# Unequal Income Effects of Home Insulation across Heterogeneous Households: A Microsimulation Analysis for the Netherlands

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***Abstract***
We calculate income effects of home insulation at the individual household level and show how these effects are distributed across heterogeneous households, which differ in terms of income, house type, and ownership status. The analysis is motivated by the observation that welfare effects of home insulation and heat-pump adoption are ambiguous and unevenly distributed among households, while unequal welfare effects of energy transition policies may be at odds with the idea of a just energy transition. To this end, we develop an innovative modeling platform that links a new energy microsimulation model for the built environment (HESTIA) to an existing income simulation model (MIMOSI) and to administrative microdata on the income and wealth position, ownership situation and energy consumption of each individual household in The Netherlands. The annual income effects of dwelling insulation and heat-pump adoption consist of the higher rent or mortgage costs due to retrofit and installation investments (adjusted for subsidy), lower gas expenditure, and the change in rent allowance or mortgage interest deduction. Calculations indicate that the average investment cost per home to meet insulation standards is approximately €18,000. On average, gas savings in volume amount to around 32% of original gas consumption. In the base case, the median income effect is 1.3% for tenants in the social housing sector, compared to -0.2% and -0.1% for homeowners and tenants in the commercial housing sector, respectively. Variations in assumptions regarding gas prices, interest rates, and energy savings have a limited impact on these median income effects. Across all scenarios, the income effects would be significantly less favorable without policy measures to support insulation efforts. Approximately 15% of homeowners and private renters experience a negative income effect exceeding 1%. These households are typically characterized by relatively large homes, low incomes, low gas consumption, and older occupants.

***Keywords***: Home insulation, income effects, microsimulation, microdata, just energy transition

# 1. Introduction

Climate change and welfare inequality represent two of the most pressing and far-reaching challenges facing Europe in the coming decades. Driven by ambitious climate targets and persistently high energy costs in recent years, governments and individual citizens within the European Union (EU) have increasingly prioritized investments in energy efficiency improvements within the built environment. Energy efficient retrofitting of residential buildings stands out as a pivotal intervention, delivering private advantages such as reduced energy expenditures and enhanced domestic comfort, alongside broader societal benefits, including lower CO2 emissions, diminished social costs linked to energy poverty, and decreased reliance on natural gas imports amid geopolitical uncertainties. In light of these considerations, the European Union Energy Performance of Buildings Directive (EU/2024/1275) stipulates a mandatory 16% enhancement in the energy performance of residential buildings by 2030.

Despite its potential, the private welfare effects of home insulation remain uncertain and are unevenly distributed. High initial investment costs and uncertain payback periods, influenced by fluctuating energy prices and evolving policies, create significant challenges for homeowners. Additionally, the feasibility and cost-effectiveness of insulation vary markedly across households due to differences in dwelling characteristics and quality, ownership status, and income levels. While large-scale home renovation programs may, in theory, offer opportunities to improve energy efficiency and reduce inequality, they also risk exacerbating income and welfare disparities in practice due to the heterogeneity among homeowners.

These disparities underscore the complex relationship between insulation policies and broader issues of equity and social justice within the context of the energy transition. An energy transition that fails to ensure equitable access to the benefits of home renovation may not only deepen existing inequalities but also undermine public support for climate policies. In response, the revised European Union Energy Efficiency Directive (EU/2023/1272) highlights the importance of addressing energy poverty by strengthening regulatory frameworks to identify and remove barriers to energy efficiency renovations.

Designing effective, efficient, and equitable policies to promote home insulation adoption requires a detailed analysis of the distributional effects of its private costs and benefits. National-level estimates often obscure substantial household heterogeneity, which has significant implications for equity and subsidy allocation. This study employs a newly developed microsimulation modeling platform and microdata to assess the private costs and benefits of home insulation in the Netherlands. Specifically, the platform integrates two microsimulation models: the existing MIMOSI income simulation model used by the Netherlands Bureau for Economic Policy Analysis (CPB) and the HESTIA spatial energy simulation model for the built environment, newly developed by the Netherlands Organization for Applied Scientific Research (TNO) and the Netherlands Environmental Assessment Agency (PBL). The models are soft-linked to each other and to administrative microdata of Statistics Netherlands (CBS) containing detailed information on the income and wealth positions, ownership status, and energy consumption of individual households in the Netherlands. We use these tools to evaluate, for the first time, the distributional income effects of retrofitting all homes in the Netherlands to comply with the 'Insulation Standard,' established by the Dutch government in 2021 (Ollongren, 2021; Nieman, 2021). This standard indicates when a home is sufficiently insulated to be made gas-free, serving as a benchmark for achieving adequate, future-proof insulation.

The analysis adopts a "what-if" approach, examining the hypothetical costs and benefits of retrofitting all existing Dutch homes to meet the insulation standard. While we abstract from temporal and practical feasibility, the primary research questions addressed include: For how many and which households does investing in insulation measures yield a net positive or negative effect on disposable income? What is the distribution of income effects across different household types? How does the distribution of these income effects shift under varying energy prices and interest rates? Our findings enrich the policy discourse by offering granular evidence on the distributional impacts of home insulation policies, thus informing strategies for equitable and effective energy transitions.

The income effects of home insulation in this study are defined as the net impact of investment costs passed through as higher housing expenses, offset by reductions in energy bills resulting from decreased gas consumption after insulation. Investment costs are calculated at the level of individual dwellings, based on the requirements needed to meet the Insulation Standard, given the current energy performance and characteristics of each property. The analysis assumes conditions prevailing in 2023, including the quality and composition of the housing stock, investment costs, and interest rates. We operate under the assumption that building owners—whether corporate or private—are responsible for ensuring compliance with the insulation standard. For rental properties, we consider two scenarios: either the landlord passes the incurred costs to tenants via rent increases, or the costs are absorbed entirely by the landlord in cases of social housing. For owner-occupied homes, we assume that investments are financed through a mortgage, leading to increased housing costs through mortgage repayments and interest. We further account for changes in disposable income due to alterations in rent allowances and mortgage interest deductions resulting from these financial adjustments. The total income effect is expressed as a percentage change in disposable income relative to the pre-insulation baseline. Finally, we explore how variations in energy prices and interest rates influence the distribution of income effects across individual households.

The structure of this article is as follows. In section 2, we position our study in relation to the existing literature. In section 3, we present our methodology, consisting of the new model infrastructure and the associated microdata, plus the key assumptions used in the calculations. In Section 4, we present our results for investment costs and energy savings involved in home insulation, broken down by different types of households and dwellings. In Section 5 we present the calculated income effects broken down by income category, housing type, and type of home ownership. In Section 6, we draw key conclusions and discuss implications for policy and follow-up research.

# 2. Literature

Our analysis relates to several strands of literature. First, the HESTIA energy simulation model builds upon a long tradition of bottom-up data-driven microsimulation modeling for the built environment, assessing end-use energy consumption in residential buildings - including the impact of building retrofits (cf. Deb and Schlueter, 2021; Kavgic et al., 2010; Swan and Ugursal, 2009). At its core, the HESTIA model estimates energy use at the level of individual dwellings based on fundamental physical laws governing building energy dynamics, incorporating detailed information about building geometry, materials, systems, and occupancy patterns to simulate energy performance accurately. The primary strength of this approach is its high accuracy and ability to uncover determinants of energy consumption. However, this precision comes at the cost of being data- and computationally intensive, posing challenges for large-scale applications. Deb and Schlueter (2021) therefore advocate hybrid approaches that leverage both data-driven models and physical principles, while underscoring the critical role of data-driven energy modeling in building retrofits. HESTIA adheres to this recommendation by integrating a bottom-up approach, which leverages individual building-level data, with the broader scale and extensive dataset characteristics of top-down approaches (PBL & TNO, 2023; TNO & PBL, 2023).

A key contribution of this study is the soft-linking of the HESTIA model with the macroeconomic income accounting model (MIMOSI) and administrative microdata on household occupants. This integration allows us to assess the income effects of retrofitting at the household level. Most existing energy models that evaluate the costs and benefits of home retrofitting primarily focus on buildings as the unit of analysis. Households, when considered, are often treated as inputs related to energy demand behavior. In contrast, our analysis moves beyond this conventional approach by explicitly linking dwelling characteristics to occupant profiles including data on income, wealth and homeowner status, thereby enabling a comprehensive examination of how energy-saving investments affect the incomes of heterogeneous households.

Second, the results of our analysis relate to empirical studies examining the costs and benefits of house retrofitting, including estimates of realized energy savings (Aydin et al., 2017; McCoy and Kotsch, 2021; Liang et al., 2018; Papineau et al., 2024). For the Netherlands, prior research by the Netherlands Environmental Assessment Agency (PBL, 2020) estimated net energy costs before and after retrofitting for 20 household types in representative mid-terrace houses, factoring in required investment costs. The findings suggested that budget neutrality—higher housing rents offset by lower energy bills—was often unfeasible, with significant variation across household groups. For many homeowners, even in the long run, energy savings did not fully compensate for the costs of retrofitting. However, PBL (2020) did not account for the high energy prices observed in recent years, nor did it consider combinations of insulation measures or subsidy schemes. A related study by TNO (2020) examined retrofitting costs and benefits for a broader set of dwelling types but did not specifically address its feasibility. This study expands upon that work by considering all housing types, differences in energy efficiency quality of dwellings, and combinations of insulation measures and subsidies to calculate income effects across heterogenous households, differentiating the results by income groups, housing types and ownership situations under various assumptions regarding interest rates and energy prices. Other recent empirical studies for the Netherlands further illustrate the complexity of retrofitting outcomes. Eichholtz et al. (2023) analyzed realized energy savings for over 1,300 homes in Limburg, while Roberdel et al. (2023) investigated energy efficiency improvements in social housing across income groups over five years post-renovation, based on quasi-experimental data from 125,000 households. Our predicted energy savings exceed realized savings reported in these studies, primarily because of differences in sampling methods – unlike specific subsets of homes, our study examines the entire housing stock in the Netherlands – and because our model assumes compliance with the Insulation Standard, whereas actual retrofits often fall short of this standard.

Third, our study relates to studies that assess the observed difference between predicted and actual energy savings after adoption of energy saving technologies, including building retrofitting (e.g. Allcott en Greenstone 2017, Aydin et al. 2017, Fowlie et al. 2018). Possible explanations for discrepancies between technical model predictions and realized energy savings include overly optimistic expert estimates, errors in the implementation of insulation, or behavioral changes by residents (Zou et al., 2018). With regard to the latter, prior research has shown that lower energy costs resulting from improved insulation can induce higher energy consumption, partially offsetting the expected savings—a phenomenon referred to as the rebound effect (Aydin et al., 2017; Gillingham et al., 2016; Sorell et al., 2009). Multiple studies indicate that, despite the rebound effect, net energy savings persist following retrofitting (Fowlie et al., 2018; Hong et al., 2006; Liang et al., 2018; Metcalf & Hassett, 1999). In an extensive review of 40 years of energy efficiency policies, Saunders et al. (2021) argue that while rebound effects are non-trivial, energy efficiency programs have generally been effective. Similarly, Eichholtz et al. (2023) demonstrate that reduced gas consumption resulting from insulation in the Netherlands remains stable up to nine years post-retrofit, suggesting minimal or no rebound effect. However, contrasting evidence exists. Peñasco and Díaz Anadón (2023) analyze insulation programs in England and Wales (2005–2017) and find that while significant reductions in gas consumption occur in the first year post-retrofit, these effects largely dissipate within two to four years. They attribute this to behavioral factors (including the rebound effect) and other household investments that increase energy use, such as home extensions. Furthermore, they observe substantial variations in long-term insulation impacts across household types, influenced by income and housing characteristics. The HESTIA model used in this study does not explicitly simulate rebound effects but accounts for household behavior by calibrating expected energy savings against historical consumption data at different insulation levels (see Section 3).

Fourth, this study contributes to the expanding body of literature on a just and inclusive energy transition (Bird and Hernández, 2012; Bouzarovski & Simcock, 2017; Sovacool, 2021; Heffron & McCauley, 2017). We show how costs and benefits of home retrofitting vary across heterogeneous households. By differentiating outcomes based on income groups, home types and ownership situations, this study aims to provides insights into how targeted policies and subsidy schemes can enhance fairness and accessibility in energy efficiency improvements. In doing so, it aligns with ongoing efforts to integrate equity considerations into energy transition policies, ensuring that vulnerable households are not disproportionately affected and that the transition yields widespread societal benefits (Sovacool, 2021). For example, principal-agent problems prevalent in rental housing, where landlords finance insulation improvements while tenants benefit from lower energy bills, imply a misalignment of costs and benefits that may hinder investments (Ürge-Vorsatz and Tirado Herrero 2012). The Netherlands has a relatively large social housing sector, which is more tightly regulated than the commercial rental sector—among other things, through performance agreements on housing renovations aimed at addressing the aforementioned principal-agent problems. In response to the high energy prices of recent years, the Dutch government recently introduced a measure prohibiting landlords from passing on insulation investment costs to tenants in the social housing sector. This protection does not apply to tenants in the commercial rental sector. In our analysis, we account for these differences and demonstrate that, as a result, the net benefits of insulation are, on average, significantly higher for tenants in the social housing sector compared to those in the commercial rental sector. We show that low-income households in the commercial rental sector are particularly at risk of experiencing negative income effects after home insulation, whereas comparable low-income households in the social rental sector benefit significantly. These differences are crucial to consider when striving for a fair and inclusive energy transition.

Finally, our study relates indirectly to research on the influence of energy efficiency (labels) on property values in the housing market (e.g. Aydin et al. 2020, Brounen and Kok 2011, Kahn, M.E., N. Kok, 2014). For example, Aydin et al. (2020) show that the average value of Dutch homes increases by 2.2 percent when energy efficiency increases by 10 percent. From an analysis with repeated sales of the same homes (before and after energy efficiency improvements) for the period 2008-2015, they infer that the investment in energy efficiency is fully translated into a higher sales value. Brainbay (2022) analyzes the effect of a better energy label on home value (see here), and finds that a home with energy label C yields on average 7.9% more than a comparable home labeled G. This capital gain increases after 2021, presumably due to a wider housing market and higher energy prices. In a well-functioning housing market, the higher home value equals the net present monetary value of all the benefits of a well-insulated home—including lower energy bills, reduced susceptibility to energy price fluctuations and increased home comfort. In our analysis, of all these benefits, we calculate only that of the lower energy bill – and thus a portion of the home value increase due to energy efficiency improvements.

# 3. Method

## 3.1 Income effects

We calculate the income effects of home insulation as the pass-through of the investment costs required to meet the insulation standard minus the energy cost savings *(Δ Energy costs)* due to insulation (Equation 1). The change in housing costs involves rent increases or additional mortgage costs including repayment, depending on the home-ownership *(Δ Housing costs)*. We also take into account changes in disposable income due to changes in rent allowance as a result of any rent increase and change in mortgage interest deduction as a result of an increase in mortgage payments *(Δ Disposable income)*. We express the total change in disposable income as a percentage change, relative to the situation before insulation measures were taken (*Disposable income$_{before\ insulation}$*). As follows:

$$Income\ effect = \frac{\Delta\ Housing\ costs + \Delta\ Energy\ cossts + \Delta\ Disposable\ income}{Disposable\ income\ _{before\ insulation}} \tag{1}$$

In calculating the income effect, we assume that the investment leads to immediate energy savings. We then calculate the change in net expenses for that same year, assuming a full calendar year. Thus, we always show the income effect for the first year after insulation.

For rental properties, the basic principle is that the owner-landlord must ensure that the property will meet the insulation standard. In principle, the costs incurred can then be passed on to the tenant in the form of a rent increase. We distinguish between rent increases for social housing and other (private) rental housing. As noted before, for the first group of homes, the costs of home renovation can no longer be passed on to the tenant; this is the case if the renovation is completed after January 1, 2023. This ruling stems from the National Performance Agreements for Public Housing agreed in 2022 (Min BZK 2022) between the interest groups of housing associations (Aedes) and tenants (the Woonbond), the Association of Dutch Municipalities (VNG) and the Minister of Internal Affairs & Kingdom Relations (BZK). Private landlords can pass on the investment costs to the tenant, but can take advantage of a new subsidy scheme (SVOH) (RVO 2021) that reimburses 30% of the investment costs. In our analysis, this rent increase is based on the

HESTIA model calculation of investment costs (see section 3.2), which we then convert to an expected rent increase according to the rules of the National Rent Commission (Rent Commission, 2018). These rules imply that a renovation subsidy leads to a lower rent increase. For households entitled to income-dependent rent subsidies, we also take into account the change in rent subsidies after home insulation.

For owner-occupied housing, we assume that all owner-occupiers finance the investment amount through a mortgage. We abstract from choice behavior regarding the use of equity or other possible sources of financing – in order to keep the analysis tractable and given that our analysis has a "what-if" nature, where financing bottlenecks do not play a role. We therefore assume financing via a mortgage for all owner-occupiers, disregarding individual borrowing capacity and standards. This mortgage is annuitized, has a term of 25 years and applies at the average mortgage rate in the Netherlands of 4% in 2023. This results in an annual mortgage payment amount, where we assume tax deductibility of mortgage interest. We conducted robustness checks on the income effects for other interest rates (see Table 5).

All homes where insulation measures are implemented require less energy to maintain the same temperature in the dwelling. The HESTIA energy model for the built environment (see section 3.2) calculates the decrease in gas consumption needed to achieve the same level of comfort, in terms of indoor temperature, in the home after insulation. This difference in energy demand is then converted into savings on energy bills. Of course, the financial savings depend on the energy price. Because of the large uncertainty about future energy prices, we work with three energy price scenarios (see section 3.3).

### 3.2 Modelling platform

We developed a new microsimulation modeling platform that soft-links two microsimulation models and makes use of administrative microdata at the household-level (see Figure 1). The first model is the HESTIA spatial energy simulation model for the built environment, newly developed by the Netherlands Organization for Applied Scientific Research (TNO) and the Netherlands Environmental Assessment Agency (PBL). We employ HESTIA to calculate for each individual home an insulation package that allows the home to meet the minimum values for the insulation standard for each building section (see Appendix 1). The model then calculates the associated investment costs and the resulting savings in energy demand and energy costs at the level of individual homes. This HESTIA output is used as input to the second model, which is the exiting microsimulation model MIMOSI of the Netherlands Bureau for Economic Policy Analysis (CPB). MIMOSI takes the HESTIA produced data on investment costs and energy savings of per individual home to calculate how each households' disposable income changes due to the pass-through of investment costs on housing costs, in combination with lower energy costs and changes in rent allowance as a result of any rent increase and change in mortgage interest deduction allowances (see Figure 1). For this purpose, MIMOSI is also linked to administrative microdata from CBS Statistics Netherlands[1] on the income and wealth position and ownership situation of each individual household (see section 3.3). Such a calculation and coupling of data and models at this level has not been done before for the whole of the Netherlands.

[1] Microdata catalogue | CBS

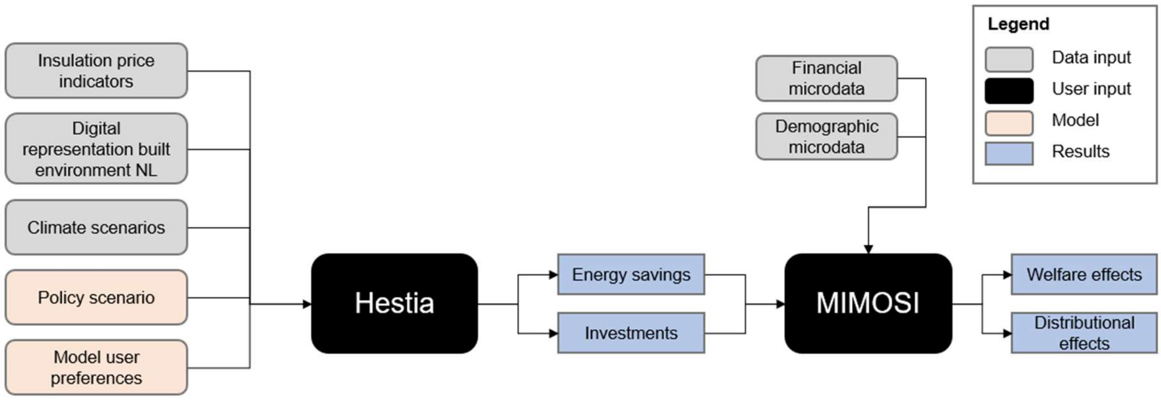



*Figure 1: The modelling & data platform deployed to calculate income effects of home insulation*

the existing MIMOSI income simulation model used by the Netherlands Bureau for Economic Policy Analysis (CPB) and the HESTIA spatial energy simulation model for the built environment, newly developed by the Netherlands Organization for Applied Scientific Research (TNO)

**HESTIA model**

The primary objective of the Hestia model (PBL & TNO, 2023) is to evaluate investments in the housing stock that are needed to improve energy efficiency. This includes both insulation measures and adoption of energy system installations, with investment decisions based on cost-benefit analyses. The model is calibrated to reproduce national statistics on gas consumption in residential buildings and the adoption rates of measures such as home insulation. Hestia can simulate scenarios based on parameters that influence the cost-benefit analysis of investments, including energy prices, insulation or system standards, subsidies, and the costs of materials and installations. In the analysis presented here, households in the Hestia model do not independently perform a cost-benefit analysis for insulation choices. Instead, an insulation standard is imposed on households within the model.

The core of the model is formed by a digital 3D representation of the entire housing stock based on the 3D BAG dataset (TU Delft 2024), which provides a complete picture of the technical properties of each house in the Netherlands, including the surface and insulation metrics of individual building components and types of installations. The model provides a digital representation of the housing stock in the Netherlands for the period 2000-2050. Calibration of the model reckons with housing stock changes over time in terms of composition as a result of demolition and new construction, energy demand, and other properties. To identify the income effects of insulation measures, in our analysis HESTIA calculates for each home the investment costs to meet the insulation standard, given the current energetic quality of the home and the insulation measures needed for the home. To this aim HESTIA uses material and construction cost indices from an annually updated dataset for the Netherlands based on market analyses (RVO 2022) to determine the costs of energy saving measures, which then adds up to the total costs of energy saving per house to meet the insulation standard.

Using the detailed data on dwelling characteristics (e.g. year of construction, surface area, type of dwelling) and technical characteristics per building component, HESTIA then calculates the energy demand for space heating, cooking, electrical appliances, domestic hot water and cooling for each dwelling in the Netherlands – corrected for local and annual temperature differences. The model reproduces the actual situation since the year 2000 based on historical data and simulates future energy demand per home based on given scenarios. The energy demand for space heating is primarily determined by the amount of heat transmittance through walls, doors, roofs and facades. This heat loss depends on the degree of insulation of these various building components combined with the difference between indoor and outdoor temperatures.

More specifically, Hestia utilizes a single zone heat transmission approach to calculate per individual dwellings the net amount of energy input required ($ED_{HI}$) as the product of functional space heating demand ($E_{SH}$) and the efficiency of the heating installation ($F_{HI}$):

$$ED_{HI} = E_{SH} * F_{HI} \tag{2}$$

The functional energy demand for space heating ($E_{SH}$) refers to the amount of energy that needs to be generated by a heating installation disregarding heating installation efficiency. It is included in the HESTIA model in terms of a heat balance calculation, defined as the net sum of the cumulative heat loss ($L$) and heat gain ($G$) of individual building components ($B$), heat loss through ventilation ($L_V$), and an indoor temperature correction factor ($C$), according to:

$$E_{SH} = \{-[(\sum_B L_B + L_V) * C] + \sum_B G_B\} * F_{HI}. \tag{3}$$

The heat loss of an individual building element depends on its surface area and insulation quality. The total heat loss for all individual building parts is corrected for a climate effect, defined as the fraction between the amount of degree days in a given view year compared to the amount of degree days in the reference year of 2020. The heat loss through ventilation is calculated based on technical information on the amount of connections and installation-specific key figures. Heat gain refers to higher indoor temperatures due to the presence of people, appliances and solar radiation, the latter being a function of the total amount of glass and the extent to which the type of glass in a given dwelling allows solar radiation. The correction factor corrects the heat loss calculation for the fact that better-insulated buildings have a higher indoor temperature and thus an increased temperature differential between the indoor and outdoor temperatures—the increase in heat loss per building component ($L_B$) partially offsets the reduced heat permeability due to insulation. It is defined as

$$C = 1 + \alpha * \beta^{L_B(kWh/m^2)} \tag{4}$$

with parameters $\alpha$ = 7.2 and $\beta$ = 0.96 yielded by calibration of the model based on energy demand statistics (reference) and $L_B^{(kWh/m2)}$ the heat loss per building component in kWh per m2. Lastly, heating installation efficiency parameters ($F_{HI}$ ) are based on Seasonal Performance Factors (SPFs) rather than Coefficients of Performance (COPs), i.e. that they refer to efficiency of a heating installation in practice rather than in a controlled setting.

People's heating behavior is taken into account by fitting the model calculations to measured historical energy consumption at a low aggregate housing group level. In doing so, the model allows for the inclusion of an aggregate behavioral component, for example, by downscaling aggregate gas consumption in response to high gas prices. To this aim, all homes in the Netherlands are categorized based on their housing type, ownership type, construction year class, and energy label. For each housing category, a linear relationship was estimated between the standard annual energy consumption and the size of the dwelling in square meters. This process yields a representative consumption level per dwelling size within each category, referred to as the reference consumption. Because these same housing characteristics are also known in Hestia, the reference consumption for each home in Hestia can subsequently be determined. By applying location-specific factors, the gas consumption of all homes in a neighborhood in Hestia aligns with the gas consumption levels measured by CBS (Statistics Netherlands) in that neighborhood. This approach allows Hestia to account for differences in gas consumption between comparable homes in different neighborhoods.

The reference consumption of a home provides an average estimate for each housing category. There is significant variation in energy consumption between housing categories before retrofitting insulation. For example, detached homes tend to consume more energy on average than terraced houses, and older homes typically have higher energy consumption. Furthermore, energy consumption is generally higher in homes with lower energy labels. Within each housing category, energy consumption also varies depending on the floor area of the home. In this way, Hestia accounts for the fact that the potential energy savings achieved through retrofitting insulation can vary significantly between homes with different characteristics.

HESTIA also models the relationship of the housing stock and investment decisions with number of infrastructure networks. For example, the model identifies the costs of necessary changes to gas and electricity networks as a consequence of chosen investment options, which then play a role in the cost-benefit calculation of these options at the individual housing level. Also, the ingrowth of heat networks is endogenously modeled by HESTIA, the presence of which in turn affects the costs and (energetic) benefits of heat supply as an investment option.

The model reproduces national statistics on gas consumption of homes in the built environment and the adoption rate of energy saving measures, including insulation measures. HESTIA can calculate scenarios based on parameters that affect the cost-benefit trade-off of investments, including energy prices, standards for insulation or installations, subsidies, and costs of materials and installations. In the context of this study, however, households do not independently make a choice for insulation based on a cost-benefit calculation, but adhere to an insulation standard that is imposed on households for the sake of our analysis.

**MIMOSI model**

The existing microsimulation model MIMOSI, developed and maintained by The Netherlands Bureau for Economic Policy Analysis (CPB), is used to simulate the effects of tax and benefit policies on households' disposable income (CPB 2016, Goderis and Vlekke 2023). It simulates the effects of changes in real gross income and tax-benefit policies on net household disposable income. The simulation results are normally used by CPB to estimate changes in poverty, income inequality, the effective marginal tax rate and the government budget. MIMOSI is also used to regularly forecast year-on-year changes in real disposable income of Dutch households (CPB 2024).

MIMOSI does not simulate any behavioral responses to policy changes, but essentially performs an accounting exercise for households by calculating the impact of policies on all household income components. It does so by going through all the steps from gross income to disposable income shown in Table 1.

***Table 1.*** *Stylized overview of the Dutch system of taxes and benefits*

| | |
|---|---|
| Gross wages | + |
| Gross profits | + |
| Gross benefits | + |
| Gross pensions | + |
| (Assumed) gross income derived from wealth* | + |
| (Assumed) income derived from home ownership† | + |
| **Gross income** | |
| Taxes | - |
| Income tax credits | + |
| Fiscal effect of tax deductions | + |
| **Net income** | |
| Allowances | + |
| Various individual allowances and compensation schemes | + |
| **Disposable income** | |

*Source: Goderis and Vlekke 2023.*

* Income derived from financial wealth is not taxed directly. Instead, the tax authority makes assumptions about the amount of income derived from the total amount of net household wealth.

† Home ownership is taxed indirectly by assuming that one derives income from owning a home (*'eigenwoningforfait'*).

In short, gross income can consist of wages, profits, benefits, pensions, or income derived from wealth or home ownership. Net income is then calculated as gross income minus taxes plus income tax credits and the fiscal effect of tax deductions. Finally, disposable income is calculated as net income plus allowances and compensation schemes. We use MIMOSI to assess for each household the impact of home insulation measures on disposable income. As noted in section 3.1, home insulation affects income via a pass-through of insulation investment costs on housing costs minus the reduced energy bill due to insulation. In MIMOSI this is effectuated by calculating the change in a households' disposable income due to changes in their rent allowance that comes with a rent increase or a change in mortgage interest deduction due to an increase in mortgage expenses (depending on the home ownership status). The resulting total income effect is expressed as a percentage change of disposable income as compared to the income before the insulation measures were taken.

### 3.3 Data

The HESTIA model uses a broad spectrum of input data to construct a realistic digital image of the built environment in the Netherlands. First, the model is based on use a digital 3D representation of the housing stock with information on the surface area of facade, floor, windows and doors plus insulation levels of individual building components (CBS 2018, TU Delft 2021, PBL & TNO 2023, TNO & PBL 2023). The model is calibrated on historical microdata about energy consumption and energy mix plus data on outdoor temperatures. Information on the evolution development of the housing stock due to construction, demolition and splitting of dwellings is taken from the Spatial Scanner (PBL 2024), which is also used to make the Spatial Outlook for the Netherlands (PBL 2022). Costs of insulation measures per $m^2$ area and ventilation systems per dwellings are based on the Arcadis cost indices – an annually updated database of costs based on market analyses (RVO 2022). Costs for heat installations, solar water heaters and PV panels are based on cost key figures from the VESTA-MAIS model (PBL 2021), while costs for heat networks are determined by expert judgment from PBL (PBL & TNO 2023). The cost key figures used in the HESTIA model are extrapolated to the future on the basis of cost development curves, which are based on trend analysis of historical data from the cost indices database of Arcadis (RVO 2022).

The MIMOSI model used to run on a representative sample of data for 100,000 Dutch households, obtained from Statistics Netherlands. For the benefit of this analysis, however, MIMOSI was coupled to administrative microdata for all 8 million households in the Netherlands. More specifically, MIMOSI was linked to administrative microdata from CBS on each individual household's gross and net income, wealth and ownership status. Concrete data involve information on level of gross and net income, source of income (own income, salary, welfare benefits, pension), savings and (mortgage) debts, rent subsidies, property status and year of construction of the house, household composition and age of the head of household.

Homes that already meet the insulation standard evidently need not to be considered in our calculations. We therefore limit our analysis to homes built before 1992, because homes built more recently are already reasonably to well insulated thanks to new regulations and standards set in the 1992 Building Code (Bouwbesluit 1992). Moreover, we limit our analysis to homes with a gas connection, because we calculate energy savings from insulation in terms of gas savings. This means that we include in our calculation 5,4 million of the total 8 million homes in the Netherlands.

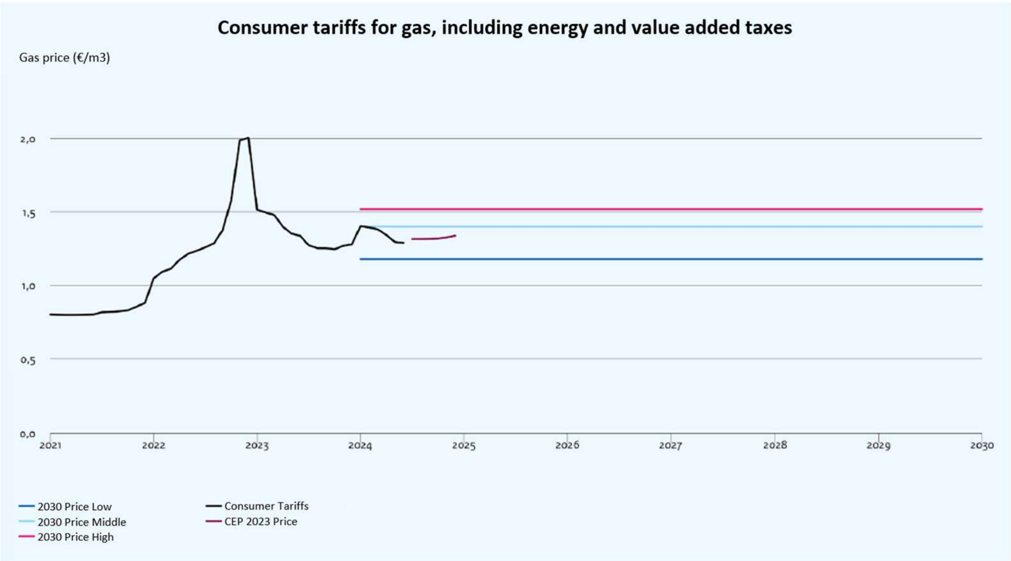



*Figure 1: Consumer tariffs for gas, including energy and value added taxes.*

As mentioned, due to the high uncertainty about future energy prices, we adopt thee energy price scenarios: middle, high and low. These price scenarios are based on estimates from the 2022 Netherlands Climate and Energy Outlook (KEV) for the year 2030 (PBL 2023). The KEV 2023 'middle' energy price serves, together with an interest rate of 4%, as our base case. Figure 1 shows these scenario's for gas prices (including taxes).

# 4. Investment costs and energy savings

## 4.1 Investment costs

Using the HESTIA model, we compute an insulation package for each individual house that allows each building component of the house—such as the cavity wall, roof insulation, or new glass—to meet the minimum values for the national insulation standard (see Annex 1) (Nieman 2021). This package of measures and the associated investment costs enables the individual home to meet the insulation standard. Subsequently, HESTIA models the difference in energy demand for residential heat before and after implementing the insulation package.

The model calculations show that the total investment cost for insulation of all homes in The Netherlands built before 1992 is about 86 billion euros (excluding VAT). Of this, 16 billion euros relate to housing owned by social housing associations. In addition, owner-occupied houses account for 60 billion euro. In total, insulation measures are adopted in 5,4 of the in total 8 million homes in the country. The median investment costs to reach the insulation standard is approximately €15,000 per home. Investment costs are highest for owner-occupiers with about €19,000, and lower for commercial and social rented properties at over €11,000 (see Table 2).

*Table 2. Median investment costs by housing and property type*

| **Housing type** | **Privately Owned** | **Social Rent** | **Commercial Rent** | **Total** |
|---|---|---|---|---|
| Semi-detached | 22,410 | 15,201 | 22,708 | 21,451 |
| Corner house | 19,101 | 13,904 | 17,759 | 17,233 |
| Multi-family house | 11,389 | 8,105 | 9,368 | 8,923 |
| Terraced house | 15,999 | 12,141 | 15,370 | 14,613 |
| Detached | 31,699 | 19,637 | 34,370 | 31,720 |
| Total | 19,187 | 10,912 | 11,239 | 15,073 |

Source: HESTIA; incl. VAT, excl. subsidy, natural moment

These differences can be explained in part by differences in the mix of housing types within these groups of home-owners: among owner-occupiers, the terraced house is the most common housing type; among renters—both social and commercial—it is the multifamily house (apartment). As might be expected, there are clear differences in investment costs between housing types. At over €9,000, the median investment cost for a multi-family house is much lower than that for a terraced house, namely over €15,000. For detached houses, median investment costs are the highest at nearly €32,000. It is noticeable that even within housing types there are still large differences in median costs between owner-occupied and rental properties: for example, insulating a rental apartment has median costs ranging between €8,000 and €9,000, while for owner-occupied apartments this is more than €11,000. This may be related to the size of the homes. For homes built after 1945, investment costs do not differ greatly between year of construction classes. Especially for houses built before 1900, a large variation in investment costs occurs.

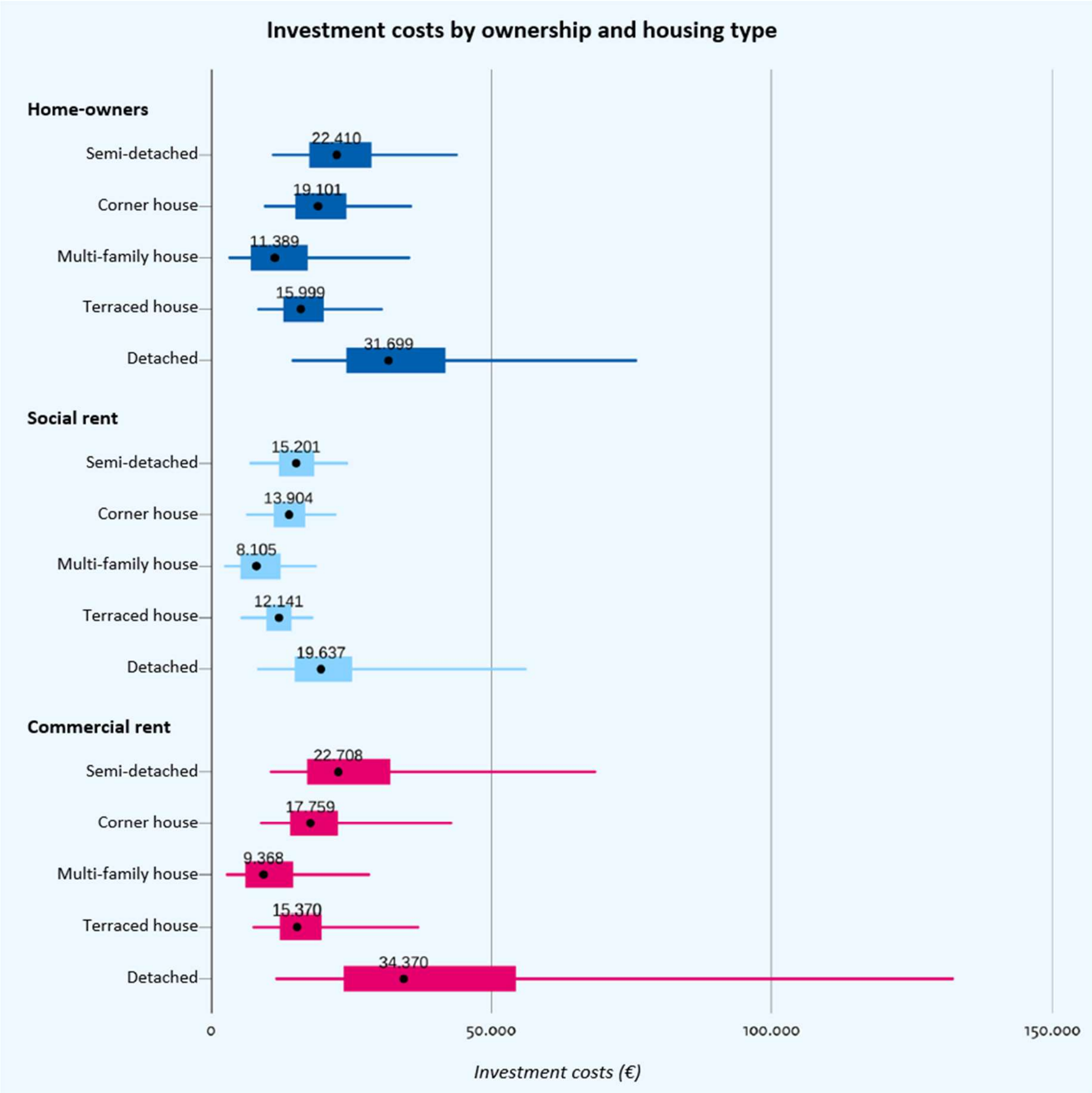
The median costs to insulate a home to the insulation standard amounts to €15,000, but the average investment cost is €18,000 (see Table 2). Costs vary widely between homes, due to differences in year of construction and insulation measures needed. For example, on average, insulating the roof is the most expensive whereas crack sealing is relatively cheap. On average, insulating doors is a relatively expensive part of the insulation package, because many houses have not yet had this done. The opposite is true for insulating windows.

*Table 3. Average investment costs by building component of bringing a house built before 1992 up to the insulation standard.*

| **Building component** | **Costs in euro's*** |
|---|---:|
| Windows | 1,181 |
| Facade (incl. cavity wall) | 2,650 |
| Roof | 5,720 |
| Floor | 3,118 |
| Crack sealing | 769 |
| Door | 4,248 |
| Total | 17,690 |

** Incl. VAT, excl. Subsidy.*

Figure 3 shows the distribution of investment costs by housing and property type. It is noticeable that there is a large variation at the upper end in investment costs for detached homes, particularly for private rental homes. The number of detached private rental homes with a pre-1992 construction year where investments are required to meet the insulation standard is quite limited; for the last 5% of those homes, however, investment costs exceed €132,000.




Source: HESTIA. The box shows the median with the 25th and 75th percentiles. Dots show the median costs. The lines show the 5th and 95th percentiles, respectively.

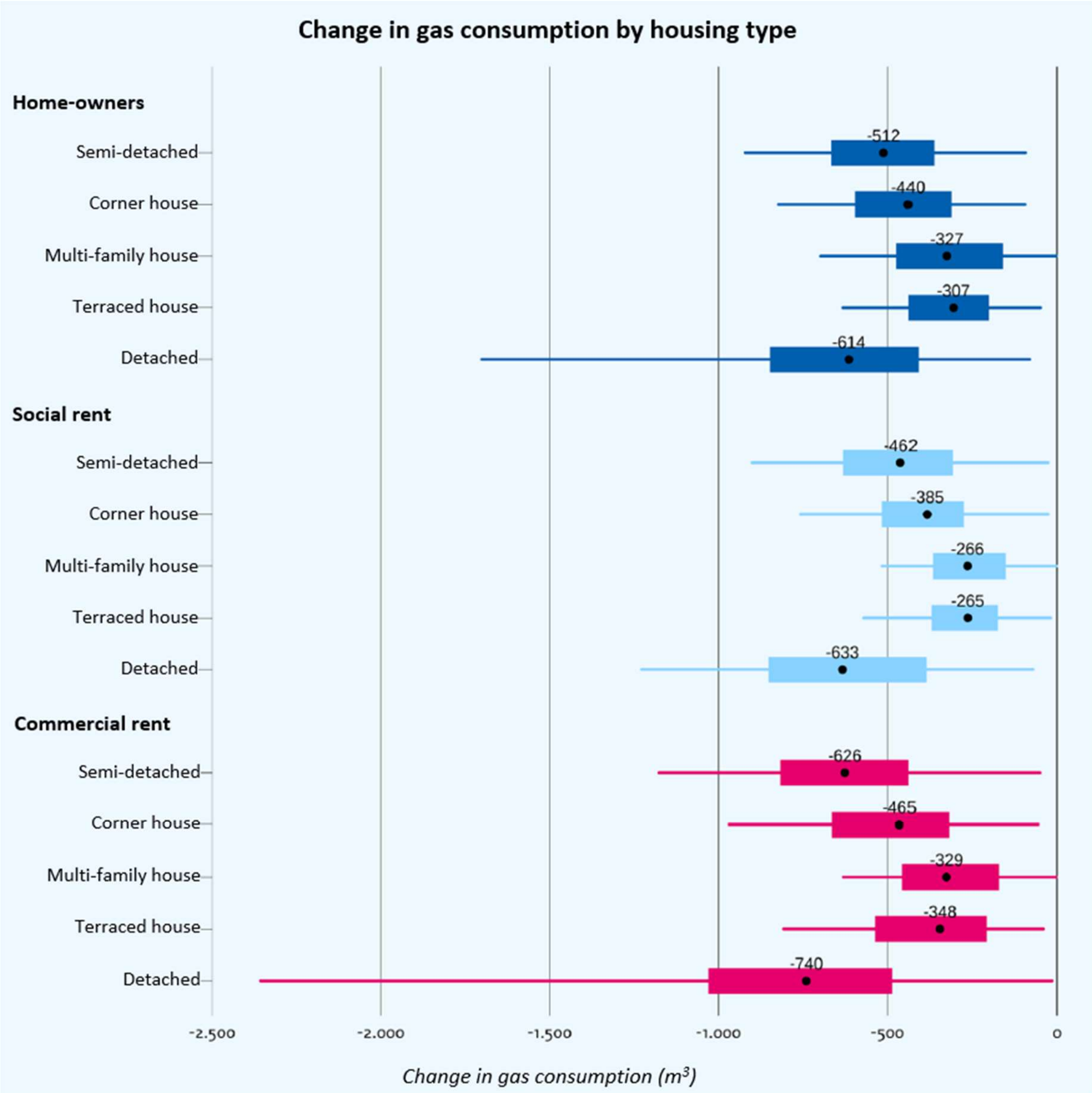
*Figure 3: Investment cost by ownership and housing type (incl. VAT)*[2]

## 4.2 Energy savings

Using the HESTIA model, we calculate an average energy savings of over 400 $m^3$ of gas for the group of homes in question. This is about 32% of the average gas consumption before insulation. The gas savings from insulation measures are calculated for the year 2024, implying that the baseline already takes into account an additional 10% energy saving due to behavioral responses to the high energy prices of 2022. Figure 4 shows the distribution of energy savings by property type and type of home. It is immediately noticeable that the

[2] The box shows the median with the 25th and 75th percentiles. Dots show the median costs. The lines show the 5th and 95th percentiles, respectively.

savings are highest in detached houses, followed by semi-detached houses. In owner-occupied homes, the annual savings in natural gas use average about 460 $m^3$. In the rental sector, which includes smaller homes and households with lower average incomes, the average savings are about 300 to about 370 cubic meters in the social and commercial rental sectors, respectively.




Source: HESTIA

*Figure 4: Change in gas consumption by housing type (in cubic meters per year)*

Figure 4 also shows that the dispersion in savings within a given housing type is large, with most notable outliers to be found in terms of high energy savings. The dispersion is particularly large for detached houses, especially for the limited group of detached commercially rented houses in our analysis. The variation is also relatively large for semi-detached houses. For the larger group of mid-terrace houses in which the owners themselves live, 5% of the houses save more than 627 $m^3$ and 5% of the houses save less than 51 $m^3$. In general, it is noticeable that for the 5% of dwellings at the "low" end of the distribution, the savings are actually small, especially when it comes to apartments, corner houses and intermediate houses.

The median energy bill savings for owner-occupied housing at the median energy price for 2030 is approximately between 44 and 51 euros per month for the different income classes. The effect of energy savings on energy bills is, of course, determined by the gas price used. At the low energy price, the median savings is between about 37 and 43 euros per month. At the high energy price, it is between 48 and 55 euros per month. In the rental sector, the median savings are smaller, related to the smaller average dwellings—and thereby building units—in this sector. In the social housing sector, the median savings are about 33 euros per month at the price from the base case, and in the commercial rental sector the savings are about 11 euros per month higher. In the tail of distribution, for commercial renters, there are outliers of more than 108 euros per month of energy savings.

Calculations by the Hestia model reveal that energy savings do not increase proportionally with the size of a home. This can be explained by two factors: differences in heating behavior and variations in the quality of energy labels between smaller and larger homes. Regarding heating behavior, reference consumption data indicate that heating behavior differ between larger and smaller homes. On average, larger homes consume less gas per square meter, which may be explained from a routine to leave certain rooms in larger homes unheated or only partially heated during winter. In our simulation exercise, this results in minimal energy savings when these unheated rooms in homes are insulated. In contrast, smaller homes typically heat a larger proportion of the total space, making the potential energy savings per square meter relatively higher. As for the second factor, energy savings also depend on the initial energy label of a home, which varies with the size of the property. Underlying data for the Netherlands show a non-linear relationship between quality of energy labels and dwelling size: depending on the house type, the proportion of dwellings with a high-quality label increase up to a certain size threshold, after which the proportion of these higher-quality labels decreases.

Figure 5 illustrates the relationship between energy savings and the size of a home for different housing types. The median gas savings, measured in cubic meters, are slightly lower in medium-sized homes compared to small homes. In the largest homes, gas savings are higher than in medium-sized homes, but the variation is much greater. The results for the largest homes are less reliable, as this group is smaller and includes atypical properties, such as farmhouses.

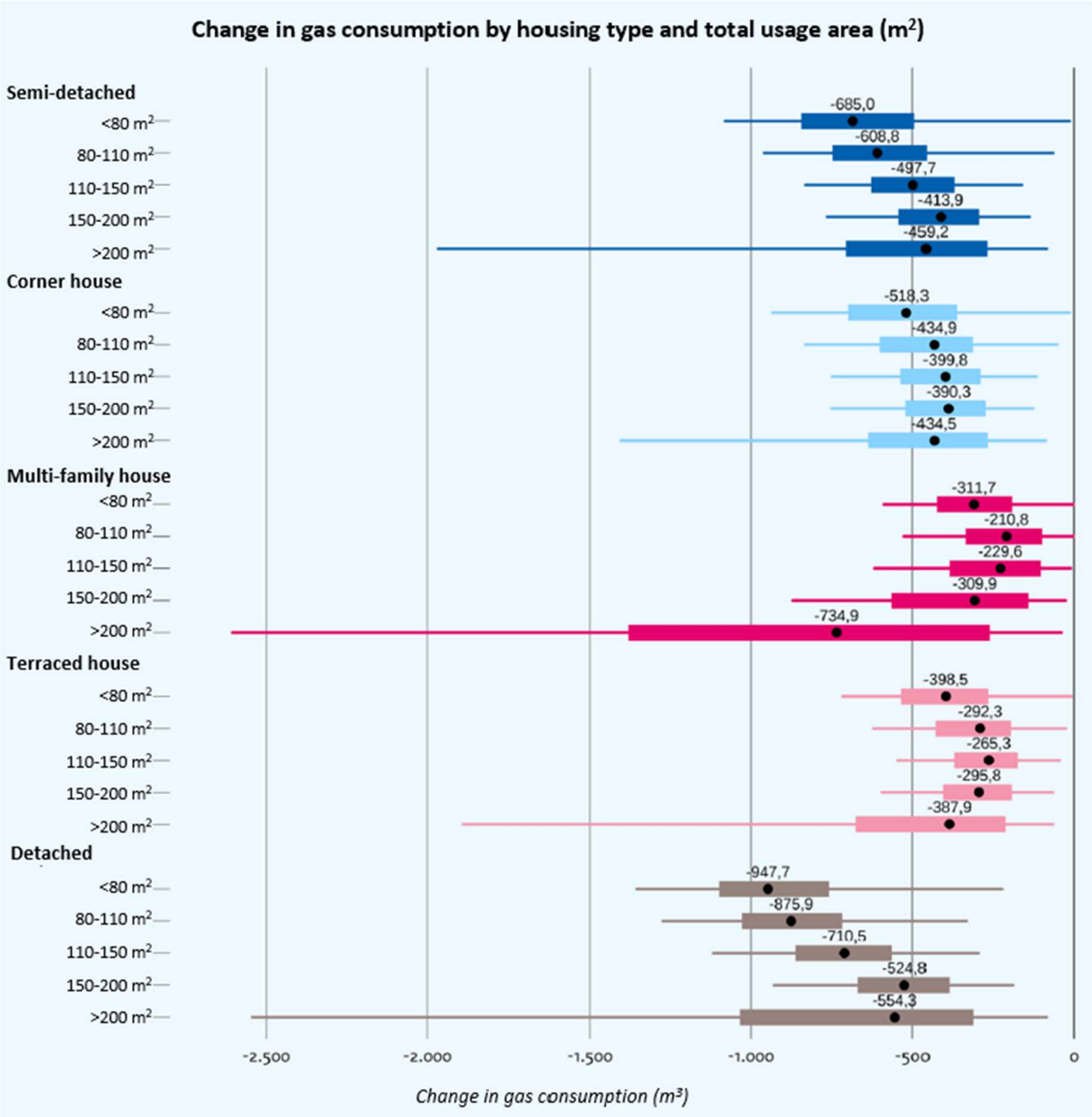



*Figure 5: Change in gas consumption by housing type and size (in cubic meters per year)*

# 5. Income effects

## 5.1 All households

This section examines the calculated income effects of home insulation, considering the combined impact of investment costs and energy savings (discussed in Section 4) on disposable income. The analysis adopts the perspective of households, in contrast to the previous section, which focused on homes. As defined by equation (1) income effects ar defined in terms of the pass-through of the investment costs on housing costs minus the energy cost savings relative to disposable income before home insulation. A ceteris paribus approach is employed, meaning the calculated income effects reflect only the costs and benefits of insulation measures, while other factors potentially influencing income effects are not considered. The net income effect of home insulation at the household level is determined by the balance between increased housing costs (including higher rent or mortgage payments), higher rent allowances or mortgage interest deductions, and reductions in energy expenditures. Hence, a positive income effect indicates that energy expenditure savings exceed the cumulative costs of home insulation, resulting in a net financial benefit for the household.

Before presenting the income effects for different household groups, we begin with an overall assessment of the proportion of households for which investing in home insulation result in a positive income effect. Additionally, we assess how these effects are distributed between owner-occupied and rented homes. For rental housing, we place particular emphasis on the income effects for tenants in the commercial rental sector. Incumbent tenants in the social housing sector almost universally experience a positive income effect, as they are currently exempt from rent increases following insulation due to the aforementioned government ruling that in the social rental sector home insulation costs in cannot be passed on to tenants in the form of higher rents (Min BZK, 2022). The results indicate that, for all analyzed households combined, the income effect of insulating homes to meet the insulation standard is approximately neutral, with a median of 0.1% in our baseline scenario. This calculation assumes mid-2023 energy prices and an interest rate of 4% (see Table 3).

*Table 3. Median income effects (in %) for households with different ownership statuses under different gas prices (interest 4%)*

| **Energy price** | **Low** | **Middle (base case)** | **High** |
|---|---|---|---|
| Privately owned | -0.4 | **-0.2** | 0.2 |
| Commercial Rent | -0.2 | **-0.1** | 0.0 |
| Social housing | 1.1 | **1.3** | 1.4 |
| Total (incl. social housing) | -0.1 | **0.1** | 0.1 |

Among them are incumbent tenants in the social housing sector for whom, as mentioned above, the income effect is almost always positive. This group of tenants comprises about 30% of the households we analyzed (see Table 4). For owner-occupiers and commercial renters—together about 70% of the households we analyzed—home insulation leads to a median income effect of respectively -0.2% and -0.1%. At the low energy price, median income effects for these groups decreases to respectively -0.4% and -0.2% and increases to 0.2% and 0.0% at the high energy price (see Table 3). For social housing renters, the median income effects increases to about 1.4% at the high energy price and decreases to about 1.1% at the low energy price.

*Table 4. Percentage of home-owners, tenants in the commercial and social housing sector with a home built before 1992 that is post-insulated, by income class.*

| **Income level** | **Privately Owned** | **Social Rent** | **Commercial Rent** | **Total** |
|---|---|---|---|---|
| < 120% minimum | 1.5 | 14.8 | 2.6 | 18,9 |
| 120% minimum – 1x median | 11,4 | 7,0 | 1,9 | 20,3 |

| | | | | |
|---|---|---|---|---|
| 1x median -1,5x median | 13,8 | 5.2 | 2,2 | 21.2 |
| 1,5x median – 2x median | 12.4 | 2,0 | 1,3 | 15.7 |
| 2x median – 3x median | 13.7 | 0,9 | 1,1 | 15.6 |
| >3x median | 7,7 | 0,1 | 0.4 | 8,3 |
| Total | 60.5 | 30.1 | 9.5 | 100 |

The income effects become more positive at lower interest rates and diminish at higher interest rates (see Table 5). If investments in home insulation are financed with a zero-interest loan, the median income effect at mid-range energy prices is approximately 0.0% for owner-occupiers and 0.4% for commercial renters. On the one hand, this indicates that at 0% interest rates, the median income effects range from neutral to slightly positive, suggesting that retrofitting is, from a financial perspective, a no-regret investment for a significant share of these household types. On the other hand, compared to the baseline scenario (4% interest rate) and the higher interest rate scenario (6%), income effects tend to skew slightly negative, implying that additional financial support would be required for the median household to make home insulation cost-neutral.

*Table 5. The share of households with a positive income effect at different interest rates (median energy price )*

| **Interest rate** | **0%** | **2%** | **4%** | **6%** |
|---|---|---|---|---|
| Privately owned | 0.0 | -0.1 | -0.2 | -0.4 |
| Commercial Rent | 0.4 | 0.1 | -0.1 | -0.3 |
| Total (incl. social housing) | 0.3 | 0.2 | 0.1 | 0.0 |

Note: Social housing is missing as a separate row in the table because there the income effect is (almost) always positive

Figure 5 illustrates the distribution of income effects for different income groups and housing categories (owner-occupied, social rental, and commercial rental) in the baseline scenario, along with the median income effect for each category. For half of the households (represented by the boxes in Figure 5), income effects range between -0.4% and +0.9% in the baseline scenario. Among households with above-median incomes who do not reside in the social housing sector, 90% experience income effects between -1.6% and +2.5%. Notably, the most significant income effects are observed in the lower and upper 5% tails of the distribution for the lowest-income households outside the social housing sector, with the "negative tail" extending further than the "positive tail." Households with incomes below 120% of the minimum wage who reside in owner-occupied or commercially rented housing account for over 4% of the households analyzed (see Table 4). The majority of households with incomes up to 120% of the minimum wage are renters in the social housing sector. For 90% of these households, income effects range between 0% and +3.9%.

In the commercial rental sector, rent increases are determined by investment costs adjusted for subsidies. Consequently, the variation in investment costs, as presented in Section 4, is also reflected in rent increases. In the baseline scenario, the median rent increase for commercial renters is approximately €48 per month. A quarter of commercial tenants face rent increases exceeding €71 per month, while another quarter experience increases of less than €28 per month. Under the rent commission method, there are no limits on rent increases (Huurcommissie, 2018), and it is assumed that all investment costs are passed on to tenants. For 5% of tenants, the calculated rent increase exceeds €163 per month. Even for households with incomes up to 120% of the minimum wage in commercially rented housing, the rent commission method results in significant rent increases for the top 5% of the distribution, with rent increases exceeding €144 per month. In contrast, tenants in the social housing sector do not face rent increases since, as mentioned before, landlords in this sector (i.e. the social housing associations) bear the investment costs.

In the baseline scenario, households in the social housing sector with incomes up to 120% of the minimum experience a median income effect of 1.7%, with relatively low variability. For 5% of this low-income group, the income effect from insulation is 3.9% or more. This group, which represents approximately 15% of all households analyzed (see Table 4), benefits the most from home renovations meeting the insulation standard. Notably, about two-thirds of energy-poor households fall within this group (TNO, 2023). Additionally, households with higher incomes who rent in the social housing sector also experience relatively favorable income effects; this group comprises about 15% of all households included in the analysis.

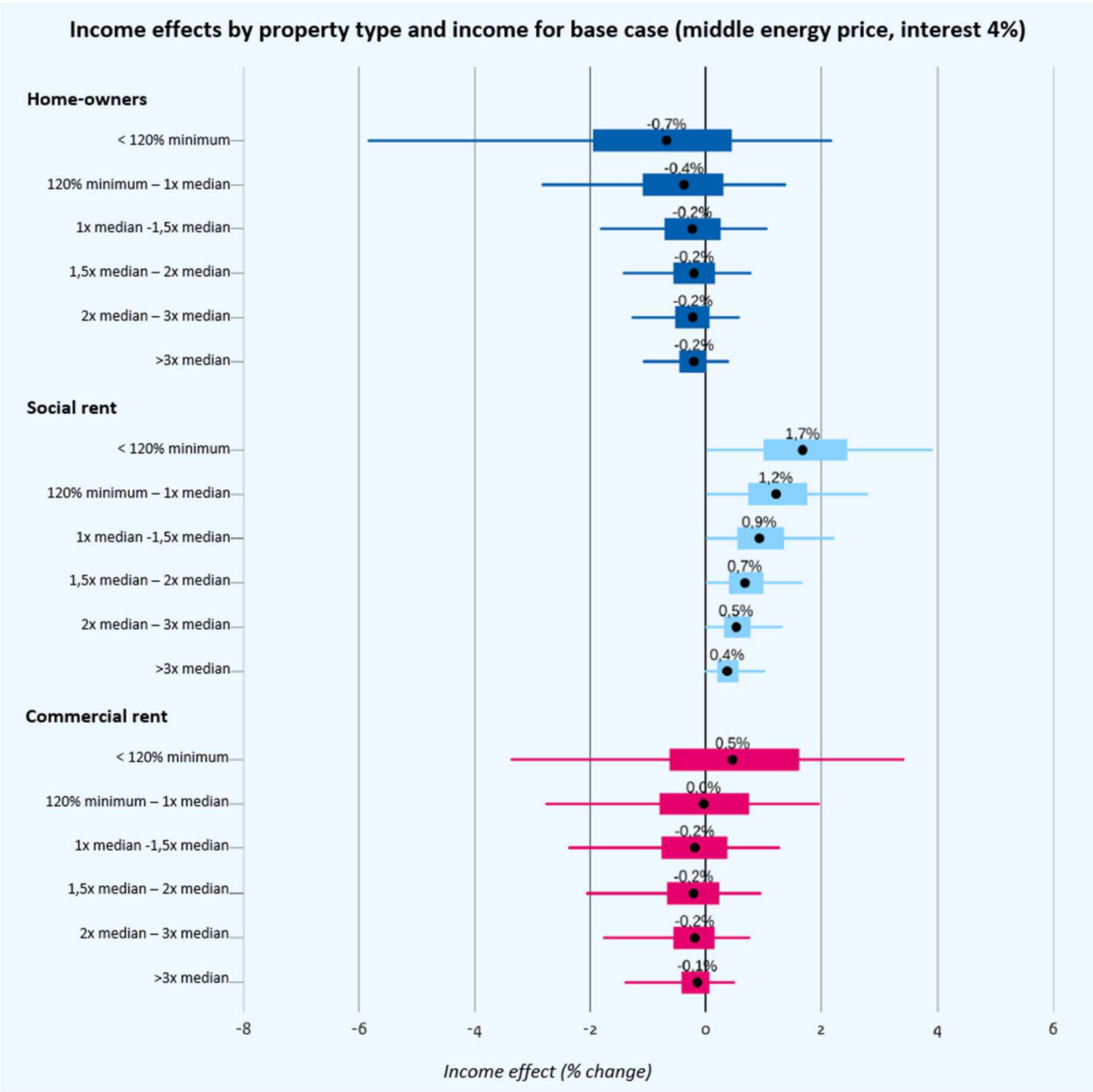



*Figure 5. Income effects by property type and income for base case (middle energy price, interest 4%)*

Among homeowners and tenants in the commercial rental sextor, the median income effect is approximately -0.2% for most income groups. An exception is owner-occupiers with the lowest incomes – up to 120% of the minimum wage, representing about 1.5% of the analyzed population – who experience higher negative median income effects, averaging -0.7%. For 90% of this group, income effects range from -5.8% to +2.2%. In contrast, households in the lowest income bracket within the commercial rental sector – about 2.6% of the studied households – have a median positive income effect of 0.5%. For 90% of this group, income effects range from -3.4% to +3.4%.

Both the magnitude and distribution of income effects exhibit an inverse relationship with household income. Lower income effects at the higher end of the income distribution can partly be attributed to a denominator effect: an absolute net income effect constitutes a smaller proportion of disposable income for higher-income households compared to lower-income households. Incumbent tenants in the social housing sector experience positive income effects across all energy price and interest rate scenarios analyzed. This is because they do not bear the costs of insulation while benefiting from lower energy bills post-insulation.

The results indicate that income effects vary significantly both between and within income groups. These variations are evident in both the owner-occupied and rental sectors and are most pronounced for households with the lowest incomes. The differences within income groups are a logical consequence of the substantial variation in energy quality and other housing characteristics among households with similar incomes (see Section 2.3). At first glance, the income effects for owner-occupiers and commercial renters appear similar, but there are key distinctions between these groups. First, while both groups finance the investment costs (minus any subsidies) through loans, only owner-occupiers benefit from mortgage interest deductions, which lower financing costs. Tenants, who bear these costs indirectly, do not receive this tax benefit. Second, total renovation investment costs are substantially lower on average for privately rented properties, partly because these dwellings are, on average, smaller in size.

The income effects would be significantly more negative without policies designed to promote insulation. These policies include insulation subsidies for owner-occupiers and private landlords, as well as agreements with social housing associations to prevent the transfer of investment costs to tenants through rent increases. To evaluate the impact of these policies, we calculated income effects in their absence, assuming no insulation subsidy schemes and rent increases for tenants in the social housing sector based on the Rent Commission method. In this scenario, median income effects are negative for nearly all income groups, affecting both homeowners and renters (see Figure 6). For lower-income groups, the absence of these policies leads to markedly more negative income effects compared to Figure 5. Specifically, for households with incomes up to 120% of the social minimum in owner-occupied or commercially rented housing, the average income effect decreases by 1.2 and 0.7 percentage points, respectively. For tenants in social housing sector, the income effect remains slightly positive but drops significantly by 1.4 percentage points, from +1.7% to +0.3%.

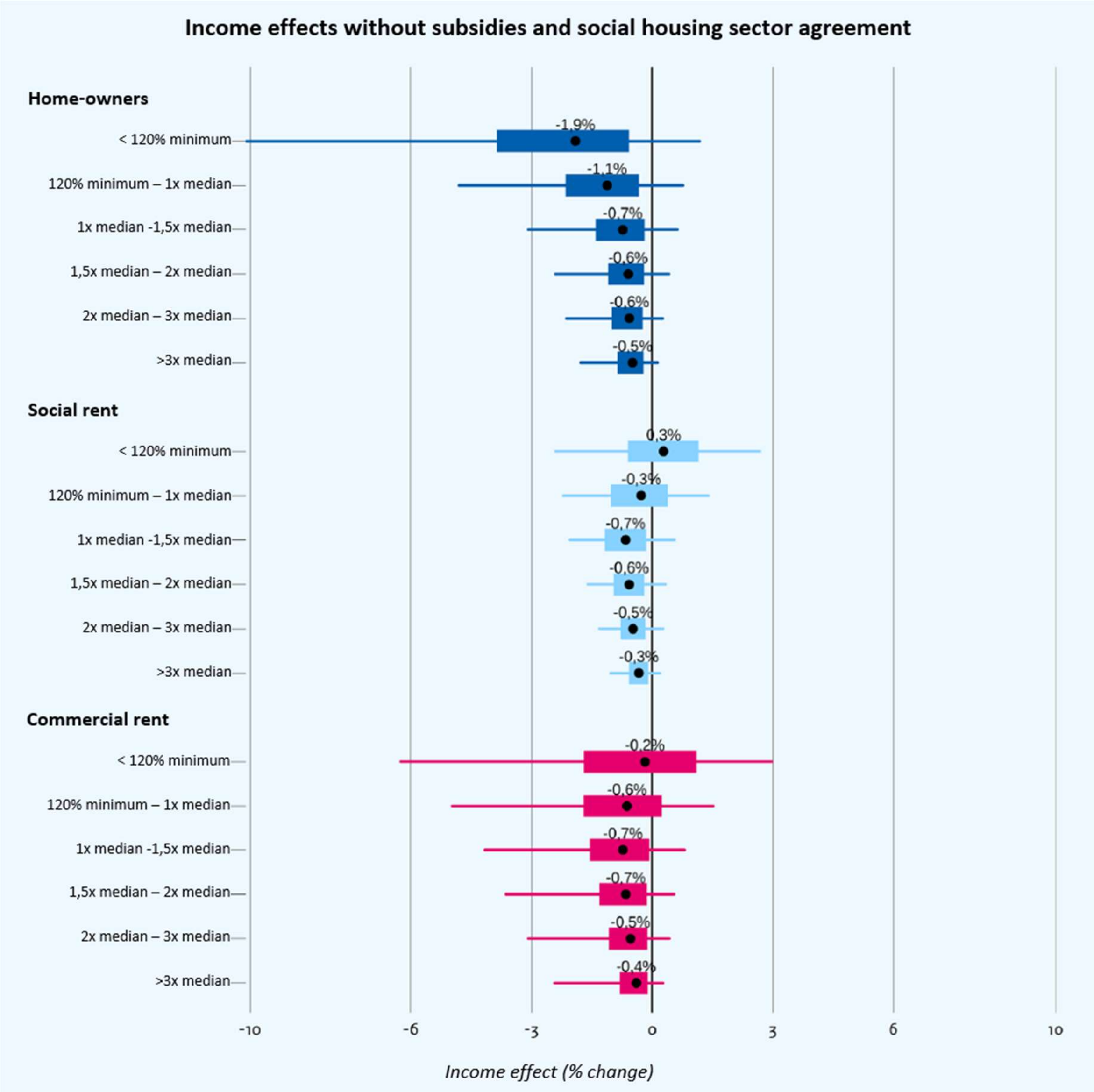



*Figure 6. Income effects by property type and income (middle energy price, interest 4%), without subsidies and National Performance Agreements with social housing associations*

## 5.2 Households with income effects lower than -1%

For approximately 15% of households living in owner-occupied or commercially rented housing, the income effect is relatively strongly negative, defined in this section as at least -1%. Residents in social housing are excluded from this analysis, as incumbent tenants in the social housing sector do not face rent increases due to home insulation investments, and thus do not experience a negative income effect. We conducted a logistic regression analysis to identify which housing and household characteristics increase the likelihood of experiencing a relatively large negative income effect of at least -1%. By comparing the odds ratios derived from the logistic regression, we assessed which characteristics pose the greatest risk of an income effect below -1%. The odds ratios indicate how much more or less likely it is for a household with a specific characteristic to experience a significant negative income effect compared to a reference group. The results, presented in Figure 7, reveal that negative income effects are most common among low-income households, those living in large dwellings, and those with low gas consumption.

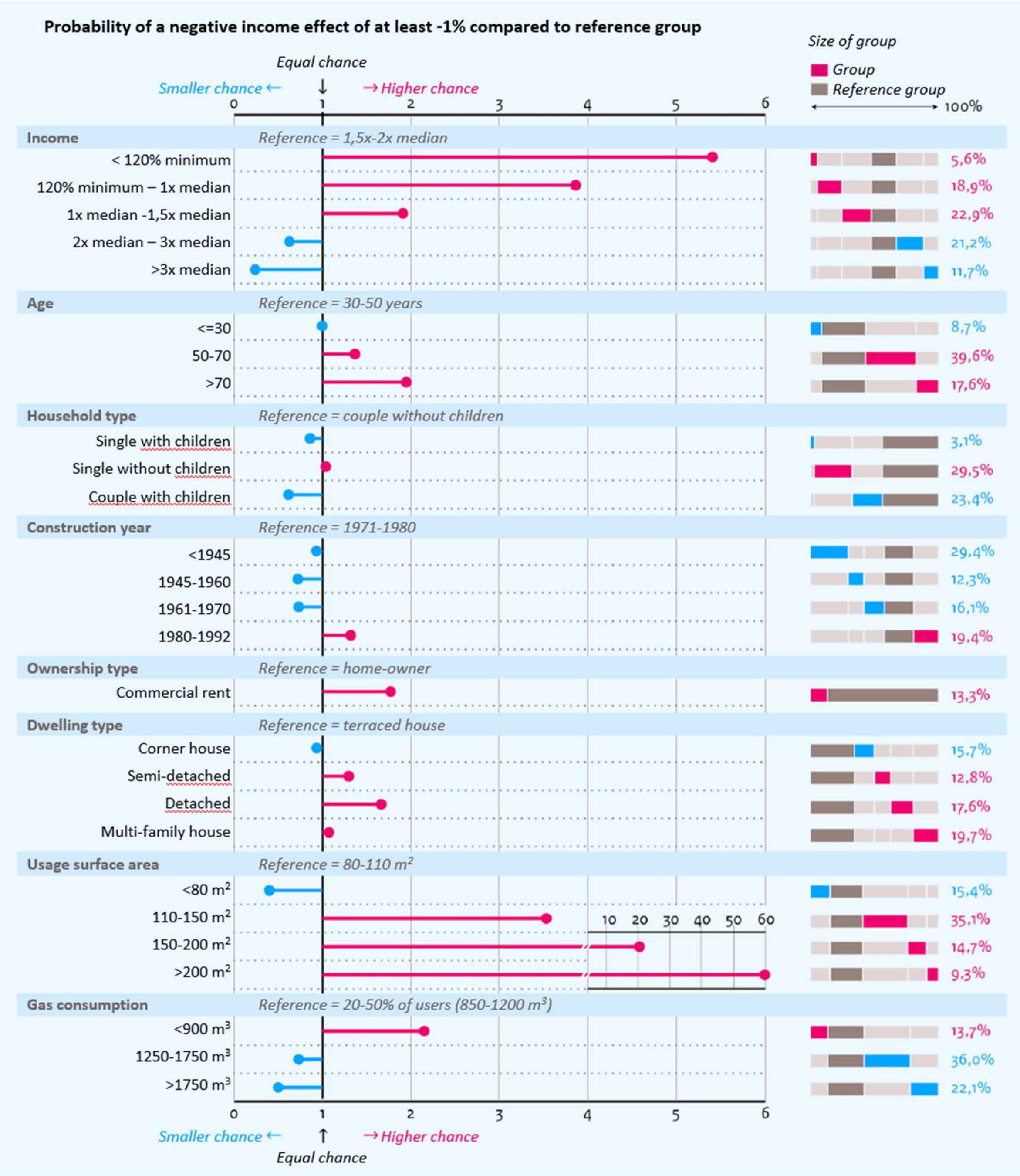



*Figure 7 Probability of negative income effect of at least -1% (compared to reference group) **

**Excluding social housing*

Figure 7 also shows that households residing in homes between 110–150 m² are 3.5 times more likely to experience an income effect below -1% compared to households in homes between 80–110 m². Furthermore, low-income households are significantly more vulnerable to negative income effects: households with incomes up to 120% of the social minimum are over five times more likely to face a strong negative income effect than those with incomes between 1.5 and 2 times the median income. Age also plays a notable role: households where the primary income provider is over 70 years old are twice as likely to experience a strong negative income effect. In contrast, the impact of construction year, housing type, and household type was found to be relatively minor after adjusting for other factors.

# 6. Discussion and conclusions

Insulating homes is a crucial step in making the housing stock more sustainable and preparing it for future heating systems. However, the welfare effects of home insulation are ambiguous and unevenly distributed among households. This inequality is significant because disproportionate welfare impacts of energy transition policies may conflict with the principles of a just energy transition. Moreover, a perceived lack of fairness in such policies could undermine societal support for climate initiatives. Designing effective and equitable energy transition policies, therefore, necessitates a detailed understanding of their impacts on individual households, moving beyond average effects on a hypothetical average household.

Against this background, we examined the distribution of income effects across heterogeneous household groups, calculating these effects at the individual household level. This study leveraged a novel modeling platform that soft-links the MIMOSI income simulation model and the HESTIA energy simulation model for the built environment to household-level administrative data. These data include detailed information on income, financial wealth and ownership status for all households in the Netherlands. The income effects of home insulation in this study are defined as the net impact of investment costs passed through as higher housing expenses, offset by reductions in energy bills resulting from decreased gas consumption after insulation.

Our findings reveal that households with homes that need retrofitting experience on average a median income effect close to zero if their dwellings are post-insulated to meet the Insulation Standard. However, there are substantial differences in income effects both between and within income groups, with the greatest variation observed among households with the lowest incomes. Incumbent tenants in the social housing sector, who frequently have below-median incomes, experience consistently positive income effects from gas savings. This outcome is largely due to a recent government ruling preventing the costs of insulation measures from being passed on to tenants in social housing. Conversely, approximately 15% of homeowners and tenants in the commercial rental sector experience income losses exceeding 1%. This group disproportionately includes low-income households, occupants of larger homes, and those with the lowest gas consumption. Such differences within income groups reflect significant variation in energy quality and housing characteristics among households with similar incomes. Additionally, the magnitude and variability of income effects increase as household income decreases. For low-income households, the larger income effect is partly due to a denominator effect, as absolute investment amounts constitute a higher proportion of disposable income. Notably, this disparity is unrelated to higher investment costs.

Policies aimed at encouraging home insulation significantly influence income effects. Our results demonstrate that, without policies such as insulation subsidies for owner-occupiers and private landlords or agreements with social housing associations to prevent rent increases, the average income effects would have been negative for most homeowners and tenants. Nevertheless, developing an effective policy toolkit to target support for low-income households in energy-inefficient homes has proven challenging in the Netherlands. Surprisingly, there is only a weak correlation between household income and the energy quality of housing (Batenburg et al., 2023).

The share of energy-efficient homes varies little across income groups, contrary to common assumptions. Many high-income households reside in poorly insulated homes, such as historical monuments or homes built in the popular 1930s style. Conversely, a large proportion of social housing—where low-income households are concentrated—already features good energy quality. As a result, the overlap between policies targeting energy poverty (low-income households) and those aiming to improve energy efficiency (low-quality homes) is limited. Currently, income-independent subsidies for insulating energy-inefficient homes disproportionately benefit higher-income households, while generic low-income subsidies are distributed across both poorly and adequately insulated homes.

Designing equitable policies for housing sustainability is further complicated by the differing financial perspectives of individual households and society at large. While subsidies improve the financial attractiveness of insulation for individuals, they do not generate additional welfare at the societal level, as subsidies merely redistribute resources. In this study, we estimated total investment costs of approximately €86 billion (excluding VAT) to insulate all homes built before 1992. Of this amount, €16 billion is invested by social housing associations, while €60 billion is borne by individual homeowners. Additionally, reduced gas consumption due to insulation decreases government revenue from gas taxes, further lowering the net financial benefits from a societal perspective. Thus, large-scale home insulation is more costly for society as a whole than for individual households, while the aggregate financial returns are also lower.

Despite these challenges, the societal benefits of home insulation can outweigh the costs in the long term. Post-insulating the entire Dutch housing stock to meet the Insulation Standard would reduce gas consumption by an average of 32%, equating to approximately 2.2 billion cubic meters annually across 5.4 million homes. This reduction represents national financial savings of around €1.1 billion per year at mid-range energy prices (excluding taxes). Furthermore, societal costs are partially offset by additional benefits, such as reduced CO2 emissions. Climate change imposes substantial financial burdens on society, and mitigating these effects is a significant benefit of insulation. Moreover, improving energy efficiency through insulation prepares homes for complementary technologies, such as low-temperature heating and heat pumps. These future investments become more cost-effective when combined with home insulation, lowering the long-term costs of CO2 reduction. Other benefits include reduced reliance on foreign gas supplies, lower social costs associated with energy poverty, improved living comfort, and less financial vulnerability to energy price fluctuations.

This study underscores the importance of well-designed, equitable policies for promoting housing sustainability. While home insulation offers substantial benefits at both individual and societal levels, achieving a just energy transition requires careful consideration of the diverse and unevenly distributed impacts on households. Addressing these challenges effectively can ensure that the energy transition is both inclusive and socially supported.

## References

Allcott, H., M. Greenstone, 2017, Measuring the welfare effects of residential energy efficiency programs, NBER Working Paper No. 23386

Arcadis / RVO, 2023, Kostenkentallen voor het nemen van energiebesparende maatregelen (Digipesis).

Aydin, E., N. Kok, D. Brounen, 2017, Energy efficiency and household behavior: The rebound effect in the residential sector. *The RAND Journal of Economics*, 48(3), 749–782.

Aydin, E., D. Brounen, N. Kok, 2020, The capitalization of energy efficiency: Evidence from the housing market. *Journal of Urban Economics*, *117*, 103243.

Bird, S., & Hernández, D. (2012). Policy options for the split incentive: Increasing energy efficiency for low-income renters. Energy Policy, 48, 506–514.

Bouwbesluit, 1992, Bouwbesluit. Online bouwbesluit (link).

Bouzarovski, S., & Simcock, N. (2017). Spatializing energy justice. Energy Policy, 107, 640–648.

Brounen, D., N Kok. 2011, On the economics of energy labels in the housing market, *Journal of Environmental Economics and Management* 62(2), 166-179.

Centraal Bureau voor de Statistiek, 2018, Woononderzoek (WoON) | Energiemodule 2018.

Centraal Bureau voor de Statistiek, 2023, Monitor Energiearmoede 2020.

CE Delft, 2021a, Evaluatie van de energiebelasting: terugkijken (1996-2019) en vooruitzien (2020-2030)

CE Delft, 2021b, Energiearmoede in de warmtetransitie, Onderzoek naar beleidsinstrumenten

Centraal Planbureau, 2016, MIMOSI: Microsimulatiemodel voor belastingen, sociale zekerheid, loonkosten en koopkracht (link). Versie 30 maart 2016.

Centraal Planbureau, 2022a, *Centraal Economisch Plan 2022.*

Centraal Planbureau, 2022b, *Macro Economische Verkenning 2023.*

CPB, 2024, Augustusraming 2024 (cMEV 2025) (link). Versie 16 augustus 2024.

Deb, C. A. Schlueter, 2021, Review of data-driven energy modelling techniques for building retrofit, *Renewable and Sustainable Energy Reviews*, 144, 110990

De Nederlandsche Bank, 2023, Isoleren en compenseren: reactie van huishoudens op de energiecrisis.

Eichholtz, P., L. Kattenberg, N. Kok, 2023, Al jarenlang hoog rendement van woningisolatie maakt subsidies vrijwel overbodig. *ESB*, 108(4817), 28-31. Gebaseerd op: Kattenberg, L., P. Eichholtz en N. Kok, 2022, The Efficacy of Energy Efficiency: Measuring the Returns to Home Insulation, Research Paper Maastricht University, October 2022

European Commission, 2023. Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast). *Official Journal of the European Union* (link).

European Commission, 2024. Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast). *Official Journal of the European Union* (link).

Fowlie, M., M. Greenstone, C. Wolfram, 2018, Do energy efficiency investments deliver? Evidence from the weatherization assistance program. *The Quarterly Journal of Economics*, 133(3), 1597–1644.

Gillingham, K., D. Rapson, G. Wagner, 2016, The rebound effect and energy efficiency policy, *Review of Environmental Economics and Policy* 10(1), 68–88.

Goderis, B. and M. Vlekke, 2023, Tax and Benefit Policies to Reduce Poverty in the Netherlands: A Microsimulation Analysis, *International Journal of Microsimulation* 16(1), 108–133.

Guerra-Santin, O., T. Rovers, P. van den Brom, S. Marchionda, L. Itard (2021). The actual performance of energy renovations in the Dutch residential sector: An Analysis of Measured Energy Performance and Resident Perceptions in Monitored Renovation Projects (link).

Heffron, R. J., & McCauley, D. (2017). The concept of energy justice across the disciplines. Energy Policy, 105, 658–667.

Hong, S.H., T. Oreszczyn, I. Ridley et al., 2006, The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings. *Energy and Buildings*, 38(10), 1171–1181.

Huurcommissie, 2018, Beleidsboek huurverhoging na woningverbetering. Versie: juni 2018 (link).

Kahn, M.E., N. Kok, 2014, The capitalization of green labels in the California housing market, *Regional Science and Urban Economics* 47, 25-34.

Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., & Djurovic-Petrovic, M. (2010). A review of bottom-up building stock models for energy consumption in the residential sector. Building and Environment, 45(7), 1683–1697.

Liang, J., Y. Qiu, T. James et al., 2018, Do energy retrofits work? Evidence from commercial and residential buildings in Phoenix. *Journal of Environmental Economics and Management*, 92, 726–743.

Metcalf, G.E., K.A. Hassett, 1999, Measuring the energy savings from home improvement investments: Evidence from monthly billing data. *The Review of Economics and Statistics*, 81(3), 516–528.

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (BZK); Centraal Bureau voor de Statistiek (CBS), 2019, WoON2018energie: release 1.0 – Energiemodule WoON2018. DANS (link).

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (BZK), 2022, Nationale Prestatieafspraken Volkshuisvesting en Ruimtelijke Ordening (link).

Nieman, 2021, Rapport standaard en streefwaardes bestaande woningbouw; Referentie warmtevraag bestaande bouw.

Ollongren, 2021. Duurzame ontwikkeling en beleid: Kabinetsaanpak Klimaatbeleid. *Brief van de Minister van Binnenlandse Zaken en Koningkrijksrelaties.* Den Haag, 18 maart 2021.

Peñasco, C., L. Díaz Anadón, 2023, Assessing the effectiveness of energy efficiency measures in the residential sector gas consumption through dynamic treatment effects: Evidence from England and Wales, *Energy Economics* 117, 106435,

Planbureau voor de Leefomgeving (PBL), 2018, Meten met twee maten: een studie naar de betaalbaarheid van de energierekening van huishoudens

Planbureau voor de Leefomgeving (PBL), 2020, Woonlastenneutraal koopwoningen verduurzamen. Verkenning van de effecten van beleids- en financieringsinstrumenten. PBL-publicatie 4152. (auteurs: Frans Schilder, Marieke van der Staak).

Planbureau voor de Leefomgeving (PBL), 2020, Functioneel Ontwerp Vesta MAIS 5.0. Versie 13 april 2021.Planbureau voor de Leefomgeving (PBL), 2022, Klimaat- en Energieverkenning 2022.

Planbureau voor de Leefomgeving (PBL) & TNO, 2023, Functioneel ontwerp Hestia 1.0: Ruimtelijk energiemodel voor de gebouwde omgeving. Versie augustus 2023.

Planbureau voor de Leefomgeving (PBL), 2024, RuimteScanner model (link).

Rijksdienst voor Ondernemend Nederland (RVO), 2021, Subsidieregeling Verduurzaming en Onderhoud Huurwoningen (SVOH) (link). Versie 1 december 2024.

Rijksdienst voor Ondernemend Nederland (RVO), 2022, Kostenkentallen energiebesparende maatregelen (link).

Sorrell, S, J.Dimitropoulos, M. Sommerville, 2009, Empirical estimates of the direct rebound effect: A review, *Energy Policy*, 37 (4)

Sovacool, B. K. (2021). Who are the victims of low-carbon transitions? Towards a political ecology of climate change mitigation. Energy Research & Social Science, 73, 101916.

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. Renewable and Sustainable Energy Reviews, 13(8), 1819–1835.

TNO, 2020, Kosten en Baten isolatiestandaard en streefwaarden voor woningen, TNO-rapport

TNO, 2021, De feiten over energiearmoede in Nederland: inzicht op nationaal en lokaal niveau.

TNO, 2023, Energiearmoede in Nederland 2022; Een actuele inschatting op nationaal en lokaal niveau.

TNO & Planbureau voor de Leefomgeving (PBL), 2023. Hestia Release notes v1.1: Toevoeging aan het Functioneel Ontwerp Hestia. TNO 2023 P12572, 15 december 2023.

TNO, 2023b, Gezondheidskosten en energiearmoede. Een empirische analyse voor Nederland

TU Delft, 2024, 3D BAG Release Notes (link). Version 21.03.1.

Ürge-Vorsatz, D., & Tirado Herrero, S. (2012). Building synergies between climate change mitigation and energy poverty alleviation. Energy Policy, 49, 83–90.

Woonbond/Aedes, 2022, Vergoedingentabel voor faire huurverhogingen bij verduurzamingsmaatregelen, Handreiking versie 3 – 22 juni 2022.

Zou, P.X., X. Xu, J. Sanjayan, J. Wang, 2018, Review of 10 years research on building energy performance gap: life-cycle and stakeholder perspectives, *Energy and Buildings* 178, 165–181.

# Annex 1. The insulation standard

The standard for home insulation was set by the Dutch Government in 2021 and has its origins in the Dutch Climate Agreement, where it was agreed to significantly reduce CO2 emissions toward 2050, including a gradual reduction of CO2 emissions from fossil energy consumption reduction in the built environment.

The standard acts as a reference for home owners as to what can be considered good and future-proof home insulation. The standard stipulates that in the event of a future supply of sustainable sources of lower-temperature heat before 2050, the house does not need an insulation upgrade. Important principles are that all retrofit measures can be taken within the existing construction structure, in order to limit modifications of the building structure as much as possible, that maximum use is made of the space within the existing building structure, that measures are comparable to recent high-quality measures in housing renovations by social housing associations, and that, as far as possible, radical modifications to the heat delivery systems are avoided. The barriers to insulate are thus lowered as much as possible. For homes built before 1945, the standard is less strict.

The standard for home insulation is a general measure of energy efficiency, which can be translated into concrete insulation target values per individual building component. We can impose those target values within the HESTIA energy model, since the model reckons with "insulation levels" as a simplified representation of the insulation value of building components. In HESTIA we then calculate for individual homes the investments in insulation measures needed to meet the insulation levels or target values. For this study, we chose to use the minimum values per building section according to Nieman (2021, Table 24) that add up to the level at which the home meets the insulation standard. These minimum values are a sum of insulation measures in different building components that collectively simulate the approximate standard for home insulation.