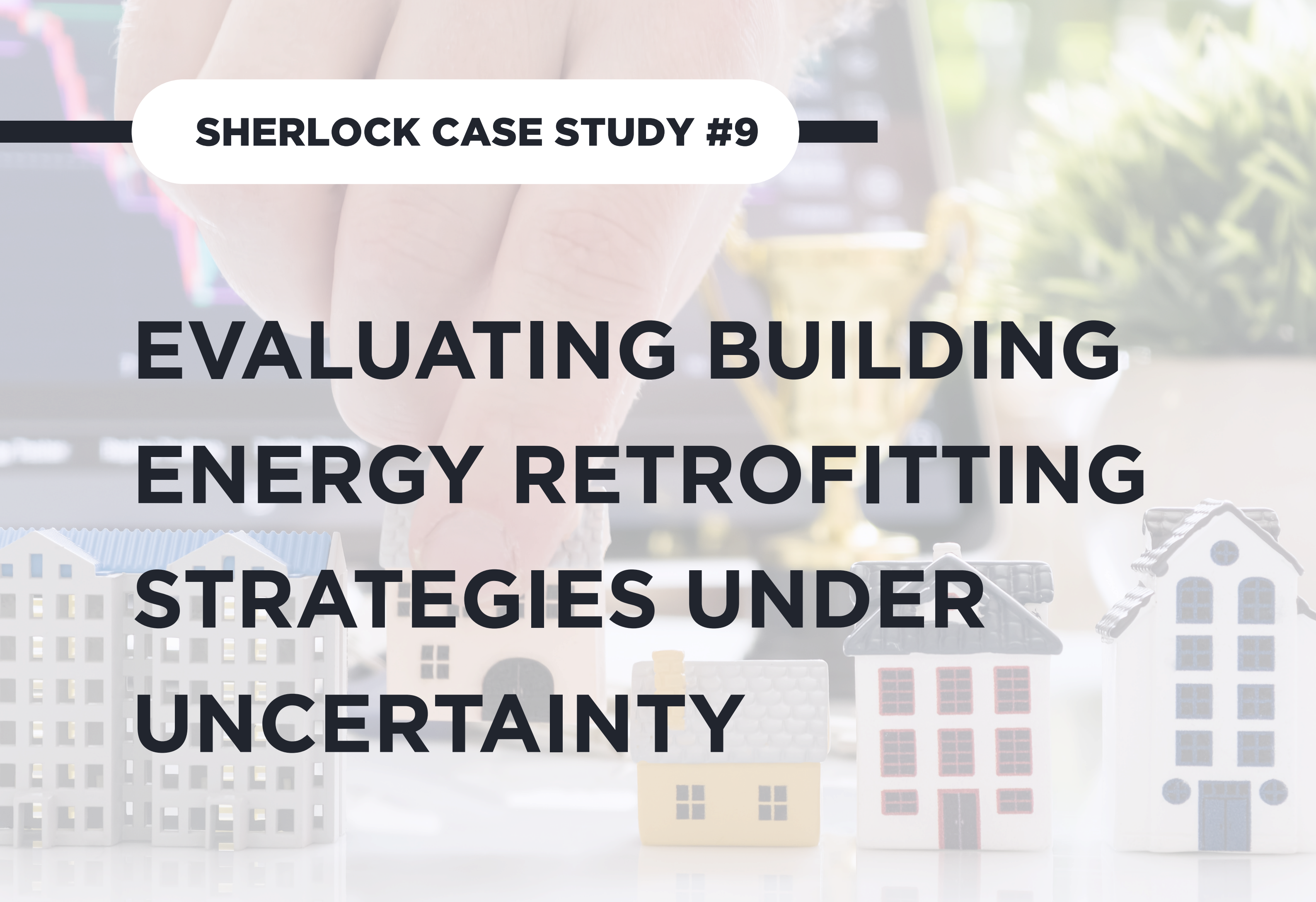

SHERLOCK CASE STUDY #9

EVALUATING BUILDING ENERGY RETROFITTING STRATEGIES UNDER UNCERTAINTY

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Overview

This case study presents ERV – the Energy Renovation tool, a software developed within the Horizon Europe RenOnBill project to support the planning and evaluation of energy renovation projects in residential buildings.

The key idea behind ERV is simple but powerful:

When you plan a renovation, many things are uncertain – from weather and energy prices to material performance and costs. ERV helps you see not only the "expected" outcome, but also the range of possible results and risks.

The tool combines:

- a simplified energy model of the building,
- a financial model (costs, savings, indicators like NPV and IRR),
- and a probabilistic approach (Monte Carlo simulation) to account for uncertainty.

The case study applies ERV to a typical Italian multi-apartment residential building and evaluates the impact of a combined retrofit: better insulation and a new heat pump, framed within an on-bill financing logic.

Context: Why We Need Better Tools for Retrofit Decisions

Buildings are responsible for around **40% of final energy consumption in the EU**, and the residential sector alone accounts for about **a quarter** of this. If Europe wants to reduce greenhouse gas emissions by **80–95% by 2050**, energy renovation of existing buildings is essential.

New buildings can be designed as "nearly zero energy buildings," but the real challenge lies in the **existing stock**, especially old social housing blocks with poor insulation and inefficient heating systems. For these buildings, decision-makers need to answer questions such as:

- Which renovation package makes sense technically and financially?
- How will energy savings and payback change if winters are milder or colder?
- What happens if energy prices rise or fall?
- How sensitive is the investment to uncertainties in costs and performance?

Traditional, purely "deterministic" calculations assume fixed values for everything (energy prices, weather, material properties). In reality, these factors vary – sometimes a little, sometimes a lot. Without accounting for this variability, there is no clear picture of risk.

ERV was created precisely to fill this gap: it allows users to evaluate retrofit options under uncertainty, not just under ideal conditions.

The ERV Tool: What It Does

ERV is designed to support both technical and financial assessment of renovation measures on residential buildings. It allows users to:

Model buildings through archetypes

Evaluate energy interventions

Combine different options with finacial analysis

1 Model buildings through archetypes

(e.g. typical Italian social housing from the 1960s) rather than needing detailed drawings and data.

2 Evaluate a wide range of energy interventions, such as:

improved insulation of walls, roofs and floors, window replacement, heating system upgrades (e.g. replacing a boiler with a heat pump), integration of solar energy.

3 Combine these technical options with financial analysis:

investment costs, energy cost savings, Net Present Value (NPV), Internal Rate of Return (IRR), Discounted Payback Period (DPBP).

The Case Study Building

The case study examines a **typical low-cost multi-apartment building** built in Italy between 1961 and 1975 for social housing.
Key characteristics:

- **6 floors**, with a total conditioned area of about **2,400 m^2** (400 m^2 per floor).
- A **surface-to-volume ratio (S/V)** of 0.5 m^2/m^3, typical of compact multi-family buildings.
- **No insulation** on walls, roof, or floor:
- wall U-value: 1.76 W/m^2K
- roof U-value: 1.85 W/m^2K
- floor U-value: 1.30 W/m^2K
- **Single-glazed windows**, with a U-value of 5.7 W/m^2K.
- Heating system with:
- an older open-chamber gas boiler (efficiency ≈ 0.76),
- traditional radiators,
- standard distribution and regulation efficiencies.

The building is located in **Turin (Northern Italy)**, a relatively cold climate with:

- average winter external temperature around 5.7 °C,
- about **2617 heating degree days**,
- heating season from mid-October to mid-April (12 hours of heating per day).

This configuration represents a very common situation in many European cities: **aged building stock, poor envelope, and outdated heating equipment**.

Methodology: How ERV Evaluates the Building

ERV uses a simplified but robust energy model based on steady-state heat balance and standard building physics. It estimates:

heat losses through walls, roof, floor and windows

ventilation and infiltration losses

internal heat gains from occupants and appliances

solar gains through the window

From these elements, the tool calculates:

- the building's annual heating energy need,
- the fuel or electricity consumption, based on system efficiencies,
- and the resulting energy bill.

In parallel, a financial model evaluates:

- investment costs for each retrofit package,
- annual savings on energy costs,
- and financial indicators such as: Net Present Value (NPV), Internal Rate of Return (IRR), Discounted Payback Period (DPBP), considering a defined time horizon (e.g. 20 years) and a chosen discount rate.

What makes this case study particularly interesting is the **uncertainty analysis**:

- ERV identifies more than **30 uncertain parameters** (geometry, thermal properties, climate, energy prices, costs, etc.).
- For each parameter, the user can define the **range and shape of variability** (for example ±15% with a normal or uniform distribution).
- Using **Monte Carlo simulations**, the tool generates thousands of random combinations and calculates how results spread.

The outcome is not a single value but a **probability distribution** for energy demand, bills, investments and financial performance, with associated **confidence intervals** (e.g. 95% confidence range).

For this particular case study, the analysis focuses mainly on four key uncertain parameters:

- wall U-value (Uw),
- heating degree days (HDD),
- retrofit costs,
- and energy price (Eprice).

The Retrofit Scenario

The planned renovation combines two major interventions:

External wall insulation

- 5 cm of additional insulation on the external walls,
- using a material with very low thermal conductivity (k ≈ 0.003 W/mK).

Replacement of the gas boiler with a heat pump

- the new heat pump has a Coefficient of Performance (COP) of about 4.5,
- it delivers much more useful heat per unit of electricity consumed than the old boiler.

Domestic hot water is not considered, since it is not directly affected by these specific measures.

Investment costs

- Wall insulation alone would cost about €225,000.
- Replacing the boiler with a heat pump alone would cost around €127,000.
- However, because better insulation reduces the required heating capacity, the actual combined investment is lower than the simple sum:
- the total investment is about €291,500,
- saving around €58,000 compared to doing both independently at their original sizing.

Energy impact

After the renovation:

- Heat losses drop from 412 MWh to about 217 MWh per year.
- Due to the high efficiency of the heat pump, energy consumption for heating falls dramatically to around 54.8 MWh per year.
- The annual energy bill decreases from about €54,600 to roughly €14,900.

This corresponds to a bill reduction of more than 70%, which is substantial for residents and building owners.

Monte Carlo analysis on the renovated configuration shows that:

- the influence of wall U-value uncertainty on losses and consumption is much smaller than before (thanks to the extra insulation),
- variability related to climate and energy prices still has a significant effect,
- investment cost itself has its own uncertainty (since it combines two separate cost blocks), but this remains manageable.

Long-Term Financial Performance (20-Year Horizon)

To assess whether the investment is financially attractive, the tool evaluates the project over a **20-year period**.
In the base case (without loans or incentives), with an assumed discount rate of 8% and modest annual increases in fuel and electricity prices, the results are:

- **Net Present Value (NPV):** about **€112,500** (positive, which means the investment is financially worthwhile overall).
- **Internal Rate of Return (IRR):** around **12.8%**, higher than the assumed discount rate.
- **Discounted Payback Period (DPBP):** about **11.1 years**, meaning the investment is recovered (in discounted terms) a bit after the halfway point of the 20-year horizon.

When uncertainty is taken into account, ERV provides **confidence intervals** for these indicators. For example:

- the NPV can vary within a significant range (tens of thousands of euros) depending on how actual temperatures, prices, and performance evolve,
- uncertainties in energy prices and climate affect the long-term NPV differently than uncertainties in U-values or fixed costs.

One interesting finding is that, over 20 years, uncertainty in wall thermal transmittance has a stronger impact on NPV than one might expect from its short-term influence on annual losses. This is due to the way the tool perturbs parameters: wall properties are fixed once (they do not change year to year), while heating degree days vary yearly around an average, and their effects partly compensate over time.

ERV can also simulate the combined effect of all uncertainties, providing a global picture of how risky or robust the renovation is on a long-term financial basis.

Effect of Loans and Incentives

The tool is also used to test how financial conditions can improve project attractiveness:

Loans

If 50% of the investment is covered by a loan at an interest rate lower than the discount rate (for example, 3.5%), the NPV and IRR both improve.

- With a 5-year repayment period, or a 10-year one, the NPV increases,
- the IRR rises (up to above 17% in the 10-year case),
- and the payback time shortens (down towards 9–10 years).

Government incentives

When simulating a case where 65% of the investment through tax incentives spread over 10 years – similar to some existing schemes for energy renovation – the results are even more favourable:

- the NPV climbs to nearly €240,000,
- the IRR reaches almost 19%,
- and the discounted payback time drops to around 6.5 years.

Conclusions and Takeaways

This case study demonstrates how the ERV Energy Renovation tool can be used to:

- model building energy performance and retrofit scenarios using archetypes and simplified physics,
- combine this with clear and transparent financial indicators,
- and, crucially, integrate uncertainty on technical, climatic and economic parameters through Monte Carlo simulation.

For the residential building in Turin, the combined intervention of wall insulation and heat pump replacement:

- cuts energy consumption and bills by more than 70%,
- generates a positive NPV over 20 years,
- and shows robust performance even when uncertainties are considered.

The analysis also highlights that:

- ignoring uncertainty can lead to an incomplete view of risk,
- probabilistic approaches offer a better basis for decision-making,
- and policy tools such as loans and incentives can significantly enhance the attractiveness of renovations.

In practical terms, ERV provides decision-makers, investors, and public authorities with a structured way to explore “what if” scenarios, understand the spread of possible outcomes, and design renovation strategies that are not only energy-efficient and climate-friendly, but also financially sound and resilient to uncertainty.

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