Optimized Modernization Decisions in Multifamily Houses: The Impact of Tax Regulations on Private Landlords' Retrofit Choices

Kinga Poplawska[a,b], Stella Vierboom[a], Nico Fuchs[a], Dirk Müller[a]

[a] *RWTH Aachen University, E.ON Energy Research Center,*
Institute for Energy Efficient Buildings and Indoor Climate, Germany
[b] *kinga.poplawska@eonerc.rwth-aachen.de, CA*

Abstract:

Decarbonizing the residential building sector to meet climate targets necessitates a substantial reduction in primary energy demand, thereby creating a significant modernization requirement for the existing building stock. However, current modernization rates remain insufficient, particularly in multifamily houses where decision-making processes are complex due to the landlord-tenant dilemma and distinct financing constraints. These financial barriers are further compounded by the intricate fiscal regulations governing property modernization. The application of fiscal instruments is dependent on the investor's profile, as tax regulations distinguish between owner-occupation and rental activities. Moreover, the progressive nature of the tax system ensures that the actual financial relief varies according to the landlord's individual taxable income. Since modernization measures directly alter the taxable income base, their fiscal integration redefines the economic viability and effective total cost. Despite their impact on investment returns, specific tax regulations are frequently neglected in decision-support models for building retrofits. Such models, often implemented using Mixed-Integer Linear Programming (MILP), typically overlook these complexities. Consequently, a holistic financial view incorporating tax effects is needed to determine optimal modernization decisions.

In this study, we develop an optimization approach that incorporates the German tax framework into the investment decision process. We extend an existing MILP model for building energy systems to integrate the specific tax treatment of expenses for private landlords into the objective function. The model optimizes the selection, sizing, and operation of the energy system while determining optimal building envelope measures. Our study compares how income tax and value-added tax mechanisms affect modernization decisions relative to a baseline scenario without taxation.

Results show that integrating German income tax framework for private landlords increases the economic viability of capital-intensive measures, such as deep insulation. Specifically, the progressive income tax system creates a leverage effect: private landlords with higher taxable incomes benefit from depreciation potentials, reducing annualized total costs by up to 16%. These findings demonstrate the relevance of integrating tax conditions into energy system modeling to inform the development of effective policy instruments.

Keywords:

Modernization Decisions; MILP Optimization; Tax Regulations; Energy Retrofit; Private Landlord Income Taxes

1. Introduction

The building sector accounts for approximately 36% of total emissions in the European Union (EU), making it the largest energy consumer and a key emissions driver [1]. Achieving climate neutrality by 2050 thus requires accelerated retrofit efforts and a transition to climate-friendly technologies [2]. Within this sector, multi-family houses (MFH) play a significant role. In the European Union, MFH constituted approximately 48% of the total building stock in 2024, while an average of 32% of the population resided in rented households [3]. The German residential sector, in particular, is characterized by an exceptionally high share of tenants, accounting for 53% of the population [3].

Modernization planning in MFH involves high complexity due to the landlord-tenant dilemma, heterogeneous investors, and a dense regulatory framework, including building energy regulation, subsidy schemes, and rental law [4]. The German Building Energy Act (GEG) sets mandatory energy efficiency standards for building retrofits and operation, requiring new heating systems to operate with at least 65% renewable energy, while subsidy programs like the Federal Funding for Efficient Buildings (BEG) provide grants and low-interest loans for low-carbon technologies and deep retrofits [5]. These regulatory instruments aim to accelerate the transition to low-carbon technologies. However, market shares in the MFH sector in Germany show that fossil fuel systems, such as gas and oil boilers, account in sum for 53.5% of the market, while renewable energy systems, such as heat pumps, account for only 3.3% [6]. To effectively accelerate modernization rates in MFH, holistic models are needed that comprehensively capture the influence of regulatory conditions on private landlords.

Various engineering approaches provide methods for evaluating modernization measures with different levels of accuracy [4, 7]. Among these, MILP models are particularly effective for determining cost-optimal building energy systems (BES) by minimizing annualized total costs [8]. Studies have also examined regulatory instruments such as GEG, subsidies, and rental law in techno-economic planning of residential building retrofits [4, 9]. What remains largely unaddressed are specific tax regulations. Tax policy instruments function as key steering mechanisms for investment incentives and liquidity, with their investor-specific application altering financial boundary conditions. Since modernization measures influence the taxable income base, this integration redefines effective total costs. The German tax system distinguishes between different types of income and applies a progressive income tax schedule, implying that energy-related investments can influence the effective tax burden through depreciation, loss carryforwards, and the classification of expenditures as maintenance or production costs [10]. While tax regulations influence the effective financial burden of an investment, their multilayered complexity — characterized by frequent legislative changes and numerous special provisions — often leads to their omission in existing techno-economic frameworks [11]. Considerable interpretative leeway often requires consultation with tax advisors. Consequently, tax regulations are frequently omitted from decision models in scientific studies [11]. Earlier work has shown that integrating income tax and value-added tax into a detailed financial planning model can increase the attractiveness of capital-intensive technologies such as combined heat and power and photovoltaic systems, but simplifying assumptions like a constant income tax rate may underestimate the progression effect and distort results [11]. The available literature further suggests that accelerated depreciation and the visibility of tax benefits could strengthen incentives for energy efficiency investments, especially for commercial owners and landlords, but these mechanisms have not been empirically validated in the context of private MFH landlords [12]. Against this background, the present study develops a MILP-based optimization approach that integrates the German tax framework into the modernization decision of a representative private landlord in a multifamily house, thereby enabling a more realistic assessment of how tax regulations shape cost-optimal modernization pathways.

1.1. Tax Regulations in Modernization Planing

German income tax is levied on an individual's taxable income, with the specific determination method depending on the underlying category of income [13]. The resulting tax liability is calculated based on a progressive schedule (Income Tax Act, § 32a), where marginal tax rates range from 0% for the basic tax-free allowance up to a maximum of 45% [14]. Within the annual tax return, private landlords can claim income-related expenses to reduce their overall taxable income. This fundamental fiscal framework serves as the starting point for evaluating how specific tax policy instruments influence investment decisions in the building sector.

Taxation of Energy-Related Modernization Measures for Private Landlords

Energy-related modernization measures can influence a landlord's tax position indirectly by reducing taxable income through deductible income-related expenses, thereby lowering the effective income tax according to the progressive tax schedule. Rental income forms part of private asset management and is classified as income from letting and leasing, grouped under the broader category of excess income [11]. Taxable income is thus determined by the surplus income method, where revenues from rent are reduced by income-related and, where applicable, special expenses. In this context, income-related expenses encompass all expenditures that serve the acquisition, safeguarding, and maintenance of rental income. Relevant examples include financing costs such as loan interest and bank fees, ongoing operation and maintenance costs, inspection and administrative expenses, as well as energy-related modernization costs. For energy-related modernization measures carried out in rented dwellings, tax law provides two alternative treatments that differ in the timing of deductibility [10]:

- **Direct deduction:** The first option classifies modernization measures as maintenance expenses allowing for an immediate deduction of the incurred costs as income-related expenses in the year of payment. This immediate deductibility provides a liquidity advantage in the year of the investment.
- **Deduction via depreciation:** The second option applies when modernization measures are classified as production costs, which increase the book value of the property and are deducted over time through depreciation.

An exclusion principle determines the applicable classification: energy-related modernization measures are generally treated as maintenance expenses, unless the specific legal conditions for recognition as production costs are met. This distinction is crucial for assessing the temporal allocation of tax deduction potentials and, consequently, the present value of the resulting tax relief.

Under German tax law, the criteria for classifying expenditures as production costs depend on the distinction between subsequent acquisition-related costs and subsequent production costs [15]. Acquisition-related production costs are triggered if modernization measures are implemented within the first three years of ownership and the total expenditures exceed 15% of the building's initial purchase price. In contrast, subsequent production costs may arise regardless of the timing of the investment, provided the measures result in a physical extension or a material improvement of the residential property. In 2025, the definition of material improvement was refined to include a reduction in final energy consumption or demand by at least 30% through energy modernization measures [16]. Independent of the achieved final energy consumption or demand, the tax assessment of a material improvement also depends on individual and building-specific characteristics. A material improvement is likewise present if the measures significantly extend the useful life of the building or increase the building quality beyond a merely timely renewal [17]. These characteristics encompass the following categories of building equipment and condition, where improvement in at least three out of the six is required: electrical installation and information technology, windows and thermal insulation, sanitary equipment, heat and energy supply, generation, and storage.

In contrast to maintenance expenses, production costs cannot be deducted immediately but are instead allocated over time through depreciation. Under current fiscal regulations, depreciation systematically allocates the acquisition and production costs of residential buildings over standardized useful lives. These annual rates typically range between 2% and 3%, depending on the building's original completion date (Table 1) [18]. These annual deductions serve as income-related expenses that reduce taxable income [15]. The annual depreciation deduction — together with other rental-related costs — is claimed as income-related expenses that reduce taxable income. For production costs from modernizations, the depreciation application depends on the property's residual book value: if residual value exists, costs are added cumulatively to expand the depreciable basis; if fully depreciated, costs establish a new depreciable basis [15, 19].

Table 1. *Overview of annual depreciation rates and useful life for residential properties [20].*

Category	Building Year / Condition	Useful Life	Annual Rate
New Build (Residential)	From 2023	33 Years	3.0%
Existing (Residential)	1925 – 2022	50 Years	2.0%
Old Build (Residential)	Before 1925	40 Years	2.5%

Tax Regulatory of Private Energy Generation

Unlike residential leasing, which is generally exempt from value-added tax (VAT), revenues generated from energy production in Germany are subject to national VAT regulations. Remunerated energy supplies — such as grid feed-in or heat delivery to third parties — qualify as taxable transactions (Value-Added Tax Act). In these cases, VAT is collected from the customer and remitted to the tax authority, ensuring the tax burden ultimately falls only on the private end consumer.

Photovoltaic (PV) systems currently benefit from extensive income and VAT exemptions designed to reduce administrative complexity and incentivize deployment. Under current regulations, the supply and installation of PV systems up to 30 kWp and battery storage are subject to a zero VAT rate, effectively allowing investment costs to reflect net prices. Furthermore, revenues from PV operations — including feed-in tariffs and self-consumption — are exempt from income tax for systems up to 30 kWp per residential unit (Income Tax Act). While this prevents such revenues from increasing the landlord's taxable income, it also precludes the deduction of related expenses, such as maintenance, financing interest, or depreciation.

In contrast, the tax treatment of combined heat and power (CHP) systems in MFH remains highly complex, as it overlaps commercial grid feed-in with private self-consumption and tenant supply. While such systems are primarily relevant for larger-scale district heating or neighborhood concepts, their administrative burden and technical overhead often outweigh the benefits for individual residential buildings. Consequently, CHP systems are excluded from the scope of this study to focus on the most prevalent modernization pathways for the existing building stock.

1.2. Contribution and Structure of the Study

Tax regulations have rarely been incorporated into building modernization planning processes, primarily due to their complexity and volatility [11]. Neglecting the tax perspective may lead to deviating optimal modernization decisions, which in turn can affect the assessment and effectiveness of regulatory instruments such as subsidies. A further challenge is that tax regulations differ depending on investor type — such as private landlords, owner-occupiers, and housing companies — and therefore require individual treatment. Despite this relevance, the complex interaction between the German Income Tax Act and depreciation allowance regulations has not yet been systematically integrated into a MILP model structure, representing a research gap in the detailed modeling of tax frameworks within energy modernization investment decisions.

This paper addresses this gap by extending an existing mathematical optimization model to incorporate the tax framework and the financial implications of energy modernization measures in MFH for private landlords. Two research questions guide this work:

- First, how does the integration of tax regulations alter the economic assessment and investment incentives within mathematical optimization models for energy modernization in MFH?
- Second, what is the magnitude and influence of tax relief on the economical optimal modernization decision?

2. Methodology

The methodology integrates the German tax framework into the modernization decision process for a representative private landlord. Section 2.1 presents the MILP optimization framework for building energy system and envelope design. Section 2.2 describes the tax module, which extends the objective function by integrating the German tax regulatory framework for private landlords as investor-specific fiscal boundary conditions.

2.1. Optimization Framework

Building on previous work, this study extends a MILP model that supports energy modernization decisions in residential buildings and was originally developed at RWTH Aachen based on the framework by Schütz et al. [21]. The model selects and sizes energy conversion and storage technologies and defines building envelope measures while minimizing either annualized total costs or operational emissions over a 15-year planning horizon. The model utilizes hourly time-series to ensure load coverage, requiring all thermal and electrical demands to be met across the optimization period. Furthermore, the model accounts for the interdependence between the building hull and the energy system, as envelope retrofits directly reduce heating demands, thereby influencing optimal system sizing. The selection and operation of the energy system are driven by the objective of economic cost minimization, ensuring that both sizing and dispatch are optimized for financial efficiency. The optimization is performed at single-building level using archetype data from TABULA and is implemented in Python with Gurobi as the MILP solver. Input data include building archetypes based on the TABULA typology, weather data, and technical, economic, and ecological parameters. Pre-processing consists of three sequential steps: (1) data preparation, in which building, location, weather, and technology-specific inputs are unified; (2) load profile generation using the energy balancing model and and domestic hot water demand profiles; and (3) clustering, which reduces the full annual time series to six representative days to limit computational effort.

The technology portfolio comprises systems for power and heat generation as well as energy storage. Electricity is supplied by PV and CHP units. For heat generation, the optimization includes air-source heat pumps (ASHP), gas boilers (BOI), electric heaters (EH), and pellet boilers (Pellet BOI). Additionally, solar thermal energy is utilized through both flat-plate (STCFP) and vacuum tube collectors (STCVT). Storage capacity is provided by thermal energy storage (TES) and batteries (BAT), including a dedicated domestic hot water tank (TES-DHW). The optimization assumes that all legacy energy systems have reached their end-of-life, necessitating a full replacement and allowing for a complete redesign of the building's energy system. The pellet BOI is not considered in this study due to maintenance requirements, and its unsuitability as a peak load boiler. Device performance is represented by constant or temperature-dependent efficiencies, where ASHP, PV, and solar thermal efficiencies vary with ambient conditions and all remaining technologies are modeled with static efficiencies. The building envelope measures cover exterior walls, roof, windows, and ground floor against the soil. For each component, an initial retrofit state is defined before the optimization. Three discrete states are available: standard state (1), moderate retrofit (2), and deep retrofit (3).

2.2. Implementation of Tax Module for Private Landlords

The optimization model is enhanced with a tax module that integrates the fiscal consequences of modernization measures for a representative private landlord into the objective function. The tax module extends the existing MILP formulation by introducing an additional annualized term that captures the income tax and value-added tax implications of the chosen retrofit strategy, while preserving the linear optimization structure. As a result, the model evaluates retrofit options with respect to post-tax annualized costs rather than purely pre-tax expenditures, allowing the model to account for investor-specific fiscal consequences when selecting modernization measures. Figure 1 provides an overview of the structure of the tax module and its coupling with the underlying MILP.

As illustrated in Figure 1, the extended model receives two distinct input streams. The existing building input data from the base model — comprising archetype, weather, and technical parameters — are supplemented by investor-specific input data required by the tax module: yearly income, religious affiliation, marital status, date of acquisition, and property value. These parameters allow the pre-processing step to establish the income tax baseline, specifically the yearly pre-modernization income tax liability l_t^{tax}, which serves as the reference for all subsequent tax calculations. The property's acquisition date and value determine the basis for tax deductions, as modernization expenditures are classified as capitalized production costs subject to systematic depreciation

The tax module consists of two tax regulatory implementation blocks. The first block integrates the Value Added Tax Act by applying the zero VAT rate to PV and BAT investment costs, deviating from the base model assumption of a uniform 19 % VAT rate for all measures. The second block implements the Income Tax Act: it defines tax-relevant investment costs by excluding PV and BAT expenditures and any received subsidies, determines the post-modernization income tax liability L_t^{tax} and classifies the modernization measure according to German tax law as either a direct deduction as maintenance expenses or a deduction via depreciation over the useful life. The annual tax reduction $l_t^{\text{tax}} - L_t^{\text{tax}}$ resulting from this classification is then discounted to present value and annualized, yielding the annualized tax reduction C^{tax} that enters the objective function as a cost-reducing term. The model assumes private rental ownership for the entire building and precludes owner-occupancy to ensure the applicability of a uniform tax regime for modernization expenditures.

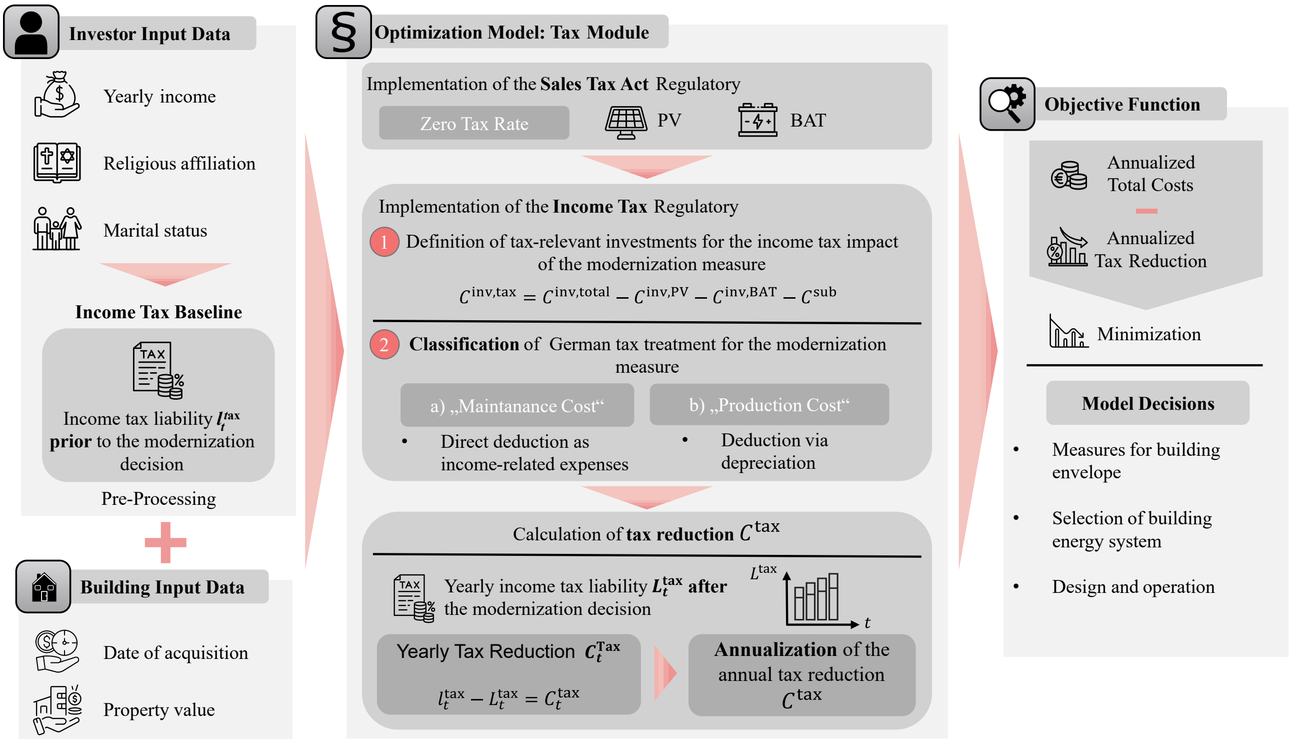

Figure 1. Integration of the fiscal assessment module for private landlords within the MILP-based modernization optimization framework.

The objective function minimizes the annualized total costs C^{total} over the observation period. The base model is extended by an annualized tax effect term C^{tax}, which reduces total costs when modernization expenditures generate tax savings for the private landlord according to Eq. (1).

$$C^{\text{total}} = C^{\text{inv}} + C^{\text{maint+insp}} + C^{\text{en}} - C^{\text{feed}} - C^{\text{sub}} - C^{\text{tax}} \tag{1}$$

The resulting objective function consists of annualized total costs C^{total}, comprising annualized investment costs C^{inv}, maintenance and inspection costs $C^{\text{maint+insp}}$, energy costs C^{en} , revenues from electricity feed-in C^{feed}, annualized subsidies C^{sub}, and annualized tax effect C^{tax}. The model assumes a one-time investment where assets are fully depreciated with zero residual value. While the physical capital recovery factor (CRF) is applied component-specifically to account for differing technical lifetimes, the fiscal depreciation of modernization measures — and the resulting tax effects — are deducted over the remaining useful life of the building.

Annualized Tax Effect C^{tax}

As outlined in Section 1.1, energy-related modernization measures affect the private landlord's tax position by reducing taxable income $I_t^{\text{tax,landlord}}$ through deductible income-related expenses, thereby lowering the effective income tax liability L_t^{tax} according to the progressive tax schedule. The annualized tax effect C^{tax} entering the objective function comprises two additive components according as shown in Eq. (2): the annualized income tax saving $C^{\text{tax,income}}$, which captures the reduction in income tax liability L_t^{tax} resulting from deductible modernization expenditures, and the annualized VAT saving $C^{\text{tax,VAT}}$, which reflects the zero VAT rate applicable to PV and BAT under the German Value Added Tax Act.

$$C^{\text{tax}} = C^{\text{tax,income}} + C^{\text{tax,VAT}} \tag{2}$$

The annual income tax saving in year t is the difference between the income tax liability prior to modernization l_t^{tax} and the liability after modernization L_t^{tax}. The income tax liability L_t^{tax} varies throughout the observation period, as the temporal allocation of deductible expenditures depends on the tax classification of the modernization measure: immediate deduction as income-related expenses concentrates the tax effect in the year of investment, whereas depreciation distributes it over the remaining useful life of the property. To account for the time value of money — reflecting the investor's opportunity cost compared to alternative investments — savings are discounted at a calculation interest rate of $i = 0.02$. This present value is annualized using the capital recovery factor CRF according to Eq. (3).

$$C^{\text{tax,income}} = \text{CRF} \cdot \sum_{t=0}^{T-1} \frac{1}{(1+i)^t} \cdot \left(l_t^{\text{tax}} - L_t^{\text{tax}}\right) \tag{3}$$

The post-modernization income tax liability L_t^{tax} depends on the taxable income $I_t^{\text{tax,landlord}}$, which is influenced in addition by the tax-relevant investment costs $C^{\text{inv,tax}}$ through deduction. Since PV and BAT are fully exempt from income taxation, their investment costs $C^{\text{inv,PV}}$, $C^{\text{inv,BAT}}$ are excluded from the income tax calculation to avoid double counting with the VAT treatment. Any received subsidy amounts for the investment C^{sub} are likewise deducted, as they reduce the net expenditure eligible for tax deduction. The resulting tax-relevant investment cost $C^{\text{inv,tax}}$ follows Eq. (4).

$$C^{\text{inv,tax}} = C^{\text{inv,total}} - C^{\text{inv,PV}} - C^{\text{inv,BAT}} - C^{\text{sub}} \tag{4}$$

Under the Value Added Tax Act a zero VAT rate applies to the supply and installation of PV systems and associated battery storage, deviating from the standard 19 % rate applied to all other investment measures in the base model. The resulting annualized VAT saving, as shown in Eq. (5), is accounted for within the income tax saving term $C^{\text{tax,income}}$.

$$C^{\text{tax,VAT}} = \text{CRF} \cdot \left(1 - \frac{1}{1.19}\right) \cdot \left(C^{\text{inv,PV}} + C^{\text{inv,BAT}}\right) \tag{5}$$

Classification of Modernization Expenditures

A central determinant of the tax effect is whether modernization expenditures are classified as immediately deductible maintenance expenses $C_t^{\text{tax,exp}}$ or as production costs subject to depreciation $C_t^{\text{tax,dep}}$. The binary variable $B^{\text{dep}} \in \{0, 1\}$ indicates this classification, where $B^{\text{dep}} = 1$ represents depreciation-based treatment. This classification is triggered if either the time-cost criterion ($B^{\text{dep,cost}}$) or the energy efficiency criterion ($B^{\text{dep,energy}}$), summarized in Table 2, is met.

Table 2. *Criteria for classification as production costs* $C_t^{\text{tax,dep}}$.

Binary variable	Criterion	Condition for $B = 1$
$B^{\text{dep,cost}}$	Time & cost	Modernization within 3 years of acquisition $\wedge$ $C^{\text{inv,tax}} \geq 0.15 \cdot c^{\text{acq}}$
$B^{\text{dep,energy}}$	Energy efficiency	$E^{\text{save}} = \dfrac{e^{\text{use,before}} - E^{\text{use,after}}}{e^{\text{use,before}}} \geq 0.30$

The energy saving fraction E^{save} is determined endogenously by the optimizer based on energy balances for heating and domestic hot water, using a gas boiler baseline. To implement these rules within the MILP framework, we define the threshold indicators ΔC^{inv} and ΔE^{mod} as shown in Eq. (6) and Eq. (7).

$$\Delta C^{\text{inv}} = C^{\text{inv,tax}} - 0.15\, c^{\text{acq}} \tag{6}$$

$$\Delta E^{\text{mod}} = E^{\text{save}} - 0.30 \tag{7}$$

Using the Big-M method with a sufficiently large constant M and a small tolerance $\varepsilon > 0$, the criteria are linearized as expressed in Eq. (8) and Eq. (9).

$$\Delta C^{\text{inv,tax}} \geq -M(1 - B^{\text{dep,time}}), \qquad \Delta C^{\text{inv,tax}} \leq -\varepsilon + M\, B^{\text{dep,time}} \tag{8}$$

$$\Delta E^{\text{mod}} \geq -M(1 - B^{\text{dep,energy}}), \qquad \Delta E^{\text{mod}} \leq -\varepsilon + M\, B^{\text{dep,energy}} \tag{9}$$

The final classification B^{dep} is modeled as a logical OR-relation according to Eq. (10), ensuring the measure is treated as a production cost if at least one criterion is satisfied.

$$B^{\text{dep}} \geq B^{\text{dep,time}}, \qquad B^{\text{dep}} \geq B^{\text{dep,energy}}, \qquad B^{\text{dep}} \leq B^{\text{dep,time}} + B^{\text{dep,energy}} \tag{10}$$

As defined in Eq. (11), the auxiliary variable D_t, selects the active deduction based on the value of $B^{\text{dep}} \in \{0, 1\}$.

$$D_t = \begin{cases} C_t^{\text{tax,dep}}, & B^{\text{dep}} = 1 \\ C_t^{\text{tax,exp}}, & B^{\text{dep}} = 0 \end{cases} \tag{11}$$

To avoid bilinear terms, the auxiliary variable D_t selects the active deduction through the Big-M constraints formulated in Eq. (12) and Eq. (13).

$$D_t \leq C_t^{\text{tax,dep}} + M_t(1 - B^{\text{dep}}), \qquad D_t \geq C_t^{\text{tax,dep}} - M_t(1 - B^{\text{dep}}) \tag{12}$$

$$D_t \leq C_t^{\text{tax,exp}} + M_t B^{\text{dep}}, \qquad D_t \geq C_t^{\text{tax,exp}} - M_t B^{\text{dep}} \tag{13}$$

Hence, $B^{\text{dep}} = 1 \Rightarrow D_t = C_t^{\text{tax,dep}}$(depreciation) and $B^{\text{dep}} = 0 \Rightarrow D_t = C_t^{\text{tax,exp}}$(immediate expense). If modernization costs are classified as production costs ($B^{\text{dep}} = 1$), the incremental depreciation $C_t^{\text{tax,dep}}$ acts as an additional deductible expense to determine the updated taxable income $I_t^{\text{tax,landlord}}$. Equation (14) represents this incremental value as the difference between the modernized and baseline depreciation paths.

$$C_t^{\text{tax,dep}} = A_t^{\text{dep,after}} - a_t^{\text{dep,before}} \tag{14}$$

The variables $a_t^{\text{dep,before}}$ and $A_t^{\text{dep,after}}$ denote the yearly depreciation paths of the building without and with modernization, respectively. The annual deductible amount $A_t^{\text{dep,after}}$ is determined by applying the applicable depreciation rate δ^{dep} to the updated asset value ($C^{\text{acq}} + C^{\text{inv,tax}}$) according to Eq. (15). To maintain a linear MILP formulation while accounting for the remaining building life, the model utilizes binary variables to track the full depreciation periods and any remaining partial amounts in the final year of the relief horizon. This ensures that the total tax-relevant investment is fully recovered over the standardized useful life, potentially extending the fiscal relief beyond the building's original depreciation schedule. Unlike the original depreciation $a_t^{\text{dep,before}}$ on c^{acq}, which is limited to the building's remaining useful life, the investment triggers a renewed cycle. This enables the full updated acquisition value to be claimed over a new standardized horizon.

$$A_t^{\text{dep,after}} = \delta^{\text{dep}}\left(c^{\text{acq}} + C^{\text{inv,tax}}\right) \tag{15}$$

If modernization costs are classified as immediately deductible maintenance expenses ($B^{\text{dep}} = 0$), the full deduction of the tax-relevant investment occurs in t=0 according to Eq. (16).

$$C_0^{\text{tax,exp}} = C^{\text{inv,tax}}, \qquad C_{t\geq 1}^{\text{tax,exp}} = 0 \tag{16}$$

Post-Modernization Income Tax Liability

Together with the remaining deductible items — tax-relevant maintenance costs and inspection costs $C^{\text{main+insp}}$ — the post-modernization taxable income $I_t^{\text{tax,landlord}}$ results from the base taxable income $i_t^{\text{tax,landlord}}$ prior modernization, which serves as a model input. The calculation of the taxable income $I_t^{\text{tax,landlord}}$ follows the formulation in Eq. (17), which accounts for the selected deduction.

$$I_t^{\text{tax,landlord}} = i_t^{\text{tax,landlord}} - D_t - C_t^{\text{main+insp}} \tag{17}$$

Based on $I_t^{\text{tax,landlord}}$, the annual income tax liability L_t^{tax} is determined. To preserve the linear model structure, the non-linear progressive income tax function is approximated via piecewise linear interpolation, using support points ($I_t^{\text{tax,landlord}}$, L_t^{tax}) at the statutory income thresholds to accurately capture the tariff's curvature. The annual tax saving is derived as the difference relative to the pre-modernization liability l_t^{tax}, annualized, and integrated into the objective function as $C^{\text{tax,income}}$. If deductible expenses exceed the taxable income $i_t^{\text{tax,income}}$, the unabsorbed loss is handled via carryback and carryforward mechanisms. The model bounds the one-year carryback by the initial excess loss and the pre-modernization income. Similarly, the applied carryforward in subsequent periods is constrained by the accumulated remaining loss and the respective year's taxable income.

3. Use Case

Our study examines the impact of tax boundary conditions on modernization decisions for a representative MFH archetype constructed in 1978 [22]. The building comprises six apartments with an average unit size of 74.5 m^2, resulting in a total heated floor area of 446.91 m^2. This size aligns with a typical occupancy of approximately two residents per unit. The building envelope is assumed to be in an unrenovated state, with space heating provided by a conventional low-temperature gas boiler with an efficiency of 92 %.

Economic parameters are sourced from the German catalogue for municipal heat planning, encompassing both technology and energy carrier costs [23]. A value-added tax of 19 % is applied to all investments, excluding PV and battery systems. The model assumes a 15-year observation period for the operation of the BES, while building-related assessments are based on the building's total lifespan. We examine the case with GEG requirements and without, while maintaining a constant effect of funding measures. Individual funding measures from BEG are included in the investment calculations. Financial incentives under the EEG are integrated by offsetting PV revenues against fuel costs. Table 3 summarizes the assumed energy price scenario and GEG-compliant revenue streams.

Table 3. *Energy price parameters and statutory revenue streams for 2025.*

	Electricity	Gas	Biogas	El Feed	PV (EEG) *
ct/kWh	34.9	10.6	15.0	8.3	7.6 – 12.9

*Dependent on the installed power.

Private Landlord Input Data

The model represents six private landlords within the building as a homogeneous investor group to ensure a uniform tax treatment. An acquisition date of 2010 is defined for all apartments to establish a reference for the building's purchase value and its subsequent tax treatment, specifically for determining the depreciation basis. Based on 2010 market data for North Rhine-Westphalia in Germany, an average purchase price of 1,780 €/m^2 is applied, yielding an acquisition value of 116,234 € per apartment. The private landlords are assumed to modernize the central building energy system in 2025.

Private landlords in Germany exhibit highly heterogeneous income distributions across five quintiles [24]. Although landlords are present in all brackets, the majority (65 %) are situated in the two upper quintiles, reflecting higher average incomes compared to the general population. To evaluate the resulting tax-driven investment incentives, we define three representative taxable income classes for the optimization: low (20,000 €/year), medium (60,000 €/year), and high (90,000 €/year). This selection captures the fiscal impact across the full spectrum of relevant marginal tax rates.

4. Results

In this section, we present the results of the tax-integrated case studies for a representative private landlord in the MFH sector. Each case study evaluates how tax regulations modify the cost-optimal modernization decision relative to a base scenario without tax modeling, thereby quantifying the impact of fiscal instruments on retrofit depth and technology choice. First, we analyze the influence of the landlord's taxable income under a setting where GEG requirements and subsidy schemes remain binding. This case study investigates how the interaction between progressive income taxation, depreciation-based deductions, and policy-driven investment incentives affects the optimal modernization strategy. Second, we isolate the effect of taxable income in a scenario without GEG-induced retrofit obligations but with subsidies still in place, allowing us to assess to what extent tax deductibility alone can steer modernization decisions in the absence of regulatory pressure.

Figure 2 depicts the optimal BES design, envelope retrofit states, and cost outcomes including post-tax annualized total costs together with upfront investment cost across the baseline and three taxable-income classes under GEG requirements and BEG subsidies.

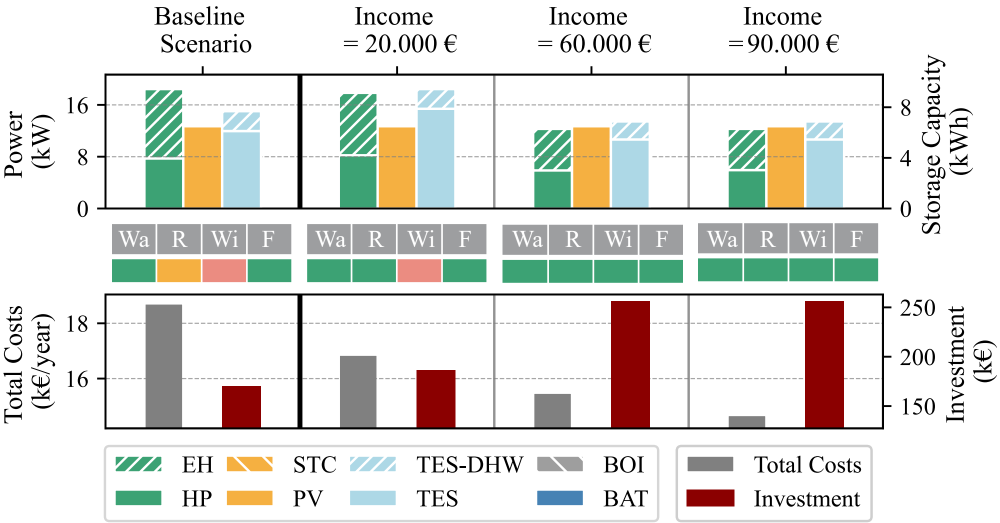

Figure 2. *GEG scenario with subsidies using tax-integrated objective across taxable-income classes. The middle plot indicates envelope states for exterior walls (Wa), roof (R), windows (Wi), and ground floor (F) as standard (red), moderate (yellow), or deep retrofit (green).*

In all cases, the optimization selects the same building energy system. For each scenario, the optimal design consists of an ASHP, an EH, a PV, a TES, and a TES-DHW. Differences arise in the extent of building envelope modernization. For low taxable incomes, the optimization selects a moderate retrofit strategy, upgrading only selected envelope components such as the roof and windows. For higher taxable-income levels, the optimization shifts to a deep retrofit, in which all relevant envelope components reach the highest efficiency level. Consequently, the deep retrofit significantly lowers the building's space heating demand, allowing the optimizer to downsize the required capacity of the heating devices.

Total investment costs scale with taxable income as high-income landlords opt for these more comprehensive insulation measures. As shown in Table 4, the integration of taxation progressively reduces the annualized total costs compared to the baseline scenario. While the baseline costs stand at 18,541 €/year, they drop by 7.5% to 17,148 €/year for the lowest income bracket of 20,000 €, and fall further to 15,513 €/year for the 90,000 € bracket, representing a total cost reduction of 16.3%. This economic improvement is driven by a synergistic effect between subsidies and tax benefits. The deeper retrofits triggered by higher income levels unlock significantly higher subsidy payments, which surge by 57.3% from 1,214 €/year in the baseline to 1,910 €/year in the highest bracket. Simultaneously, the annual tax savings scale by 144%, rising from 1,488 €/year for low-income landlords to 3,629 €/year for those in the 90,000 € bracket. Higher investment costs increase the annual depreciation volume, which — due to the progressive tax schedule — is applied at higher marginal rates. This leverage effect is the primary driver behind the decrease in post-tax annualized total costs for high-income landlords. Ultimately, these findings demonstrate that the progressive nature of income taxation, when paired with depreciation-based deductions, effectively overcompensates for higher upfront investments and incentivizes a significantly deeper level of energy modernization.

Table 4. *Annualized impacts of energy efficiency modernization measures for different taxable income levels of private landlords with GEG compliance and subsidy receipt.*

Scenario	Baseline	€20,000	€60,000	€90,000
Total costs in $\frac{€}{\text{year}}$	18,541	17,148	16,116	15,513
Subsidies in $\frac{€}{\text{year}}$	1,214	1,453	1,909	1,910
Tax impact in $\frac{€}{\text{year}}$	-	1,488	3,024	3,629

Figure 3 presents the optimal modernization decisions when only subsidy schemes are active and GEG requirements are not enforced. In contrast to the GEG scenario, the choice of the building energy system is highly sensitive to the landlord's taxable income, demonstrating a phased transition toward electrification as tax leverage increases. This shift is accompanied by a continuous reduction in annualized total costs, which drop by 14.8% from 18,209 €/year in the baseline to 15,513 €/year in the highest income bracket.

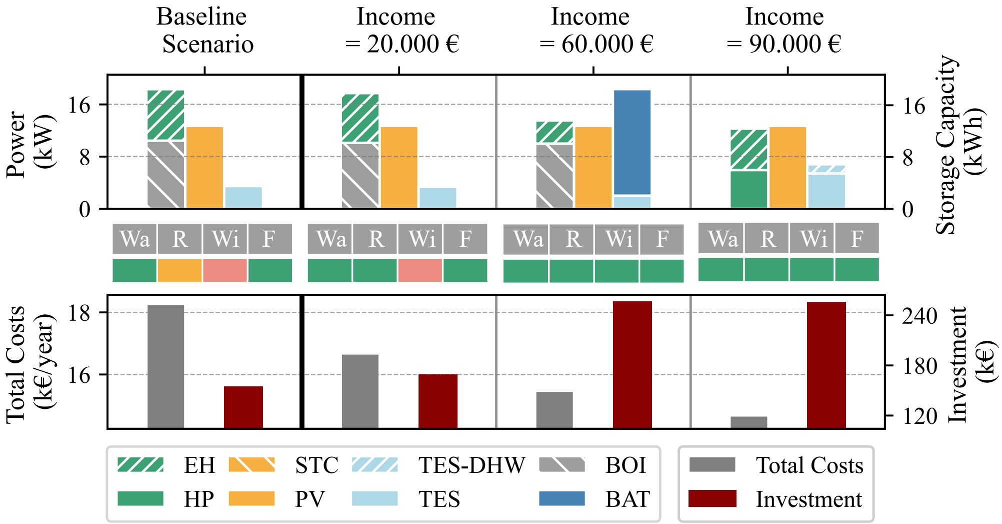

Figure 3. *Subsidy scenario without GEG using a tax-integrated objective across different taxable income levels. The middle plot indicates the chosen envelope states for exterior walls (Wa), roof (R), windows (Wi), and ground floor (F) as standard (red), moderate (yellow), or deep retrofit (green).*

In the baseline scenario and at a taxable income of 20,000 €, the optimization selects a fossil-based BOI system supplemented by an EH and PV. At this income level, the annualized tax impact (1,288 €/year) is insufficient to induce a technology switch. Consequently, the energy system remains unchanged, and economic incentives are directed toward partial envelope upgrades, such as improving the roof to a deep retrofit standard. Despite the constant technology choice, total annualized costs decrease by 6.6% to 17,008 €/year compared to the baseline scenario. As taxable income rises to 60,000 €, the increased tax relief shifts the economic optimum, resulting in an expanded energy system. While the BOI is retained, the optimization now integrates a BAT to maximize PV self-consumption. Simultaneously, the optimal envelope configuration reaches a full deep retrofit state, including window modernization. Combined with an amplified tax impact of 2,908 €/year total annualized costs are reduced by 11.5% relative to the baseline to 16,108 €/year. At a taxable income of 90,000 €, the tax leverage fundamentally alters the cost-minimal solution. Tax savings of 3,629 €/year and maximized subsidies of 1,910 €/year offset the higher upfront investment costs of an ASHP. Consequently, the optimization phases out the BOI in favor of a fully electrified system comprising an HP, EH, PV, and thermal energy storage. This comprehensive modernization achieves the lowest post-tax annualized total costs across the scenario, reducing them by 14.8% relative to the baseline to 15,513 €/year.

Since the model classifies modernization measures as production costs deducted via depreciation, the progressive income tax schedule directly dictates the optimal investment strategy. At lower incomes, limited tax relief yields a cost-optimum based on fossil systems with minimal envelope upgrades. As income increases, the higher value of depreciation allowances compensates for greater capital expenditures. Thus, the integration of taxation and subsidies shifts the cost-minimal solution toward capital-intensive, fully electrified systems for higher-income brackets, reducing total annualized costs even without strict regulatory mandates.

5. Discussion

The integration of the German tax framework into the MILP optimization reveals that fiscal effects are decisive factors in modernization logic. Because of the progressive income tax schedule, high-income landlords achieve significantly lower post-tax annualized total costs — with reductions of up to 16% — even when implementing the exact same measures as lower-income landlords. Since approximately 65% of private landlords in Germany fall into the two highest income quintiles, this tax leverage effect actively drives cost-minimal decarbonization for the majority of the market. Conversely, the remaining 35% face insufficient tax incentives, economically locking them into fossil-based systems absent regulatory mandates. To prevent a two-tier modernization landscape, policymakers must introduce income-scaled subsidy structures — such as higher grant rates — that adequately compensate lower-income landlords for their lack of tax leverage.

Regarding fiscal mechanics, German tax law strictly bases depreciation on historical acquisition costs rather than current market values. Thus, the observed tax leverage stems from new modernization capital expenditures, allowing private landlords to generate depreciation volume independent of the property's market appreciation. Furthermore, the applied real discount rate of $i = 0.02$ adequately reflects the low-risk profile of these investments. While capital markets might offer higher nominal yields, retrofits are primarily driven by asset preservation — complying with regulations and preventing anticipated value and rental income losses associated with unrenovated buildings.

Methodologically, the model evaluates a single investment cycle over a 40-year tax-horizon, assuming the original building is fully depreciated. A more comprehensive approach would incorporate multiple reinvestment cycles, accounting for both the physical replacement of components and the recurring fiscal effects of subsequent modernizations over the building's extended lifespan. Additionally, the temporal distribution of these tax write-offs is crucial. Whether modernization costs are depreciated linearly over several decades or deducted directly via accelerated schemes significantly impacts the annualized costs due to the time value of money. However, capturing these dynamic reinvestment cycles and time-variable tax effects requires a dynamic annuity factor, which would substantially increase model complexity.

While focused on Germany, the mechanism of reducing the taxable base through investment-related depreciation — coupled with progressive taxation — is common across many European systems. Therefore, the risk of a two-tier modernization landscape is a broadly applicable structural challenge. However, the magnitude of these disparities depends heavily on the fiscal instrument. Jurisdictions utilizing tax credits reduce the final tax liability directly via a fixed subsidy rate, independent of the investor's marginal tax bracket. This decouples the fiscal incentive from the progressive tax schedule, significantly mitigating the income-based disparities observed in our deductions-based case study. Ultimately, our optimization framework can be readily adapted to evaluate various international tax regimes and design equitable decarbonization incentives.

Future research should evolve this framework by incorporating debt financing to account for the deductibility of loan interest, but also repayments and interest payments. Furthermore, a holistic model must incorporate the intricacies of the landlord-tenant dilemma. Since landlords do not directly benefit from tenant energy savings, including modernization levies, CO_2 cost sharing, and explicit rental income is needed. Furthermore, integrating photovoltaic tenant electricity contracts introduces new complexities, as landlords might qualify as small entrepreneurs, facing additional value-added and income tax obligations. Finally, extending the framework to condominium structures with mixed owner-occupiers and renting landlords would better reflect the institutional reality of the German building stock and identify potential conflicts in joint modernization decisions.

6. Conclusion

Our study introduced an optimization approach that integrates the German tax framework into modernization decisions for MFH, focusing on the fiscal realities of private landlords. To capture these investor-specific boundary conditions, we extended an existing MILP model for building energy systems and envelope measures. By incorporating income and value-added tax effects into the objective function, we evaluated post-tax annualized total costs across varying taxable income levels. This approach enabled a comprehensive comparison between tax-influenced modernization strategies and a traditional pre-tax baseline, while fully accounting for statutory GEG requirements and federal subsidy programs.

The results demonstrate that integrating tax mechanics substantially alters cost-optimal strategies, reducing post-tax annualized total costs by up to 16%. Under GEG constraints and active subsidy regimes, the optimizer identifies a moderate envelope retrofit as the cost-minimal solution for low taxable incomes (20,000 €/year). Conversely, for medium (60,000 €/year) and high (90,000 €/year) income brackets, the model dictates deep insulation across all building components coupled with heat pump systems. This structural shift is driven by amplified depreciation deductions at higher marginal tax rates. Consequently, tax deductions systematically improve the economic viability of capital-intensive deep retrofits. This shift in the optimal building envelope design simultaneously increases eligible subsidy allocations, thereby compounding the overall reduction in annualized total costs.

When isolating the pure economic drivers by removing GEG mandates, the analysis reveals that tax effects dictate the optimal energy system choice alongside envelope measures. At lower income levels, the model defaults to fossil-based configurations due to insufficient tax leverage. However, as taxable income increases, amplified tax savings and parallel subsidy receipts offset the higher capital expenditures of low-carbon technologies, rendering fully electrified heat pump systems economically optimal. Thus, existing tax relief mechanisms inherently favor capital-intensive decarbonization investments for high-income households.

Consequently, the progressive income tax framework induces a structural asymmetry in modernization incentives. The resulting tax leverage renders capital-intensive deep retrofits highly cost-effective for landlords in upper income brackets, while those with lower taxable incomes remain constrained by insufficient fiscal relief. Although regulations and subsidies shift pre-tax optima toward renewables, their overall efficacy is highly contingent upon the investor's tax position. From a policy perspective, relying on current tax-based instruments primarily subsidizes decarbonization among financially robust actors. To align modernization incentives across all income groups and accelerate MFH decarbonization, policymakers must design more progressive support mechanisms—such as elevated grant rates or enhanced depreciation options specifically targeted at lower-income earners. Ultimately, our study underscores that evaluating building policies solely on pre-tax cost metrics fundamentally misrepresents their true economic effectiveness, as post-tax perspectives drastically alter both technology attractiveness and the distribution of benefits among investors.

While this study demonstrates the profound impact of taxation, the current framework is limited by its assumptions of full equity financing and a single, static investment cycle. Future research must therefore integrate debt-financing mechanisms and address the landlord-tenant dilemma by incorporating modernization levies, explicit rental incomes, and tenant-electricity models. Additionally, extending the optimization to mixed-ownership condominium structures will ensure the model fully reflects the institutional realities of the existing building stock.

Acknowledgments

We gratefully acknowledge the financial support by the Federal Ministry for Economic Affairs and Energy (BMWE), promotional reference 03EN1100A

Nomenclature

Abbreviations

ASHP	Air-source heat pump
BAT	Battery storage
BEG	Federal Funding for Efficient Buildings
BES	Building energy system
BOI	Gas boiler
CHP	Combined heat and power
CRF	Capital recovery factor
EEG	Renewable Energy Sources Act
EH	Electric heater
GEG	Building Energy Act
MFH	Multi-family house
MILP	Mixed-integer linear programming
PV	Photovoltaic system
STCFP	Solar thermal flat-plate collector
STCVT	Solar thermal vacuum tube collector
TES	Thermal energy storage
TES-DHW	Domestic hot water storage tank
VAT	Value-added tax

Variables

B^{dep}	Prod. costs class. binary
$B^{\text{dep,energy}}$	Energy eff. class. binary
$B^{\text{dep,time}}$	Time & cost class. binary
$C^{\text{ann,total}}$	Post-tax ann. total costs
$C^{\text{inv,tax}}$	Tax-relevant inv. costs
C^{sub}	Received subsidy amounts
C^{tax}	Total ann. tax effect
$C^{\text{tax,income}}$	Ann. income tax saving
$C^{\text{tax,VAT}}$	Ann. VAT saving
$C_t^{\text{tax,dep}}$	Incremental depr. yr t
$C_t^{\text{tax,exp}}$	Maint. expenses yr t
D_t	Selected tax deduction
E^{save}	Energy saving fraction
$E^{\text{use,after}}$	Post-mod. energy use
$I_t^{\text{tax,landlord}}$	Taxable income yr t
L_t^{tax}	Post-mod. tax liability yr t
ΔC^{inv}	Inv. cost threshold diff.
ΔE^{mod}	Energy saving threshold diff.

Parameters

c^{acq}	Acquisition cost
$e^{\text{use,b}}$	Pre-mod. energy use
i	Interest rate
$i_t^{\text{tax,landlord}}$	Pre-mod. taxable income
$l_t^{\text{tax,landlord}}$	Pre-mod. tax liability
M, ε	Big-M parameters
T	Observation period
δ^{dep}	Statutory depr. rate

References

[1] European Commission. Energy efficiency in buildings. In: *European Commission – Department: Energy – In focus* (Feb. 2020). URL: `https://commission.europa.eu/news/focus-energy-efficiency-buildings-2020-02-17_en`.

[2] European Parliament. Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast) (Text with EEA relevance). en. In: (Apr. 2024).

[3] Eurostat. *Housing in Europe*. eng. LU: Publications Office, 2025. URL: `https://ec.europa.eu/eurostat/web/interactive-publications/housing-2025` (visited on 03/27/2026).

[4] L. Kühn, N. Fuchs, L. Braun, L. Maier, and D. Müller. Landlord–Tenant Dilemma: How Does the Conflict Affect the Design of Building Energy Systems? en. In: *Energies* 17.3 (Jan. 2024), p. 686. ISSN: 1996-1073. DOI: `10.3390/en17030686`. URL: `https://www.mdpi.com/1996-1073/17/3/686` (visited on 12/19/2024).

[5] Forschungsnetzwerke Energie. *Regulatorische Rahmenbedingungen im Forschungsbereich Energiewendebauen*. Tech. rep. Forschungsnetzwerke Energie, 2024. URL: https://www.forschungsnetzwerke-energie.de/lw_resource/datapool/systemfiles/agent/fnepublications/4f460090-d324-11ef-8b06-a0369fe1b6c9/live/document/BF-Modul_Geba%CC%88ude_Regulatorische_Rahmenbedingungen.pdf.

[6] dena. Praxisleitfaden für Wärmepumpen in Mehrfamilienhäusern. Status Quo. Erfahrungen. de. In: *Deutsche Energie-Agentur* (2024).

[7] V. Harish and A. Kumar. A review on modeling and simulation of building energy systems. en. In: *Renewable and Sustainable Energy Reviews* 56 (Apr. 2016), pp. 1272–1292. ISSN: 13640321. DOI: 10.1016/j.rser.2015.12.040. URL: https://linkinghub.elsevier.com/retrieve/pii/S1364032115014239 (visited on 10/27/2025).

[8] M. Wirtz, M. Hahn, T. Schreiber, and D. Müller. Design optimization of multi-energy systems using mixed-integer linear programming: Which model complexity and level of detail is sufficient? en. In: *Energy Conversion and Management* 240 (July 2021), p. 114249. ISSN: 01968904. DOI: 10.1016/j.enconman.2021.114249. URL: https://linkinghub.elsevier.com/retrieve/pii/S0196890421004258 (visited on 10/27/2025).

[9] N. Fuchs, J. Baumgärtner, L. Maier, and D. Müller. Development of an optimization-based methodology for subsidy programs of residential buildings. en. In: *Applied Thermal Engineering* 260 (Feb. 2025), p. 124880. ISSN: 13594311. DOI: 10.1016/j.applthermaleng.2024.124880. URL: https://linkinghub.elsevier.com/retrieve/pii/S1359431124025481 (visited on 10/27/2025).

[10] D. Steck. *Praxiswissen Immobilien und Steuern: die wichtigsten Steuerarten*. 3., völlig überarbeitete Auflage. Haufe Fachbuch. Freiburg: Haufe-Lexware, 2022. ISBN: 978-3-648-15836-4.

[11] R. Kunze. Techno-ökonomische Planung energetischer Wohngebäudemodernisierungen : Ein gemischt-ganzzahliges lineares Optimierungsmodell auf Basis einer vollständigen Finanzplanung. In: (2016). DOI: 10.5445/KSP/1000054969. URL: https://publikationen.bibliothek.kit.edu/1000054969 (visited on 05/10/2025).

[12] K. Neuhoff, H. Amecke, A. Novikova, K. Stelmakh, J. Deason, and A. Hobbes. *Using Tax Incentives to Support Thermal Retrofits in Germany*. eng. Research Report. CPI Report, Climate Policy Initiative, 2011. URL: https://www.econstor.eu/handle/10419/65870 (visited on 03/23/2026).

[13] *Einkommensteuergesetz (EStG)*. Bundesrecht, Stand: November 2025. URL: https://www.gesetze-im-internet.de/estg/.

[14] I. A. und Qualifikation der Universität Duisburg-Essen. *Einkommensteuertarif 2025: Grenz- und Durchschnittssteuersätze*. https://www.sozialpolitik-aktuell.de/files/sozialpolitik-aktuell/_Politikfelder/Finanzierung/Datensammlung/PDF-Dateien/abbIII21a.pdf. 2025.

[15] J. Lindauer. Immobilien und Steuern. de. In: *Immobilien und Steuern*. Wiesbaden: Springer Fachmedien Wiesbaden, 2020, pp. 1–106. ISBN: 978-3-658-29332-1 978-3-658-29333-8. DOI: 10.1007/978-3-658-29333-8_1. URL: http://link.springer.com/10.1007/978-3-658-29333-8_1 (visited on 05/15/2025).

[16] I. d. W. i. D. e. (IDW). *Abgrenzung von Erhaltungsaufwand und Herstellungskosten bei Gebäuden in der Handelsbilanz (IDW ERS IFA 1 n.F.)* 2024. URL: https://www.idw.de/idw/idw-aktuell/idw-ers-ifa-1-n-f-zur-abgrenzung-von-erhaltungsaufwand/-und-herstellungskosten-bei-gebaeuden.html.

[17] R. u. Partner. *Energetische Sanierung, Erhaltungsaufwand oder Herstellungskosten?* April 2025. URL: https://www.roedl.de/themen/fokus-public-sector/2025/april/energetische-sanierung-erhaltungsaufwand-oder-herstellungskosten.

[18] F. Nordrhein-Westfalen. *So ermitteln Sie die Abschreibung für Ihr Vermietungsobjekt*. Abruf am 16.11.2025. URL: https://www.finanzamt.nrw.de/steuerinfos/privatpersonen/haus-und-grund/so-ermitteln-sie-die-abschreibung-fuer-ihr.

[19] *EStR R 7.4 (Zu § 7 EStG)*. Einkommensteuer-Richtlinien, R 7.4, Stand: November 2025. URL: https://datenbank.nwb.de/Dokument/443548_7___4/.

[20] *§ 7 EStG - Einzelnorm*. URL: https://www.gesetze-im-internet.de/estg/__7.html (visited on 03/27/2026).

[21] T. Schütz, L. Schiffer, H. Harb, M. Fuchs, and D. Müller. Optimal design of energy conversion units and envelopes for residential building retrofits using a comprehensive MILP model. en. In: *Applied Energy* 185 (Jan. 2017), pp. 1–15. ISSN: 03062619. DOI: 10.1016/j.apenergy.2016.10.049. URL: https://linkinghub.elsevier.com/retrieve/pii/S0306261916314933 (visited on 10/27/2025).

[22] ista. *So sieht das typische Mehrfamilienhaus aus*. Juli 2020. URL: https://www.ista.com/fileadmin/twt_customer/countries/content/Germany/Images/Content_Hub/20200805_Content-hub_Studie_Mehrfamilienhaus_Web_final.pdf.

[23] Deutsche Energie-Agentur (Hrsg.) (dena, 2025). Begleitdokument KWW-Technikkatalog Wärmeplanung. de. In: (2025). URL: https://www.kww-halle.de/praxis-kommunale-waermewende/bundesgesetz-zur-waermeplanung.

[24] C. Oberst, P. Sagner, and M. Voigtländer. Private Vermieter in Deutschland. Mit einem besonderen Fokus auf Köln und Düsseldorf, Gutachten im Auftrag des Kölner Haus- und Grundbesitzervereins von 1888 und Haus und Grund Düsseldorf und Umgebung. In: (2025). URL: https://www.iwkoeln.de/fileadmin/user_upload/Studien/Gutachten/PDF/2025/Gutachten-Private-Vermieter-in-Deutschland.pdf.