

Simple digital solution for buildings energy efficiency estimations

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Abstract. With rising energy demands and environmental challenges, the need for energy efficiency becomes urgent. This paper presents a user-friendly, simple digital tool for evaluating energy-saving measures in private buildings, including lighting upgrades, insulation of walls and roof, window replacements, and energy-efficient appliances. The tool estimates energy and financial savings and calculates key financial indicators such as payback period (PBP), net present value (NPV), and internal rate of return (IRR). It aims to support informed decision-making by offering personalised recommendations and scenario comparisons. The developed tool promotes sustainability and cost-effective energy use across diverse building types.

1 Introduction

Global energy demand continues to rise due to population growth, urbanisation, and industrialisation, intensifying the urgency to reduce greenhouse gas (GHG) emissions [1, 2]. Energy efficiency is a key strategy for minimising environmental impact and reducing energy costs. Buildings, particularly private residential and commercial ones, account for about 40% of energy use and over 33% of energy-related GHG emissions in the European Union [3].

In response to these challenges, there has been a growing emphasis on implementing energy efficiency measures in private buildings. Energy-saving measures, such as better insulation, efficient lighting, heating, ventilation, and air conditioning system upgrades, can lead to significant reductions in consumption and emissions as well as lower utility bills. Although previous studies have demonstrated that individuals tend to prioritise personal benefits when considering energy efficiency measures, it is crucial that these benefits are explicitly clear to motivate adoption [4]. However, individuals often lack knowledge of energy efficiency measures and the user-friendly and accessible tools to assess potential benefits. The development of simple digital tools used to evaluate and enhance energy efficiency in private buildings represents a crucial step towards achieving these objectives [5]. Addressing this gap, this paper introduces a user-friendly, simple digital tool designed explicitly for private buildings, aiming to evaluate the impact of various energy efficiency measures such as lighting improvements, insulation of walls and roof, replacement of windows, and replacement of domestic appliances and make informed decisions to enhance energy efficiency in private buildings.

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Through a comprehensive analysis of these measures, the tool enables users to assess potential energy savings and financial returns associated with various efficiency measures. By integrating key financial metrics such as payback period (PBP), net present value (NPV), and internal rate of return (IRR), the tool provides a comprehensive assessment of the economic viability of energy efficiency investments in private buildings. Moreover, by implementing simple calculations and providing actionable insights, the tool enables users to make informed decisions aligned with sustainability objectives and monetary savings. The developed tool is designed to be intuitive, requiring minimal technical knowledge. Key features of the digital tool include:

- User-friendly and intuitive interface that guides users through the process.
- Simple assessment modules for key building elements.
- Personalised recommendations based on historical energy use and building characteristics.
- Financial analysis through financial metrics such as PBP, NPV, and IRR.
- Scenario analysis allowing users to test and compare different investment options.

The tool is applicable to residential and small commercial buildings and supports a wide range of users, from homeowners to consultants. The paper focuses on the tool's development and its demonstration of capabilities within the Lithuanian context. The tool is developed in Microsoft Excel using Visual Basic and macros.

2 Methodology

The methodology employed in this paper follows a systematic approach designed to evaluate and quantify energy efficiency measures in private buildings using secondary data and a simple digital tool. This approach comprises several sequential steps, each critical for assessing current energy consumption patterns, identifying opportunities for improvement, and estimating the financial implications of implementing energy-saving interventions. A detailed description of each step and the key formulas used for calculations is provided below.

2.1 Data collection

Lighting. Detailed data on the building's lighting infrastructure must be gathered. This includes the total number of bulbs installed or replaced, their capacity, average daily usage duration, the cost of new bulbs, and the electricity tariff paid to the supplier.

Appliances. Information on the energy consumption of household appliances, such as refrigerators, washing machines, dishwashers, and others slated for replacement, should be collected. Data should include annual energy consumption for old and new appliances, usage frequency (e.g., cycles per week or hours per week), appliance capacity, and replacement costs.

Insulation. This module includes data on annual heat consumption, heated area, heat tariff, area designated for insulation (walls and roof), window replacement area, costs for insulation and replacement, estimated annual energy savings, and any applicable state subsidies or support.

Financial Analysis. To compute key financial indicators, parameters for financial evaluation, including the discount rate (in %) and the analysis period (in years), should be specified.

Users provide this data through an interface based on simple, color-coded numeric field inputs in Excel, ensuring ease of use, particularly for non-experts.

2.2 Energy and financial calculations

2.2.1 Lighting module

The annual energy consumption of each bulb is calculated using the formula:

$$EC_i = Cap_i \cdot T_i \cdot 365; \quad (1)$$

where EC_i is the annual electricity consumption of bulb i (in kWh), Cap_i is the capacity of bulb i (in W), T_i is the average daily operation time of bulb i (in hours).

The annual energy saved by replacing old bulbs with new ones is:

$$ES_i = (EC_{old} - EC_{new}) \cdot NB_i; \quad (2)$$

where ES_i is the annual electricity savings of bulb i (in kWh), NB_i is the number of bulbs of type i .

Monetary savings without investment costs are calculated as:

$$MS_i = ES_i \cdot EITariff; \quad (3)$$

where MS_i is the monetary savings per year of bulb i (in EUR), $EITariff$ is the electricity tariff (in EUR/kWh).

If the investment in bulb replacement is included, the monetary savings are:

$$MSInv_i = MS_i - BP_i; \quad (4)$$

where $MSInv_i$ is the monetary savings per year of bulb i (in EUR) including the price of bulb i , BP_i is the price of bulb i (in EUR).

The total annual results of the lighting module are calculated by summing up the results of each bulb i .

2.2.2 Appliances module

For appliances where annual energy consumption before and after replacement is known (e.g., refrigerator), calculations follow the same method as the lighting module. For appliances with energy and water consumption per cycle (e.g., washing machines, dishwashers), the following formulas are used:

$$EC_j = ECC_j \cdot NC_j \cdot 52; \quad (5)$$

$$WC_j = WCC_j \cdot NC_j \cdot 52; \quad (6)$$

where EC_j and WC_j are the annual electricity and water consumption of appliance j (in kWh and litres, respectively), ECC_j and WCC_j are the per-cycle energy and water consumption of appliance j (in kWh/cycle and litres/cycle, respectively), NC_j is the number of cycles that appliance j is used per week.

For appliances defined by their capacities in kW and the average number of hours they are used per week (e.g., ovens, stoves):

$$EC_j = ECap_j \cdot NH_j \cdot 52; \quad (7)$$

where $ECap_j$ is the energy capacity of appliance j (in kW), NH_j is the average number of hours that appliance j is used per week.

Other parameters and total results are calculated similarly to those in the lighting module.

2.2.3 Insulation module

Three energy efficiency measures are considered: wall insulation, roof insulation, and window replacement. The investment in each is computed as:

$$INV_k = MA_k \cdot MP_k; \quad (8)$$

where INV_k is the investment in measure k (in EUR), MA_k is the insulated/replaced area of measure k (in m²), MP_k is the cost of implementing measure k (in EUR/m²), k corresponds to

the energy efficiency measure: $k = 1$ (wall insulation); $k = 2$ (roof insulation); $k = 3$ (window replacement).

Annual energy savings (in %) in this module can be considered in two ways: estimated savings can be entered by the user, if known, or default values defined by expert assessment can be used. If any one of the measures is implemented individually, savings are estimated to be 5% per year. Then, annual energy savings (in kWh) are calculated as:

$$ES_k = HC \cdot (HS_k/100); \quad (9)$$

where ES_k is the annual heat savings (in kWh) if measure k is implemented, HC is the total annual heat consumption (in kWh), HS_k is the annual energy savings (in %) if measure k is implemented.

Total results are calculated in the same way as in the other modules, except for total energy savings in %. Default annual savings assumptions based on expert assessment are:

- One measure implemented: 5%.
- Two measures implemented: 10%.
- All three measures implemented: 50%.

2.2.4 Financial analysis

The financial viability of the implemented energy efficiency measures is assessed using key financial indicators: PBP, NPV, and IRR. PBP is determined as the duration required for the cumulative savings to offset the initial investment [6]. It is calculated by identifying the year in which the cumulative cash flow becomes positive.

NPV represents the present value of all future cash flows generated by the energy efficiency measures over the project's lifetime, discounted at a predefined rate. The formula for NPV is [7]:

$$NPV = \sum_{t=1}^n \frac{CF_t}{(1+r)^t} - TINV; \quad (10)$$

where CF_t is the cash flow in year t , r is the discount rate (in %), $TINV$ is the total investment (in EUR), n is the number of years of the analysis period.

IRR is the discount rate for which the NPV is zero [8]:

$$\sum_{t=1}^n \frac{CF_t}{(1+IRR)^t} - TINV = 0. \quad (11)$$

IRR is typically computed iteratively using financial software or numerical methods.

3 Results

To demonstrate the performance of the developed tool, demo calculations were performed using sample data reflecting typical energy efficiency measures in Lithuania. The test case involved a typical 100 m² private house, with assumptions aligned with the Lithuanian long-term renovation strategy [9]. Key results from each module are presented below.

3.1 Lighting module results

The lighting module assessed replacing 10 conventional incandescent bulbs (2 of 5 types) with energy-efficient alternatives. The upgraded versions offer significantly lower power consumption while providing equivalent luminous output. The standard one-time zone electricity tariff of the public supplier in Lithuania was used, which in April 2024 was 0.214 EUR/kWh [10]. Table 1 presents the summarised assumptions and the total annual results for the lighting module.

Table 1. Summary of assumptions and results for the lighting module.

Parameter	Value/Range	Parameter	Value/Range
Number of bulbs replaced	10 (2 of 5 types)	Bulb price (EUR)	3-10
Capacity of old bulb (W)	40-100	Total investment (EUR)	64
Capacity of new bulb (W)	6-20	Total energy saved (kWh)	1533
Daily usage (hours)	5-10	Total savings (EUR)	264

The results demonstrate that lighting upgrades are highly cost-effective. After considering the initial investment, annual energy savings exceeded 1500 kWh, translating into monetary savings of over 264 EUR per year. The payback period is extremely short – less than one year. This finding underscores the importance of considering both the short-term costs and long-term benefits when evaluating energy efficiency measures.

3.2 Appliances module results

In this module, the analysis of replacing outdated household appliances with modern, energy and water-efficient models was performed. The evaluated categories include electricity-only devices (e.g., refrigerators, ovens) and those consuming electricity and water (e.g., dishwashers, washing machines).

The tariff for drinking water supply and sewage treatment from the public supplier in Kaunas, Lithuania, as of April 2024, was used, which for individual houses was 2.48 EUR/m³ with VAT [11]. Table 2 provides an overview of the summarised assumptions and the total annual results for the appliances module.

Table 2. Summary of assumptions and results for the appliances module.

Parameter	Value/Range	Parameter	Value
Number of appliances replaced	8	Total investment (EUR)	3700
Capacity of old appliance (kW)	0.2-10	Total energy saved (kWh)	5060
Capacity of new appliance (kW)	0.1-8	Total water saved (litres)	4368
Weekly usage (hours)	10-35	Total savings (EUR)	-2606
Appliance price (EUR)	150-700		

The total annual energy savings from appliance upgrades exceeded 5000 kWh, with water savings of over 4300 litres. However, the total investment required (3700 EUR) significantly reduces short-term cost-effectiveness. Without considering investment, annual monetary savings were over 1000 EUR, primarily driven by significant reductions from water heaters and cooktops. However, the net savings after investment were negative in the short term (-2600 EUR/year).

This emphasises the importance of adopting a long-term perspective when evaluating the economic viability of appliance upgrades and the necessity of considering both short-term costs and long-term benefits. While energy-efficient appliances offer long-term financial benefits, the upfront investment cost can be a barrier for some homeowners.

3.3 Insulation module results

In the insulation module, the impact of upgrading the thermal envelope (walls, roof, and windows) on space heating demand was examined. Assumptions included a total annual heating demand of 8000 kWh and realistic estimates of material costs and insulation effectiveness.

The heat tariff was based on the average for the year 2023 from the heat supplier in Lithuania, which was 0.0618 EUR/kWh [12]. Table 3 presents the summarised assumptions and the total annual results for the insulation module.

Table 3. Summary of assumptions and results for the insulation module.

Parameter	Value			Parameter	Value
Elements insulated/replaced	Walls	Roof	Windows	Estimated annual savings after implementation (%)	50
Area of insulation/replacement (m ²)	200	100	20	Total investment (EUR)	16352
Unit insulation costs (EUR/m ²)	99	25	53	Total energy saved (kWh)	4000
State support (%)	30			Total savings (EUR)	-16105

The cumulative effect of insulation improvements results in an annual heat energy saving of 4000 kWh, or 50% of the baseline heating demand. In monetary terms, this equates to almost 250 EUR/year. However, even after subsidies, the total investment remains high (16352 EUR), leading to a poor financial return over short and medium timeframes. Despite this, the benefits of improved insulation extend beyond cost savings – enhanced indoor comfort, reduced environmental impact, and increased property value should also be considered.

It should be noted that non-energy benefits, such as improved comfort, health, well-being, job creation, or community development, were not assessed using the tool. However, it is essential to acknowledge that while insulation measures offer long-term energy and cost savings, the upfront investment cost can be substantial.

3.4 Financial performance of the project

A comprehensive financial evaluation of all combined upgrades (lighting, appliances, and insulation) was conducted using a 20-year analysis horizon and an 8% discount rate. Table 4 presents the key results of financial indicators for the 20-year analysis period.

Table 4. Summary of project results for the analysis period of 20 years.

Parameter	Value	Parameter	Value
Total investment (EUR)	20116	Total savings with investment (EUR)	13264
Total energy saved (kWh)	211867	Payback Period (Years)	14
Total water saved (litres)	87360	Net Present Value (EUR)	-5275
Annual monetary savings (EUR)	1669	Internal Rate of Return (%)	5.03

Additionally, Fig. 1 illustrates the cumulative cash flow trajectory of the project.

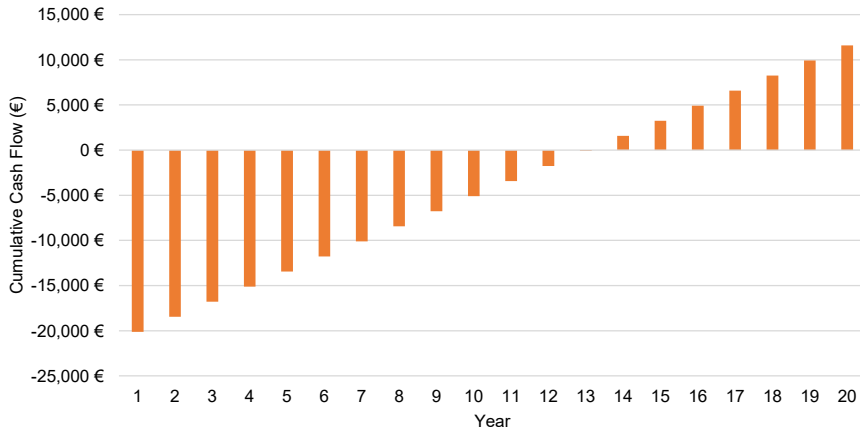


Fig. 1. Cumulative cash flow for the analysed project.

This visual representation of the project’s financial performance demonstrates that from year 14 onwards, the cumulative cash flow becomes positive, indicating the point at which the project begins to recoup its initial investment.

The results confirm that energy efficiency interventions vary significantly regarding financial performance. Lighting upgrades are universally favourable, with short payback and immediate positive returns. Appliance upgrades offer considerable savings but are constrained by high initial costs. While technically effective in reducing heat loss, insulation measures have the highest investment and the longest return period.

While full technical validation with measured data or dynamic simulation is not yet performed, internal logic and consistency checks were conducted. For example, changing insulation parameters predictably reduced heating demand and switching to efficient appliances yielded expected savings and reductions in estimated consumption.

4 Conclusions

The developed tool demonstrates the capability to analyse and evaluate energy efficiency measures in residential buildings. The Lithuanian case study confirms the tool’s usefulness in assessing both technical and financial aspects of potential upgrades.

The analysis highlighted that simple measures like lighting upgrades and appliance replacements offer relatively short payback periods and compelling long-term benefits. In contrast, more capital-intensive interventions, such as insulation, demand significant investment and are often only feasible with external financial support.

Incentives and subsidies play a critical role in promoting energy efficiency, especially for measures with longer payback periods. Policymakers should also focus on public awareness campaigns and provide homeowners with accessible financing options to facilitate adoption.

From the homeowner’s perspective, prioritising high-impact, financially viable interventions and actively monitoring performance post-implementation can ensure sustained benefits.

The developed tool offers several advantages. It is simple to use, requires minimal input and is based on a familiar spreadsheet platform (Excel). This makes it particularly useful for raising energy awareness among homeowners or for educational purposes. Users receive instant feedback on how selected measures impact energy use and estimated savings. However, the tool also has limitations. These include the lack of detailed simulation

capabilities, limited climatic and occupancy variability and no current link to dynamic energy modelling. The tool is best suited for preliminary analysis and educational purposes.

Future enhancements of the tool may include the integration of renewable energy technologies (e.g., solar panels, heat pumps), a wider range of efficiency measures, an improved user interface, and advanced financial analysis capabilities. Future research should explore regional differences in energy efficiency impacts, investigate socio-economic drivers behind energy-related decisions and evaluate the combined benefits of energy efficiency and renewable integration for residential buildings. Future development may also include calculation of CO₂ emissions and integration with national renovation programs.

In summary, this study underscores the importance of a holistic approach to energy efficiency – balancing short-term costs with long-term environmental and economic benefits. By leveraging digital tools and collaborative policy frameworks, stakeholders can foster a transition toward more sustainable and resilient residential energy systems.

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