Scientific Bulletin
of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 11, Number 1, 2025

Study on Optimizing Energy Consumption of an Energy. Independent House Project

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Abstract - The ability of a residence to completely meet its energy needs from renewable sources on its own, hence lowering reliance on traditional networks, is known as energy independence. In this paper, concrete solutions will be analyzed and proposed for optimizing electricity consumption in the particular case of an autonomous house project. To achieve the objective, three short, medium and long-term solutions will be proposed which will be analyzed using the principles of economic engineering.

Keywords: Energy consumption, Electric energy, Autonomous house, Energy-independent.

I. INTRODUCTION

Considering the current energy crisis and the increasing dependence on electricity networks, especially in the current context of Romania where the capping of electricity prices is being stopped, I have chosen to address the subject of optimizing residential electricity consumption in this paper. Only by expanding electricity from renewable sources, such as the use of photovoltaic panels, will we be able to cover this energy need. For this reason, we should focus on using green energy in our homes and also find alternative solutions to reduce energy consumption [9].

Renewable sources play a significant role because in the near future they will contribute to the world's electricity consumption, since energy production from fossil fuels is not a sustainable practice, both because of the negative impact on the environment and because the fuels are available in limited quantities. However, there is an inexhaustible and clean source of energy, namely solar energy [4].

II. CONCEPTUAL AND THEORETICAL FRAMEWORK

2.1 The importance of perception towards energy-independent house

Human demand for energy is constantly increasing. A home that produces at least as much energy as it consumes is considered energy independent.

The foundation of an energy-independent home is an integrated strategy that optimizes consumption through modified architectural design and the utilization of renewable resources, fusing the concepts of smart technology and passive energy efficiency [10]. This entails implementing sustainable technical and architectural solutions that optimize local resources, managing energy efficiently, and guaranteeing long-term comfort. Therefore, by lowering consumption and improving the home's total energy performance, the idea encourages energy autonomy [11].

A passive house and a practically zero-energy house are integrated energy efficiency concepts that combine sustainable technologies, efficient systems, and optimal architecture to guarantee the home's energy autonomy and drastically cut energy usage [2].

2.2 Energy-efficient appliances

By avoiding energy waste while in use, energy-efficient appliances, are essential to lowering domestic power consumption. By reducing greenhouse gas emissions, these appliances not only save household energy expenditures but also make a substantial contribution to environmental sustainability. Adopting them is a sensible and efficient way to maximize household energy use, directly assisting initiatives to improve energy autonomy and lower overall consumption in residential structures [3].

2.3 Integration of photovoltaic systems

Since integrated photovoltaic systems enable local energy generation from renewable sources and significantly lessen reliance on the traditional grid, their installation in homes is crucial to achieving energy

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autonomy. According to latest research, PV systems with storage of batteries have the ability to significantly reduce building carbon emissions and meet up to 90% of a home's energy needs. Therefore, a strong technical-economic option for effective consumption in self-sufficient households is photovoltaic technology [8].

2.4 Other solutions to reduce electricity consumption

Additionally, an effective and environmentally friendly way to lower the amount of power needed for home heating and cooling is to install high-performance thermal insulation for exterior walls and roofs. Depending on the situation, climate, and technical features of the building, investments in high-performance thermal insulation materials can lower energy consumption by 60% to 81%, according to studies by Amani (2025) and Shahee, Abdoos, and Aslani (2024).

In the context of the shift to energy-autonomous homes, such actions also help to lower CO_2 emissions and improve indoor thermal comfort, proving their economic and environmental effectiveness [1],[5].

III. METHODOLOGIES

This paper focuses on the analysis of the electricity consumption of an independent house in Romania, Timis County. A single-family house with 4 members is considered. The house design, the parameters of the house structure and construction are described and illustrated, the electricity consumption for heating the house and water, the use of consumables, the energy needs and the availability of solar energy are taken into account. The methodology used involves theoretical documentation regarding autonomous house and energy consumption, as well as practical analysis of the independent house.

To carry out this study, the principles of economic engineering were used, more precisely the construction of cash-flow variants for each of the 3 alternatives, followed by the comparison of the alternatives and the selection of the optimal variant through the global utility method. Finally, the critical path method will be used to know the duration of the implementation process, the necessary resources and the cost of implementation.

IV. RESULTS

The main economic problem faced by the residents of the house is the high price and consumption of electricity and its ever-increasing costs. Many people find themselves in this situation, especially residents of houses with many consumers.

4.1 Technical details of the house

I chose to optimize the electricity consumption of a specific house in Timiș County and transform it into an energy independent house.

House structure

The house has an area of 210 m^2, with 150 m2 of usable space, consisting of a ground floor and an attic. On the ground floor there is a kitchen and a living room. In the attic there are 3 bedrooms and a bathroom. The outdoor courtyard has 600 m2 with a swimming pool, gazebo and a pond. It also has a pantry.

Consumers

- Kitchen consumers: dishwasher, LED interior lighting, microwave oven, juicer, toaster, electric oven, hob, coffee maker, refrigerator.
- Living room consumers: television, LED interior lighting, internet, air conditioning
- Bedroom consumers: television, air conditioning, iron, LED interior lighting, laptop, etc.
- Bathroom consumers: washing machine, hairdryer, LED interior lighting, etc.
- Outdoor consumers: outdoor lighting, heat pump pool, pond, gazebo

Sources for producing light

The main source for producing light inside the house are LED bulbs (wall lamp, mirror, lamp, panel, chandelier, strip) and outside there are both LEDs (spots, garlands, garden lamp) and incandescent bulbs (in the pantry) [6].

Average consumption per home

Following the calculations made for each room in the house (kitchen, bathroom, living room, bedrooms, exterior) with specific consumers depending on their power, average usage and consumption over time, we have the following results:

- Total consumption in the kitchen is 5,262KW/day, 157.86KW/month, 1894.32 KW/year
- Average total consumption in the living room and hallway is 2,448KW/day, 73.44KW/month, 881.28KW/year
- Average total consumption in the bedrooms is 3,530KW/day, 105.9KW/month, 1270.8KW/year
- Average total consumption in the bathroom is 2,614KW/day, 78.42 KW/month, 941.04KW/year
- Average outdoor consumption is 1,822KW/day, 54.66 KW/month, 655.9 KW/year
- Total KW/day ≈ 15.676, total KW/month 470.28, total KW/year 5,643.34

Considering the invoice price formula = active electricity price + mandatory additional taxes (transportation tariff + distribution tariff + cogeneration contribution + green certificates + excise duties + VAT etc.) and the sum of the components per kWh: 0.65 (active energy) + 0.2361 (distribution) + 0.013

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(transportation) + 0.00333 (cogeneration) + 0.0725 (green certificates) + 0.005 (excise duties) = 0.97993 Ron/kWh.

We have the following observations, according to ANRE website at the current price on the free electricity market, it would be estimated to pay:

• The cost per day with VAT is 18.26 Ron/day
• The cost per month with VAT is 548,442 Ron/month
• The cost per year with VAT is 6,580.56 Ron/year

4.2 Solving the problem in the short, medium and long-term using the principles of Economic Engineering

a. Defining alternatives

In order to solve the problems found, I propose the following alternatives:

1. Calling on a program to replace worn-out equipment with more efficient and effective ones.

2. Purchasing and implementing a photovoltaic system.

3. Investing in solutions to reduce electricity consumption.

b. Development of alternatives

1. New electrical and electronic household equipment with energy efficiency class A+, A++ and even A+++ will be purchased. The following categories are proposed: washing machine, refrigerator, air conditioner, built-in electric oven (see Table1).

The total investment for a single appliance in each category is 12,598 RON, in total approximately 62KW of energy are saved monthly, i.e. 41,893 Ron saved per month and 15,290,945 Ron/year.

2. Purchase and implementation of a photovoltaic system.

The offer available for purchasing the system is illustrated below (Table 2).

Table 1: Comparative energy consumption of equipment

Equipment	Consumption of old equipment	Consumption of new equipment (Class A++)	Energy depreciation
Washing machine	60KW/month	38KW/ month	22KW
Refrigerator	36KW/ month	24KW/ month	12KW
Air conditioning	45KW/ month	32KW/day	13KW
Built-in oven	30KW/ month	15KW/ month	15KW

Table 2: Offer 6kW single-phase photovoltaic system

Total value with VAT - Materials	25.743 lei
Total value with VAT - Green stamp duty	191 lei
Total value with VAT - Prosumer file	1.600 lei
Grand total with VAT	27.535 lei
Total value other materials	1.000 lei
Total value – Labor	5.000 lei
Total labor VAT	6.000 lei

Project implementation

A photovoltaic system was installed for the house, consisting of:

• 14 photovoltaic panels LONGI SOLAR tip LR5-66HIH 500-0.500kWp (d.c.) = 7.00 kWp (d.c.)

• 1 three-phase inverter Marea SOLAX type SOLAX X3-MIC-6K-G2 400V 6KW (d.c.)

The following is an illustration of the GANT diagram (see Fig.1), with the activities, resources, and time available for implementing the home's photovoltaic system.

The technical information of the system is illustrated below (Table 3).

The production capacity of the system throughout the year is favorable (see Fig. 2) and the amortization of the investment is satisfactory (Table 4), after a few years it implies a considerable profit (Fig. 3) as shown by the simulation results.

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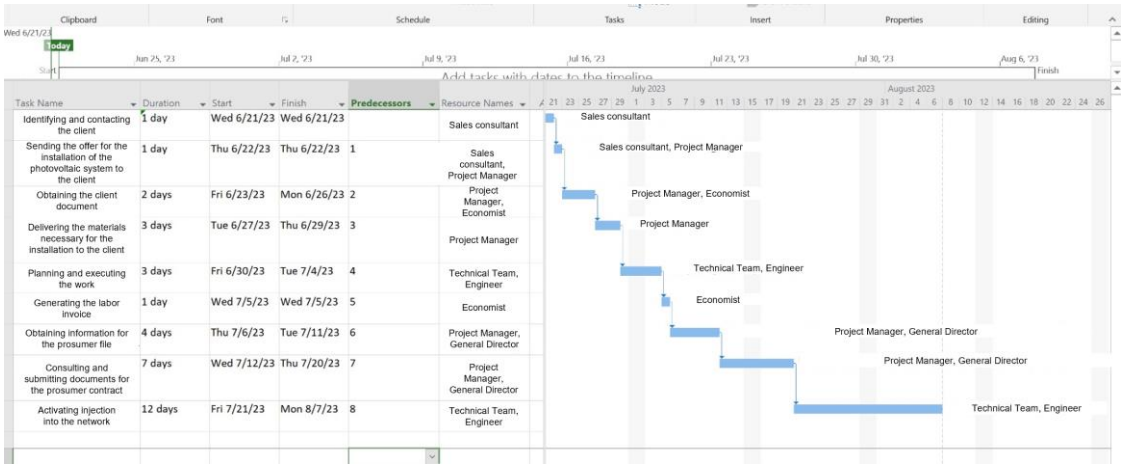


Fig. 1. Gantt chart of PV system installation stages.

Table 3: Project information

Project information			
Project name	C.P House	Project number	1
Location	Romania/Timisoara	AC Grid Voltage:	Single-phase~230 V
Ambiental temperature	-	Low Temperature Record:	-20◦ C 25◦ C 42◦ C
Application	-	Average High Temperature:	250.0kWh/month
Total number of PV modules	14	High Temperature Record:	6.37kWp
Number of inverters	1	Other Consumed Loads:	6 kW
Annual energy yield	6.768,08 kWh	PV Peak Power	0.95%

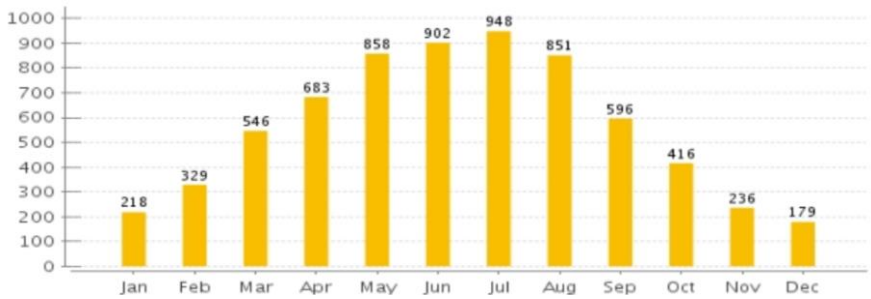


Fig. 2. Annual capacity in kWh.

Table 4: Return on Investment

Personal Investment	5.500 €	Load Ratio	0%
Loan Amount	0 €	Interest Rate:	0 €
System Lifespan:	25 years	Output Power Reduction Rate:	0.8% /year
Annual Power Output:	6,825.68 kWh/year	Electricity Price:	0.27 € /kWh
Electricity Subsidy:	0.1 € /kWh	Total Profit:	34,469.684 €
Annual Profit:	1,378.787 € /year	Net Profit:	28,969.684 €
ROI:	526.72%	Annual ROI:	21.07%

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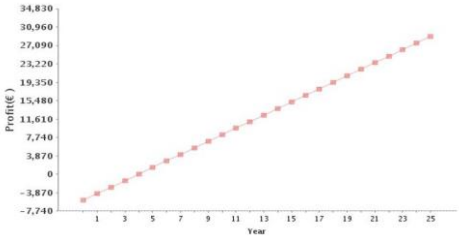


Fig. 3. Profit chart.

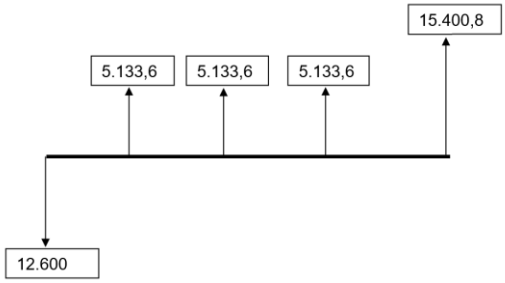


Fig. 4. Cash flow diagram for Table 5.

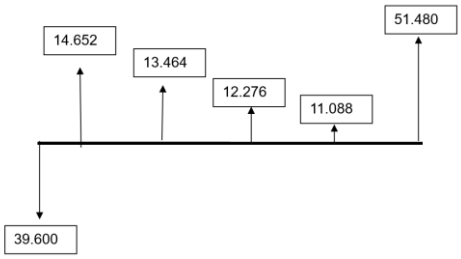


Fig. 5. Cash flow diagram for Table 6.

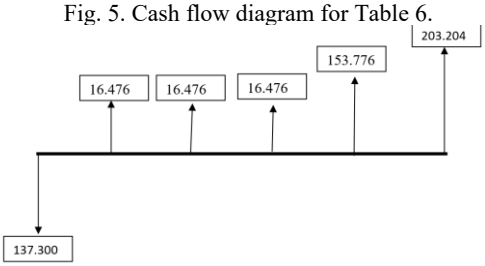


Fig. 6. Cash flow diagram for Table 7.

3. Investing in solutions to reduce electricity consumption

• Replacing exterior joinery with thermally insulated joinery;

Cost: thermally insulated joinery according to calculations = 15,000 euros

Materials: trypan and insulating window joinery

• Thermal insulation of exterior building elements (exterior walls, terraces, roof covering and other similar elements);

Cost: thermos-system facade with labor + materials = 12,000 euros

Materials: polystyrene, mesh, adhesive

• Thermal insulation of hot water distribution pipes;

Materials: polystyrene thermally insulated pipe

Total estimated price 27,450 €

c. Building cash flow scenarios for each alternative

Cash flow diagrams and tables indicate the level of financial resources that are formed because of the efficient execution of the activity and that are available, that is, found in the form of liquidity. The level of liquidity of the company is usually different from that of potential financial resources that result from the surplus of profitable activities, due to the circulation of liquidity through the company [7].

1. I apply for a personal loan with a fixed interest rate from Raiffeisen Bank (Table 5, Fig.4):

Interest rate of 10.75% for a period of 3 years

Total=12,598 LEI

Bank loan=12,600 LEI

$$A=P*[i*(1+i)N/(1+i)N-1] = 12,600*[0.1075*(1+0.1075)3/(1+0.1075)3-1] =5,133.6 \text{ LEI}$$

P – represents the initial amount invested or the value of the loan obtained.

N – the number of periods for which the loan is obtained (e.g. months, years, etc.).

i – the interest rate for the period for which the loan was obtained.

2. A fixed-interest personal loan is applied for from CEC Bank (Table 6, Fig. 5):

Interest rate of 12% for a period of 4 years

Total=39,535 LEI

Bank loan=39,600 LEI

3. A fixed-interest personal loan is applied for from CEC Bank (Table 7, Fig. 6):

Interest rate of 12% for a period of 4 years

Total=137,250 LEI

Bank loan=137,300 LEI

Table 5: Repaying at the end of each year a portion of the loan plus the related interest so that the total annual amounts paid are equal

Year	Amount due at the beginning of the year	Interest/Year	Amount due at the end of the year	Interest-free payment	Total annual payment
1	12.600	1.354,5	13.954,5	3.779,1	5.133,6
2	8.820,9	948,24	9.769,14	4.185,36	5.133,6
3	4.635,54	498,32	5.133,86	4.635,28	5.133,6
Total		2.801,06	-	12.599,74	15.400,8

Tabel 6: Repayment at the end of each year of the amount of 9,900 lei and the interest for that year

Year	Amount due at the beginning of the year	Interest/Year	Amount due at the end of the year	Interest-free payment	Total annual payment
1	39.600	4.752	44.352	9.900	14.652
2	29.700	3.564	33.264	9.900	13.464

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3	19.800	2.376	22.176	9.900	12.276
4	9.900	1.188	11.088	9.900	11.088
Total		11.880	-	39.600	51.480

Table 7: Repayment of the loan in a single installment at the end of 4 years and payment of interest at the end of each year

Year	Amount due at the beginning of the year	Interest/Year	Amount due at the end of the year	Interest-free payment	Total annual payment
1	137.300	16.476	153.776	0	16.476
2	137.300	16.476	153.776	0	16.476
3	137.300	16.476	153.776	0	16.476
4	137.300	16.476	153.776	137.300	153.776
Total		65.904	-	137.300	203.204

d. Analysis, comparison of alternatives and selection of the optimal variant (global utility method)

To determine the optimal alternative, the global utility method will be used (Table 8). Therefore, for the three proposed variants (alternatives), 5 selection criteria will be established, with the help of which the matrix of inhomogeneous consequences will be created (Table 9).

Table 8: Global utility method

Nr. Crt. / Criteria / Alternatives		C1 Available balance	C2 Cost of implementing alternatives	C3 Payback period (years)	C4 Implementation time (days)	C5 Forecast of improvement of the house's activity
1	Replacement of worn equipment	13.000	12.598	8 years	8	3
2	Implementation of photovoltaic system	27.800	27.535	20 years	34	1
3	Consumption reduction solutions	140.000	137.250	10 years	90	2

Table 9: Global utility method

Criteria Alternatives	C1 Available balance	C2 Cost of implementing alternatives (lei)	C3 Payback period (days)	C4 Implementation period (days)	C5 Forecast regarding the improvement of the house's activity	Ug
1. Replacement of worn equipment	0	1	1	1	0	3
2. Implementation of photovoltaic system	0,11	0,88	0	0,68	1	1,67
3. Solutions to reduce consumption	1	0	0,83	0	0,5	2,33

V. RESEARCH RESULTS AND LIMITATIONS

The global utility method's findings show that replacing obsolete household appliances with energy-efficient A++ models (Ug = 3) is the most efficient way to achieve a balance between minimal investment and quantifiable monthly savings. Though it is less ideal because of their greater costs and longer payback times, the solar system (Ug = 1.67) and thermal insulation (Ug = 2.33) are both feasible.

The cost of replacing high-efficiency appliances, the large initial investment needed for photovoltaic systems and building insulation, and the lack of customer education and knowledge on long-term energy and cost benefits are the limitations.

The originality of the research is given by the way the content is presented, the realistic simulation of an actual residential building, complete with technical details daily, monthly, and annual energy use per room. With the help of original tables, graphs, and figures, the problem is tackled utilizing the concepts of economic engineering for three customized alternatives. Each alternative is assessed using the global utility approach, critical path analysis, and customized cash flow diagrams.

VI. CONCLUSIONS AND FINAL REMARKS

After analyzing the energy usage of a 210 m² home with an attic and ground floor, we discovered that,

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given the state of the energy market, the annual consumption would be roughly 5,643 kWh, with an estimated cost of more than 6,500 RON. The kitchen was found to be the main source of consumption, and households with high consumption profiles are more financially strained due to the complicated power tariff system. This thorough investigation supported the necessity of putting certain energy-saving and autonomy-boosting ideas into practice.

Reducing consumption was directly impacted by the first suggested option, which was to replace outdated home appliances with A++ energy class models. The ensuing monthly savings, which total about 41 RON, cause the investment to recoup quickly and result in yearly savings of more than 490 RON.

The second option, which involved installing a 6 kWp photovoltaic system, has shown itself to be incredibly energy-efficient. The system can achieve energy independence and fully meet the demands of the residence with an average monthly production of 484 kWh. The ROI of 526.72%, the predicted net profit of about €29,000 over 25 years, and the annual recovery rate of more than 21% demonstrate the durability and profitability of this kind of project from a financial standpoint. According to the global utility technique, this option was the best one since it had the most balanced costs, benefits, and degree of immediate feasibility.

The third option, which entails significant upfront costs, improves the building's overall efficiency and lowers energy losses during the colder months by replacing the woodwork and insulating the exterior walls and pipes. With significant long-term benefits in terms of thermal comfort and passive energy efficiency, this solution is essential for a comprehensive energy independence package even though it has no immediate effect on the electricity bill.

Using the global utility method, it was shown that the best course of action is to replace appliances with energy-efficient models, then install a photovoltaic system and thermal insulation. The three solutions must be viewed as complimentary components of an integrated system, where efficiency, local production, and loss reduction work in concert, in order to truly attain energy independence.

However, the implementation of the independent system is necessary for significant energy production, and for this we have created a Gantt chart with the activities necessary for the implementation of the project, the duration of each activity and the available human resources.

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