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An ex-post analysis of treatment and interaction effects

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Energy coaching and 'fix team' retrofitting to mitigate energy poverty: An ex-post analysis of treatment and interaction effects

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ABSTRACT

Rising energy prices across Europe have increased concerns over energy poverty. Despite significant scholarly focus on financial relief measures instituted by national governments, locally tailored crisis measures have remained overlooked. This study delves into the Dutch context, where part of the government's response to the energy crisis was decentralised, allowing municipalities considerable discretion in experimenting with energy poverty interventions. It compares two strategies: 'energy coaching' services – offering advice on sustainable energy practices – and shallow retrofitting by 'fix teams' – installing minor energy-saving measures in homes. The impact of these interventions on residential comfort, sustainable behaviour adoption, and (financial concerns regarding) energy bills is assessed through an extensive survey involving treatment and control groups coupled with detailed administrative data on households and dwellings. Results indicate that, on an aggregate level, local interventions significantly enhanced perceived comfort and reduced energy bills among the treatment groups. Comparing individual interventions, notably, more extensive ones such as fix teams and comprehensive energy coaching were significantly more impactful than those involving a single visit, highlighting the importance of continuous engagement. Additionally, we found that energy poverty status significantly amplified the effectiveness of these interventions, thereby stressing the importance of focusing efforts on vulnerable households.

1. Introduction

In recent years, the rising energy prices across Europe have increased concerns regarding energy poverty, a phenomenon characterised by households' inability to afford adequate energy services to maintain a comfortable standard of living [1,2]. This complex and multifaceted problem, linked with factors such as income, energy needs, and the energy efficiency of housing, calls for localised, tailored, and targeted solutions that are context-specific [3,4]. Specifically in-person home visits for energy coaching and shallow retrofitting have been recognised as effective strategies, although their overall impact is still understudied [5,6].

Energy coaching typically involves motivated volunteers providing guidance and feedback to residents to encourage sustainable behaviour and offer practical tips for reducing energy consumption, aiming to increase residential comfort and affordability of energy [7]. The terms 'energy coaching' and 'energy advice' are often used interchangeably, but this paper adopts the former terminology for uniformity since this is the preferred term in the Netherlands, where the interventions took place [8]. Whereas typical information campaigns have a broad target audience, the distinguishing feature of energy coaching is that it is "*specific to individuals and their circumstances*" [9]. Ambrose et al. [10] identified four distinct energy coaching services: reducing energy costs through switching suppliers or tariffs, reducing energy demand through energy efficiency improvements and awareness of energy-conserving behaviour, increasing income by guidance on energy-related benefit claims, and navigating consumer rights. In-door behavioural advice could range from pointing residents to likely high-consuming appliances, washing at lower temperatures, switching off lights, and keeping doors in living areas closed to ensure they remain warm. The nature and frequency of these interventions can vary significantly.

Critics have argued that an emphasis on energy coaching serves a neoliberal form of governmentality, attributing the blame for energy poverty to individual responsibility [11]. They suggest that 'behavioural

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interventions' presuppose that better-informed individuals will naturally make *smarter* or *more ethical* choices leading to lower energy consumption. However, energy consumption patterns frequently extend beyond an individual's direct sphere of influence, providing an obstacle to the effectiveness of demand-side advice services [12,13]. Moreover, low-income households, particularly those in inefficient dwellings, are often already doing as much as they can to conserve energy and reduce their bills, and if pushed further, some may end up sacrificing residential comfort by severely restricting their use of heating [14]. Simcock and Bouzarovski [5] emphasise that while energy coaching can be beneficial, if done thoroughly, it should complement, rather than replace, more substantial structural improvements of housing conditions.

A rather understudied physical intervention that is increasingly popular is shallow retrofitting, often seen as an interim measure before undertaking more comprehensive, deep renovation work [15,16]. The difference between the two lies in the fact that deep renovations, though expensive, encompass comprehensive insulation measures throughout all building components aimed at achieving (near) zero-energy status, whereas shallow retrofits offer a more cost-effective alternative, focusing primarily on reducing heat loss through small-scale insulation and draught proofing [17,18]. Shallow retrofits are typically carried out in stages, beginning with a basic 'home energy audit' to identify easily achievable efficiency upgrades [19,20], followed by installation of top-up insulation and the optimisation of hydraulic distribution within domestic space heating systems, among other services [21,22].

This paper aims to evaluate the effectiveness of energy coaching and shallow retrofitting interventions in improving the well-being of those affected by energy poverty. In an early study on home visits, Darby [23] states that 'success' should be assessed in terms of gains in energy savings, comfort, health, and financial relief from energy costs. It is important to emphasise that these can sometimes be in conflict; for instance, setting the thermostat to very low temperatures may achieve energy savings and financial relief but potentially at the cost of reduced comfort or unhealthy living conditions. Focusing on the Netherlands, where local governments have significant leeway to address energy poverty with community-specific solutions, this study investigates the effectiveness of tailored strategies such as 'fix teams' and 'energy coaching' services. Importantly, this study introduces a pioneering approach by integrating survey data on perceived impacts with administrative microdata detailing respondents' actual living conditions and background characteristics. This methodological innovation allows for a nuanced analysis that not only confirms the existence of an impact but also illustrates the conditions under which these interventions succeed.

The paper is structured as follows: Section 2 introduces the Dutch interventions under study. Section 3 reviews related literature on similar interventions and their effects on criteria such as occupants' comfort, sustainable behaviour, energy bills, and financial concerns relating to energy bills, resulting in the formulation of hypotheses. Subsequently, Section 4 outlines the methodology, including survey data collection and statistical analysis, followed by Section 5, which presents the empirical results of the Dutch interventions' effectiveness. Finally, in Sections 6 and 7, we discuss results and present recommendations for future policymaking and research avenues.

2. The partly localised Dutch response to the energy crisis

Historically, the Netherlands experienced relatively low levels of energy poverty compared to other European countries, with Dutch policymakers not recognising it as a distinct policy issue [24]. Nevertheless, Mulder et al. [25] found that, prior to the 2021 energy price hike, over 8 % of households spent >10 % of their income on energy. Furthermore, Croon et al. [26] showed that a small portion of the population faces intense energy poverty, characterised by significant poverty gaps, making them rather vulnerable to fluctuations in energy prices.

During the energy crisis, starting in 2021 and peaking after Russia's invasion of Ukraine, the Dutch government significantly altered this decade-long position, intervening extensively in the energy sector [27]. While it aimed to limit interventions to provide only targeted support to those in need, thus minimising market distortions while preserving incentives for energy conservation, the costliest measures were broad-based, including both tax cuts and a price ceiling [28]. However, the Dutch government also announced a targeted energy allowance for low-income households and designated funds for local energy poverty interventions. Moreover, it dedicated €368.5 million to municipalities, earmarked explicitly to address drivers of energy poverty according to local needs and circumstances [29]. Still, considerable autonomy was granted, enabling municipalities to experiment with innovative strategies towards this objective.

Within this policy context, municipalities predominantly adopted two targeted approaches (see Fig. 1): one aimed at providing information to low-income households on sustainable behaviour and efficient appliance and heating system use, and the other directed at small but impactful physical improvements of their homes [30]. While local interventions frequently tried to combine these two strategies, the former strategy principally sought to promote sustainable behaviours and energy conservation, thereby helping to lower energy expenses. In contrast, the second strategy aimed to reduce energy bills through shallow retrofitting. Therefore, the strategies addressed different drivers of energy poverty, the former targeted the high energy demand of households and the latter focused on the energy inefficiency of the dwelling.

This study examines three local initiatives (detailed characteristics provided in Table 1): two aligned with the behavioural strategy but differing in scale – one basic and one comprehensive in terms of visit frequency and duration – and another focusing on the physical strategy through shallow retrofitting. Despite being established prior to the onset of the energy crisis, all three initiatives received municipal support as part of the energy crisis funding. They all target low-income households with their services and aim to mitigate energy poverty, alongside a secondary objective of training 'coaches' or 'fixers' facing barriers to employment.

3. The impact of energy coaching and shallow retrofitting services

In this section, the existing literature on the impact of energy coaching and shallow retrofitting services is examined, focusing on occupants' perceived comfort, their adoption of sustainable behaviour, reduction of energy bills, and alleviation of financial concerns. These studies serve as the basis for formulating hypotheses that guide the analysis of the findings in this paper and inform the subsequent discussion on the effectiveness of the interventions under study.

3.1. Improvement of occupants' comfort

The rationale behind a causal relationship between energy coaching and occupants' comfort stems from the notion that making informed decisions on energy-related behaviour leads to reduced residential consumption and enhances the overall comfort of living spaces. For instance, proper ventilation advice can lead to significant improvements in terms of reduced dampness and improved thermal comfort [31,32]. Moreover, Bashir et al. [33] demonstrated that providing guidance on energy conservation and installing draft-resistant measures enhanced residents' perceptions of warmth and comfort. Notably, Darby [23] already found that when energy coaching is targeted at households living in poverty, it can yield considerable advantages in terms of comfort, health, and well-being, with approximately 75 % of residents reporting a warmer and more comfortable indoor environment. Further, Baker et al. [19] observed that thermal comfort substantially improved after an energy coaching intervention, particularly in cases where

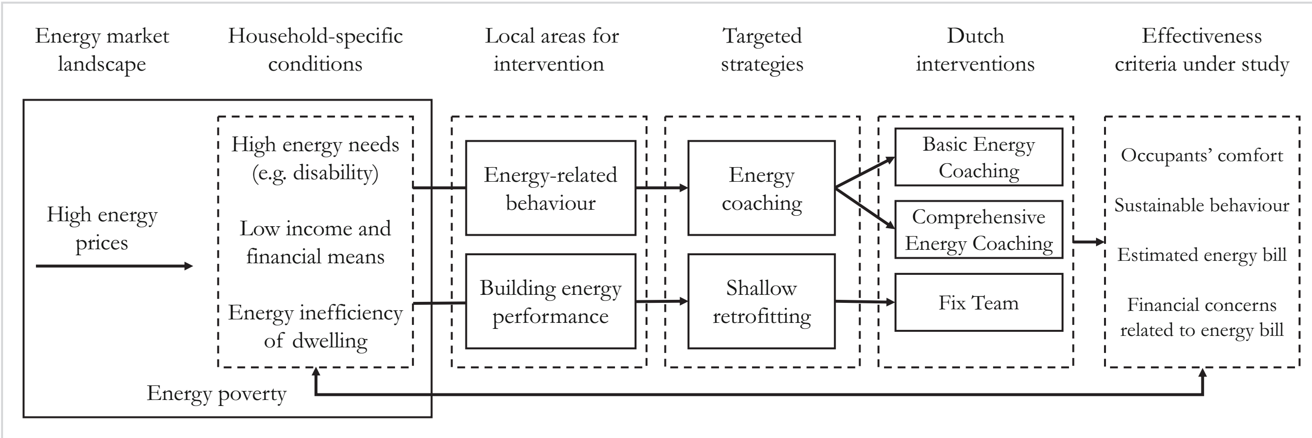

Fig. 1. Conceptual framework highlighting the potential impact of targeted Dutch interventions on energy poverty outcomes.

households previously demonstrated energy rationing. Ringel [34] noted that some residents may resist accepting energy coaching when it necessitates compromising on thermal comfort.

Shallow retrofitting can have a more direct effect on residential comfort as perceived by occupants since energy efficiency improvements, like draught-proofing, enable a more consistent distribution of warmth within the dwelling, and therefore reduce the risk of dampness and mould [18]. While quantifying occupants' comfort poses challenges, one method involves examining energy usage increases related to comfort-seeking. For instance, Lomas [35] measured that households might allocate a portion of their energy cost savings as a result of shallow retrofits towards enhancing their thermal comfort, potentially offsetting as much as 50 % of the expected energy savings. This suggests the presence of trade-offs between the various outcomes under study in this article. Another thing to consider is interaction terms. Elnagar et al. [17] underscored the influence of building typology for enhancements in thermal comfort. Moreover, Barrella et al. [16] reported that shallow retrofits had more profound impact on the perceived residential comfort of occupants in 'hidden energy poverty', those constraining energy usage due to financial constraints, yet again highlighting the interaction between energy rationing and perceived comfort improvements.

H1.1. All local interventions under study improve occupants' perceived residential comfort.

H1.2. Shallow retrofitting has a greater impact on perceived residential comfort than energy coaching.

3.2. *Adoption of sustainable behaviour*

Energy coaching, by highlighting consumption patterns and their financial and environmental impacts, has been documented to positively affect residents' awareness towards sustainability and encourage sustainable behaviour. Baker et al. [19] and Reeves [21] suggested that simple actions such as closing curtains at dusk, using appliances more efficiently, and lowering thermostat settings are influenced by energy coaching. Darby [23] estimated that behavioural change alone can lower energy consumption by up to 10 %. Once behaviour is adopted for over three months, it is likely to persist for at least a year, demonstrating the enduring impact of energy coaching on household habits. However, the effectiveness of energy coaching in altering sustainable behaviour is not uniform. Schneider et al. [8] noted significant behavioural changes following a visit of an 'energy coach', but crucially, this reduction was observed only among those who were made aware of their higher-than-average energy consumption, pointing to a social comparison effect [36]. Contrarily, Revell and Stanton [37] and Mahapatra et al. [38] reported minimal impact of home visits on changing behaviour, even when residents proactively requested the advice. Darby [23] suggested that the success of energy coaching in changing behaviour is significantly influenced by the interplay between the advisor's characteristics, the client's profile, and the context of the advice given. Further complexity is added by Bouzarovski et al. [39], who observed that energy coaching services in the UK are not sufficiently tailored to the needs and behavioural patterns of migrant groups, negatively affecting the relevance and therefore effectiveness of the advice provided.

The behavioural impact of physical interventions, such as a Fix Team's shallow retrofitting, is less intuitive. Yet, these interventions can still promote sustainable behaviour, as evidenced by Mahapatra and Gustavsson [40] who found that technicians installing retrofit measures act as vital information sources, shaping residents' interactions. Revell and Stanton [41] further argued that integrating behavioural advice with physical interventions can have substantial impacts, emphasising a holistic 'systems view' on behaviour rather than focusing solely on outputs from individual devices. Notably, while shallow retrofitting can lead to significant energy efficiency improvements, they might also trigger 'rebound effects' [42], as previously hinted at in the context of comfort-seeking. Following this logic, recipients may respond by adopting less sustainable behaviour, or simply ceasing energy rationing behaviour as demonstrated by Sunikka-Blank and Galvin [43], since they feel they can 'afford' to do so post-intervention. The impact of shallow retrofitting on sustainable behaviour may thus result from spillover effects [44]. These effects can be positive, due to increased awareness of energy consumption and a drive to avoid the cognitive dissonance of living unsustainably in an eco-friendly home, or negative, exemplified by moral licensing where residents believe they have 'done enough' by improving energy efficiency, leading to rebound effects. Thus, while shallow retrofitting can contribute to sustainable practices, its indirect nature and potential for rebound effects may limit its overall effectiveness compared to the more direct and targeted approach of energy coaching.

H2.1. All local interventions under study promote the adoption of sustainable behaviour practices.

H2.2. Energy coaching is more effective in fostering the adoption of sustainable behaviour practices than shallow retrofitting.

3.3. *Reduction of energy bill*

Energy coaching promotes efficient behaviour, which reduces the amount of energy required to maintain a given indoor temperature and therefore the energy bill [18]. Especially when targeting households in financial distress, Boardman and Darby [9] estimated a potential 10 % reduction in energy bills post-intervention. Emphasising this, Ramsden

Table 1
Background of the Dutch local interventions under study.

	Basic energy coaching	Comprehensive energy coaching	Fix team
Starting year	2014	2016	2018
Location	Utrecht	Arnhem	Amsterdam
Target group	Low-income households	Low-income households	Low-income households in energy-inefficient dwellings
Background of service providers	Local job seekers with technical expertise	Volunteers, freelancers, and job seekers transitioning to full-time employment	Long-term unemployed and skilled refugees
Training duration	3–6 weeks	6 weeks	26 weeks
Training trajectory of service providers	Theory on energy conservation, conversational techniques, social skills, system usage, and administration (incl. shadowing a colleague)	Theory on target groups, motivational techniques, energy measurement, and administrative protocol (shadowing a colleague during one visit)	One-on-one apprenticeship involving theoretical instruction coupled with substantial practical implementation of energy-saving measures
Visit frequency	1–2 visits	3–5 visits over six months	2–6 visits (on average 3 visits)
Duration of 1 visit	1–1.5 h	2 h	6 h
Support provided	Focus on behavioural advice, along with providing an energy box containing small energy-saving measures	Focus on behavioural advice, with the service provider also implementing basic energy-saving measures	Focus on implementing energy-saving measures with some behavioural advice
Nature of advice	Structured questionnaire offering saving tips (minimising shower time, washing with full loads, defrosting the fridge, etc.)	Structured questionnaire offering saving tips (minimising shower time, washing with full loads, defrosting the fridge, etc.)	Help with issues like curtain length, radiator clearance, ventilation, and behaviour-based energy-saving
Implemented energy-saving measures	The energy box contains radiator foil, draft strips, LED bulbs, power strips, shower timers, and showerheads	Applying radiator foil, draft strips, door brushes, letterbox brushes, window insulation film, power strips, and occasionally radiator fans	Hydronic balancing, ventilation maintenance, infrared scanning, installing draft strips, replacing thresholds, upgrading frame profiles and door frames, applying radiator foil and window frame foil

[31] and Reeves [21] reported average annual savings of around £125 to £129 for households in the UK, which were attributable to behavioural change. One Dutch study reported that a year after the visit of an energy coach, gas consumption had decreased by 8.4 % and electricity consumption by 6.3 % [8], and another Dutch study estimates that when socially and technically equipped energy coaches visit households more than once the annual cost-saving potential could be around 100 euros [45]. Nonetheless, studies by Revell and Stanton [41] and Mahapatra et al. [38] reported only minimal reductions, suggesting a variance in the impact of energy coaching on energy bill affordability.

Reducing energy bills is also a key goal of shallow retrofits, but in this case primarily achieved by enhancing the efficiency of the dwelling rather than promoting more sustainable behaviours. For example, a study from Spain showed that straightforward actions like weather stripping can reduce heating demand by 5 % to 19 % [16]. In the UK, Green et al. [7] found that a blend of home energy audits and small physical upgrades, along with energy coaching, was linked to a monthly reduction of about £15 in energy bills, but the authors also note that while the savings from behavioural changes are uncertain, the potential energy savings from efficiency improvements or replacing appliances also vary widely. When effectively targeted at households with clearly identifiable and solvable energy challenges, shallow retrofitting can address relatively straightforward issues with high impact at low cost. Still, the direct nature of these interventions, shallow retrofitting tends to produce more consistent reductions in energy bills compared to energy coaching.

H3.1. All local interventions under study reduce the estimated energy bills of households.

H3.2. Shallow retrofitting yields greater reductions in estimated energy bills than energy coaching.

3.4. Alleviation of financial concerns related to energy bills

The role of energy coaching has been particularly highlighted in exploring the alleviation of financial concerns related to energy bills. An early study by Darby [23] already stressed increased confidence and control over heating post-coaching. Moreover, Forster et al. [46] observed within the Traveller Community in Northern England that trust in energy advisors led to increased comfort with energy bills, anxiety reduction, and a general sense of being more in control over energy finances. Ramsden [31] noted that this positive effect is not only limited to a better understanding and management of energy consumption but also extends to broader financial stability, as advisors often assist households in accessing and applying for entitled benefits, thereby reducing financial stress further.

Energy efficiency improvements reduce energy expenses and subsequently lower stress levels, as conceptualised by Hernandez et al. [47], who identified energy insecurity as a significant contributor to chronic stress in low-income households. Jessel et al. [48] emphasised that physical housing deficiencies, economic struggle, and stress are often interconnected, and argue that living with energy insecurity encapsulates the fears and potential mental health implications stemming from the inability to afford energy bills. While primarily focused on physical measures to improve energy efficiency, shallow retrofitting efforts often incorporate energy coaching elements that impact households' energy management. Baker et al. [19] found that interventions in which physical measures were combined with advice increased residents' awareness and confidence regarding their energy use at home, empowering them to take independent action towards energy conservation. This thus suggests a synergistic effect of energy efficiency improvement and awareness increase. Despite the potential of both interventions, their mechanisms differ significantly, and the current lack of substantial evidence in the literature prevents the formulation of a specific expectation about their relative impacts.

H4. All local interventions under study alleviate financial concerns related to energy bills.

4. Data and methodology

4.1. Dataset and transformations

The data for this study originates from a natural field experiment commissioned by the Dutch government, focusing on three local interventions: Basic Energy Coaching, Comprehensive Energy Coaching, and Fix Teams, detailed in Table 1. We compared treatment groups, which had undergone one of the local interventions, with control groups, consisting of households that had applied but not yet received a visit. While assignment to treatment and control groups was thus not randomised, the fact that all had registered for the service implies a comparable baseline in terms of their motivation for or necessity of the intervention. They were recruited for the study through an email disseminated by the organisations implementing the interventions, which contained a link to an online questionnaire. The treatment group was invited to complete the survey between December 19, 2022, and March 4, 2023, on average 134 days post-intervention. The control group was invited concurrently with the confirmation of their initial appointment, with their participation window spanning from December 12, 2022, to March 12, 2023. Participation was voluntary and uncompensated.

The questionnaire, detailed in Appendix Table A-1, was designed to be completed within five minutes and was available in Dutch, English, Turkish, Arabic, and Polish. Participants were asked about their experiences in terms of residential comfort (e.g., "Do you experience cold in your home?"), sustainable behaviour (e.g., "Do you shower for less than 5 minutes?"), and financial concerns ("Are you worried about paying your energy bill?"). Answers were recorded on a 6-point Likert scale, ranging from 'never' to 'always'. Occupants' comfort and sustainable behaviour are composite indices derived from the average responses to four questions. For sustainable behaviour, one of the four elements assessed was the indoor temperature setting on thermostats, with answers categorised into six equally sized brackets; cooler temperature settings indicating greater sustainability.[1] Additionally, households were asked to estimate their monthly energy costs. We excluded indoor temperatures and energy bills that were >1.5 times the interquartile range (IQR).

For a deeper understanding of the divergences and characteristics between control and treatment groups, respondents granted explicit permission to augment our dataset with extensive household-level microdata from Statistics Netherlands [49].[2] This data (see Tables 2 and 3) includes household characteristics and dwelling features, with a reference date of January 1st, 2020. It is important to note that this data precedes the survey by approximately three years, which, though a limitation, was deemed acceptable due to its relevance and reliability. Table 2 also includes the outside temperature at the day the survey was conducted.

This research places significant emphasis on various energy poverty indicators, detailed in Table 3. The methodology for these assessments is extensively outlined by Statistics Netherlands [50]. These indicators include two widely recognised metrics [51]: 'Low-income, high cost' (LIHC) and 'Low-income, low energy efficiency' (LILEE). Additionally, the study incorporates a binary indicator reflecting a high energy burden, defined as households where the percentage of disposable income allocated to residential energy exceeds 10 %. This threshold is roughly double the median income share spent on energy and aligns with the established criterion for classifying energy poverty in the Netherlands [50]. Table 2 further elaborates on the energy burden, presenting it as a scaled variable. Both LIHC and energy burden are based on actual energy expenditures rather than required spending, as provided by Statistics Netherlands. Similar to other household characteristics and dwelling features, the indicators are referenced as of January 1st, 2020, prior to the onset of the energy crisis.

Subsequently, statistical analyses were performed to explore variable distributions and relationships between the control and treatment groups across the three interventions. Descriptive statistics for Mann-Whitney U tests and Chi-square tests are presented in Tables 2 and 3. Notably, employing one-hot encoding to categorise nominal data in Table 3 highlighted issues with infinite Variance Inflation Factors (VIFs). Consequently, we systematically excluded variables that exhibited multicollinearity, applying a threshold VIF of 5.

Furthermore, diagnostic tests for residuals, including Q-Q plots, the Shapiro-Wilk test for normality, residual scatter plots, and the Breusch-Pagan test for homoscedasticity, unveiled significant skewness in several continuous variables. This led us to apply logarithmic transformations to variables such as outside temperature, household income, household size, construction year, and floor area to mitigate these disparities.

In addressing missing data, we employed a missing value indicator for each potential control and interaction variable, facilitating differentiation between data missing at random and potential biases. To preserve our sample size, we adopted Multiple Imputation by Chained Equations (MICE), a technique that iteratively predicts missing values based on inter-variable relationships within the dataset. This process generates multiple imputed datasets, each embodying the inherent uncertainty of the missing data, resulting in a unified set of robust estimates [52].

Upon completing the imputation process, we employed Propensity Score Matching (PSM), an econometric tool crucial for enhancing the comparability of treatment and control groups in observational studies [53]. By calculating and matching propensity scores derived from a comprehensive set of observed covariates, we sought to balance the groups in terms of baseline characteristics [54]. This approach is vital in studies where random assignment is not feasible, as PSM helps to minimise potential selection biases, allowing for more reliable attributions of observed outcomes to the interventions. Integrating MICE and PSM provides a solid foundation for the causal inference in our analysis.

4.2. GLM and probit regression models

To assess the impact of the interventions, we used Generalised Linear Models (GLMs) and ordered probit regression models. Specifically, the GLM was applied to analyse the continuous dependent variable, which was the estimated monthly energy bill, while the ordered probit model was used for the three ordinal dependent variables – occupants' comfort, sustainable behaviour, and financial concerns regarding the energy bill.

Both models can be formulated as $Y^{(*)} = \alpha + \beta_1 X_1 + \cdots + \beta_n X_n + \varepsilon$. However, the fundamental difference in the application lies in their treatment of the dependent variable. The GLM directly models the linear relationship between the independent variables $(X_1, \ldots, X_n)$ and the continuous dependent variable Y through the coefficients β.[3] In contrast, the ordered probit model is tailored for ordinal outcomes. It assumes a

[1] Cooler temperature settings may stem from financial constraints and/or poor housing quality, described by Sunikka-Blank and Galvin [43] as the 'prebound effect', rather than from a fundamental commitment to sustainability. These frugal behaviours often come at the expense of residential comfort. Nevertheless, both factors lead to the same outcome: the adoption of practices that lead to energy conservation practices, which justifies using cooler temperature settings as an indicator of sustainable behaviour, particularly in the Dutch climate.

[2] Under certain conditions, this microdata is accessible for statistical and scientific research. For further information: microdata@cbs.nl.

[3] In this context, GLM resembles Ordinary Least Squares (OLS) but extends its capabilities by supporting various error term ε distributions and linking functions.

Table 2
Descriptive statistics for scaled variables: mean/median, standard deviation, and Mann-Whitney *U* test results by intervention status (control vs. treatment).

	Basic energy coaching					Comprehensive energy coaching					Fix Team				
	Control		Treatment		Test	Control		Treatment		Test	Control		Treatment		Test
	($N = 56$)		($N = 78$)			($N = 95$)		($N = 120$)			($N = 35$)		($N = 83$)		
	M	SD	M	SD	MWU[a]	M	SD	M	SD	MWU[a]	M	SD	M	SD	MWU[a]
Occupants' comfort	3.7	1.0	3.7	1.2	2.154	3.4	1.2	3.7	1.1	6.626**	2.9	1.1	3.4	1.1	1.834**
Sustainable behaviour	4.9	0.7	4.8	0.9	1.545	4.3	0.9	4.6	0.8	6.850***	4.8	0.9	4.9	0.9	1.179
Estimated monthly energy bill (in €)	177.1	82.3	160.2	76.6	1.203	179.7	65.4	161.2	64.1	1.493	214.1	122.4	168.2	79.7	838
Financial concerns related to energy bill	3.2	1.5	3.0	1.5	1.712	3.5	1.4	3.6	1.3	5.791	4.8	1.3	3.4	1.5	626***
Standardised annual income (in €1000)	23.2	6.8	25.3	11.3	1.426	23.5	10.7	20.9	8.2	3.635**	17.3	6.1	23.0	11.7	1.361**
Energy burden (in %)	4.6	2.3	4.7	4.6	1.324	5.5	2.8	5.7	2.6	4.719	7.4	3.5	4.9	3.1	570***
Number of people per household	1.7	1.1	1.8	1.1	1.488	1.9	1.3	1.7	1.0	3.885	1.9	1.4	1.7	1.1	1.112
Outside temperature at survey (in °C)	5.4	3.2	4.0	9.3	1.333***	5.6	3.7	3.6	1.6	3.613***	6.4	2.6	2.0	2.0	279***
Age (of household reference person)[b]	65.5	17.7	54.0	16.7	1.127*	53.0	14.4	56.0	14.2	4.598	61.0	14.4	56.0	13.8	947
Construction year [b]	1973	32.1	1963	32.2	1.258	1964	29.1	1957	31.0	3.820	1954	29.8	1945	35.2	993
Floor area in square meters [b]	80.0	23.3	76.0	20.9	1.283	90.0	24.1	88.0	22.9	4.081	67.5	34.7	64.0	20.3	892

[a] The performed Mann-Whitney U test was two-tailed. Significance level set at * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
[b] Median given instead of mean.

Table 3
Descriptive statistics for dummy variables: mean, standard deviation, and Chi-square test results by intervention status (control vs. treatment).

		Basic energy coaching					Comprehensive energy coaching					Fix team				
		Control		Treatment		Test	Control		Treatment		Test	Control		Treatment		Test
		(N = 56)		(N = 78)			(N = 95)		(N = 120)			(N = 35)		(N = 83)		
		M[a]	SD	M[a]	SD	$\chi2$ [b]	M[a]	SD	M[a]	SD	$\chi2$ [b]	M[a]	SD	M[a]	SD	$\chi2$ [b]
Household type	Single person	0.56	0.50	0.53	0.50	0.04	0.46	0.50	0.55	0.50	1.27	0.67	0.48	0.61	0.49	0.07
	Couple without children	0.31	0.47	0.29	0.46	0.00	0.24	0.43	0.18	0.39	0.69	0.07	0.25	0.10	0.30	0.02
	Single parent family	0.02	0.14	0.03	0.18	0.00	0.21	0.41	0.19	0.39	0.00	0.07	0.25	0.17	0.38	1.14
	Couple with children	0.10	0.31	0.15	0.36	0.20	0.09	0.29	0.08	0.27	0.00	0.20	0.41	0.11	0.32	0.67
Education level (of reference person)	Higher education	0.32	0.48	0.18	0.39	1.11	0.37	0.49	0.30	0.46	0.40	0.15	0.38	0.28	0.45	0.32
	Vocational education	0.32	0.48	0.28	0.46	0.01	0.42	0.50	0.36	0.48	0.26	0.31	0.48	0.17	0.38	0.58
	Elementary (or no) education	0.36	0.49	0.54	0.51	1.49	0.22	0.42	0.34	0.48	1.95	0.54	0.52	0.56	0.50	0.00
Housing tenure	Social rental	0.81	0.39	0.69	0.46	1.37	0.76	0.43	0.83	0.37	1.20	0.84	0.37	0.80	0.40	0.02
	Private rental	0.13	0.33	0.19	0.39	0.36	0.04	0.19	0.04	0.19	0.00	0.06	0.25	0.07	0.26	0.00
	Owner-occupation	0.06	0.24	0.12	0.33	0.43	0.20	0.40	0.13	0.34	1.36	0.10	0.30	0.13	0.34	0.01
Dwelling typology	Apartment	0.52	0.50	0.71	0.46	3.35*	0.47	0.50	0.46	0.50	0.00	0.58	0.50	0.82	0.39	5.62**
	Terraced house	0.40	0.49	0.22	0.42	3.10*	0.44	0.50	0.36	0.48	0.80	0.27	0.45	0.14	0.35	1.82
	End-terraced house	0.08	0.28	0.07	0.25	0.00	0.04	0.19	0.14	0.53	4.55**	0.12	0.33	0.04	0.20	1.16
	Semi-detached house	0.00	0.00	0.00	0.00	–	0.05	0.22	0.04	0.19	0.00	0.03	0.17	0.00	0.00	0.16
Background features (dummy variables)	Migration background	0.27	0.45	0.19	0.39	0.65	0.34	0.48	0.18	0.39	5.63**	0.37	0.49	0.46	0.50	0.38
	Female reference person	0.50	0.51	0.42	0.50	0.35	0.54	0.50	0.60	0.49	0.44	0.63	0.49	0.64	0.48	0.00
	Energy inefficient dwelling	0.33	0.48	0.31	0.46	0.01	0.43	0.50	0.50	0.50	0.74	0.43	0.50	0.21	0.41	3.97**
Energy poverty status (dummy variables)	Energy burden ≥10 %	0.02	0.14	0.03	0.18	0.00	0.09	0.29	0.05	0.23	0.41	0.13	0.35	0.07	0.26	0.37
	Low-income, high cost (LIHC)	0.02	0.14	0.08	0.28	1.01	0.11	0.32	0.12	0.32	0.00	0.17	0.38	0.09	0.28	0.70
	Low-income, low energy efficiency (LILEE)	0.08	0.28	0.12	0.33	0.08	0.08	0.27	0.26	0.44	9.35***	0.13	0.35	0.07	0.26	0.37

* Significance level set at * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
[a] Since these variables are exclusively categorical and binary, the mean represents the proportion of households with this specific characteristic.
[b] Chi-square tests are based on the observed frequencies (counts) rather than the calculated proportions (means) of the dummy variables.

latent continuous variable Y^*, shaped by the coefficients β, underlies the ordinal outcomes we observe (Y). This model categorises Y^* into the ordinal outcomes based on set thresholds, meaning a household's perceived residential comfort could range from 1 (very low) to 6 (very high), depending on where Y^* falls within these thresholds.

Moreover, we also aim to explore the influence of varying groups of control variables across our dataset. Therefore, we conducted a series of six models, as displayed in Table 4. This structured analysis began with

Table 4
Overview of control variables by model.

Control variable category	Models 1 and 2	Models 3 and 4	Models 5 and 6
Weather condition	Outside temperature (in °C, log)	Outside temperature (in °C, log)	Outside temperature (in °C, log)
Household characteristics		Age of HRP* Standardised income (in €, log) Number of people per household (log) Single person (dummy) Single parent family (dummy) Couple with children (dummy) Higher education of HRP* (dummy) Elementary education of HRP* (dummy) Migration background of HRP* (dummy) Gender of HRP* (dummy) Social rental (dummy) Owner-occupation (dummy) Energy burden LIHC (dummy) LILEE (dummy)	Age of HRP* Standardised income (in €, log) Number of people per household (log) Single person (dummy) Single parent family (dummy) Couple with children (dummy) Higher education of HRP* (dummy) Elementary education of HRP* (dummy) Migration background of HRP* (dummy) Gender of HRP* (dummy) Social rental (dummy) Owner-occupation (dummy) Energy burden LIHC (dummy) LILEE (dummy)
Dwelling features			Construction year (log) Floor area (log) Apartment (dummy) Terraced house (dummy) Inefficient dwelling (dummy)

* Household reference person.

the exclusive consideration of outside temperature in models 1 and 2. It then expanded to include household characteristics in models 3 and 4, and ultimately incorporated dwelling features in models 5 and 6. This progressive inclusion of variables allowed for a nuanced understanding of their individual and combined effects on the dependent variables under study.

4.3. Analysis of interaction effects

To discern the conditions under which our interventions are most effective, we analysed interaction effects between key variables and the interventions. Our focus is on significant interactions that either amplify or mitigate the interventions' impacts. Identified from our literature review as critical for enhancing intervention effectiveness, the emphasis is on energy poverty indicators (LIHC, LILEE, energy burden) as interaction terms.

To analyse all interaction terms ($\beta_{interaction}X_{interaction}$) within the same model framework, we opted for GLM with a cumulative logit link function for the ordinal dependent variables. This function is particularly effective for ordinal outcomes as it models the cumulative probabilities up to each ordinal level, thereby respecting the ordered nature of the response variable. Before conducting this analysis, we ensured that GLM was appropriate for our ordinal data by testing assumptions such as linearity and independence of residuals. This preliminary validation helps confirm that the models can robustly analyse complex interactions without bias.

In this analysis, we employed marginal plots to facilitate the interpretation of these interactions. These visual tools illustrate how the interactions between variables and interventions impact predicted outcomes, thus pinpointing the conditions under which interventions are most likely to have an impact. This approach allows for a nuanced understanding of effects that might be obscured in conventional tabular analysis.

5. Results

5.1. Treatment effects of local interventions

In this part of the results section, we present our findings from testing the hypotheses outlined in Section 3. This analysis evaluates the impact of various interventions on the output criteria, individually and collectively. The regression analyses produced variable outcomes, as elaborated in Table 5. Additional models incorporating fewer covariates are presented in Appendix Table A-2 for further examination.

Exploring Hypothesis 1.1, predicting that both forms of local interventions – energy coaching and shallow retrofitting – would enhance Occupants' Comfort, our analysis reveals nuanced results. The Basic Energy Coaching intervention, with a beta coefficient of 0.023 and a statistically insignificant *p*-value of 0.816, appears to exert no influence on perceived comfort levels. In contrast, the Comprehensive Energy Coaching intervention suggests a more promising outcome, with a beta coefficient of 0.144 and a marginally significant *p*-value of 0.059. Notably, the Fix Team intervention stands out with its robust beta coefficient of 0.338 and a p-value of 0.011, demonstrating a statistically significant and strong improvement in perceived comfort levels. Our findings thus support Hypothesis 1.2 in that shallow retrofitting has a greater impact on perceived residential comfort than energy coaching. Furthermore, the aggregated data from all local interventions combined confirms the positive effect, evidenced by a beta coefficient of 0.107 and a significant p-value of 0.038, reinforcing the overarching hypothesis of the beneficial impact of local interventions on issues like indoor temperature, draughts, and moisture problems.

Investigating Hypothesis 2.1, which suggests that local interventions can encourage the adoption of Sustainable Behaviour, the probit model again demonstrates varied results. The Basic Energy Coaching intervention did not significantly impact sustainable behaviour adoption, with a beta coefficient of 0.077 and a *p*-value of 0.489. However, the results for the Comprehensive Energy Coaching intervention do suggest a potentially positive influence, with a beta coefficient of 0.144 and a marginally significant p-value of 0.061. The Fix Team is the only local intervention with a negative beta coefficient of −0.127, though this result is not statistically significant ($p = 0.374$), implying no clear detrimental impact but rather an unexpected direction in the effect. In support of Hypothesis 2.2, these findings suggest that energy coaching, particularly if executed thoroughly, is more effective in promoting sustainable behaviour practices than shallow retrofitting. Aggregated data across all local interventions show a beta coefficient of 0.053 with a *p*-value of 0.325, which suggests a lack of significance overall, thus

Table 5
Regression results (Probit and GLM) for the impact of the three local interventions individually and collectively on four dependent variables, with results adjusted for household characteristics and dwelling features, corresponding to Model 5 and 6 in Table 4.

Dependent variable	Model type	Intervention	Coefficient (β)[a]	Std. error	P-value[a]	Pseudo-R^2[b]	Log-likelihood	Sample (N)
Occupants' Comfort	Probit	Basic Energy Coaching	0.023	0.099	0.816	0.046	−353.99	134
		Comprehensive Energy Coaching	0.144*	0.076	0.059*	0.034	−596.94	214
		Fix Team	0.338**	0.133	0.011**	0.047	−317.04	118
		Local Interventions (aggregated)	0.107**	0.052	0.038**	0.017	−1,456.30	466
Sustainable Behaviour	Probit	Basic Energy Coaching	0.077	0.111	0.489	0.040	−294.58	114
		Comprehensive Energy Coaching	0.144*	0.077	0.061*	0.042	−499.77	212
		Fix Team	−0.127	0.143	0.374	0.036	−257.87	104
		Local Interventions (aggregated)	0.053	0.054	0.325	0.012	−1,176.80	430
Estimated Energy Bill	GLM	Basic Energy Coaching	−0.128	0.111	0.248	0.333	−129.58	106
		Comprehensive Energy Coaching	−0.168*	0.096	0.081*	0.276	−152.48	121
		Fix Team	−0.059	0.132	0.656	0.343	−117.79	97
		Local Interventions (aggregated)	−0.144**	0.060	0.015**	0.147	−434.57	324
Financial Concerns regarding Energy Bill	Probit	Basic Energy Coaching	−0.074	0.109	0.495	0.047	−200.18	124
		Comprehensive Energy Coaching	0.007	0.079	0.925	0.047	−333.76	212
		Fix Team	−0.428***	0.153	0.005***	0.165	−155.70	109
		Local Interventions (aggregated)	−0.096*	0.055	0.081*	0.043	−729.05	445

[a] Significance level set at * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
[b] McFadden's pseudo-R^2 (Probit models) and Cox and Snell's pseudo-R^2 (GLM) indicate model fit, yet do not quantify the variance explained by independent variables.

indicating minimal combined impact on fostering sustainable behaviour.

Hypothesis 3.1 posits that local interventions lead to reductions in Estimated Energy Bills, and since this dependent variable is continuous, we used GLM models. The Basic Energy Coaching intervention, with a beta coefficient of −0.128 and a *p*-value of 0.248, does not achieve statistical significance, implying limited effectiveness in lowering energy costs. Conversely, Comprehensive Energy Coaching has a more notable impact, reducing estimated energy bills with a beta coefficient of −0.168 and a marginally significant p-value of 0.081. The Fix Team intervention, however, shows an insignificant beta coefficient of −0.059 ($p = 0.656$), indicating no substantial effect on energy costs. Regarding Hypothesis 3.2, the results thus suggest that shallow retrofitting does not outperform energy coaching in reducing estimated energy bills. Notably, when all interventions are considered collectively, they demonstrate a significant combined effect, decreasing energy bills with a beta coefficient of −0.144 ($p = 0.015$), thus highlighting the hypothesis that local interventions can substantially lower household energy expenditures.

Finally, turning to Hypothesis 4, Table 5 indicates the probit model yields varied effects for the impact of local interventions on Financial Concerns regarding Energy Bills. Basic Energy Coaching shows a negative but insignificant beta coefficient of −0.074 ($p = 0.495$). Similarly, Comprehensive Energy Coaching has a negligible beta coefficient of 0.007 with a *p*-value of 0.925, indicating no impact. In contrast, the Fix Team intervention markedly reduced financial concerns regarding energy bills, with a beta coefficient of −0.428 and a highly significant p-value of 0.005, offering strong support for this approach's effectiveness. Aggregating the interventions, we observe a beta coefficient of −0.096 with a p-value of 0.081, suggesting a marginally significant reduction in financial concerns regarding energy bills, primarily driven by the impact of the Fix Team intervention.

In conclusion, our analysis reveals varying impact of local interventions on different outcome criteria. While Basic Energy Coaching showed limited impact, Comprehensive Energy Coaching demonstrated marginally significant impact on Occupants' Comfort improvements, Sustainable Behaviour adoption, and Estimated Energy Bill reductions. Moreover, the Fix Team intervention stood out with significant positive effects on Occupants' Comfort and highly significant alleviation of Financial Concern regarding Energy Bills. Collectively, the interventions demonstrated significant effects on improving perceived residential comfort and reducing estimated energy bills.

5.2. Interaction effects

In the investigation of interaction effects, our focus is on significant interaction terms that modify the impact of interventions, as discussed in Section 3.3. While our primary emphasis remains on energy poverty indicators as crucial interaction terms, we have also observed pronounced interaction effects in a select few other covariates.

In the previous section, we already established aggregated Local Interventions' statistically significant positive impact on Occupants' Comfort. Fig. 2 further illustrates this relationship by demonstrating that as households experience a higher energy burden – defined as the percentage of their disposable income dedicated to residential energy services – the positive effect of Local Interventions on comfort levels tends to amplify. It depicts a noteworthy positive interaction suggesting that when these factors – energy burden and one of the local interventions – are considered together, their combined impact is more significant expected by simply adding their individual effects. This interaction is indicated by a beta coefficient of 0.10, with a *p*-value of 0.04, signifying statistical significance.

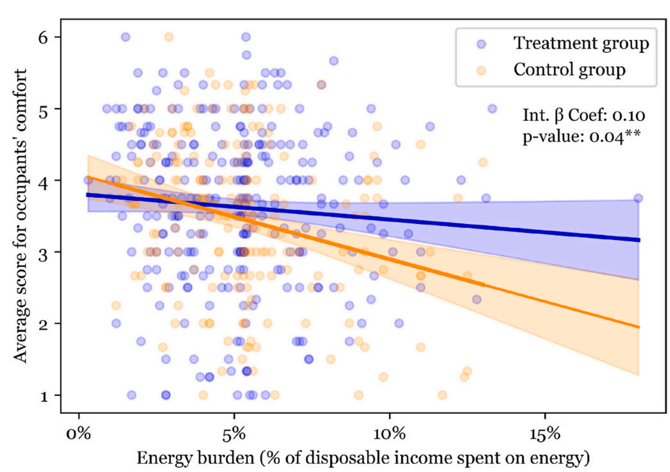

Fig. 2. Interaction effect between energy burden (the percentage of disposable income spent on residential energy services) and Local Interventions (aggregated) on Occupants' Comfort, illustrated with a 90 % confidence interval shading.

We also observed statistically significant increases in sustainable behaviour adoption among households classified under the Low-Income Low Energy Efficiency (LILEE) indicator when these households received support from (one of the) Local Interventions. LILEE serves as another measure of energy poverty. Unlike the energy burden, which is a continuous variable, LILEE categorises households as either energy poor or not. Fig. 3 demonstrates the dynamics between this variable and the effects of the three interventions, both individually and collectively. Specifically, Basic Energy Coaching resulted in an interaction coefficient of 0.62 (p = 0.05), indicating a statistically significant positive effect. Comprehensive Energy Coaching showed a more pronounced effect, with an interaction coefficient of 0.72 (p = 0.08), though this was only marginally statistically significant. Similarly, the Fix Team intervention displayed a marginally significant positive impact, with an interaction coefficient of 0.56 (p = 0.06). When all local interventions were combined, the aggregate data indicated a robust interaction effect, with a statistically significant coefficient of 0.59 (p = 0.03).

In addition to the interaction effects related to energy poverty indicators, our analysis identified two significant interaction effects involving specific local interventions and covariates. As illustrated in Fig. 4a, a highly significant negative interaction effect was observed between home ownership status and the effectiveness of the Comprehensive Energy Coaching intervention in reducing estimated energy bills (beta coefficient of −0.23, p-value <0.01). This effect implies that the intervention was notably more effective for households that do not live in a dwelling owned by them (i.e., households that rent privately or socially) than owner-occupying households. Fig. 4b reveals another significant negative interaction effect concerning household composition. Specifically, the interaction between being a couple with children and the effectiveness of the Fix Team intervention in alleviating financial concerns about energy bills was significant (beta coefficient of −0.13, p-value = 0.02). This suggests that the intervention was more effective in reducing financial stress for household types other than those consisting of couples with children.

6. Discussion

The main purpose of this analysis was to delve into the effectiveness of three local interventions – Basic Energy Coaching, Comprehensive Energy Coaching, and Fix Teams – in addressing energy poverty within the unique Dutch context, where a decentralised approach has granted significant policy discretion to municipalities.

We assessed whether these interventions fulfilled their aims by comparing outcomes related to perceived residential comfort, adoption of sustainable behaviours, estimated reductions in energy bills, and alleviation of financial concerns related to energy bills in both a control and a treatment group. Our results indicate varied outcomes, with the Fix Team and Comprehensive Energy Coaching interventions showing positive effects. A significant finding was the importance of strategically targeting these interventions at households in energy poverty. This discussion section will explore the broader implications of these results for the field of energy justice, evaluating the effectiveness of local interventions, comparing various intervention approaches, and examining the specific conditions under which these interventions prove most effective.

Despite our initial hypotheses predicting that all three interventions

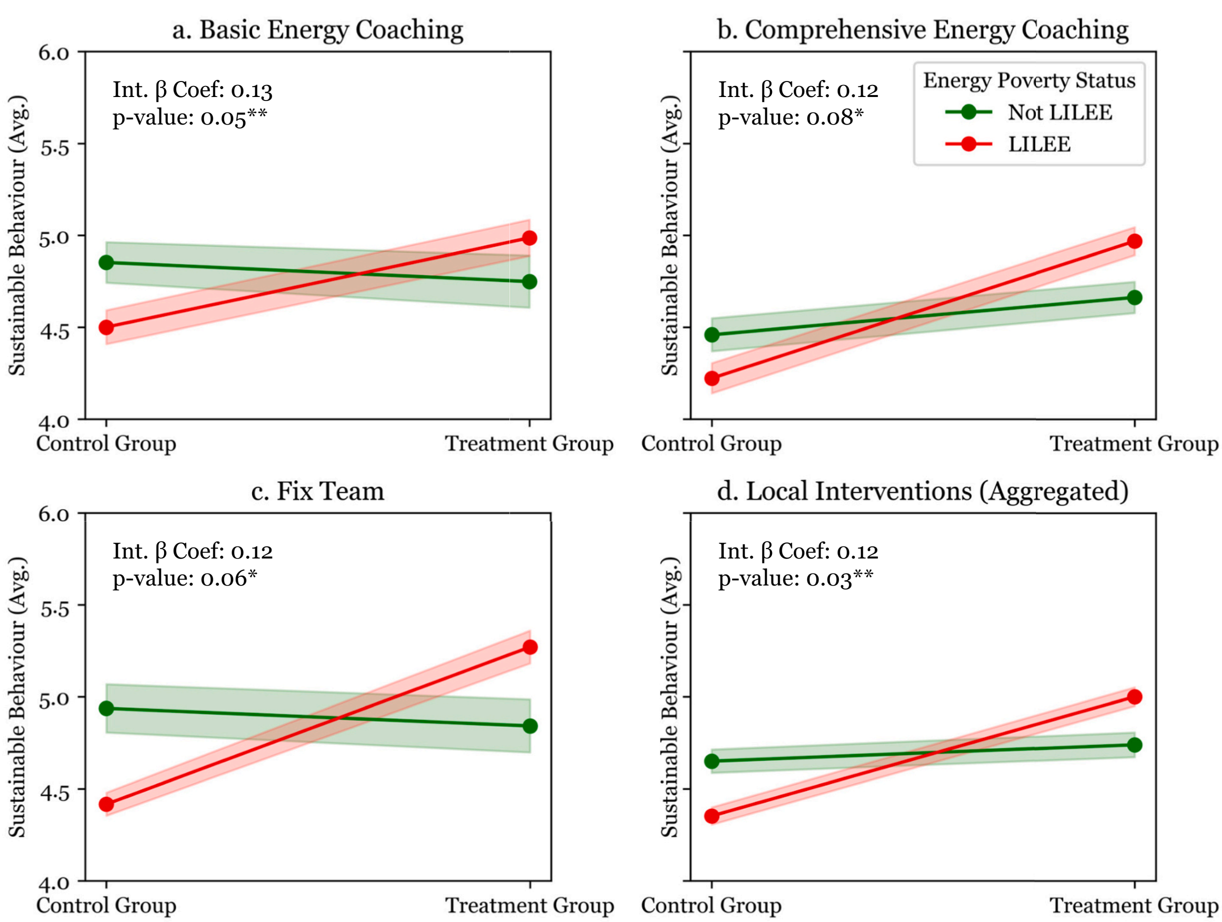

Fig. 3. Interaction effects between the Low-Income Low Energy Efficiency (LILEE) indicator and Local Interventions (individually and aggregated) regarding their impact on the adoption of Sustainable Behaviour, illustrated with a 90 % confidence interval shading.

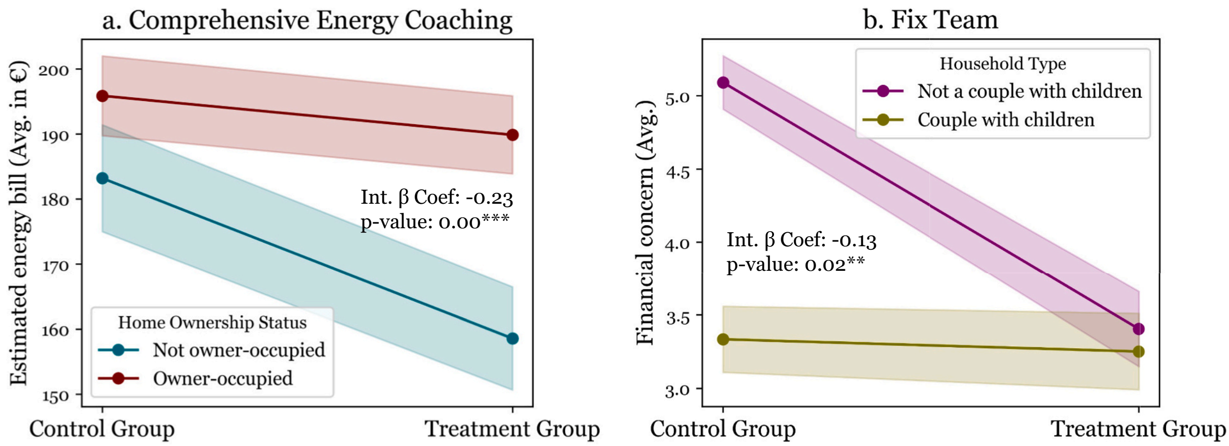

Fig. 4. Interaction effects of a.) owner-occupant status on the effectiveness of Comprehensive Energy Coaching in reducing Estimated Energy Bills, and b.) being a couple with children on the effectiveness of the Fix Team intervention in alleviating Financial Concerns regarding Energy Bills, both illustrated with a 90 % confidence interval shading.

would positively impact the four criteria, based on existing literature, our analysis revealed a more complex outcome. On an individual level, only the Fix Team intervention, which primarily focused on shallow retrofitting, led to statistically significant improvements in residents' perceived comfort and their financial concerns regarding energy bills. While the Comprehensive Energy Coaching produced marginally significant improvements (at a confidence level under 90 %) in perceived comfort, sustainable behaviour, and energy bill reductions, these were not as pronounced. When viewed collectively, however, the interventions as a whole did lead to significant improvements in both perceived comfort and energy bill reductions. The interaction effects observed in our study were particularly telling. Notably, all interventions had a more substantial impact on households experiencing energy poverty, defined either as those living on a low income in inefficient homes or those spending a significant portion of their income on energy.

The absence of marginally significant effects from the single-visit Basic Energy Coaching is surprising, given that prior studies, such as those by Ramsden [31] and Baker et al. [19], highlighted positive outcomes from interventions involving one or two home visits in terms of enhancing comfort levels and reducing energy bills. However, the fact that Comprehensive Energy Coaching and Fix Team interventions showed more substantial results *does* align with suggestions from previous studies [18,33] that the success of interventions is closely tied to the thoroughness of their design and implementation.

Moreover, the Fix Team intervention enhanced occupants' comfort and alleviated financial concerns regarding energy costs, yet unexpectedly it did not lead to significant reductions in energy bills. It was also the only intervention to exhibit a negative (albeit insignificant) beta coefficient for sustainable behaviour. This outcome may suggest a rebound effect, where households, feeling more comfortable and less concerned about energy costs post-intervention due to improved insulation, might increase their energy use for heating, thereby not reducing their overall energy expenditures [42]. This would align with the findings of Barrella et al. [16] that shallow retrofits notably influence those in 'hidden energy poverty' who were rationing energy pre-intervention. Alternatively, the enhanced perceptions of comfort and alleviated financial concerns regarding energy costs could be partially attributed to a psychological impact, akin to a 'placebo' effect, rather than a reflection of actual material changes, which is indeed sometimes observed in self-reporting [55]. To gain a deeper understanding of interrelationships and reasons behind specific behaviour, qualitative research, such as interviews, could be invaluable. For instance, exploring whether people adjust their temperature settings post-intervention due to increased awareness of environmental impact or out of financial concern would shed light on the nuanced motivations behind behavioural change. While such propositions warrant further investigation, it underscores the necessity of looking beyond changes in energy usage alone when evaluating local interventions and considering factors like perceived comfort and financial stress.

Another crucial contribution of this study is the interaction effects we found. They indicate that the effectiveness of the interventions under study notably depended on the energy poverty status of households. Local interventions were markedly more effective for those facing substantial energy burdens, defined as a high proportion of disposable income spent on domestic energy services, and for households classified as LILEE (Low Income, Low Energy Efficiency). These findings align with theoretical suggestions by Darby [23] that local interventions would prove more effective when well-targeted at households in need, and are now supported quantitatively in this study. They also correspond with recent studies that emphasise the predictive value of high energy burdens in determining the urgency of assistance needed [56,57]. LILEE as an interacting effect suggests that local interventions could be particularly beneficial for households that ration energy in poorly insulated homes, supporting findings from Baker et al. [19] and Barrella et al. [16]. This ties into the broader discussion of rebound *and* prebound effects [43,58], which could have influenced the observed outcomes.

Our findings also reveal less straightforward interaction effects. First, the significant negative interaction between owner-occupancy and the effectiveness of the Comprehensive Energy Coaching intervention on estimated energy bill reductions could be due to generally higher responsiveness to energy-saving strategies when the occupants do not have the authority to make more permanent changes to the property, making them more reliant on behaviour-based interventions to manage energy consumption [59]. If so, it is likely that these behavioural changes extend beyond those assessed in our study (see Table A-1 in the Appendix), as we do not observe an interaction effect on our composite Sustainable Behaviour effectiveness criterion. Secondly, the greater effectiveness of the Fix Team intervention in alleviating financial concerns in households other than those consisting of couples with children could be due to different financial pressures and priorities. Couples with children may have less flexibility in reducing energy costs, for example, because bigger family size necessitates higher utility usage [60]. Conversely, other household types, such as singles and childless couples, might see more significant financial relief from interventions that reduce energy bills, as their discretionary spending is less constrained by fixed costs such as club membership, childcare, and healthcare.

These insights underscore the importance of considering heterogeneity in designing, implementing, and evaluating energy poverty alleviation strategies. They resonate with broader calls for targeting policies at the most vulnerable and tailoring them to local communities' specific needs and contexts. This is particularly important as untargeted financial relief measures may raise energy prices when supply is already constrained by distorting the market and creating inefficiencies [61], deter investments essential for energy efficiency improvement [62], contribute to inflation by boosting liquidity across the board [63], and most importantly fail to adequately assist the most vulnerable groups [64]. Our findings highlight the need for more controlled experimental designs in future research to better delineate the complex interactions of local interventions, thereby enhancing their robustness and generalisability. This research could opt for a randomised design and more comprehensive sample sizes to overcome some of the limitations of this study. For instance, the significant reductions in energy bills noted in the aggregated intervention data compared to the single interventions could be more reflective of the broader sample size rather than the effectiveness. Nevertheless, adjustments for covariates and propensity score matching have mitigated some observational data challenges, as clearly shown in Appendix Table A-2. Had we not adjusted for a range of household characteristics and dwelling features, we would have drawn flawed conclusions due to the non-randomness of our control and treatment groups. This highlights the importance of gathering detailed information about respondents, particularly in post-intervention analysis.

The indirect effects of interventions are outside the scope of this study but, although more challenging to track, present a compelling avenue for future research due to their more elusive nature. For example, recent literature suggests that energy coaching services could serve as potential user and process intermediaries towards broader sustainability goals [65,66]. While our analysis of single-visit Basic Energy Coaching did not directly influence the dependent variables, these coaches have in any respect already crossed the threshold and can therefore provide diverse forms of assistance to households. By gaining a better understanding of a household's situation and through personal interaction, they can positively influence long-term improvements in living conditions. This includes helping with eligibility checks for benefits, handling official letters, and providing other financial advice. They can also point residents towards more extensive support services [67], like the Fix Team under study in this paper. Therefore, these interventions may indirectly help to build trust within social networks and towards institutions [68].

7. Conclusions

This study provides insights into the effectiveness of energy coaching and shallow retrofitting services in mitigating energy poverty, focusing on three interventions: Basic Energy Coaching, Comprehensive Energy Coaching, and Fix Teams. The collective impact of these interventions significantly enhanced occupant comfort and reduced household energy bills. Notably, the Fix Team intervention stood out for its substantial impact on both comfort levels and financial relief regarding energy costs. The Comprehensive Energy Coaching also demonstrated promising, albeit marginally significant, effects on comfort levels and adoption of sustainable behaviour. However, the Basic Energy Coaching yielded no significant results. Additionally, the effectiveness of these interventions was particularly marked in households experiencing energy poverty, where improvements in comfort and adoption of sustainable practices were most significant.

Consequently, our research contributes to the field of energy poverty mitigation by offering a comprehensive comparative assessment of different local interventions within the unique decentralised Dutch context. The research is pioneering in integrating both perceived impact through survey data and actual living conditions and background characteristics of respondents via administrative microdata, which facilitates a more nuanced and accurate impact assessment. This dual-data approach allows researchers to move beyond merely confirming the presence of an impact to understanding for whom these interventions are most effective. This shift in focus could significantly refine future strategies and policies in the fight against energy poverty.

The findings underscore several key messages and takeaways. Firstly, local interventions prove to be effective, significantly enhancing household well-being at modest costs. Secondly, a more comprehensive approach involving multiple visits has been shown to significantly boost effectiveness compared to interventions involving only a single visit. Thirdly, the importance of targeted strategies is highlighted through interaction effects; interventions tailored to households in greater need – those experiencing energy poverty – yield more substantial benefits. Lastly, these interventions can be more effectively designed and implemented by acknowledging the diverse needs of local communities and developing tailored alleviation strategies that consider specific factors such as energy efficiency, household types, and ownership status.

Hence, the policy implications are profound. While we clearly highlighted the necessity for policymakers to explore targeted and tailored interventions, the European energy crisis revealed that governments struggle to quickly identify in-need households due to missing or unreliable data. Therefore, improving data collection and sharing among key stakeholders like government, community centres, (local) faith-based organisations, and housing associations is crucial. Additionally, understanding the diverse aims and outcomes of interventions such as energy coaching and shallow retrofitting is essential. Policymakers must consider whether short-term building energy efficiency upgrades or changes in behavioural patterns are more pertinent to enhance well-being in their specific local contexts. Moreover, our results imply that more comprehensive designs of local interventions, which are more costly and require multiple visits and sustained engagement, are crucial for effectiveness. Policymakers should therefore prioritise these thorough approaches, recognising that the initial higher costs will be justified by the significant long-term benefits in terms of environmental sustainability and resident well-being.

Looking ahead, our findings prompt a call for more expansive future research into local interventions addressing energy poverty. To prepare for imminent crises and facilitate a more just energy transition, it is crucial to engage in comprehensive comparative studies similar to this one. Future research should incorporate detailed respondent information to accurately correct for disparities between control and treatment groups, particularly when utilising observational data, but also to improve understanding of the nuanced interaction dynamics that influence intervention effectiveness. Moreover, employing larger sample sizes and adopting randomised controlled designs would enhance the robustness of results. Additionally, longitudinal studies exploring these interventions' long-term effects could provide invaluable insights into their sustained efficacy and the enduring benefits they deliver.

In conclusion, this study highlights the potential of local interventions in energy poverty mitigation and household well-being. It establishes recommendations for policy-making that emphasise targeted and comprehensive approaches, tailored to the local context. The continued exploration and refinement of these strategies will be essential in shaping resilient energy systems that are both inclusive and equitable.

CRediT authorship contribution statement

T.M. Croon: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **E. Maghsoudi Nia:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **S. He:** Writing – review & editing, Software, Resources, Methodology, Data curation. **Q.K. Qian:** Writing – review & editing, Supervision, Methodology, Conceptualization. **M.G. Elsinga:** Writing – review & editing, Supervision, Methodology, Conceptualization. **J.S.C.M. Hoekstra:** Writing – review &

editing, Supervision, Methodology, Conceptualization. **C. Van Ooij:** Resources, Methodology, Investigation, Data curation, and Conceptualization. **A.J. Van der Wal:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

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Appendix

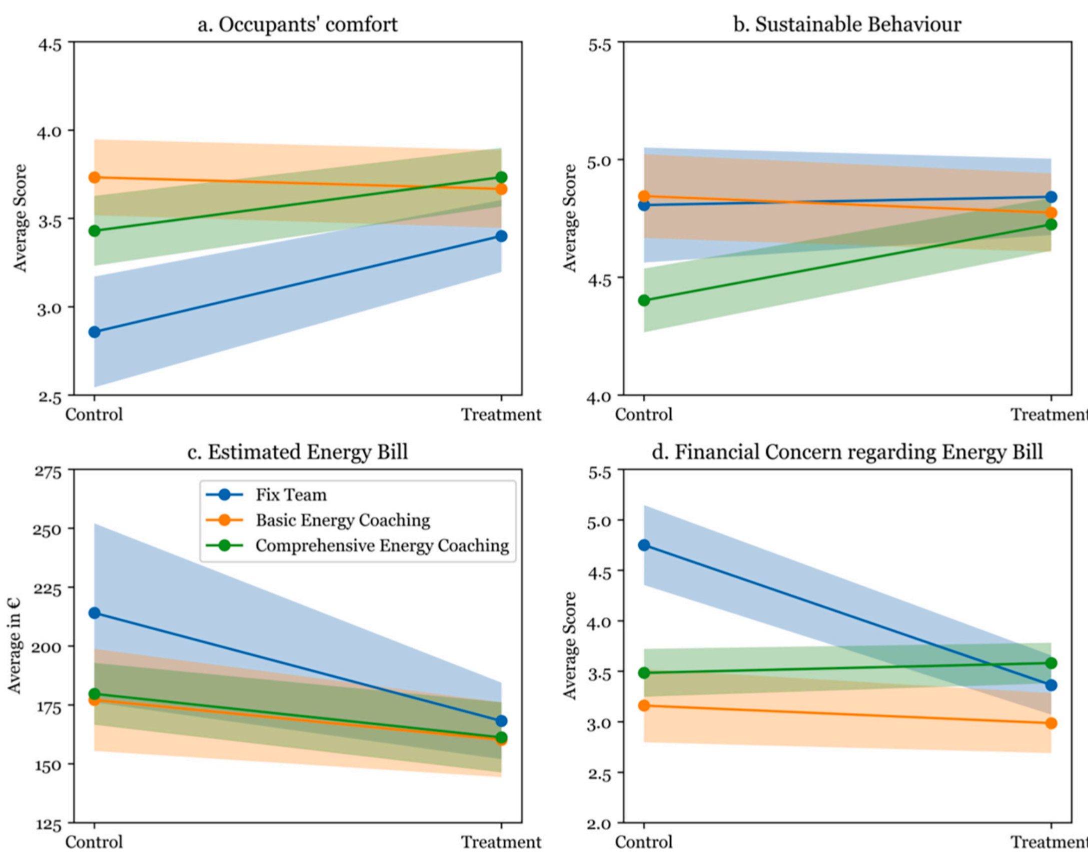

Fig. A-1. Comparison of unadjusted average outcomes between control group and treatment group per intervention.

Table A-1
Questionnaire.

		1. Never	2. Rarely	3. Sometimes	4. Regularly	5. Often	6. Always
Occupants' comfort	Do you experience cold in your home?	▢	▢	▢	▢	▢	▢
	Do you experience draughts in your home?	▢	▢	▢	▢	▢	▢
	Do you experience dampness and/or mould in your home?	▢	▢	▢	▢	▢	▢
	Did you experience heat in your home last summer?	▢	▢	▢	▢	▢	▢
Sustainable behaviour	Do you turn off the lights in rooms where no one is present?	▢	▢	▢	▢	▢	▢
	Do you shower for less than 5 min?	▢	▢	▢	▢	▢	▢
	Do you put on a warm sweater or grab a blanket when you feel cold at home?	▢	▢	▢	▢	▢	▢
	At what temperature do you set the thermostat during the day?	Open answer (in °C)*					
Financial concern	Are you worried about paying your energy bill?	▢	▢	▢	▢	▢	▢
Estimated energy bill	How much do you pay monthly for your energy bill?	Open answer (in €)					

* Given answers were grouped into six equally sized brackets, with cooler temperature settings indicating greater sustainability.

Table A-2
Beta coefficients and standard errors for six GLM and ordered probit models evaluating the impact of three local interventions on four dependent variables with sequential control for outcome temperature (1 and 2), household characteristics (3 and 4), and dwelling features (5 and 6).

Basic energy coaching	(1) GLM	(2) Probit	(3) GLM	(4) Probit	(5) GLM	(6) Probit
Occupants' comfort		−0.007		−0.006		0.023
		(0.091)		(0.096)		(0.099)
Sustainable behaviour		−0.029		−0.041		0.077
		(0.099)		(0.105)		(0.111)
Financial concerns related to energy bill		−0.072		−0.099		−0.074
		(0.098)		(0.104)		(0.109)
Estimated energy bill	−0.167		−0.204*		−0.128	
	(0.102)		(0.106)		(0.111)	
Comprehensive energy coaching	**(1) GLM**	**(2) Probit**	**(3) GLM**	**(4) Probit**	**(5) GLM**	**(6) Probit**
Occupants' comfort		0.109		0.134*		0.144*
		(0.070)		(0.076)		(0.076)
Sustainable behaviour		0.221***		0.142*		0.144*
		(0.071)		(0.076)		(0.077)
Financial concerns related to energy bill		0.035		0.014		0.007
		(0.072)		(0.078)		(0.079)
Estimated energy bill	−0.159*		−0.140		−0.168*	
	(0.093)		(0.094)		(0.095)	
Fix team	**(1) GLM**	**(2) Probit**	**(3) GLM**	**(4) Probit**	**(5) GLM**	**(6) Probit**
Occupants' comfort		0.229*		0.239*		0.338**
		(0.121)		(0.127)		(0.133)
Sustainable behaviour		−0.041		−0.134		−0.127
		(0.130)		(0.139)		(0.143)
Financial concerns related to energy bill		−0.393***		−0.397***		−0.425***
		(0.136)		(0.146)		(0.153)
Estimated energy bill	−0.133		−0.068		−0.059	
	(0.128)		(0.128)		(0.132)	
Local interventions (aggregated)	**(1) GLM**	**(2) Probit**	**(3) GLM**	**(4) Probit**	**(5) GLM**	**(6) Probit**
Occupants' comfort		0.084*		0.102**		0.107**
		(0.049)		(0.051)		(0.052)
Sustainable behaviour		0.091*		0.051		0.053
		(0.051)		(0.053)		(0.054)
Financial concerns related to energy bill		−0.085		−0.093*		−0.096*
		(0.052)		(0.054)		(0.055)
Estimated energy bill	−0.164***		−0.166***		−0.144**	
	(0.059)		(0.058)		(0.060)	

* Significance level set at * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, with standard errors in parentheses.

Data availability

The authors do not have permission to share data.

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