Anticipating the Energy Discount: A Valuation Framework for Real-Estate Investors

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Abstract

In response to increasingly stringent energy-efficiency requirements, the renovation of the building stock has become a central component of climate policy. This document proposes a valuation framework that incorporates regulatory constraints and economic uncertainties in order to assess energy-renovation strategies. We quantify the impact of these interventions on a building's value, taking into account renovation trajectories, future cash flows, and associated risks. The approach relies on a detailed modeling of the building and the simulation of coherent scenarios.

Keywords: Energy renovation, real-estate valuation, regulation, green value, brown discount, sustainable buildings, DCF.

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Executive Summary

The energy transition of the Swiss building stock is a critical component of the country's pathway toward its 2050 climate targets. Buildings account for nearly 40% of Switzerland's final energy consumption and more than 22% of direct greenhouse gas emissions. In an environment marked by tightening regulations, rising societal expectations, and heterogeneous cantonal requirements, real estate investors face increasing uncertainty regarding the scope, timing, and cost of the renovations required to achieve regulatory compliance.

This report develops a valuation framework that explicitly integrates energy performance into the financial assessment of income-producing buildings. Relying on a discounted cash flow (DCF) model, the methodology incorporates: (i) the technical condition of the asset, (ii) component-level life cycles, (iii) future regulatory pathways, (iv) investment cost levels and volatility, and (v) the evolution of operating expenses, rents, and vacancy risks.

The approach compares two investment trajectories: a *baseline strategy*, which maintains the asset without targeting any specific energy improvement, and a *constrained strategy*, which complies with anticipated regulatory requirements (e.g., minimum CECB classes, fossil-fuel heating bans, or HDI thresholds). The difference between the net present values of these trajectories defines the *energy discount* or *brown discount*. This discount reflects both the expected cost of future upgrades and the uncertainty surrounding the interventions required.

To capture these uncertainties, the model introduces a stochastic representation of key variables, including energy prices, construction costs, post-renovation performance outcomes (performance gap), component lifetimes, and vacancy rates. The resulting simulations generate a full distribution of net present values rather than a single point estimate. This enables a detailed risk assessment through indicators such as the coefficient of variation, Value-at-Risk (VaR), and Expected Shortfall (ES). Buildings that are already renovated and certified thus benefit from a valuation premium stemming from lower exposure to regulatory and technical uncertainty.

The empirical application conducted on multiple Swiss real estate portfolios shows that the cost of compliance varies widely depending on the initial condition of the asset, its typology, and the regulatory scenario considered. Assets with poor energy performance (CECB classes F or G, high HDI, fossil-fuel heating systems) exhibit a substantial brown discount, driven not only by high capital expenditures but also by the elevated dispersion of outcomes across scenarios. Conversely, recently built or renovated buildings demonstrate stronger resilience to future regulatory requirements, improved visibility on future cash flows, and significantly lower valuation volatility.

Overall, the proposed framework provides owners, managers, and investors with an operational tool to anticipate the financial implications of the energy transition on real estate assets. It supports strategic renovation planning, quantifies associated risks, and reframes green value not as a discretionary premium but as the financial materialization of reduced uncertainty and regulatory vulnerability. This methodology thus offers a robust analytical foundation for navigating the evolving landscape of sustainable real estate investment.

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1 Introduction and Context

In Switzerland, the building stock accounts for around 40% of final energy consumption (OFEN, 2023) and 22.2% of greenhouse gas emissions (residential and commercial) (OFEV, 2023). According to the Federal Office for the Environment, emissions fell from 16.7 million tonnes of CO_2 in 1990 to 9.05 million in 2023, corresponding to a decrease of 45.9% over the period, or 1.8% per year. The current renovation rate remains insufficient to meet the climate targets set by the Confederation. However, effective technologies are available to improve the energy performance of buildings, with significant potential for reducing greenhouse gas emissions. As a result, buildings remain a priority target of decarbonization policies at all institutional levels.

Over the past fifteen years or so, various public policy instruments have been mobilized to accelerate energy renovation: stricter legislation, subsidies, tax incentives, and awareness campaigns. Despite these efforts, the results are deemed insufficient to achieve the Confederation's 2050 objectives, and some cantons have already opted for more stringent measures, such as mandatory renovation of buildings rated F or G on the CECB scale.

Several barriers to renovation are well identified: payback periods perceived as too long, misalignment between those who bear the costs (owners) and those who benefit from the gains (tenants), complexity of technical choices, lack of information on renovation pathways, and regulatory uncertainty. The Swiss context is particularly affected by this asymmetry, as nearly 58% of dwellings are occupied by tenants.

In a changing regulatory environment and under rising climate pressure, real estate investors seek to better understand the true value of energy renovation measures. A meaningful assessment must go beyond a simple calculation of energy savings and also integrate the impacts on future capital expenditures, operating costs, rents, and resale value. The cash flows associated with renovations must be linked to the technical condition of the building and the residual value of its components.

Real estate valuation thus becomes a multidisciplinary issue. Investment decisions can no longer be dissociated from the technical dynamics of the building, public policy developments, or economic uncertainties. The long holding periods typical of the sector reinforce the need to account for future regulatory scenarios and the risk of non-compliance. Valuation is therefore no longer limited to determining *whether* a renovation is profitable, but rather *when* and *how* it should be carried out.

In light of these challenges, this study proposes a methodological framework for analysing different energy renovation strategies using a discounted cash flow (DCF) valuation model. The model incorporates component lifetimes, projected costs, regulatory requirements, and future uncertainties. It allows for the comparison of several legally constrained pathways and for assessing their impact on both the expected value of the building and its risk profile. The tool aims to provide owners with a robust analytical basis for the valuation of income-producing properties in the context of the energy transition. Unlike hedonic approaches based on past transaction prices, this method does not seek to estimate a market value, as the necessary transaction data are not available, but to provide an internal financial estimate based on technical and regulatory scenarios.

2 The Swiss Real Estate and Regulatory Context

The structure of the Swiss building stock plays a central role in the energy transition.[1] Only 17 % of buildings were constructed after 2000, which means that the vast majority of the stock is potentially inefficient from an energy perspective. These older buildings often require deep renovations to meet current performance standards, particularly in terms of thermal insulation and emissions reduction.

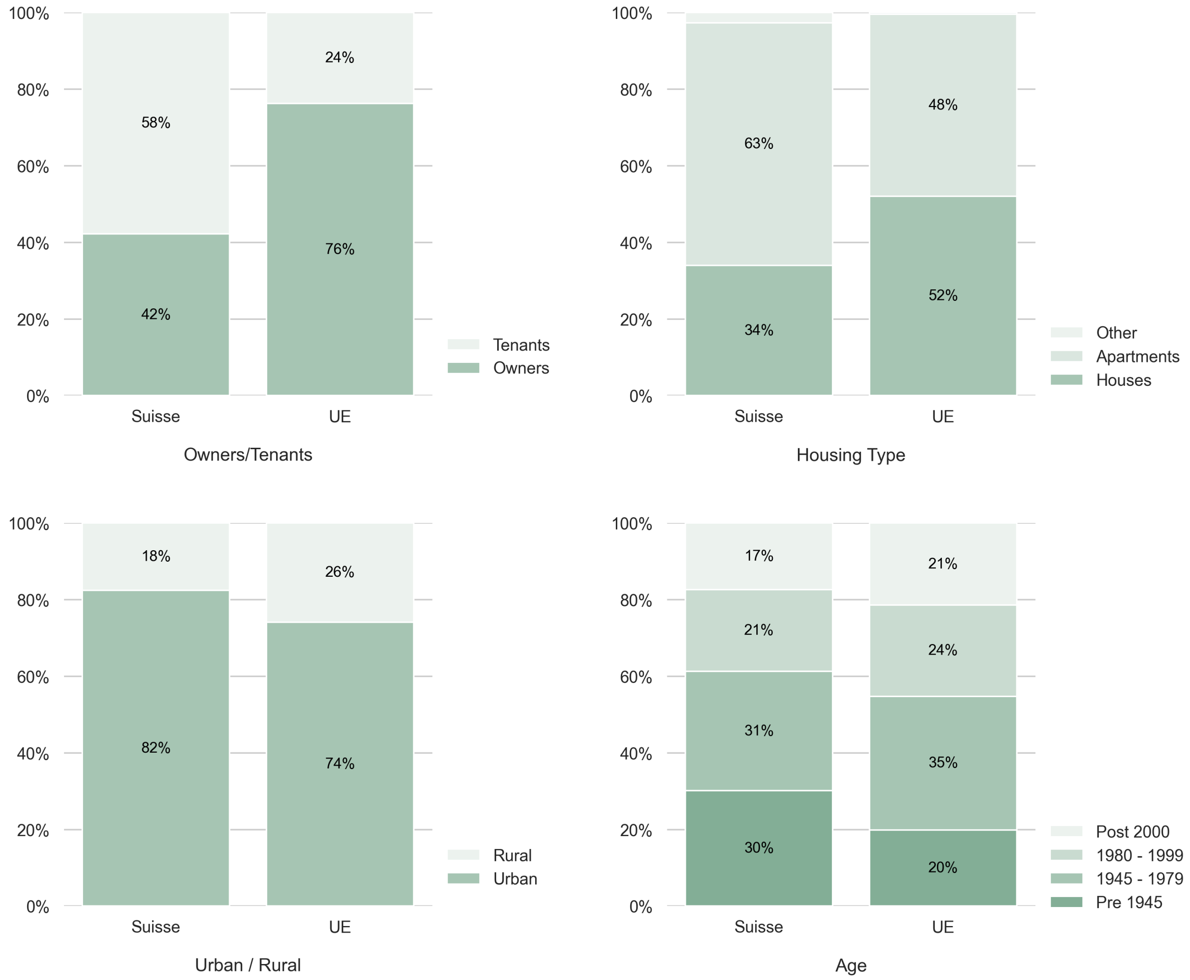
The Swiss market is also characterized by a predominance of rental housing, especially in urban areas. In 2021, 57.7 % of dwellings were occupied by tenants, a figure well above the European average (30.1 %). This imbalance between owners and tenants reinforces the so-called "split incentive": investments are borne by the owner, while the economic benefits (for example, lower energy bills) accrue to the tenant.

The high share of apartments in the building stock (63.3 % versus 46.3 % in the EU) and limited access to homeownership contribute to a concentration of ownership in the hands of investors, whether private (individual owners) or institutional (real estate funds, pension funds, etc.), who generally do not occupy the dwellings they own. In 2021, 67.2 % of buildings were owned by private individuals, 11.7 % by legal entities, and 14.4 % by co-ownerships.

From an energy perspective, space heating accounts for around 70 % of the consumption of a residential building. Heating oil remains the main energy source (more than 30 %), followed by natural gas (around 25 %). The dependence on fossil fuels increases the urgency of decarbonizing the building stock.

[1] The figures mentioned mainly come from the Federal Statistical Office (FSO) and Eurostat (OFS, 2022; Eurostat, 2021).

Figure 1: Comparison of real estate market statistics between Switzerland and the average of the 27 member states of the European Union (Eurostat, 2021).



To support the transition, various energy certification systems have been introduced to reward high-performance buildings. In Switzerland, the most widely used are the CECB (Cantonal Energy Certificate for Buildings) and the Minergie label. The CECB assigns a rating from A (very efficient) to G (very energy-intensive), based on energy consumption and CO_2 emissions. The enhanced version, CECB+, complements this assessment with renovation recommendations. The Minergie label, launched in 1998, imposes high standards for insulation, ventilation, and energy efficiency. More demanding variants include Minergie-P for very low-energy buildings and Minergie-A for net-zero or energy-positive buildings. Internationally, other labels such as LEED, BREEAM, or DGNB complement this normative landscape, particularly for institutional investors. A summary table of the main systems is provided in the Appendix (see Appendix A).

At the regulatory level, Switzerland is gradually aligning itself with European climate objectives, although it is not a member of the European Union. The Climate Protection Act, adopted in 2023, sets a target of carbon neutrality for the building stock by 2050. It also provides financial incentives to support the phase-out of fossil-fuel heating systems.

However, the operational implementation of these objectives falls under cantonal responsibility, which leads to a diversity of approaches. The national regulatory framework is defined by the Model Regulations of the Cantons in the Energy Sector (MoPEC), whose latest update, MoPEC 2025, is being prepared to reinforce requirements on energy efficiency for both new and existing buildings. Although its adoption is voluntary, most cantons are progressively incorporating it into their legislation. Among other things, the model aims to generalize the ban on replacing fossil-fuel heating systems with new fossil-fuel systems, a principle already applied in a majority of cantons.

In parallel, the Building Programme is a major incentive instrument. Co-financed by the Confederation and the cantons, it provides financial support for energy renovations, notably through subsidies for insulation, the replacement of fossil-fuel heating systems, and energy audits. In return, the granting of certain subsidies is subject to strict conditions, such as achieving a specified level of energy performance or providing a CECB+ certificate.

In Zurich, the new Energy Act prohibits replacing an end-of-life fossil-fuel heating system with another fossil-fuel system. In Geneva, a heat demand index (HDI) threshold of 450 $MJ/m^2 \cdot$year has been set: any building exceeding this value must be renovated. In the canton of Vaud, buildings rated F or G on the CECB scale are now subject to mandatory renovation, with stricter requirements for large floor areas.

The regulatory environment has changed significantly in recent years, with a gradual tightening of energy requirements. Despite differences between cantons, a common framework is emerging, supported by strengthened federal policies. This evolution is gradually reducing legal uncertainty while creating new compliance challenges. In this context, strategic investment planning requires analytical tools capable of integrating differentiated regulatory scenarios and anticipating the impact of future legal obligations on the valuation of real estate assets.

3 Literature Review

In the context of the energy transition, real estate valuation must integrate new parameters, in particular energy performance and regulatory requirements. This literature review presents the main approaches used to value buildings, with a focus on methods that explicitly account for energy performance. We begin by recalling the foundations of the discounted cash flow method, widely used to estimate the value of income-producing properties. We then examine hedonic studies that seek to quantify the effect of energy efficiency on transaction prices. Finally, we review the work on energy renovations, both from a technical and economic standpoint, in order to identify optimization levers and the costs associated with the energy transition in the building sector.

3.1 The Discounted Cash Flow (DCF) Method

Since the 1970s, real estate valuation has gradually incorporated more quantitative approaches based on empirical data rather than purely subjective judgements. Statistical methods have thus been proposed (Pyhrr, 1973, Wofford, 1978), although they rely on discretionary assumptions when choosing parameters. Pyhrr (1973) showed how numerical methods can be used to develop models that help investment decision-makers account for three dimensions: the degree of uncertainty, time dependence, and complexity. This model forms the basis of all modern real estate valuation models.

The DCF method is widely used in the valuation of real estate investments. It is an approach that offers a detailed perspective based on financial projections and can incorporate a variety of scenarios and assumptions. In its report on investment appraisal, The Royal Institute of Chartered Surveyors (RICS) recommends that discounted cash flow analysis be used as a valuation method. In Switzerland, this approach is recognized by FINMA, which considers it a standard method for valuing the real estate portfolios of regulated funds.

French and Gabrieli (2005) propose a standardized approach and suggest using generic forecasting software to allow the integration of uncertainty into real estate valuation. Their article is based on the discounted cash flow model, and the authors emphasize that uncertainty stems both from a lack of knowledge and from imperfect information regarding the variables used in the analysis. They propose in particular assigning probability distributions to uncertain input parameters. This allows them to derive a range of possible outcomes, and therefore a range of possible valuations.

Uncertainty and the Price of Risk

In the DCF framework, risk is incorporated through two channels: the simulation of cash flows and the adjustment of the discount rate. Simulation makes it possible to generate a distribution of net present values under different scenarios, while the discount rate reflects the required return given the perceived risk.

In financial markets, the expected return compensates for systematic risk, as in the CAPM. Real estate, however, does not fit neatly into this framework because of its heterogeneous, illiquid, and location-specific nature. The Arbitrage Pricing Theory (APT) is a more suitable alternative, as it can accommodate hedonic attributes specific to the property. Chaney and Hoesli (2012) illustrate this approach by decomposing the capitalization rate according to such attributes in order to explain observed variations in the Swiss market. According to RICS (2010), the real estate risk premium should distinguish between market risks (liquidity, location, business cycle, regulation) and asset-specific risks (vacancy rates, tenant default, lease clauses, management costs).

Historically, appraisers relied on subjective “what-if” analyses. Monte Carlo simulations subsequently enabled a more rigorous modeling of uncertainty. Baroni et al. (2006) and

Kelliher and Mahoney (2000) show how such simulations improve the robustness of valuations.

Hoesli et al. (2006) incorporate a stochastic risk-free rate using the model of Cox et al. (2005) and propose a risk premium that takes into account the specific characteristics of the building. Their approach combines financial dynamics and hedonic attributes to refine real estate valuations under uncertainty.

Real Options

Incorporating real options into investment appraisal allows the valuation of strategic flexibility, complementing traditional approaches such as DCF (Geltner and De Neufville, 2018). Real options capture the possibility to wait, defer, expand, or abandon a project, which is particularly relevant in uncertain environments such as real estate.

Several methods are used to value these options: the Black-Scholes formula, which was developed for financial markets but is limited in real estate due to illiquidity; binomial trees; and Monte Carlo simulations (Boyle, 1977). When probabilistic information is insufficient, possibilistic or scenario-based approaches can be employed (Collan et al., 2009; Stoklasa et al., 2021).

Dupuy (2003) was one of the first authors to combine real options and Monte Carlo simulations for real estate valuation. Amédée-Manesme et al. (2013) applied this approach to risk management for portfolios of commercial properties, modeling tenant behaviour as an option-like component. Barthélémy and Prigent (2009) study the optimal timing for disposing of a real estate portfolio using models derived from American options.

In the specific context of energy renovation, investment flexibility, particularly in the face of regulatory or technical uncertainty, strongly supports the use of real options. Vimpari and Junnila (2014b) thus propose modeling a green certification as a real option, enabling the evaluation of the additional value created by this decision under uncertainty.

3.2 Hedonic Studies and Energy Performance

A large body of research has sought to measure the impact of high energy performance on property value, rental income, operating costs, and capital expenditures. Typically, these studies adopt a hedonic approach to isolate the effect of building energy performance from other factors.

The hedonic method relies on transaction prices to determine the value of each characteristic, both physical (floor area, age, quality of construction, condition, etc.) and locational (neighbourhood or municipality quality, and micro-location within the neighbourhood or municipality), using a multiple regression model. It can then be used to estimate the value of any object of the same type (apartment, single-family house, multi-unit building) for which the characteristics are known. This method yields statistically reliable value estimates when the number of transactions is sufficiently large. The theoretical model of Rosen (1974) forms the basis of the hedonic method used in real estate. This approach is used to estimate property values as a function of their characteristics, such as size, location, and features. Sopranzetti (2010) discusses hedonic regression methods applied to real estate markets, while Palmquist (2005) summarizes their fundamental principles.

In practice, empirical studies apply the hedonic method to isolate the effect of an energy or environmental certification on transaction prices. The idea is to compare samples of certified and non-certified buildings, estimating their value using regression on a set of observable characteristics. The econometric model generally takes the following form:

$$\ln P_i = \alpha + \beta \mathbf{X}_i + \gamma L_i + \epsilon_i,$$

where P_i is the price of property i, $\mathbf{X}_i$ the vector of physical and locational characteristics, L_i a variable capturing the energy certification, and ϵ_i the error term. Certifications are often introduced as indicator variables, serving as proxies for the overall energy or environmental performance of the building.

Table 1 provides a non-exhaustive overview of hedonic studies focusing on building energy performance. Although results vary by context, most studies find that more energy-efficient buildings tend to sell at higher prices, command higher rents, and reduce operating costs. However, a distinction must be made between residential and commercial segments. Effects are clearer and more consistent in commercial real estate, where energy performance is often part of a broader investment strategy. By contrast, results for residential properties are more heterogeneous, partly because demand is more heavily influenced by individual preferences and transaction data are less transparent.

It also emerges that non-residential buildings benefit more from certifications that attest to good energy or environmental performance. Several reasons may explain this. On the one hand, corporate tenants are generally more sensitive to their ESG image than households. On the other hand, commercial activities, which are often more energy-intensive, directly benefit from improved energy performance. Finally, some certifications specific to commercial buildings include additional criteria related to employee well-being, further enhancing their attractiveness in the rental market.

In Switzerland, Brändle et al. (2022) analyse around 40,000 rents and 432 residential building transactions from the Wüest Partner database. They show that, all else equal, a decrease of 1 kg CO_2/m^2 per year is associated with an average increase in rents of 0.0012 to 0.0035%. Based on capitalization rates observed in transactions, the authors estimate that the market value of energy-efficient residential buildings is on average 2.18 to 3.27% higher than that of less sustainable buildings.

Table 1: Summary of results from hedonic studies

Study	Year	Region	Use type	Database	Certification	Period	Certified sample size	Total sample size	Rent premium	Price premium	Occupancy
Eichholtz et al. (2010)	2010	United States	Commercial	CoStar Group	LEED, Energy Star	2004–2007	694 (rents) / 199 (prices) 694 (rents) / 199 (prices)	8105 (rents) / 1813 (prices) 8105 (rents) / 1813 (prices)	3.7% (LEED) / 2.7% (Energy Star)	16% (LEED) / 13% (Energy Star)	
Fuerst et al. (2017)	2017	United States	Commercial	CoStar Group	LEED, Energy Star	2007–2012		2734		5%	
Fuerst and McAllister (2011b)	2011	United States	Commercial	CoStar Group	LEED	2008–2013	197 (rents) / 127 (prices)	16488 (rents) / 9120 (prices)	5%	25%	8%
Fuerst and McAllister (2011b)	2011	United States	Commercial	CoStar Group	Energy Star	2008–2013	834 (rents) / 559 (prices)	16488 (rents) / 9120 (prices)	4%	25%	3%
Fuerst and McAllister (2011a)	2011	United States	Commercial	CoStar Group	LEED + Energy Star		264	36236 (rents) / 13971 (prices)	9%	28%	
Pivo and Fisher (2011)	2011	United States	Commercial	NCREIF		2001–2008	4237		2.7%		
Chegut et al. (2011)	2011	United Kingdom	Commercial	EGI/CoStar	BREEAM	2000–2009	67 (rents) / 70 (prices)	1171 (rents) / 2023 (prices)	21%	26%	
Fuerst and McAllister (2011c)	2011	United Kingdom	Commercial	IPD	EPC			601	insignificant	insignificant	
Kok and Jennen (2012)	2012	Netherlands	Commercial	Real estate agents	EPC	2005–2010		1057	6.5%		
Veld and Vlasveld (2014)	2014	Netherlands	Commercial	CBRE	EPC	2007–2011		128	insignificant	insignificant	insignificant
Bonde and Song (2013)	2013	Sweden	Commercial	Swedish National Board of Housing	EPC	2003–2010		1283		insignificant	
Gabe and Rehm (2014)	2014	Australia	Commercial	Government	NABERS	2009–2011		673	insignificant		
Fuerst and Shimizu (2016)	2016	Japan	Residential	Government	Tokyo Green Label	2003–2011	-	23920		5%	
Fesselmeyer (2018)	2018	Singapore	Residential	REALIS	Green Mark	2000–2016		119826		2.7%	
Deng et al. (2012)	2012	Singapore	Residential		Green Mark	2000–2010	18296	55982		4–6%	
Pride et al. (2018)	2018	Alaska	Residential	Alaska MLS	Rebate program	2008–2015	309	6094		15%	
Murphy (2014)	2014	Netherlands	Residential	Survey	EPC	2008–2010	297	1324		insignificant	
Kahn and Kok (2014)	2014	California	Residential	USGBC	LEED, GreenPoint	2007–2012	5299	1600558		4.7% (Energy Star)	
Brounen and Kok (2011)	2011	Netherlands	Residential	Government	EPC	2008–2009	32000	177000		3.6%	
de Ayala et al. (2016)	2016	Spain	Residential	Survey	EPC			1507		5.4–9.8%	
Bruegge et al. (2016)	2016	Florida	Residential	Florida Solar Energy Center	Energy Star	1998–2009		5528		1.6–4.2%	
Tsai (2022)	2022	Taipei City	Residential	Government	EEWH	2013–2021	2832	85283		17.7%	
Hyland et al. (2013)	2013	Ireland	Residential	Ad website	EPC	2008–2012		15060 (prices) / 20825 (rents)	1.8–3.9%	5.2–9.3%	
Cajias and Piazolo (2013)	2013	Germany	Residential	IPD	EPC	2008–2010		2630	0.08% per 1%	0.45% per 1%	
Brändle et al. (2022)	2022	Switzerland	Residential	Wuest Partner		2017–2021		432 (prices) / 39971 (rents)	0.0012–0.0035% per 1 $kgCO_2/m^2$·year	2.18–3.27%	

3.3 Energy Renovation

Energy renovation aims to improve the performance of existing buildings in order to meet environmental requirements and reduce CO_2 emissions. The literature generally distinguishes two main strands of analysis: on the one hand, the technical aspects related to energy savings and environmental performance; on the other hand, the economic aspects related to the profitability of investments.

Energy and Environmental Impact

On the environmental side, life cycle assessment (LCA) is a standard methodological framework for evaluating the overall impact of a building over its entire life cycle (Blok and Nieuwlaar, 2016; Islam et al., 2015). This approach makes it possible to quantify energy use and emissions at each stage: construction, use, maintenance, and demolition. The use phase often accounts for 60 to 70% of GHG emissions and up to 85% of total energy consumption (Andersen et al., 2020; Sharma et al., 2011).

To estimate the energy savings associated with renovation, the literature generally distinguishes two broad modeling approaches: top-down and bottom-up. The top-down approach relies on aggregate statistical models based on regional or national data. It can reveal broad trends but lacks precision at the individual building scale. Conversely, the bottom-up approach uses detailed data specific to each building (geometry, materials, technical systems) and relies on physics-based energy simulation models such as EnergyPlus, TRNSYS, or eQUEST (U.S. Department of Energy, 2021; **?**; Mauro et al., 2015). These tools allow a fine representation of thermal flows, incorporating the interactions between building components, user behaviour, climate, and occupancy patterns. Dynamic simulations can model hourly variations in temperature, humidity, and energy consumption over the entire year. In practice, energy indicators for buildings are most often calculated using standardized “static” methods based on simplified normative assumptions. For example, heat demand is frequently estimated according to the SIA 380/1 standard, using a standard usage scenario that does not account for actual occupant behaviour or real climatic conditions. The CECB energy class is determined using its own calculation model, while CO_2 emissions are derived from emission factors taken from national reference documents such as SIA 2031, KBOB, or AMAS. While these approaches facilitate comparisons between buildings, they are less accurate than dynamic models for assessing the detailed effects of specific renovation scenarios.

Economic Evaluation of Renovation Measures

Numerous studies compare different renovation measures by analysing both their energy effectiveness and their economic profitability.

A frequently used indicator is the cost of conserved energy (CCE), which relates the initial investment to the expected energy savings over the lifetime of the measure, expressed in CHF/MWh. It is a simple metric that allows a comparison of the cost–benefit ratio of different interventions. Cohen et al. (1991) and Gorgolewski (1995) show that thermal insulation (walls, roofs) offers attractive economic returns, whereas window replacement, although common, often leads to marginal energy savings at high cost. These studies also stress the importance of integrating environmental criteria, such as CO_2 emissions, to guide renovation decisions.

However, the CCE is a static measure: it is only a ratio and does not account for the timing of cash flows. For a more comprehensive assessment, several studies draw on net present value (NPV), which compares projected costs and benefits of each measure over its lifetime. Here the focus is on the evaluation of individual interventions, rather than a global DCF analysis of the building. Verbeeck and Hens (2005) use this approach to compare various options and identify roof and floor insulation, high-performance glazing, and heating system improvements as the most profitable measures. Popescu et al.

(2012) propose complementing the economic analysis with an estimate of post-renovation property value, using a scoring function based on willingness to pay. Petersen and Svendsen (2012) employ the marginal cost of conserved energy to optimize the combination of measures. Other studies, such as Araújo et al. (2016) and Liu et al. (2018), conduct detailed cost–benefit analyses and show that interventions on technical systems (heating, windows) can be economically viable, whereas deep envelope renovations are often less profitable.

Finally, several studies frame renovation as a multi-objective optimization problem combining costs, energy performance, and emissions reduction (Evins, 2013; Asadi et al., 2012; Diakaki et al., 2008; Bragolusi and D'Alpaos, 2022). These approaches account for technical interactions between building components, budget constraints, and investor preferences, in order to identify the most suitable package of interventions according to different criteria such as NPV, energy savings, or payback time.

These studies make it possible to compare the profitability of individual measures, but a limitation is that they typically consider them in isolation. In practice, an intervention may become attractive when embedded in a comprehensive renovation strategy at the building level, taking into account technical and economic synergies between components. In this spirit, Vimpari and Junnila (2014a) asked eight practitioners to calibrate a DCF model for two office buildings, one LEED Platinum certified and the other uncertified. They find that an ecological certificate increases property value by an average of 9 %, mainly through higher yields and higher net rental income.

At the national level, Streicher et al. (2020b) assess the economic potential of renovations that comply with Minergie standards for the Swiss building stock. Their analysis is based on three cost allocation approaches: *full* (all costs are attributed to the energy renovation), *depreciation* (taking into account the residual value of existing components), and *improvement* (only costs directly linked to thermal improvements are considered). Results vary substantially depending on the approach, with a marginal cost of 120 CHF/MWh in the *full* scenario versus only 1 CHF/MWh in the *improvement* scenario, highlighting the importance of clearly defining the economic perimeter of renovation. Other studies, such as Jakob (2006), Yazdanie et al. (2017), and Ziegler (2009), analyse unit costs associated with reducing greenhouse gas emissions (CHF/t CO_2) or achieving energy savings (CHF/MWh), in order to evaluate the economic efficiency of renovation measures. Table 2 summarizes these results for the Swiss context.

Finally, Goto et al. (2023) analyse the economic feasibility of energy renovation of buildings rated F and G in the canton of Vaud, in connection with the ongoing revision of the cantonal energy law. The study considers different owner profiles (households, small investors, and institutional investors) and shows that, despite a potential reduction in energy consumption of up to 60%, the profitability of renovations remains limited without public support. In particular, these renovations are difficult to finance through conventional bank lending. The analysis evaluates several incentive schemes (subsidies, tax deductions, zero-interest loans, guarantees) and concludes that a combination of instruments would be needed to make 80% of renovations economically viable. It recommends prioritizing guarantee schemes, which are deemed more effective in broadening access to financing, especially for low- and middle-income households.

Table 2: Levelized cost of energy savings and GHG emission reductions

Study	**CHF/MWh**	**CHF/t CO_2**
Yazdanie et al. (2017)	29–82	
Jakob (2006)	100	
Ziegler (2009)		55
Streicher et al. (2020b) (full)	120	400

4 Methodology

The objective of this study is to propose a methodological framework that integrates energy performance into the financial valuation of an income-producing property using the DCF method.

In a context where regulatory and societal requirements regarding energy performance are becoming increasingly stringent, it is no longer appropriate to value a building under the assumption that it will remain in its current state. The valuation must now explicitly account for the technical characteristics of the building and their evolution over time. The condition of the components, their obsolescence, and their potential for energy improvement thus become fundamental determinants of the future economic value of a property.

The DCF model makes it possible to estimate the present value of net cash flows generated by a property over a long horizon. These cash flows, however, depend on the renovation strategy applied, which conditions the investments required, the savings generated, and the evolution of energy performance. Cash flow planning must therefore incorporate an energy retrofit plan consistent with the objectives set by legislation, cantonal standards, or market expectations. On this basis, the DCF model becomes an economic assessment tool for different renovation pathways. It also provides a way to address the question of green value, although our methodology places more emphasis on the discount applied to a building with poor energy efficiency (the *brown discount*).

The first determinant of this discount lies in the cost of achieving energy compliance. For a poorly performing building, this cost represents a major risk that can no longer be ignored in a financial valuation. The owner must anticipate an energy retrofit, the contours of which often remain uncertain: which measures will be necessary, at what cost, and with what outcome? These uncertainties (technical, economic, and regulatory) negatively affect the valuation of an inefficient asset. Conversely, a building that has already been retrofitted and whose performance is certified benefits from a higher valuation. This premium, the green value, generally exceeds the mere cost of the necessary works. It reflects reduced uncertainty, transparency regarding the energy profile, and immediate compliance with the regulatory trajectory. The reasoning is analogous to the difference between the value of a building that is still on the drawing board and that of a completed building: in the former case, many things can still go wrong; in the latter, the risk has largely disappeared. The lower a building's energy performance, the more pronounced this discount becomes. It is therefore more natural, and more robust from an analytical standpoint, to model a discount on an energy-intensive building rather than attributing a premium to a building that has already been renovated.

Our approach is based on the explicit integration of the energy trajectory into the valuation of a building. The building is assumed to be required, in the long run, to meet a minimum level of energy performance set by regulatory requirements. To measure its exposure to these requirements, we compare two valuations: one based on a constrained renovation plan that achieves the prescribed energy objectives, and the other based on an unconstrained investment plan, not bound by any regulatory trajectory. This comparison makes it possible to identify the additional cost of compliance, but also to highlight differences in risk profiles arising from uncertainty about future costs, renovation needs, and actual performance achieved. These elements are essential for assessing the regulatory and energy vulnerability of a real estate asset.

Our approach is structured in two stages. First, we define the theoretical framework. This framework builds on an adaptation of the DCF model so that it can be used to compare different renovation strategies. For each strategy considered, the model computes the net present value (NPV) by integrating investment costs, the savings generated, and the expected evolution of the building's energy performance. We formalize the notion of an investment strategy in relation to the building's technical components, then model a discount applied to poorly performing buildings using economic comparisons and synthetic indicators.

In a second stage (Section 5), we implement this methodology through a numerical assessment applied to renovation pathways and the economic parameters considered. We describe the scenarios used, the corresponding renovation trajectories, and the assumptions for costs, performance, and regulatory developments. All results are available on the dedicated platform.

4.1 Integration into the DCF Model

We use the DCF model to evaluate the value of a building under a given investment strategy, denoted s. Such a strategy defines the schedule of technical interventions on all building components. It generates a timetable of intervention costs as well as a trajectory of energy impacts over time, depending on the planned replacement, renovation, or technical retrofit decisions. These interventions directly affect energy consumption, the heat demand index (HDI), the CECB classes, and the CO_2 emissions associated with the building.

The DCF model enables the economic evaluation of a given strategy s by estimating the net present value of the free cash flows generated by the building:

$$NPV_s = \sum_{t=1}^{T} \frac{FCF_{t,s}}{(1+k)^t},$$

where $FCF_{t,s}$ denotes the free cash flows in period t associated with strategy s, and k is the discount rate. Cash flows are defined by:

$$FCF_{t,s} = L_{t,s} - OPEX_{t,s} - CAPEX_{t,s},$$

where $L_{t,s}$ is rental income, $OPEX_{t,s}$ operating expenses, and $CAPEX_{t,s}$ capital expenditures associated with the implementation of strategy s.

Rental Income

Net rental income is given by:

$$L_t = (1 - \eta_t) \cdot \alpha_t \cdot LB_t^* - \mathbb{E}[D_{t,s}],$$

where η_t is the vacancy rate, α_t is the activation rate of market rents, LB_t^* the gross market rent, and $\mathbb{E}[D_{t,s}]$ the expected level of recoverable charges.

The vacancy rate reduces the effective rent collected by reflecting the share of unoccupied space. The activation rate measures the gap between the theoretical market rent and the rents actually charged. This gap may, for instance, stem from regulatory constraints such as rent control.

Tenant demand determines the gross market rent, that is, the theoretical rent expected for a comparable property in a similar environment. The potential net rent then depends on the level of ancillary costs, which correspond to the average cost of building consumption (heating, water, electricity, etc.). These charges are passed through to the tenants, which means that the volatility arising from consumption is not borne by the owner. However, a more energy-efficient building generates lower charges, resulting in a higher potential net rent. The renovation strategy s therefore directly influences tenant charges by reducing energy consumption. It changes the structure of pass-through costs and thereby contributes to increasing the net income received by the owner. Note also that strong energy performance can enhance the building's attractiveness on the rental market (i.e., an increase in LB_t^*), as it is becoming an increasingly important criterion for tenants.

Expected recoverable charges, denoted $\mathbb{E}[D_{t,s}]$, depend directly on the building's consumption needs and on the prices of resources in period t. They are given by:

$$D_{t,s} = Q_{t,s}^{Energy} \cdot p_t^{Energy} + Q_{t,s}^{Water} \cdot p_t^{Water} + Q_{t,s}^{Heating} \cdot p_t^{Heating} + FA_t,$$

where $Q_{t,s}^{Energy}$, $Q_{t,s}^{Water}$, and $Q_{t,s}^{Heating}$ denote, respectively, the electricity, water, and heating needs of the building under strategy s in period t. The corresponding unit prices are denoted p_t^{Energy}, p_t^{Water}, and $p_t^{Heating}$. The term FA_t groups all other incidental costs, such as maintenance, administration, or common services.[2] The heating price $p_t^{Heating}$ depends on the energy carrier used (electricity, gas, heating oil, etc.), which is determined by the building's heating system.

Operating Expenses

Operating expenses (OPEX) are modelled as a constant fraction κ of rental income:

$$OPEX_{t,s} = \kappa \cdot L_{t,s}.$$

These expenditures encompass all costs related to the day-to-day operation of the building, excluding capital expenditures. They include, in particular, routine maintenance (repairs), property management fees (administration, rent collection, tenant relations), as well as insurance premiums covering building-related risks. Property taxes, land taxes, and other periodic levies are also included.

[2] The rules governing the recovery of charges differ across cantons.

Capital Expenditures

Capital expenditures (CAPEX) correspond to the investments required to implement investment strategy s. These costs are directly determined by the intervention schedule defined in the strategy (see Section 4.2). They are then adjusted using the construction cost index P_t^c to reflect the expected evolution of construction costs over time. The formula is:

$$CAPEX_{t,s} = C_{t,s} \cdot P_t^c,$$

where $C_{t,s}$ denotes the nominal cost of interventions planned in period t under strategy s.

4.2 Investment Strategy

An investment strategy, denoted s, defines the timing of technical interventions on a building. It anticipates the evolution of investment costs and the building's future energy performance. Formally, a strategy is represented as a time sequence of technical states:

$$s = \{E_t\}_{t=1}^T,$$

where $E_t \subseteq E$ denotes, in each period t, the set of technical elements present in the building after all interventions carried out up to that date. Strategy s thus specifies which interventions are undertaken, when they occur, and with which technical properties.

The technical elements that make up a building are defined by a finite set:

$$E = \{e_1, e_2, \ldots, e_N\},$$

where each element e_i represents a specific component of the building (e.g., roof, windows, heating, ventilation). Each element e_i is characterized by several parameters: the year of installation or last renovation t_i, the estimated technical lifetime d_i, the replacement cost C_i^R, and a measure of obsolescence defined by a depreciation function $v_i = \delta(\text{age}_i, d_i)$. The function δ can take different forms (linear, exponential, etc.). Each element also has specific technical properties (for example, the U-value for windows). The overall technical condition of the building can thus be summarized by an aggregated, possibly weighted, measure of the individual obsolescence indicators.

Investment strategy s specifies which elements are replaced, when, and with which upgraded technical properties. These interventions may be motivated by the end of a component's life cycle, an objective of energy improvement, or regulatory or environmental compliance requirements. Each period gives rise to a total intervention cost and an associated energy impact.

The total investment cost at time t under strategy s is expressed as:

$$C_{t,s} = \sum_{i=1}^{N} C_{i,s} \cdot I_{i,t,s},$$

where $I_{i,t,s} \in \{0, 1\}$ is an indicator variable equal to 1 if element e_i is replaced or renovated in period t under strategy s, and 0 otherwise.

The cost associated with element e_i is decomposed into a standard technical component and a component dedicated to energy retrofit:

$$C_{i,s} = C_{i,s}^R + C_{i,s}^A.$$

The energy component $C_{i,s}^A$ depends on the new energy performance features chosen for the element at replacement. For instance, replacing windows with high-performance triple-glazed units entails a higher intervention cost but significantly improves energy efficiency.

The overall energy improvement between two consecutive periods is measured by the change in energy performance:

$$\Delta f_{t,s} = f(E_{t,s}) - f(E_{t-1,s}),$$

where f is a generic function measuring energy performance (for example, HDI, CECB class, or CO_2 emissions). These indicators are directly linked to the technical condition of the building components:

$$(HDI_t, CECB_t, CO_{2,t}) = f(E_t).$$

The functional form of f depends on the indicator chosen and the standard model used. For example, heat demand may be estimated according to the SIA 380/1 standard or via dynamic thermal simulations. The CECB class is determined using the CECB model, while CO_2 emissions are estimated using emission factors drawn from national reference documents (SIA 2031, KBOB, AMAS, etc.).

Each strategy s thus defines a specific technical and energy trajectory for the building, determining both the time path of investment costs ($C_{t,s}$) and that of energy performance ($f_{t,s}$).

Discount Rate

The discount rate reflects the return required by an investor to compensate for the risk associated with future cash flows. It is generally decomposed into a risk-free rate and one or more risk premia, according to:

$$k_t = RF_t + RPM_t + RPO_t,$$

where RF_t denotes the risk-free rate, RPM_t the market risk premium, and RPO_t the risk premium specific to the asset under consideration.

Our objective is to compare different investment strategies applied to the same building. The discount rate used is therefore kept identical across all strategies to ensure a coherent comparison. In particular, no additional premium related to the building's age, energy performance, or investment profile is introduced into RPO_t. These aspects are already embedded in the projected cash flows.

4.3 modeling Uncertainties

In principle, the DCF model provides a point estimate of NPV for a given forecast scenario of future cash flows. However, it can be enriched by a stochastic approach to reflect the uncertainties affecting these cash flows. Such uncertainties relate both to exogenous economic variables and to technical parameters specific to the building.

Among exogenous variables, one can introduce uncertainty on electricity prices (p_t^E), water prices (p_t^{Water}), gas prices (p_t^{Gas}), the construction cost index (p_t^c), the risk-free rate (RF_t), as well as on the vacancy rate (η_t). These variables depend on the macroeconomic context and can be represented by probability distributions. For example, construction prices may follow an inflationary trend combined with cyclical volatility; the vacancy rate may fluctuate around a regional historical average; and the risk-free rate may incorporate long-term expectations about monetary policy.

On the side of internal technical parameters, several dimensions can also be modelled as random. The effective lifetime of technical components (d_i) varies depending on operating conditions and maintenance and can be represented by a triangular distribution around a reference value. The actual energy impact of renovation works may differ from the expected effect (the so-called performance gap), which adds uncertainty about the effective reduction in energy expenditures. Finally, the works schedule may be influenced by technical, financial, or administrative contingencies, altering the timing of cash flows.

These uncertainties can be integrated into the model via Monte Carlo simulations, yielding a distribution of NPV instead of a single value. Each simulation corresponds to a possible scenario for future cash flows. In general, one can attempt to represent the full set of possible scenarios weighted by their probability of occurrence (central scenarios being more likely than extreme ones). In this case, one simulates the standard distribution of future cash flows. It is also possible, however, to simulate more specific scenarios. For example: what values of NPV might arise in the presence of strong pressures on renovation costs or on energy prices? This approach makes it possible to characterize the entire distribution of NPV for a building under a given strategy, that is, not only the expected NPV but also its risk profile, which reflects uncertainty over costs, performance, and the regulatory environment.

4.4 Valuation and Energy Efficiency

We assume that the energy trajectory imposed by regulation is mandatory and binding. Under this assumption, a key constraint arises:

> Any real estate valuation based on the DCF method must necessarily incorporate an investment plan that is compatible with the energy trajectory imposed by regulation: $V = \mathrm{NPV}_{constrained}(k)$.

Consequently, a DCF valuation that does not account for these regulatory constraints may lead to partial or biased results.

To better measure the impact of energy efficiency, we assess the building's exposure to these regulatory requirements. To this end, we compare two strategies. The first, referred to as the **standard strategy**, consists in merely maintaining the building's technical condition with no specific energy improvement objective. It corresponds to an investment plan that only replaces components at the end of their life cycle, without targeting energy performance gains. The second, referred to as the **constrained strategy**, is the minimum strategy that complies with the regulatory trajectory. The difference in net present value between the standard and constrained strategies provides a measure of the building's exposure to mandatory energy retrofits:

$$\Delta\text{NPV} = \mathbb{E}\left[\text{NPV}_{standard}(k)\right] - \mathbb{E}\left[\text{NPV}_{constrained}(k)\right],$$

where $\mathbb{E}[\text{NPV}]$ denotes the expected NPV obtained from simulating the different sources of uncertainty. This difference primarily reflects the cost of compliance, which depends on the building's initial condition and the scale of the interventions required. When the building already meets energy requirements, this difference is zero.

However, this approach does not account for the risks associated with energy retrofit works. The exposure measure described so far captures only the expected cost of compliance but overlooks the uncertainty surrounding this trajectory. A building requiring deep retrofit presents a higher risk profile. Energy renovation works are subject to numerous uncertainties: fluctuations in construction costs, the evolution of regulatory requirements, capacity constraints in the construction sector, and so on. In addition, the choice of measures depends on the building's specific characteristics. Without a detailed energy audit, it is difficult to anticipate the actual cost, technical constraints, or achievable performance (performance gap). By contrast, a building that has already been retrofitted offers greater clarity for investors. It provides improved visibility over future cash flows, immediate compliance with regulatory trajectories, and reduced exposure to technical and economic uncertainty. This justifies a valuation above the mere saving in expected costs, due to the risks avoided.

An energy-efficient building protects its owner from the risks associated with planning and implementing a future retrofit. Its valuation should therefore reflect not only the avoidance of future investment expenditures, but also a premium linked to its reduced risk profile.

Based on the simulated distribution of NPV, we characterize the risk profile of a building using three indicators: the coefficient of variation, Value-at-Risk (VaR), and Expected Shortfall (ES).

The coefficient of variation measures the relative dispersion of NPV around its mean. It is defined as:

$$CV = \frac{\sigma[\mathrm{NPV}]}{\mathbb{E}[\mathrm{NPV}]},$$

where $\mathbb{E}[\mathrm{NPV}]$ denotes the expected NPV and $\sigma[\mathrm{NPV}]$ the standard deviation of the distribution. This ratio allows volatility to be compared across assets with different values.

Value-at-Risk (VaR) at confidence level α corresponds to the maximum NPV observed among the $100(1-\alpha)\%$ worst realizations. It is defined as the quantile of the NPV distribution:

$$\mathrm{VaR}_\alpha = \inf \left\{ x \in \mathbb{R} \,\middle|\, \Pr[\mathrm{NPV} \leq x] \geq 1 - \alpha \right\}.$$

Expected Shortfall (ES), or conditional expected loss, represents the average NPV in the $100(1-\alpha)\%$ worst realizations. It is defined by:

$$\mathrm{ES}_\alpha = \mathbb{E}[\mathrm{NPV} \,|\, \mathrm{NPV} \leq \mathrm{VaR}_\alpha].$$

These measures describe how the risk profile changes with the imposed energy trajectory. For instance, if $\alpha = 95\%$, then $\text{VaR}_{95\%}$ is the maximum NPV among the 5% worst realizations, and $\text{ES}_{95\%}$ is the average NPV across those 5% worst outcomes.

Compliance Discount via Adjustment of the Discount Rate

In the absence of a fully specified renovation plan, it is possible to represent regulatory exposure through an adjustment of the discount rate. We define a **premium** z (or brown discount) corresponding to the yield spread required by an investor to compensate for the compliance gap:

$$\mathbb{E}[\text{NPV}_{standard}(k + z)] = \mathbb{E}[\text{NPV}_{constrained}(k)].$$

This equality amounts to comparing the expectations of the two simulated distributions. It determines the increase in the discount rate required for a risk-neutral investor to be indifferent between a compliant building (constrained NPV) and a non-compliant building (standard NPV). This approach therefore expresses regulatory vulnerability as an implicit premium that reflects part of the risk arising from asymmetric future cash flows.

It is important to emphasize that the discount z derives directly from the simulated cash flows. If the simulated cash flows represent the standard distribution of future cash flows, the discount will mainly reflect the estimated value of those cash flows. In that case, the key task is to model the regulatory effects explicitly and as precisely as possible within the cash flows themselves.

One can also measure the discount under a specific scenario (such as a sharper-than-expected increase in renovation costs). In this case, future cash flows are simulated consistently with that scenario, leading to different discounts depending on the building's characteristics. A building requiring more compliance-related works should be more sensitive to the possible increase in renovation costs and should, therefore, exhibit a higher discount.

Furthermore, to represent the entire risk profile (and not only the expectation), one would in principle need to know the market's risk aversion. Without this information, only part of the risk is effectively accounted for. Ultimately, this valuation differential depends on the price of risk set by the market.

Optimal Renovation Strategy

In an efficient market, the value of a building should reflect the optimal investment strategy s^*, which is compliant with energy requirements and maximizes the net present value of future cash flows:

$$V(s^*) = \max_{s \in S} \mathrm{NPV}_s.$$

This optimal strategy depends on many factors: technical constraints of the building, regulatory requirements, optimization via packages of measures, and market expectations. In this work, we do not attempt to determine this optimal strategy. Instead, we adopt an approach in which interventions follow a standard schedule (based on component life cycles) without fine-tuned optimization. This method makes it possible to simulate a realistic path to compliance while providing a robust framework for comparing the economic and energy impacts of different regulatory scenarios.

5 Application

After establishing the conceptual framework and formalizing the valuation approach, we now present its practical application using representative numerical data. The objective is to translate this methodology into an operational tool capable of quantifying the effect of energy trajectories on the valuation of a building. The aim is therefore to show how future energy-performance requirements can be consistently integrated into a DCF model through realistic scenarios and well-defined technical and economic assumptions.

The imposed energy trajectories are determined by two types of regulatory scenarios: cantonal requirements and federal targets. These scenarios are formulated in terms of minimum energy performance, often expressed through a CECB rating and translated as a target heating demand index (HDI). Based on these requirements, we construct renovation plans consistent with the scenarios using two approaches: an aggregated global estimate, requiring minimal information, and a detailed component-based modeling. For each strategy, the intervention costs as well as their energy impacts are estimated.

The DCF model is then calibrated using reference parameters: a projection horizon of 120 years, a constant discount rate, and standardized assumptions regarding rents, vacancy rates, operating expenses, and technical inflation. Uncertainties are incorporated through probability distributions defined for each key macroeconomic variable. This framework enables the comparison of renovation trajectories according to their economic, energy, and regulatory impacts.

The detailed results from this application are accessible through a dedicated online platform, which allows users to explore the effects of different strategies on a building's value according to its technical characteristics and future energy trajectory. In this section, we summarize the main results by first presenting the assumptions used in the valuation, then the characteristics of the portfolios studied, and finally the insights drawn from the analysis.

5.1 Data

The calibration of the application relies on a minimal set of data, including the following:

- public data sources, notably the federal register of buildings and dwellings (RegBL), FSO statistics, and various cantonal databases;
- the table of market rents by canton;
- a table of discount rates by canton, divided into three zones (city, small town, countryside);
- an average estimate of cost per m^2 of energy reference area (ERA), depending on the targeted reduction in HDI.

Additionally, operational and energy data were provided for a set of 150 buildings managed by two project partners, enabling the assessment of the relevance of the estimates.

For Fund 1, an income statement covering 92 objects (some grouping multiple buildings) was provided, which allowed the identification of rental income. The associated energy data were matched with these buildings, leading to a set of 55 buildings for which all the following variables were available: rental income, HDI, CECB class, insurance value, and ERA.

For Fund 2, data were supplied for 58 buildings. Six objects were excluded due to the complete absence of energy information, resulting in a final sample of 52 buildings. For these buildings, the available variables include: insurance value, rental income, rental reserve, HDI, CECB class, and heating type. The ERA was available for only 16 of them.

5.2 Reference regulatory scenarios

In our application, we consider two types of regulatory scenarios representative of the energy-performance requirements that may be imposed on an income-producing building in the medium or long term. On the one hand, cantonal requirements, which vary by jurisdiction; on the other hand, the objectives set by the Confederation as part of the national climate policy. These scenarios constitute the starting point of our analysis and constrain the construction of renovation plans compatible with the energy trajectories defined by the authorities. Table 3 summarizes the objectives and timelines for each scenario at the cantonal and federal levels.

Cantonal requirements

The first scenario is based on regulations defined at the cantonal level. These vary across cantons but generally aim to limit energy consumption, reduce CO_2 emissions, and improve the thermal performance of the building envelope. These requirements are often expressed as a minimum CECB class, together with deadlines for the gradual abandonment of fossil-fuel heating systems.

Federal objectives

The second scenario is based on the national objectives defined by the Confederation, particularly in the framework of the Energy Strategy 2050 and the revision of the CO_2 Act. This scenario implies a gradual decarbonization of the building stock, with the ambition of reaching carbon neutrality by 2050. It assumes a significant improvement in energy efficiency and a strong reduction in emissions, approximated by a minimum CECB class C requirement.

Table 3: Objectives of cantonal and federal scenarios

Canton	Objectives	Deadline
Default	CECB: D	2040
	Decarbonized heating	2040
Geneva	HDI: 450 MJ/m^2 per year	2031
		2027 if HDI > 650 MJ/m^2 per year
	Decarbonized heating	2040
Vaud	CECB: D	2040
		2035 if ERA > 750 m^2
	Decarbonized heating	2040
Confederation	CECB: C	2050

The objectives of the scenarios are often expressed through CECB classes, which reflect both the overall energy efficiency of the building and the quality of its thermal envelope. Ideally, the evaluation should rely on a direct implementation of the CECB model, allowing the computation of this rating from detailed technical characteristics. Although the model is accessible, it requires a large number of input parameters (building geometry, materials, technical systems, etc.), which prevents its full integration within our simplified parameterization.

We therefore translate these objectives into HDI target values using Table 4. This approximation preserves consistency with regulatory requirements.

Based on these requirements, each regulatory scenario defines an energy efficiency trajectory that the building must satisfy. This translates into a progressive reduction of

Table 4: Correspondence between CECB classes and HDI values

Class CECB	**1–2 floors**		**3–4 floors**		**5–6 floors**	
	Fossil	Non-fossil	Fossil	Non-fossil	Fossil	Non-fossil
A	[0;193]	[0;165]	[0;204]	[0;176]	[0;219]	[0;190]
B	]193;245]	]165;214]	]204;267]	]176;235]	]219;297]	]190;264]
C	]245;296]	]214;263]	]267;330]	]235;295]	]297;375]	]264;338]
D	]296;348]	]263;312]	]330;392]	]295;354]	]375;453]	]338;412]
E	]348;400]	]312;361]	]392;455]	]354;414]	]453;531]	]412;486]
F	]400;452]	]361;410]	]455;518]	]414;473]	]531;610]	]486;560]
G	]452;–]	]410;–]	]518;–]	]473;–]	]610;–]	]560;–]

Note: The table is based on envelope factors and energy type. HDI values are expressed in MJ/m^2 per year. Data provided by Signa-Terre.

the HDI to be achieved before the deadline. At date t, the required reduction by the regulatory deadline is given by:

$$\Delta HDI_t = \min(HDI_t^{\text{target}} - HDI_{t-1}, 0)$$

For example, a building with an initial HDI of 650 MJ/m^2 per year and a target of 450 must reduce its consumption by 200 MJ/m^2 per year before the regulatory deadline. Conversely, if the building already satisfies the scenario requirements, no further improvement is needed. This expression therefore provides the minimum energy trajectory that any renovation plan compatible with the regulation must achieve.

5.3 Renovation plans

To translate the requirements of cantonal and federal scenarios into concrete renovation trajectories, we define two approaches to planning interventions.

The first, called the **global estimate**, is a simplified approach: it allocates an aggregated investment amount to the building without considering the life cycle or the individual condition of technical components. It allows estimation of the costs required to maintain the building or to reach a global energy target, but does not explicitly model the elements involved nor their specific effects on performance.

The second approach relies on **component-based modeling**, consistent with the methodological framework presented earlier. The building is divided into technical components (roof, windows, heating, etc.), each with a life cycle, a deterioration state, a replacement cost, and an energy impact. This more detailed approach enables the establishment of a realistic intervention schedule. However, it requires explicit assumptions on the technical parameters of each component (lifetime, unit cost, energy gain) to evaluate investment trajectories and energy efficiency in a coherent manner.

5.3.1 Investment strategy based on a global estimate

In this approach, investment costs are estimated in aggregate form, without explicitly modeling technical components. The strategy consists of two parts: an annual maintenance cash flow to keep the building in operational condition, and a one-time expenditure dedicated to energy retrofitting, planned at the scenario's regulatory deadline.

Maintenance expenditures are modelled as a constant rate of 1.23% of the building's insurance value (VA), representing average maintenance costs observed in the Swiss building stock (Source: OFQC, 1994).

The cost of energy retrofitting is estimated using a model provided by Signa-Terre. It depends on the building's ERA and the HDI reduction to be achieved. This amount is applied once, at the date imposed by the scenario (2040 for cantonal requirements or 2050 for federal requirements), independently of the actual component life cycles. Table 5 reports these assumptions.

Table 5: Cost assumptions – global estimate

Type	**Method**	**Deadline**	**Source**
Maintenance	1.23% VA	Annual	PIBAT
Energy retrofit	$f(\Delta HDI, \text{ERA})$	Scenario deadline	Signa-Terre

5.3.2 Investment strategy based on technical components

In this approach, the building is modelled as a set of technical components, each associated with a life cycle and a deterioration profile. This decomposition makes it possible to plan interventions based on component lifetime while incorporating the energy objectives defined by regulatory scenarios.

The building structure is represented as a collection of ten standard technical components. Each has a reference lifetime, shown in Table 6.

In the absence of detailed metric data, costs are estimated as a percentage of the insurance value. For each component, two cost components are provided: the standard replacement cost (C^R), required at the end of the technical life cycle, and the additional energy retrofit cost (C^A), applied when an intervention aims to improve thermal performance. Only some components have a direct impact on the HDI. The energy impact of each upgrade is modelled as a relative HDI reduction. Table 6 summarizes these values.

Investment planning extends across the entire DCF horizon of 120 years. Each component is replaced at the end of its technical life cycle. It is assumed that the energy retrofit takes place during the first cycle, while subsequent cycles correspond to standard technical maintenance throughout the model horizon.

To meet the required energy trajectory (reduction ΔHDI), the principle is the following: if a high-impact component reaches the end of its cycle before the regulatory deadline, it

Table 6: Assumptions associated with the building's technical components

ID	Component	Lifetime (years)	C^R (% of VA)	C^A	Energy impact (% HDI reduction)
1	Facades	47	7%	1%	–15% to –20%
2	Windows	35	11%	2%	–5% to –10%
3	Roof	35	8%	2%	–10% to –15%
4	Heat production/distribution	28	5%	2%	–25% to –40%
5	Ventilation	36	0%	3%	–10% to –20%
6	Sanitary installations	43	7%	–	–
7	Electricity	51	4%	2%	–
8	Other technical systems	25	2%	–	–
9	Interior finishes	36	17%	–	–
10	Miscellaneous	36	4%	–	–

Note: The table summarizes, for each technical component, the lifetime, replacement and retrofit costs, and estimated energy impact. Data provided by Signa-Terre.

is replaced at that time with an improved version. Conversely, if the regulatory deadline occurs before the component reaches end-of-life, the retrofit is brought forward to that date, even if the component has remaining lifetime.

The intervention strategy follows two principles. First, the heating system is always decarbonized, regardless of the HDI threshold. This step constitutes an independent constraint linked to reducing direct operating emissions. Second, improvements to the thermal envelope are carried out considering remaining component lifetimes: roof, windows, and facades are replaced at their deadlines by higher-performance versions. However, if natural replacement cycles are insufficient to meet the HDI target, early interventions may be triggered. In such cases, the order of interventions follows practical feasibility: first the roof, then the windows, and finally the facades. This ordering reflects practical and relative effectiveness considerations rather than a strict cost-benefit optimization (Goto et al., 2023; Streicher et al., 2020a).

5.4 Calibration of DCF model parameters

The DCF model parameters are calibrated using empirical data and internal sources to ensure consistent and representative valuation.

- The vacancy rate (η_t) is determined as the average over the past five years for the region where the building is located.
- The rent growth rate (g_t) is derived from the Homegate rent index. The market rent (LB_t^*) is estimated from a canton-level table (internal project source), and the rental reserve is computed as the difference between current rental income and the market rent. The activation rate (α_t) of this rental reserve assumes an absorption time of 15 years, smoothing the gradual adjustment toward market rent.
- Operating expenses ($OPEX_{t,s}$) are modelled from a regression on our sample of 82 buildings based on their technical and energy characteristics.
- The discount rate (k) is determined from cantonal discount rates differentiated by type of urban area.

5.5 modeling uncertainties

In this application, we introduce a stochastic modeling of uncertainties related to energy renovation. The objective is to better reflect the risks affecting future cash flows, particularly those associated with retrofit costs, actual efficiency gains, and component lifetime. These uncertainties are incorporated into the DCF model through Monte Carlo simulations.

The construction price index p_t^c is the main exogenous variable modelled. Its evolution directly influences capital expenditures (CAPEX). To simulate its future trajectory, we estimate a vector autoregressive (VAR) macroeconomic model (described in the appendix).

This model generates coherent scenarios based on simulated economic shocks.

Moreover, two technical dimensions incorporate uncertainty. The effective lifetime of technical components d_i is modelled using a triangular distribution centered on the reference value, reflecting observed variability while retaining a simple structure with explicit bounds. Similarly, the energy impact of interventions, measured by HDI reduction, is represented by a uniform distribution around the theoretical target. This modeling captures the "performance gap" often observed between predicted and actual post-renovation energy performance, while reflecting an unbiased uncertainty.

5.6 Characteristics of the portfolios studied

In this real-case application, we consider two anonymized funds that provided specific building data as well as renovation plans defined by Signa-Terre. The number of buildings included in our analysis is 55 and 52, respectively, for each fund.[3] As shown in Table 8, across all these buildings, the number of apartments is 1359 and 1045, respectively.

Both funds are primarily located in French-speaking Switzerland. Buildings in Fund 1 are located in the cantons of Vaud and Fribourg (63.6% and 16.4%), while those in Fund 2 are in the cantons of Geneva, Neuchâtel, and Vaud (59.6%, 21.2%, and 17.3%) (see also Figure 2).

Regarding the energy characteristics of the buildings, HDI levels reach 464.1 and 430.7 MJ/m^2 per year for Funds 1 and 2, respectively. The distribution of CECB classes differs across funds: Fund 1 contains fewer buildings in classes A–D (41.8% vs. 53.9% for Fund 2), fewer buildings in class E (24.6% vs. 38.4%), but a higher proportion of buildings rated F and G (34.6% vs. 7.7%). Additionally, the vast majority of buildings in both

[3] Some buildings for which certain information was missing were excluded from the analysis.

funds (83.6% and 78.8%, respectively) are heated with fossil energy (gas or oil).

Table 7: Characteristics of the portfolios studied

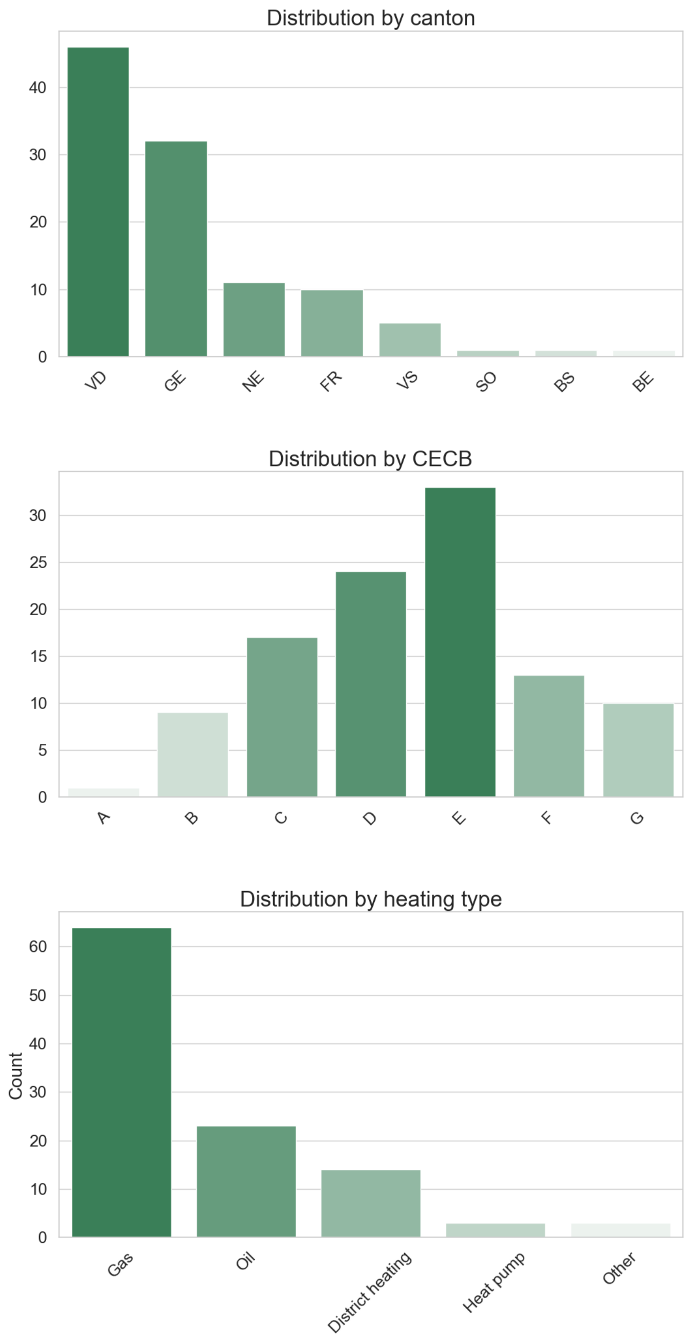
	Fund 1	Fund 2	Total
Number of buildings	55	52	107
Number of apartments	1359	1045	2404
Rents/insurance value (in %)	11.3	3.1	7.3
Canton (in %)			
Fribourg	16.4	1.9	9.3
Geneva	1.8	59.6	29.9
Neuchâtel	3.6	17.3	10.3
Vaud	63.6	21.2	43.0
Other	14.6	0.0	7.5
HDI (in MJ/m^2 per year)	464.1	430.7	447.9
CECB (in %)			
A	0.0	1.9	0.9
B	7.3	9.7	8.4
C	12.7	19.2	15.9
D	21.8	23.1	22.4
E	23.6	38.4	30.9
F	16.4	7.7	12.1
G	18.2	0.0	9.4
Heating system (in %)			
Gas	60.0	59.6	59.8
Oil	23.6	19.2	21.5
District heating	10.9	15.4	13.1
Heat pump	0.0	5.8	2.8
Other	5.5	0.0	2.8

Note: The number of apartments and commercial units is estimated for some buildings via RegBL.

5.7 Valuing the brown discount

We now discuss the *brown discount* premium z across the two funds, starting with the aggregate estimate. In practice, two cases may arise:

Figure 2: Geographical and environmental distribution of buildings



(1) The building already complies with the standards, or will be brought into compliance simply when replacing components that reach the end of their useful life before the deadline for compliance (cantonal or federal). This is the case for 10 buildings in Fund 1

and 10 buildings in Fund 2, which essentially correspond to buildings equipped with a non-fossil heating system and whose envelope has a CECB rating of D. For all these buildings, the renovation plan, defined in the absence of regulatory constraints, is the same as under the two regulatory scenarios.

(2) For buildings that do not meet these requirements (45 and 42 buildings for Funds 1 and 2, respectively), the regulatory scenarios generate an additional cost to bring the building into compliance before the deadline. This compliance discount (the *brown discount* z) is 0.23% per year for Fund 1 in the cantonal scenario and 0.66% per year in the federal scenario. For Fund 2, the discount is 0.65% per year in the cantonal scenario and 1.42% per year in the federal scenario. For some buildings with a very high IDC (above 800 MJ/m^2 per year), the *brown discount* can be particularly large and exceed 1% per year.

Although Fund 1 has a higher average IDC and therefore a greater need for energy renovations than Fund 2, its higher rental income makes it easier to absorb the financial impact of these works. The ratio of total investment to insured value is also higher for Fund 1 than for Fund 2 (72.1% versus 69.4% in the cantonal scenario and 95.8% versus 86.6% in the federal scenario). However, relative to rental income, these costs represent a smaller burden for Fund 1 than for Fund 2, which translates into a lower risk premium for the former. Table 8 summarizes these results.

To model the uncertainties associated with energy renovations, we apply the methodology described in Section 5.5 and generate 1,000 simulations over the investment horizon. For each fund, we aggregate the NPV across the buildings that do not comply with the energy requirements of the regulatory scenarios, for each simulation. The same draws are used to evaluate the results in the standard scenario as well as in the cantonal and federal scenarios. For comparison purposes, we normalize the results by dividing by the mean of

Table 8: *Brown discount* and energy renovation costs for buildings that do not comply with energy performance requirements.

	Fund 1	Fund 2	Total
Brown discount (in %)			
Cantonal scenario	0.23	0.65	0.43
Federal scenario	0.66	1.42	1.02
Costs/insured value (in %)			
Cantonal scenario	72.1	69.4	70.8
Federal scenario	95.8	86.6	91.3
Costs/rents			
Cantonal scenario	10.2	23.1	16.4
Federal scenario	13.8	28.7	21.0

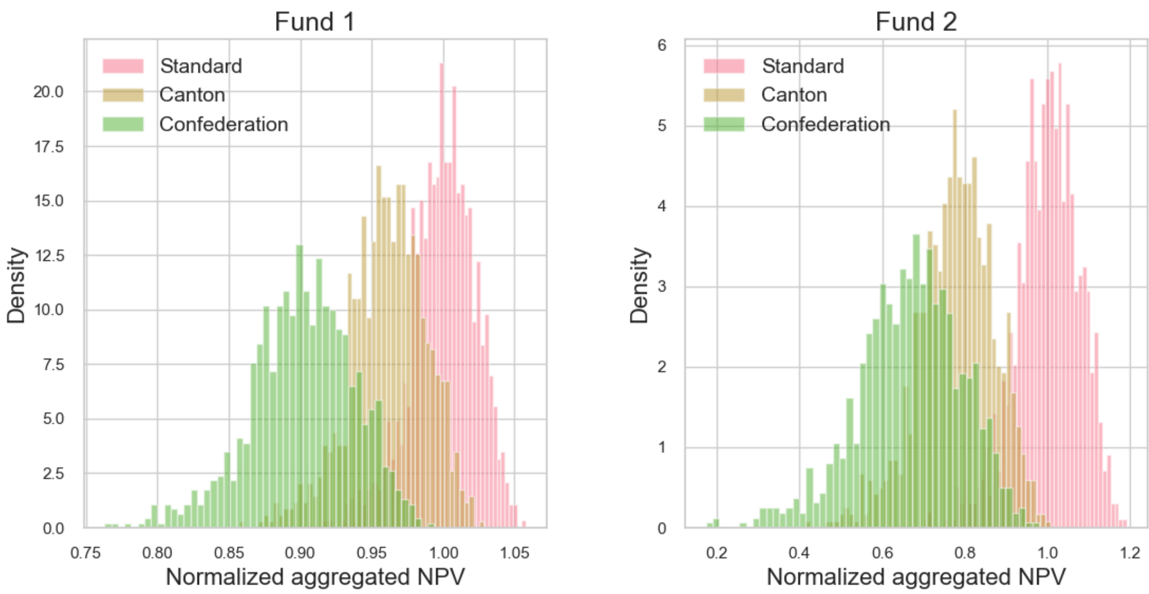
Note: Calculations are performed only on buildings that do not comply with the federal scenario: 45 buildings for Fund 1 and 42 for Fund 2.

the aggregate NPV in the standard scenario. The resulting distributions for each fund are shown in Figure 3.

As observed previously with the *brown discount*, the aggregate NPV decreases in the cantonal and federal scenarios, since regulatory requirements imply costly energy renovations, leading to higher CAPEX. For Fund 1, the cantonal scenario results in an average erosion of the aggregate NPV of 3.9%, compared with 9.9% in the federal scenario. These declines are accompanied by a moderate increase in the coefficient of variation, which rises from 0.02 to 0.03 and then to 0.04. These results confirm that, despite the increase in CAPEX induced by the regulatory scenarios, the risk profile of Fund 1 remains relatively contained, with limited dispersion around the expected value.

For Fund 2, which is more exposed to rental losses induced by the refurbishments, the effect of the regulatory scenarios is much more pronounced, with reductions in NPV reaching 22.1% and 33.3% in the cantonal and federal scenarios, respectively. At the same time, the coefficient of variation increases sharply, from 0.08 in the standard scenario to 0.12 and then 0.19, indicating much higher volatility of the aggregate NPV. The

Figure 3: Distribution of aggregate and normalized NPV for each fund.



greater exposure of Fund 2 to rental losses and construction uncertainties is therefore reflected in both the level and the dispersion of the results.

Finally, the distributions also show a marked widening under the regulatory scenarios. This effect is explained by the fact that a high level of energy renovations increases the fund's exposure to uncertainties, in particular to changes in construction costs.

Table 9 provides a more detailed characterization of the impact of the regulatory scenarios on the risk profile of each fund. For Fund 1, the 95% VaR and Expected Shortfall remain close to the central scenario, even in the federal scenario (0.84 and 0.82, compared with an average NPV of 0.90), suggesting a limited deterioration of the worst trajectories. By contrast, for Fund 2, the VaR and Expected Shortfall fall to 0.62 and 0.56 in the cantonal scenario, and even to 0.44 and 0.37 in the federal scenario, illustrating a much more pronounced risk of extreme losses. These results show that the *brown discount* manifests itself not only through a reduction in expected NPV, but also through a significant increase in the risk of adverse scenarios, particularly when the portfolio is exposed to deeper refurbishments.

Table 9: Risk statistics for the normalized aggregate NPV.

	Mean NPV	Coefficient of variation	VaR 95%	ES 95%
Fund 1	1.00	0.02	0.96	0.95
Cantonal scenario	0.96	0.03	0.91	0.90
Federal scenario	0.90	0.04	0.84	0.82
Fund 2	1.00	0.08	0.87	0.82
Cantonal scenario	0.78	0.12	0.62	0.56
Federal scenario	0.67	0.19	0.44	0.37

Note: The results are based on 1,000 simulations, normalized by the aggregate NPV in the standard scenario for each fund. The risk measures include the value at risk (VaR) and the expected shortfall (ES) at a 95% confidence level.

6 Limitations

Since our application is designed to be used with default values—particularly for building characteristics and renovation costs—its main limitation lies in the lack of precision of certain key model parameters.

On the one hand, the parameters used in the DCF model are calibrated from observed averages or internal project sources. This approach enables the comparison of different strategies but does not guarantee an absolute valuation perfectly suited to each individual building. Incorporating more granular market data would allow refinement of these calibrations and increase the model's accuracy.

On the other hand, the energy impact of interventions is difficult to quantify precisely. In our application, this impact is based on simplifying assumptions. In particular, the energy effect of component replacements is not estimated rigorously due to the absence of detailed technical data. It should also be recalled that the overall energy performance of a building results from complex interactions among technical components, their individual properties, and their synergies. A more precise modeling approach, based on physical characteristics of the building and integrating normative standards (such as the SIA 380/1 standard on heating energy needs), would be necessary to refine energy trajectories and better reflect the reality of interventions.

Furthermore, regarding public policy, our framework assumes known and binding requirements limited to renovation obligations. It does not incorporate other regulatory mechanisms that could affect value—such as rent caps, leasing prohibitions, or tax incentives. Moreover, uncertainty regarding regulatory deadlines is not modelled, even though it represents a significant risk for owners and investors.

Finally, the study does not model the entire macroeconomic system within which climate policies operate. The impact of massive renovation demand on construction-sector capacity, and therefore on prices, remains an open question. A fully feedback-based model incorporating supply, demand, employment, and migration dynamics would be needed to project these tensions more realistically. Another unmodelled effect is the potential strengthening of rental demand for renovated buildings. In practice, more energy-efficient buildings may benefit from greater attractiveness and higher rents. But in the absence of sufficient and transferable empirical data, this effect was not incorporated.

Using a sample of buildings with richer technical and energy information enabled us to test the application using real cases. However, this study also presents limitations due to the relatively small number of buildings. Moreover, the absence of detailed data on actual renovation costs prevents precise estimation of energy retrofit expenditures. These are estimated as percentages of insurance value, a method that does not account for construction or technical specificities of each building. This simplification particularly affects the estimation of the discount, which depends critically on actual costs necessary to meet energy performance targets.

Ultimately, these limitations highlight opportunities to improve the model, notably through enhanced data availability, refinement of energy-related assumptions, and gradual integration of market or behavioral mechanisms that remain difficult to model today.

7 Conclusion

This paper proposes an operational methodology for integrating future energy requirements into the valuation of income-producing buildings. Starting from an enhanced DCF framework, we explicitly model the impact of renovation trajectories on future cash flows, distinguishing between several investment strategies: a standard maintenance strategy and strategies constrained by cantonal or federal requirements.

We also introduce a stochastic modeling of key economic and technical uncertainties. Construction prices, component lifetimes, actual efficiency gains from retrofit measures, and vacancy rates are simulated to obtain a distribution of NPV, not a single value. This approach makes it possible to characterize both the expected impact of each renovation trajectory on building value and the risk profile associated with each trajectory.

This framework enables the measurement of a building's *energy vulnerability*, meaning the difference in value between a non-compliant strategy and one compliant with regulatory requirements. This difference does not only reflect the cost of compliance; it also captures a risk premium associated with uncertainty over the measures required, their cost, feasibility, and actual performance. In a market with imperfect information, it thus justifies a higher valuation for a building already renovated.

We also highlight that renovations driven by the energy trajectory structurally modify the building. By incorporating high-performance components, they increase future replacement costs and alter the long-term dynamics of CAPEX. Valuation must therefore incorporate this cyclical dimension.

Although the proposed framework provides a coherent modeling approach, it is based on several important simplifications: cost estimates remain approximate, CECB objectives are translated indirectly through HDI, and DCF model parameters are calibrated using generic average values. These limitations underscore the need to improve data availability, incorporate more mechanisms related to the functioning of the real-estate market, and develop more comprehensive models linking buildings to their economic and regulatory environment.

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A Certification systems

Numerous energy and environmental certification systems have been developed at national and international levels to encourage sustainable construction and energy renovation. Some are universal and apply to all building types; others are reserved for buildings meeting high performance standards. Most certifications evaluate buildings according to structured criteria: energy efficiency, water management, indoor air quality, material selection, overall environmental impact, and innovation. Their objective is twofold: standardizing assessments and guiding investment decisions.

Table A1 on the next page presents a summary of the main certification systems. A selection of these systems is described briefly below.

LEED (Leadership in Energy and Environmental Design) is a rating system developed by the U.S. Green Building Council (USGBC) to assess a building's environmental performance. Evaluation criteria cover a range of categories including energy efficiency, water use, indoor air quality, construction materials, and innovation in design. Buildings can receive LEED certification at different levels (Certified, Silver, Gold, or Platinum) depending on the number of points obtained.

The Energy Star program is a joint initiative of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy. It certifies buildings and products that meet specific energy efficiency standards. Unlike LEED, which evaluates buildings more comprehensively, Energy Star considers only the building's energy performance. Only buildings in the top quartile of energy performance are eligible.

Green Globes is a certification system for sustainable buildings used in the United States and Canada. It assesses seven categories: energy management, water management, resources, emissions and effluents, indoor environment, project management, and site. Green Globes uses an online evaluation process and provides feedback throughout design and construction. Buildings are rated on a 1,000-point scale and can receive one to four "Globes."

The Energy Performance Certificate (EPC) is required in Europe for buildings that are constructed, sold, or rented. The EPC provides an estimate of a building's energy efficiency on a scale from A (very efficient) to G (inefficient). It is intended to provide owners, buyers, and tenants with a clear assessment of the building's energy performance, along with recommendations for improvement.

The Global Real Estate Sustainability Benchmark (GRESB) is an industry standard for measuring the environmental, social, and governance (ESG) performance of real-estate investments worldwide. Launched in 2009 by major institutional investors, GRESB evaluates real-estate and infrastructure portfolios based on policies, practices, and ESG performance.

Table A1: Certification systems

Name of certification	Country of origin	International	Commercial/ residential	Main criteria	Levels	Year of creation	Re-certification
LEED	USA	Yes	Both	Energy, water, air quality, materials, sites, innovation	Certified, Silver Gold, Platinum	1998	Yes
Energy Star Certificate	USA	No	Both	Energy efficiency	Certified or not	1992	Yes
Energy Performance Certificate	EU	Yes	Both	Energy efficiency	A–G	2007	No
GRESB	Netherlands	Yes	Commercial	ESG (Environmental, Social and Governance)	Certified or not	2009	Yes
BREEAM	United Kingdom	Yes	Both	Energy management, water, health and well-being, pollution, transport, materials, waste, ecology and management	Pass, Good, Very Good Excellent, Outstanding	1990	Yes
NABERS	Australia	No	Commercial	Energy efficiency, water, waste, indoor environment quality	1–6 stars	1998	Yes
Green Globes	Canada	Yes	Both	Energy, water, resources, emissions, indoor environment, project management, site	1–4 globes	2004	Not specified
Living Building Challenge	USA	Yes	Both	Water, energy, health and well-being, materials, equity, beauty	Certified or not	2006	Yes
Passive House	Germany	Yes	Both	Energy efficiency, indoor air quality	None	1988	Not specified
WELL Building Standard	USA	Yes	Both	Air, water, nourishment, light, fitness, comfort, mind	Silver, Gold, Platinum	2014	Yes
HQE	France	Yes	Both	Energy, environment, health, comfort	Pass, High performance, Very high performance, Excellent	2005	Yes
DGNB	Germany	Yes	Both	Environmental, economic, socio-cultural, technical, process, site	Bronze, Silver, Gold	2007	Yes
CECB	Switzerland	No	Both	Energy efficiency	A–G	2009	No
Minergie	Switzerland	No	Both	Energy efficiency, resources, ventilation, sustainability	Minergie or not, Minergie-A or Minergie-P	2009	No

Developed in the UK, the Building Research Establishment Environmental Assessment Method (BREEAM) evaluates building environmental performance in categories including energy management, water use, health and well-being, pollution, transportation, materials, waste, ecology, and management. Points are awarded in each category, and buildings can achieve a certification level of Pass, Good, Very Good, Excellent, or Outstanding.

B VAR model

To simulate the future evolution of prices related to energy renovation, we use a vector autoregressive (VAR) model, which captures relationships among multiple macroeconomic variables over time.

In a VAR(p) model, each variable is explained by its own lagged values as well as those of other variables in the system:

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_p y_{t-p} + u_t,$$

where y_t is the vector of variables at time t, A_i are coefficient matrices, and u_t is an error term.

The model is estimated on nine quarterly series from 1985 to 2023, including energy prices, interest rates (Saron short-term rate and 10-year Confederation rate), inflation, and renovation costs. The results are shown in the table below.

Table A2: Estimated coefficients of the VAR model

Variable	GDP	Infl.	Saron	Bond	Renov. cost	Elect.	Gas	Fuel oil
Intercept	0.787	-0.162	-0.262	-0.043	-0.191	-0.246	0.042	-3.982
	(0.424)	(0.115)	(0.078)	(0.070)	(0.136)	(0.700)	(1.077)	(3.295)
L1.GDP	0.638	0.046	0.035	0.014	0.162	-0.137	0.384	1.304
	(0.095)	(0.026)	(0.018)	(0.016)	(0.030)	(0.157)	(0.242)	(0.740)
L1.Infl.	-0.497	0.704	-0.170	-0.063	-0.040	0.289	2.013	-4.574
	(0.295)	(0.080)	(0.054)	(0.049)	(0.094)	(0.488)	(0.750)	(2.295)
L1.Saron	0.168	-0.117	0.792	-0.028	-0.161	-0.832	-0.004	-3.648
	(0.306)	(0.083)	(0.056)	(0.051)	(0.098)	(0.506)	(0.778)	(2.380)
L1.Bond	-0.018	0.106	0.156	0.986	0.035	0.315	-0.924	3.890
	(0.277)	(0.075)	(0.051)	(0.046)	(0.089)	(0.458)	(0.704)	(2.153)
L1.Renov.	-0.027	0.073	0.067	0.026	0.940	0.478	0.541	0.933
	(0.133)	(0.036)	(0.024)	(0.022)	(0.042)	(0.219)	(0.337)	(1.031)
L1.Elect.	0.036	-0.014	0.019	-0.011	-0.062	-0.139	-0.487	-0.119
	(0.063)	(0.017)	(0.012)	(0.010)	(0.020)	(0.104)	(0.160)	(0.490)
L1.Gas	0.042	0.007	0.012	0.012	0.017	0.059	-0.096	0.151
	(0.042)	(0.012)	(0.008)	(0.007)	(0.014)	(0.070)	(0.108)	(0.330)
L1.Fuel oil	0.045	0.015	0.003	-0.002	0.009	-0.038	0.088	0.028
	(0.014)	(0.004)	(0.003)	(0.002)	(0.005)	(0.024)	(0.037)	(0.112)

Note: The VAR model is applied to nine Swiss macroeconomic time series. The coefficients and their standard errors (in parentheses) are estimated over the period 1985-Q1 to 2023-Q2, for a total of 154 observations.

To assess the impact of shocks in the system and the dynamic responses of the variables, we use the estimated VAR model to simulate trajectories of the endogenous variables. We perform 1000 simulations for each time-step from $t = 1$ to T. Each simulation, indexed by s ($s = 1, \ldots, 1000$), follows:

$$y_t^{(s)} = A_1 y_{t-1}^{(s)} + A_2 y_{t-2}^{(s)} + \ldots + A_p y_{t-p}^{(s)} + u_t^{(s)}$$

The error terms $u_t^{(s)}$ are generated to match the statistical properties of the estimated model, particularly the covariance matrix of residuals.