89.41	1,340.74	41.33	619.73	58.07	870.77	43.14	646.95	68.45	1026.47

4 CONCLUSION

Investments in energy production from renewable sources always have a positive effect on the economy (reducing energy consumption costs) and the ecology of a country (reducing greenhouse gases emissions). Life cycle costs analyses for different variants of integration of solar thermal collectors for water heating show that feasibility of investments in renewable energy sources is based on price difference between standard and feed-in tariff of electricity per kWh.

In this analysis, feasibility of investment in solar thermal collectors system is economically efficient only for scenarios where renewable energy sources meet energy needs in the percentage of about 50% or more. Therefore, whether a system for production of energy from renewable sources results in incomes or costs in life cycle depends on the policy of the country and values (prices) of feed-in tariff for energy from renewable sources. It is certain that all investments in renewable energy have positive impact on preservation of healthy environment, but their cost effectiveness depends on the goals and policies of economic and energy development.

In surrounding countries of Serbia and EU countries, the values of electricity feed-in tariff per kWh are twice or three times higher than in Serbia (although the price of electricity from public network is significantly higher). Political aspect of feed-in tariff values in Serbia is based on Directive on the promotion of the use of energy from renewable sources (RES Directive 2009/28/EC, 2009) according to which Serbia, as signatory of the Agreement of Energy Community, will be obliged to provide at least 20% of energy consumption from renewable sources. This percentage, which is already reached in Serbia through the production of electricity from hydro-power plants, amounts to about 24% (MERZ, 2012). As long as the target level does not increase above current production of electricity from renewable sources will not be changes in Serbia government’s efforts to support investments in other renewable energy sources.

ACKNOWLEDGMENTS

The research is done within the COST Action 1205 ″Building integration of Solar Thermal Systems (BISTS)″ supported by European Cooperation in the field of Scientific and Technical Research and the scientific research project “Physical, environmental, energy, and social aspects of housing development and climate change – mutual influences“(TP36035), financed by Ministry of Education, Science and Technological Development of the Republic of Serbia.

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