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Structural improvements to address energy poverty had most substantial thermal comfort and health effects

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Interventions to address energy poverty have expanded following the 2021–2023 energy crisis, but evidence on their effectiveness for improving health and living conditions remains limited. Here we use data from WELLBASED, a European study exploring the impact of interventions for energy poverty and improving health in six European cities. By categorizing interventions into structural, small measures, advice and financial support, we differentiate between the energy poverty and health impacts of each category. Through longitudinal analysis, we find there is little, if any, effect from small home improvements and energy advice, but that structural interventions for energy poverty have some positive thermal comfort and health effects. Direct financial support has clear positive effects on health and energy-saving practices, and when financial support fluctuates, so do participants' living conditions. Governments should invest in a range of measures, with a recognition that structural measures and consistent financial support are most effective.

Energy poverty, the inability to access adequate energy services[1], is high on the agenda in many nations. Energy poverty is linked to a range of physical and mental health conditions, accidents at home[2], excess winter and summer deaths[2–7] and aggravation of the health effects of disability[8–11]. Governments are keen to find ways to intervene, reducing exposure to energy poverty and improving health status[12,13].

Existing evidence on the effects of energy poverty interventions mainly evaluate structural interventions[14–37], such as fitting insulation, renewing the heating source or double-glazing windows, meaning evidence of the effect of other measures is not widely covered[38,39]. Alternative measures include advice interventions (energy audit, advice on benefits or energy tariffs), which help people improve their home energy efficiency. These are generally documented to have small effects, although advice delivered in person, by experienced advisers and coordinated with other forms of support can make a difference[39–45]. Another category of small home improvements involves replacing inefficient domestic appliances or distributing energy efficiency kits containing small technical fixes (for example, energy-saving light-bulbs). Finally, governments commonly offer some form of financial support for citizens who are entitled to particular benefits or in specific financial contexts[46]. Advice, small home improvements (small measures) and financial support interventions are in widespread use, maybe partly due to their relative low cost, and simplicity of delivery in comparison to more structural interventions.

Here we present analysis of data collected as part of WELLBASED, a project exploring urban interventions to address energy poverty in six cities in Europe. The aim of this Article is to demonstrate the effect of different energy poverty measures on: (1) people's ability to achieve thermal comfort in winter and (2) their health. We document people's experiences of energy poverty, especially ability to keep a home warm in winter, and their health and well-being status; as well as tracking their exposure to a range of interventions. Our research shows that structural interventions tend to result in more consistent improvements in winter thermal comfort and health, whereas other interventions produce

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Table 1 | Intervention descriptions and categories used in analysis

Intervention type	Interventions received during past 6 months	
None	No interventions	
Advice	Energy efficiency advice, including advice on energy bills Energy audit at home Attended energy efficiency group meeting	
Small measures	Support for replacement of inefficient domestic appliance Energy efficiency kit Access to home sensor data (damp, humidity, CO_2)	
Structural	Window replacement Home insulation Heating system	
Combinations of interventions received	***n***	**Intervention categories**
No intervention	404	None (*n* = 404; 37%)
Advice	95	Advice (*n* = 95; 9%)
Small measures	100	Small measures (*n* = 389; 36%)
Advice, small measures	289	
Structural	43	Structural (*n* = 206; 19%)
Advice structural	16	
Small measures, structural	30	
Advice, small measures, structural	117	
Total	1,094	

Table 2 | Financial support received by participants

Financial support	Intervention type				Total
	None (*n* = 404)	Advice (*n* = 95)	Small measures (*n* = 389)	Structural (*n* = 206)	*N* = 1,094
Any support for energy bills	52.5%	43.5%	46.0%	69.9%	52.7%
Type of support: % of participants					
Fixed financial support	45.0%	26.3%	12.6%	53.9%	35.5%
Reduction on energy bills	2.0%	8.4%	24.9%	6.8%	11.6%
In-kind or other contributions	45.0%	24.2%	22.1%	56.3%	37.2%

mixed outcomes. While investment is needed in structural measures, interventions will be more effective where policy also gives attention to consistent and relevant advice, energy debt, engagement in coping practices and health.

Energy poverty interventions

Research was conducted in six European cities: Edirne, Turkey; Heerlen, The Netherlands; Jelgava, Latvia; Leeds, UK; Obuda, Hungary; and Valencia, Spain. The central premise was to better understand the impact of urban interventions in tackling energy poverty and improving health. Energy poverty, health and well-being information was collected using self-reported questionnaires at four time points between June 2023 and September 2024 (baseline, 6, 12 and 15–18 months), completed by 1,094 participants (Supplementary Table 1). A full list of variables used in the analysis and their distribution is shown in Extended Data Table 1.

Participants were recruited because they were struggling to access adequate energy services. This was validated by the fact that 92% of our sample engaged in unhealthy coping practices (for example, limiting heating or wearing extra clothes to save money); over half were unable to achieve thermal comfort in winter (58%) or summer (69%); 46% had arrears on energy bills in the last 12 months and 45% experienced leaks, damp or rot. Sixty-three per cent of participants received an intervention during the 18 months under study, with 19% receiving structural, 36% receiving small measures and 9% advice (Table 1). Half of participants (52.7%) received some form of financial support with energy bills, including a fixed payment (35.5%) or reductions on energy bills (11.6%). Amounts of fixed payments varied depending on whether support was received for the year (25 euros to 1,500 euros) or per bill (3 euros to 300 euros), whereas, on average, bills were reduced by 44% (*n* = 126) (Table 2). Receipt of interventions or financial support was determined by engagement in WELLBASED interventions or by engagement in wider interventions led by national or city governments. Some participants may have also funded interventions privately.

The interventions received were categorized (top of Table 1): none, advice, small measures or structural (bottom of Table 1); and financial support consumption categorized to identify receipt of, or change in, support received. The demographic characteristics of participants by intervention received are shown in Extended Data Table 2. A description of the distributions of interventions by each European city can be found in Supplementary Notes; data are reported in Supplementary Tables 2 (intervention types), 3 (financial support) and 4 (changes in financial support by intervention type).

The analysis is longitudinal, exploring individual change over time, to understand responses to specific interventions. First, using measures of association to establish the strength and significance of relationships between energy poverty experiences, coping practices and health outcomes for the different types of intervention and financial support. Second, regression analysis to explore the effects of the interventions on changes in thermal comfort, controlling for energy practices and health.

How energy poverty is affected by intervention type

The relationship between intervention type, energy poverty, coping practices, financial support and health was explored through cross-tabulations. Circumstances at baseline by intervention type are shown in Fig. 1. Statistically significant associations are summarized in Fig. 2 (intervention type) and Fig. 3 (financial support).

Figure 1a–c shows circumstances at baseline by intervention type reported at follow-up. At baseline, those who later report having received structural interventions during the study period were generally in a worse position in terms of energy poverty and health compared to those who report receiving other interventions, although they were in a similar position to those not receiving any intervention. For example, at baseline 66% of those who later reported having received structural interventions struggled to keep their home warm in winter compared to 39% receiving small measures, 42% receiving advice and 77% receiving no intervention (Cramer's $V = 0.345$; $P = 1.87 \times 10^{-27}$).

We asked participants about a range of coping practices (Fig. 1b). At baseline, the majority of our sample (92%) engaged in unhealthy coping practices. For example, the proportion wearing extra clothes to keep warm ranges from 67% among those who at follow-up report having received small measures to 86% of those who do not receive any intervention (Cramer's $V = 0.154$; $P = 2.26 \times 10^{-11}$); and the proportion limiting heating to save money ranges from 59% (small measures) to 74% (structural and no intervention) (Cramer's $V = 0.132$; $P = 1.33 \times 10^{-6}$).

We go on to explore changes in circumstances over time by intervention type. A description of how variables have been coded is provided in Methods, and frequencies presented in Extended Data Table 1. Some categories do have low counts and results should be treated with caution. Nonetheless, key patterns are evident for different forms of intervention, and associations are statistically significant.

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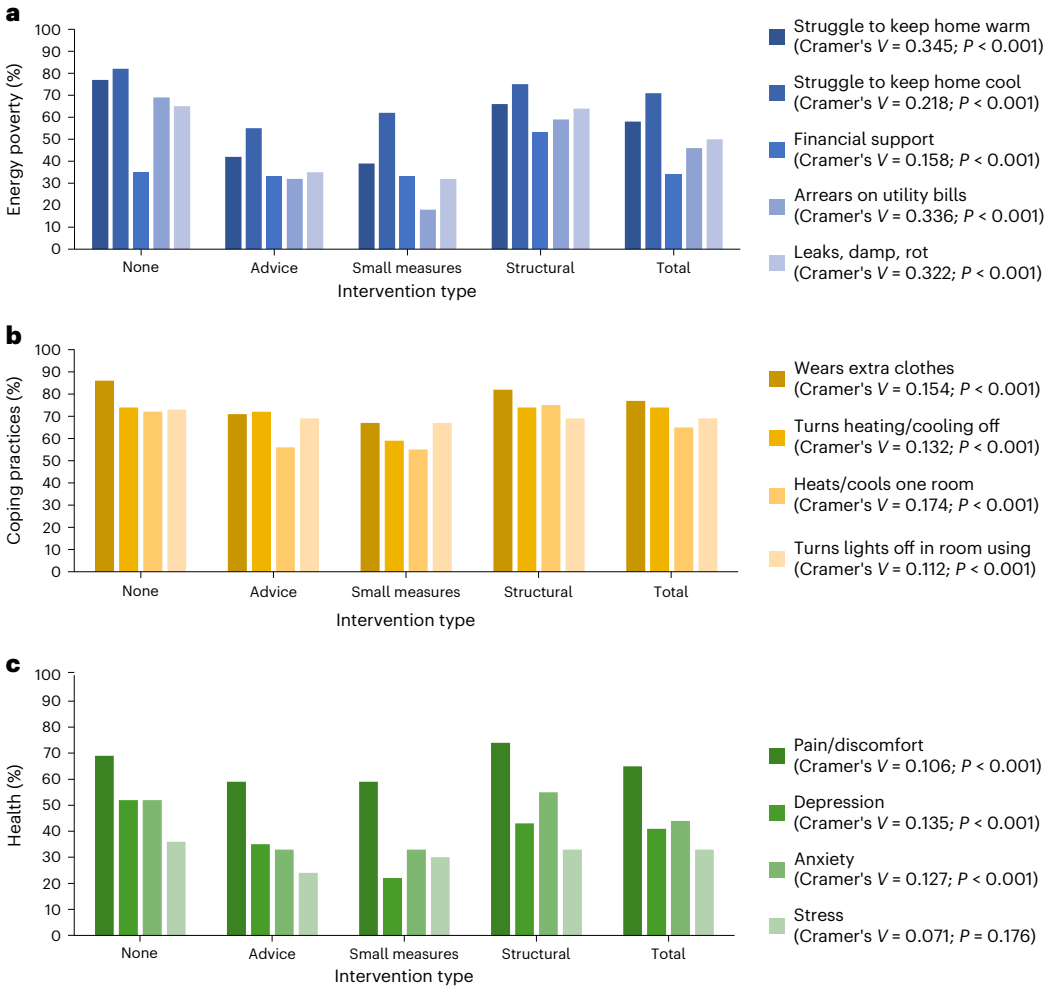


Fig. 1 | Circumstances at baseline by intervention type. a–c, Association of energy poverty (**a**), coping practices (**b**) and health (**c**) at baseline by intervention type. *P* values of less than 0.000 use threshold reporting $P < 0.001$.

We seek to capture the nuance of the variation in changes that can be experienced within as well as between intervention types. We therefore provide examples of associations in Fig. 2 (intervention type) and Fig. 3 (financial support). Figures for other variables included in the analysis are provided in Extended Data Fig. 1 (intervention type) and Extended Data Fig. 2 (financial support).

In Fig. 2a–e, we show that in homes where structural interventions have been implemented, people have become able to achieve thermal comfort (being comfortably warm in winter (35%) and cool in summer (31%)); they engage less in negative coping practices (for example, 39% have stopped or reduced the frequency of turning heating/cooling off to save money); they are better able to manage utility bills, 34% have stopped or reduced the frequency of being in arrears; and their health has improved (decrease in pain or discomfort (35%), improvements in depression (28%), anxiety (35%) and stress (25%)).

In homes implementing small measures, things have generally stayed the same in a positive way. For example, people are not experiencing problems with thermal comfort (47% report homes as already being warm) or health (over half are not depressed (52%), anxious (51%) or stressed (56%)) and rarely engaging in negative coping behaviours (for example, 23% never or rarely turn heating/cooling off to save money compared to 14% of those receiving structural interventions).

Where people have only received energy-related advice, there is a mix of experiences. Some people continue to achieve thermal comfort (46% can keep homes warm in winter), are not in arrears (65%) and continue not to experience mental health issues (43% are not depressed, 46% not anxious and 63% not stressed). But others continue to engage in unhealthy coping practices, such as wearing extra clothes (20%) or limiting when (38%) and where (28%) heating is used to save money and are also more likely to continue experiencing physical health problems causing pain or discomfort (31%).

Where no interventions have been implemented, there is also a mix of experiences. Whereas some people have become able to achieve thermal comfort in winter (34%), others still struggle in winter (39%) and summer (42%). People are better able to keep on top of utility bills (41% stopped or reduced the frequency of arrears) and report improvements in mental health (depression (38%), anxiety (36%) and stress (31%)), but they continue to engage in unhealthy coping practices to save money (35% turn heating/cooling off; 34% heat/cool only one room).

Figure 3a–e summarizes data on the receipt of financial support towards the cost of energy. There are also patterns evident here in the way that changes in support affected people's experiences. We observe that participants who reported not getting financial support over the study period achieved thermal comfort in summer (58% were or became able to keep cool) and winter (80% were or became able to keep warm). They were not having problems with arrears, damp or mental health, although some engaged in unhealthy coping practices to save money (for example, 38% were or started turning heating/cooling off).

Where people did receive financial support or started to get support throughout the observed period, they did not achieve thermal

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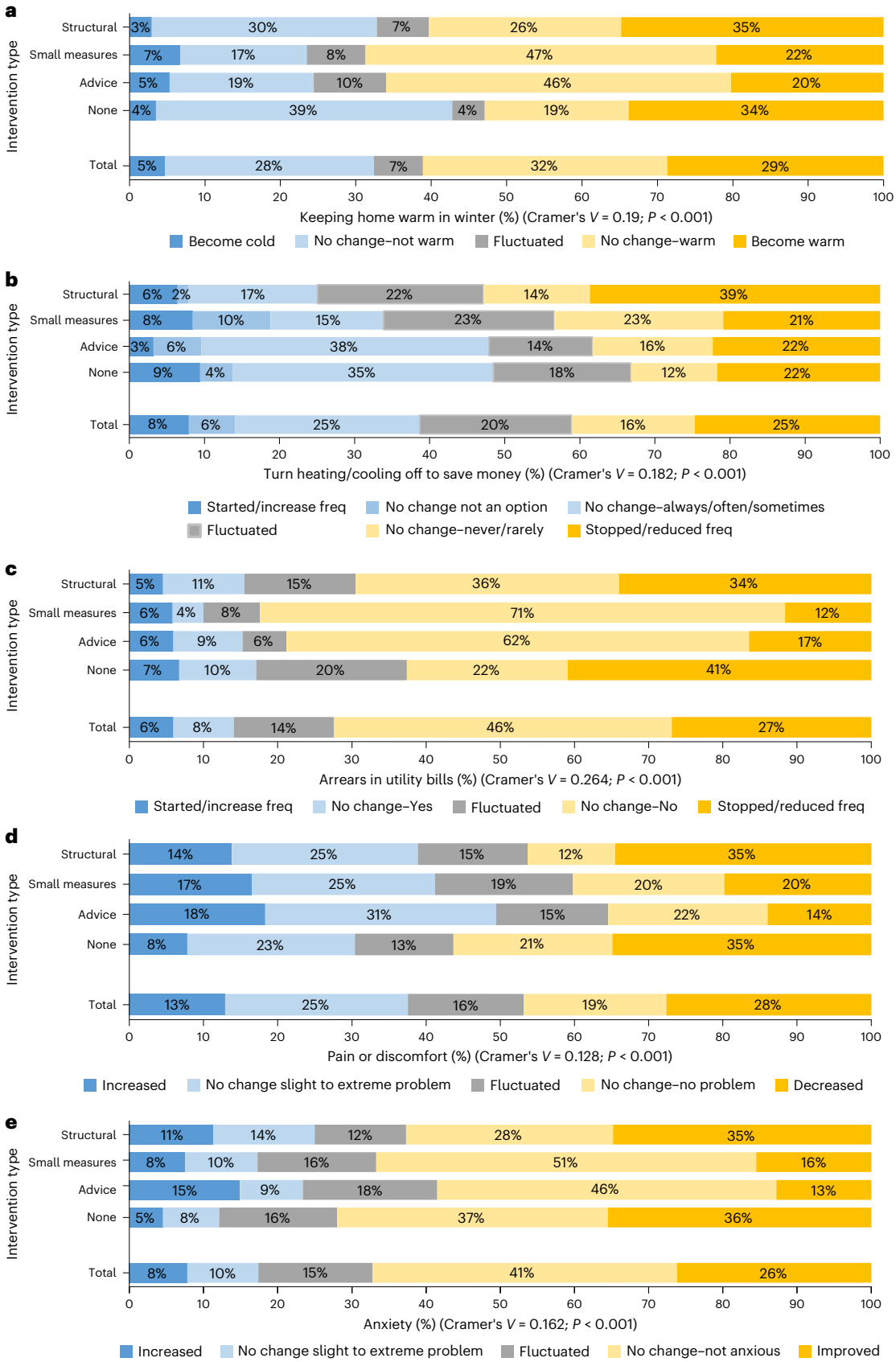


Fig. 2 | Changes in experiences by intervention type. a–e, Examples of association of intervention type by changes in ability to keep home warm in winter (**a**), turning heating or cooling off to save money (**b**), arrears in utility bills (**c**), pain or discomfort (**d**) and anxiety (**e**). *P* values of less than 0.000 use threshold reporting $P < 0.001$.

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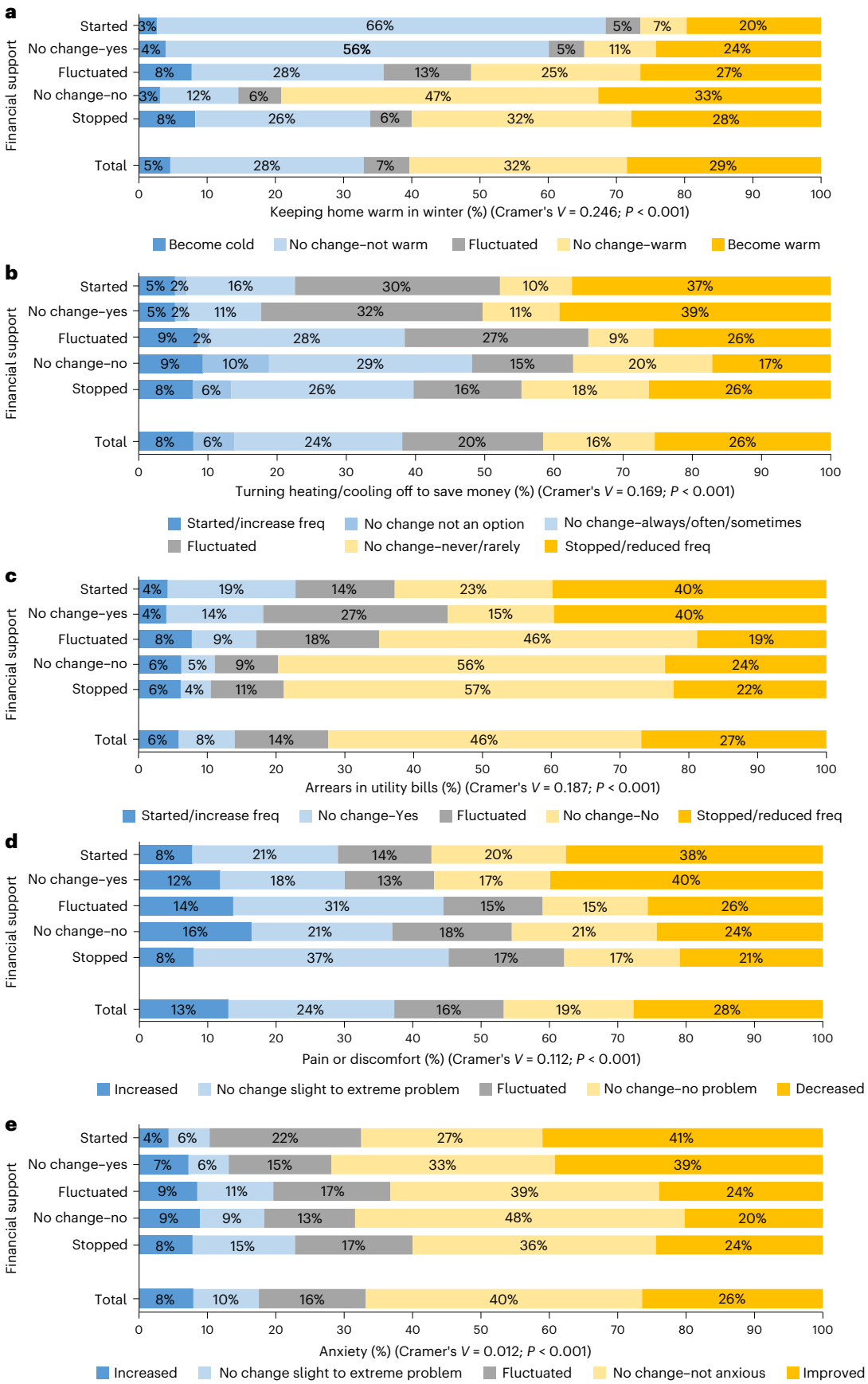


Fig. 3 | Changes in experiences by financial support. a–e, Examples of association of changes in financial support by changes in ability to keep home warm in winter (**a**), turning heating or cooling off to save money (**b**), arrears in utility bills (**c**), pain or discomfort (**d**) and anxiety (**e**). *P* values of less than 0.000 use threshold reporting $P < 0.001$.

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Table 3 | Recoding of dependent variables for logistic regression

Change in keeping home warm in winter	Model 1: struggle to keep home warm	Model 2: become able to keep home warm
Become cold	1 Not warm	0 Other
No change–not warm		
Fluctuated		
No change–warm	0 Other	
Become warm		1 Become warm

comfort (66% who started getting financial support and 56% who continued to get financial support are not warm) and had damp (75% and 68%, respectively; Extended Data Fig. 2). However, over time they reduced engagement in unhealthy coping practices (37% and 39%, respectively, stopped turning heating/cooling off) and arrears (40% stopped or reduced frequency of arrears) and reported improvements in health (38%/40% had decreased pain and discomfort; 41%/39% reported reductions in anxiety).

Where financial support stopped during the period under study problems with arrears dropped (57%). However, some unhealthy coping practices continued (34% started/continued turning heating/cooling off, and 34% started or continued to heat one room to save money). People stopped having problems with damp, although continued to have physical (37%) and mental health (15% anxiety; 16% depression) problems. Finally, fluctuations in getting financial support also showed fluctuations in achieving thermal comfort (13%), unhealthy energy practices (27%), arrears (18%) and damp (15%).

Factors associated with keeping homes warm in winter

Here we focus on one dimension of energy poverty, namely the ability to keep a home comfortably warm in winter. Two separate regression models were run to explore changes in people's circumstances based on negative experiences (people started or continued to struggle to keep their home warm) and positive experiences of thermal comfort (people became able to keep their home warm). Table 3 shows how the variable has been recoded to create the two binary dependent variables. Full results are presented in Extended Data Tables 3 and 4. A description of how the longitudinal variables have been created is presented in Extended Data Table 5.

In both models, structural interventions produced the only significant changes: these resulted in a reduced likelihood of struggling to keep a home warm in winter (odds ratio (OR) = 0.44; $P = 0.001$) and an increased likelihood of becoming able to keep a home warm (OR = 1.95; $P = 0.005$).

The likelihood of struggling to keep a home warm is higher where financial support has been received at some point (OR range from 1.95 ($P = 0.016$) to 3.30 ($P < 0.001$)); people have moved in and out of arrears on utility bills (OR = 2.10; $P = 0.013$); and with having leaks, damp or rot (OR = 6.09; $P < 0.001$). The likelihood is also higher where people are only heating one room to save money (OR = 3.31; $P < 0.001$) but also where they have stopped or reduced the frequency of heating only one room (OR = 2.85; $P = 0.002$) or this practice has fluctuated (OR = 2.26; $P = 0.019$). They are also more likely to be wearing extra clothes to keep warm, but the margin of error is high, so results should be treated with caution.

By contrast, becoming able to keep a home warm is more likely where people have stopped or reduced the frequency of arrears on utility bills (OR = 2.99; $P < 0.001$) or are not heating only one room (OR = 2.08; $P = 0.028$), although fluctuations in heating one room also increase the likelihood (OR = 2.08; $P = 0.035$). Not wearing extra clothes to keep warm as often is also significant, although again the margin of error is high. The likelihood of becoming able to keep a home warm is also lower where people have leaks, damp or rot (OR = 0.50; $P = 0.015$) (Extended Data Table 3).

The ability to achieve thermal comfort is also linked to health. The likelihood of not being able to keep a home warm is higher where there are increased levels of depression (OR = 2.19; $P = 0.027$), and where stress levels have fluctuated (OR = 2.10; $P = 0.004$). Where stress levels have reduced (OR = 1.74; $P = 0.012$) or pain and discomfort levels had fluctuated (OR = 1.91; $P = 0.017$) or decreased (OR = 1.94; $P = 0.008$), this is linked to the likelihood of becoming able to keep a home warm (Extended Data Table 4). The nature of the data do not enable cause and effect to be determined, and it could be that stress and discomfort arise because of issues with thermal comfort, rather than pre-empting them.

Discussion

Experiences of energy poverty are complex. The causes and consequences of being able to keep a home warm, receiving financial support and engaging in unhealthy coping practices can be bidirectional. We caution against predicting the ability to keep a home warm following interventions. Instead we can extract some key insights about the effects of different interventions when controlling for financial circumstances and coping practices. First, there were clear links between the level of intervention and the extent of effects. Advice only and small measures had limited effects, whereas structural measures had a more positive impact on participants lives. Structural interventions resulted in a wide range of positive experiences for those that received them, including being able to achieve thermal comfort in winter, being less likely to be in debt or engaging in unhealthy coping practices and better health. This group was more likely to be in a worse position at the outset, with more space for improvement; nonetheless, our work clearly suggests the need for more investment in structural measures.

For those receiving only advice, the effect was not statistically significant. However, we should not read into this finding that energy advice is worthless; instead it lends credence to Simcock and Bouzarovski's assertion that advice "can help to partially ameliorate energy poverty, but its impacts are limited by structural factors that are beyond the immediate influence of advisers or individual citizens"[39]. Energy advice is likely to be playing an important role in supporting more structural interventions—indeed 71% of those receiving structural measures—also received advice. Recent work from England showing the current advice provision is geographically inconsistent and may exacerbate inequalities[47], as well as being resourced in a way that makes it difficult to provide continuity of service[43], suggests there is also a need for more attention to the nature and consistency of advice provided.

The effects of financial support are more complex. Being in receipt of financial support does not resolve all challenges, as people still struggle to achieve thermal comfort. However, it could be because people cannot afford to heat their home adequately that they are eligible for support. There is a clear pattern in the data that when financial support is withdrawn, people's situations worsen. This supports a longstanding recognition that people are likely to go in and out of energy poverty over time as their circumstances change[48,49]. The fact that the presence or absence of financial support links to the fluctuation in experience of energy poverty suggests that consistency of support is important. Another financial aspect—the presence of energy bill arrears—is also strongly linked to the ability to keep warm, which suggests that policy needs to address energy debt to ensure effective outcomes.

The precariousness of energy poverty is also demonstrated where people's energy-saving practices fluctuate, for example, limiting when and where heating is used, which increases the likelihood of achieving thermal comfort and also the likelihood of struggling to keep warm. It is reasonable to speculate that limiting heating may help manage utility bills but reduce thermal comfort, whereas keeping heating on will achieve thermal comfort but may push people into arrears. The

nuances in the results show that energy poverty is a complex process and that policy interventions need to pay attention to unhealthy coping practices and financial circumstances.

The links between becoming able to keep a home warm and mental and physical health are important. Whereas we cannot track causation here, when people are cold in winter, results indicated they are more depressed and stressed; and when people are warm in winter, stress, pain and discomfort are reduced. This is a helpful confirmation of the links between health and energy poverty[2,29,30,34] and further evidence that addressing health in this context is another important strand of policy.

Methods

Project design

WELLBASED was designed to evaluate urban interventions to reduce energy poverty in six European cities (Valencia, Spain; Heerlen, The Netherlands; Leeds, UK; Edirne, Turkey; Obuda, Hungary and Jelgava, Latvia). Interventions ranged from advice to structural measures (Table 1). The types of intervention received varied by country (Supplementary Table 2).

The study sample is based on convenience sampling. In total, 1,350 participants were initially recruited to the project. Of these, 1,260 completed questionnaires, among whom 792 participants received interventions through WELLBASED via national or local government schemes or funded privately, and 468 received no interventions during the period of observation.

Data collection

WELLBASED is a mixed-methods project, using quantitative and qualitative techniques to collect data. A full description of project methods is available[50].

Questionnaires were distributed to all participants for self completion. Participants completed an initial questionnaire to provide 'baseline' data from June to September 2023. Questionnaires were then completed at 6-month intervals, providing longitudinal data at 6 months, 12 months and a final follow-up at 15–18 months after the baseline (Supplementary Table 1). Data collection finished by September 2024.

The questionnaires collected data on health and well-being, energy poverty and energy efficiency. They also collected information on any energy efficiency interventions that participants had received during the previous 6 months, whether this was through WELLBASED or not. The results presented here are based on analysis of these self-reported questionnaires, where information is available on variables used in the analysis (n = 1,094).

Creating longitudinal variables

The analysis used a longitudinal approach explored change over time by aggregating individual experiences rather than averaging change across a cohort. Variables have been coded to capture the complete experiences of participants at each time point (Extended Data Table 5). First, variables for each time point were coded in such a way that they represent their position in the timeline. These time-point variables were combined to produce a timeline of experience or behaviour for each participant. These experiences were then categorized to reflect a change in experience or behaviour that is negative (for example, homes become cold or people started or increased the frequency of a certain coping behaviour) or positive (for example, homes become warm or people stopped or decreased the frequency of a certain coping behaviour). They also reflect no change, where this can be negative (for example, still struggling to keep home warm or engaging in unhealthy energy behaviour) or positive (for example, homes remain warm or not engaging in unhealthy behaviours). Importantly, for energy poverty, they also capture 'fluctuations' where there is no consistent pattern in people's behaviour or experiences.

Extended Data Table 5 provides a worked example to show how responses to whether people can keep their home warm in winter has been coded to create a longitudinal variable, which has been categorized to show: where circumstances have become worse, that is, where previously a participant could keep their home warm, they are now not able to—labelled as 'become cold'; where circumstances have stayed the same, that is, a participant has consistently reported that they can, or cannot, keep their home warm—labelled as 'No change–yes' or 'No change–no'; where circumstances have fluctuated, meaning there is no consistent pattern in ability to keep a home warm—labelled as 'Fluctuated'; and where circumstances have gotten better, that is, a participant initially could not keep their home warm but then report that they can keep their home warm—labelled as 'become warm'.

Stages of analysis

The analysis was conducted in two stages. First, exploratory analysis looked at the relationships between different elements of energy poverty, coping practices and health with intervention type and financial support using cross-tabulations. The strength and significance of these associations was measured using Cramer's V.

The second stage of analysis focussed specifically on a key issue for those in energy poverty: the ability to keep a home comfortably warm in winter. Two binary variables were created to focus on the two extremes of experiences, and two logistic regression models were run: Model 1 identified where things had got worse, through exploring the likelihood of struggling to keep a home warm in winter; Model 2 identified where things had got better, exploring the likelihood of people becoming able to keep their warm home. Table 3 shows how the variable has been recoded to create the two binary dependent variables.

Limitations

A limitation of our work was the sample recruited. Some of our participants did not report problems associated with energy poverty in the baseline data. This is likely to influence the extent to which they are eligible for, or seek out, measures to improve thermal comfort. The mixed results for those not receiving any intervention in particular may reflect the polarity within this group where, for example, people may have already had an intervention (before the period of observation) or have not had an intervention because they cannot afford it or they are a tenant, and this is the responsibility of their landlord.

Ethics statement

Ethics approval was received by all project partners. The names of the review boards and the approval references are: Valencia, Spain: Ethics committee for research with medicines of the university clinical hospital of Valencia, reference number 2021/316; Heerlen, The Netherlands: Medical Ethical Committee (MEC)–Erasmus University Medical Center Rotterdam, reference number MEC-2022–0150; Leeds, UK: Ethics committee University of Leeds—AREA (Faculties of Business, Environment and Social Sciences), reference number 21–070; Edirne, Turkey: Trakya University Edirne Clinical Studies Ethical Committee, reference number 07/01; Obuda, Hungary: Scientific and Research Ethics Committee of the Medical Research Council of Hungary, reference number 332/2022; and Jelgava, Latvia: Central Medical Ethics committee of Latvia, reference number 01–29.1.2/2267. Informed consent was collected on paper by a research assistant.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The WELLBASED questionnaire dataset generated and analysed in this study is not publicly available because it contains sensitive participant

information that cannot be fully anonymized without compromising its scientific value. Following assessment by the project Ethics Lead, the data were determined to be suitable only for controlled access due to the risk of re-identification. The data are securely stored at Erasmus Medical Centre (Erasmus MC: Patiëntenzorg) and can only be accessed within the governance framework established for the original project. The data underlying the findings of this study are provided in the article and its Supplementary Information. Source data are provided with this paper.

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Author contributions

B.A.S.: conception and design, analysis and interpretation of data, drafting original article and article revisions. L.M.: drafting original article and article revisions. A.v.G.: acquisition of data and article revisions. M.S.: acquisition of data and article revisions.

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Competing interests

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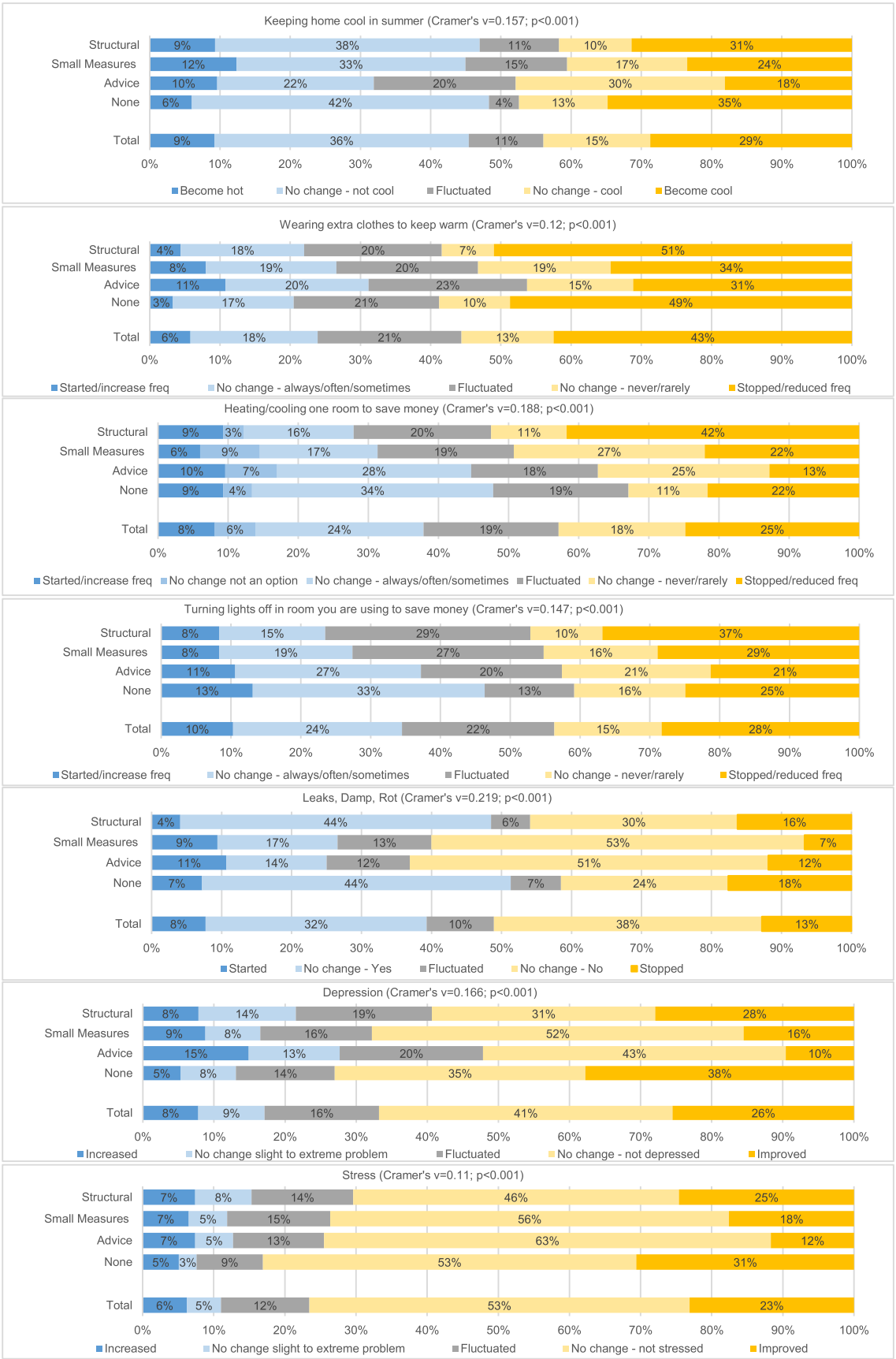
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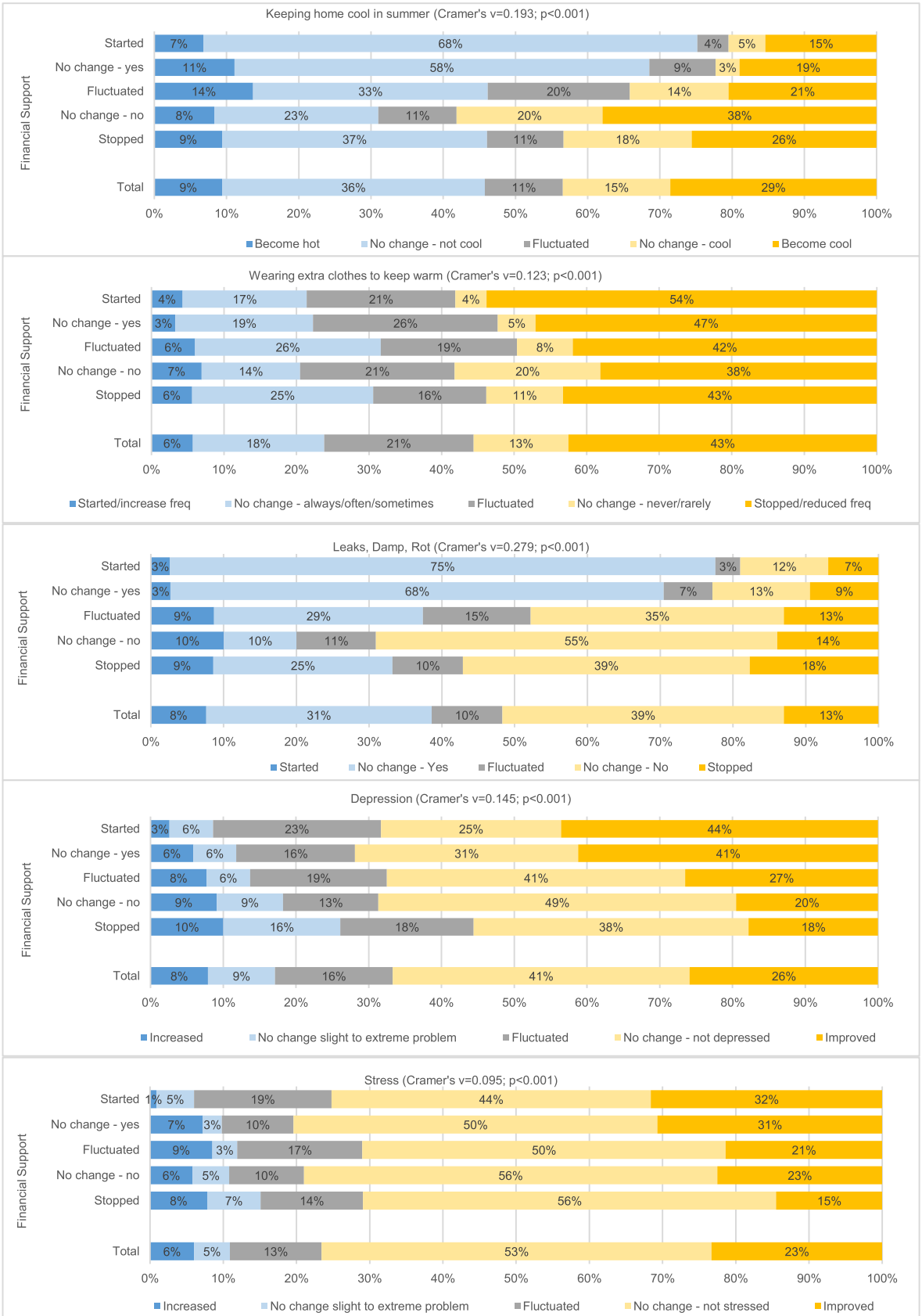
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Extended Data Fig. 1 | Changes in energy poverty experience and health by intervention type. P values of less than 0.000 use threshold reporting $p < 0.001$.

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Extended Data Fig. 2 | Changes in energy poverty experiences by financial support. P values of less than 0.000 use threshold reporting $p < 0.001$.

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Extended Data Table 1 | Variables included in analysis

Variable	Categories	%
Keeping home comfortably warm in winter	Become cold	5
	No change - not warm	28
	No change - warm	32
	Become warm	29
	Fluctuated	7
Total (n= 1082)		100
Keeping home cool in summer	Become hot	9
	No change - not cool	36
	No change - cool	15
	Become cool	29
	Fluctuated	11
Total (n= 1082)		100
Wearing extra clothes to keep warm	Started/increase freq	6
	No change - always/often/sometimes	18
	No change - never/rarely	13
	Stopped/reduced freq	43
	Fluctuated	21
Total (n= 1080)		100
Turn heating/cooling off to save money	Started/increase freq	8
	No change not an option	6
	No change - always/often/sometimes	25
	No change - never/rarely	16
	Stopped/reduced freq	25
	Fluctuated	20
Total (n= 1064)		100
Heating/cooling one room to save money	Started/increase freq	8
	No change not an option	6
	No change - always/often/sometimes	24
	No change - never/rarely	18
	Stopped/reduced freq	25
	Fluctuated	19
Total (n= 1073)		100
Turning off lights in the room you are using to save money	Started/increase freq	10
	No change - always/often/sometimes	24
	No change - never/rarely	15
	Stopped/reduced freq	28
	Fluctuated	22
Total (n= 1082)		100
Arrears in Utility Bills	Started/increase freq	6
	No change - Yes	8
	No change - No	46
	Stopped/reduced freq	27
	Fluctuated	14
Total (n= 1039)		100
Leaks, Damp, Rot	Started	8
	No change - Yes	32
	No change - No	38
	Stopped	13
	Fluctuated	10
Total (n= 1000)		100
Pain or discomfort	Increased	13
	No change slight to extreme problem	25
	No change - no problem	19
	Decreased	28
	Fluctuated	16
Total (n= 1082)		100
Depression	Increased	8
	No change slight to extreme problem	9
	No change - not depressed	41
	Improved	26
	Fluctuated	16
Total (n= 1083)		100
Anxiety	Increased	8
	No change slight to extreme problem	10
	No change - not anxious	41
	Improved	26
	Fluctuated	15
Total (n= 1083)		100
Stress	Increased	6
	No change slight to extreme problem	5
	No change - not stressed	53
	Improved	23
	Fluctuated	12
Total (n= 1080)		100

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Extended Data Table 2 | Demographic characteristics at baseline by intervention type

Demographic characteristics (at baseline)	Intervention type				
	None	Advice	Small Measures	Structural	Total
Age (mean)					
18-34	22.4%	22.8%	14.4%	22.8%	19.6%
35-64	66.3%	63.0%	58.4%	62.4%	62.4%
65+	11.3%	14.1%	25.3%	18.8%	18.0%
Total %	100.0%	100.0%	100.0%	100.0%	100.0%
n	*389*	*92*	*383*	*202*	*1066*
Sex					
Female	63.4%	72.2%	71.5%	53.0%	65.1%
Male	36.6%	27.8%	28.5%	47.0%	34.9%
Total %	100.0%	100.0%	100.0%	100.0%	100.0%
n	*391*	*90*	*383*	*202*	*1066*
Education					
None/primary	50.4%	23.9%	18.8%	48.5%	36.4%
O or A Level, HND, Professional	42.4%	52/2%	48.0%	37.6%	44.4%
Degree	7.2%	23.9%	33.2%	13.9%	19.2%
Total %	100.0%	100.0%	100.0%	100.0%	100.0%
n	*319*	*92*	*383*	*202*	*1068*
Net monthly household income					
Less than 750 Euro	62.7%	23.1%	22.7%	61.2%	44.7%
751 Euro to 1,650 Euro	30.2%	46.2%	46.0%	19.9%	35.3%
1,650 Euro or more	7.2%	30.8%	31.3%	18.9%	20.1%
Total %	100.0%	100.0%	100.0%	100.0%	100.0%
n	*391*	*91*	*383*	*201*	*1066*
Dwelling type					
Detached house	42.2%	7.9%	13.9%	53.6%	31.6%
Semi-detached or terraced house	12.1%	28.9%	13.6%	18.0%	15.0%
Flat or other	45.7%	63.2%	72.5%	28.4%	53.3%
Total %	100.0%	100.0%	100.0%	100.0%	100.0%
n	*372*	76	*346*	*183*	*977*
Tenure					
Owner	52.2%	27.6%	39.6%	63.0%	47.9%
Tenant – Market rate	22.3%	40.8%	30.1%	12.0%	24.5%
Tenant – reduced rate/free or other	25.5%	31.6%	30.3%	25.0%	27.6%
Total %	100.0%	100.0%	100.0%	100.0%	100.0%
n	*372*	76	*346*	*184*	*978*

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Extended Data Table 3 | Logistic regression results for struggling to keep home warm and becoming able to keep home warm

		Model 1: Struggles to keep home warm				Model 2: Become able to keep home warm			
Variable	**Categories**	**OR**	**95% CI**		**p-value**	**OR**	**95% CI**		**p-value**
			Lower	Upper			Lower	Upper	
Intervention	None	REF				REF			
	Advice	1.39	0.68	2.82	0.365	0.81	0.38	1.69	0.569
	Small Measures	0.90	0.54	1.49	0.670	1.08	0.66	1.78	0.760
	Structural	0.44	0.27	0.72	0.001	1.97	1.23	3.17	0.005
Financial support	No change - no	REF				REF			
	Stopped	1.523	0.93	2.52	0.096	0.10	0.60	1.63	0.967
	No change - yes	2.48	1.37	4.51	0.003	0.72	0.39	1.36	0.317
	Fluctuated	1.95	1.13	3.33	0.016	0.79	0.45	1.39	0.412
	Started	3.30	1.18	6.34	<0.001	0.62	0.31	1.25	0.182
Wearing extra clothes	No change - never/ rarely	REF				REF			
	Started/increased freq	5.77	1.94	17.19	0.002	0.72	0.22	2.37	0.588
	No change - always/ often/sometimes	13.92	5.25	36.88	<0.001	1.05	0.44	2.50	0.912
	Fluctuated	5.20	2.05	13.14	<0.001	2.36	1.08	5.18	0.032
	Stopped/reduced freq	3.65	1.46	9.09	0.006	4.87	2.29	10.37	<0.001
Turn off heating	No change - never/rarely	REF				REF			
	Started/increased freq	1.78	0.74	4.30	0.200	1.13	0.45	2.84	0.792
	No change - always/ often/sometimes	0.94	0.47	1.92	0.871	1.22	0.60	2.48	0.579
	Fluctuated	10.87	0.56	2.10	0.803	0.82	0.42	1.58	0.550
	Stopped/reduced freq	0.91	0.49	1.713	0.775	0.72	0.39	1.33	0.291
Heat one room	No change - never/ rarely	REF				REF			
	Started/increased freq	1.79	0.72	4.42	0.209	1.06	0.39	2.89	0.902
	No change - always/ often/ sometimes	3.31	1.65	6.64	<0.001	1.61	0.78	3.30	0.196
	Fluctuated	2.26	1.14	4.46	0.019	2.08	1.05	4.12	0.035
	Stopped/reduced freq	2.85	1.48	5.48	0.002	2.08	1.08	3.98	0.028
Turn off lights	No change - never/ rarely	REF				REF			
	Started/increased freq	0.44	0.20	0.10	0.049	1.69	0.76	3.77	0.198
	No change - always/ often/sometimes	0.60	0.30	1.20	0.151	1.92	0.95	3.90	0.069
	Fluctuated	0.88	0.47	1.64	0.688	1.48	0.78	2.78	0.228
	Stopped/reduced freq	0.97	0.53	1.78	0.924	1.15	0.62	2.14	0.651
Arrears on Utility bills	No change - no	REF				REF			
	Started/increased freq	1.78	0.83	3.82	0.142	1.25	0.57	2.75	0.576
	No change - yes	1.35	0.66	2.75	0.417	1.13	0.53	2.42	0.747
	Fluctuated	2.10	1.17	3.75	0.013	1.62	0.91	2.89	0.101
	Stopped/reduced freq	0.78	0.47	1.30	0.338	2.99	1.84	4.86	<0.001
Damp/rot	No change - no	REF				REF			
	Started	2.08	1.07	4.03	0.031	1.12	0.58	2.14	0.740
	No change - yes	6.09	3.62	10.24	<0.001	0.50	0.29	0.88	0.015
	Fluctuated	2.76	1.54	4.93	<0.001	0.85	0.46	1.55	0.594
	Stopped	1.49	0.82	2.72	0.191	1.48	0.85	2.57	0.165
Chi sq; df; p-value				*368.287; 38; <0.001*				*206.51; 38; <0.001*	
Nagelkerke Pseudo Rsq				*0.453*				*0.295*	

Controlling for gender, household composition and housing tenure. Two-sided significance tests. Statistically significant results highlighted in yellow. P values of less than 0.000 use threshold reporting p < 0.001.

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Extended Data Table 4 | Logistic regression results for how thermal comfort is associated with health

		Model 1: Struggles to keep home warm				Model 2: Become able to keep home warm			
Variable	**Categories**	**OR**	**95% CI**		**p-value**	**OR**	**95% CI**		**p-value**
			Upper	Lower			Upper	Lower	
Intervention	None	REF				REF			
	Advice	0.79	0.43	1.45	0.453	0.59	0.30	1.15	0.119
	Small measures	0.62	0.42	0.90	0.013	0.56	0.37	0.83	0.004
	Structural	0.42	0.27	0.64	p<0.001	1.74	1.14	2.66	0.011
Financial support	No change - no	REF				REF			
	Stopped	2.22	1.44	3.42	p<0.001	1.17	0.75	1.84	0.490
	No change - yes	7.51	4.64	12.18	p<0.001	0.51	0.30	0.86	0.012
	Fluctuated	3.61	2.26	5.78	p<0.001	0.76	0.46	1.26	0.283
	Started	9.90	5.71	17.16	p<0.001	0.40	0.22	0.73	0.003
Pain/ Discomfort	No change - no problem	REF				REF			
	Increased	0.78	0.44	1.37	0.381	1.46	0.81	2.65	0.211
	No change - slight to extreme problem	1.35	0.82	2.23	0.244	1.30	0.75	2.25	0.357
	Fluctuated	0.90	0.89	0.58	0.664	1.91	1.12	3.25	0.017
	Decreased	0.79	0.49	1.26	0.320	1.94	1.19	3.18	0.008
Depression	No change - not depressed	REF				REF			
	Deteriorated	2.19	1.10	4.40	0.027	0.39	0.16	0.94	0.036
	No change - mild/mod/severe	1.53	0.74	3.18	0.252	0.55	0.25	1.24	0.149
	Fluctuated	1.20	0.72	2.00	0.496	1.16	0.67	1.95	0.578
	Improved	1.17	0.73	1.89	0.519	1.09	0.67	1.79	0.720
Anxiety	No change - not anxious	REF				REF			
	Deteriorated	0.74	0.37	1.45	0.376	1.73	0.84	3.58	0.136
	No change - mild/mod/severe	1.44	0.71	2.91	0.309	0.97	0.45	2.10	0.934
	Fluctuated	0.90	0.53	1.50	0.669	0.980	0.57	1.68	0.939
	Improved	1.01	0.63	1.91	0.971	1.16	0.725	1.85	0.539
Stress	No change - not stressed	REF				REF			
	Deteriorated	1.45	0.72	2.93	0.296	0.50	0.21	1.22	0.128
	No change - mild/mod/severe	1.51	0.65	3.52	0.340	0.37	0.12	1.14	0.083
	Fluctuated	2.10	1.27	3.47	0.004	0.89	0.52	1.53	0.665
	Improved	1.01	0.65	1.57	0.951	1.74	1.13	2.69	0.012
	Chi sq; df; p-value	*220.756; 30; p<0.001*				*145.138; 30; p<0.001*			
	Nagelkerke Pseudo R sq	*0.281*				*0.203*			

Controlling for gender, household composition and housing tenure. Two-sided significance tests. Statistically significant results highlighted in yellow. P values of less than 0.000 use threshold reporting p < 0.001.

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Extended Data Table 5 | Creating longitudinal variable to capture where things have changed or where they have stayed the same

1. Variables for each time point are recoded to position them in the timeline

Variable	Response set	Baseline t_0	6 mths t_1	12 mths t_2	18 mths t_3
Keep home warm in winter	No	1000	100	10	1
	Yes	2000	200	20	2
	Missing	9000	900	90	9

2. Individual time period variables are combined (summed) to create a single timeline: $t_0t_1t_2t_3$
For example:

	t_0	t_1	t_2	t_3	Combined t0-t3
Keep home warm in winter	Yes	No	No	Missing	
	2000	100	10	9	2119

3. The combined variable is categorised to identify changes, or not, in experiences. Categories are based on the condition there are valid entries for at least two time periods. Where this condition is not met responses are assigned as missing. For example:

Keep home warm in winter					
t_0	t_1	t_2	t_3	Combined t0-t3	Category
Yes	No	No	Missing		
2000	100	10	9	2119	Become cold
No	Missing	No	No		
1000	900	10	1	1911	No change – not warm
Yes	Yes	Yes	Yes		
2000	200	20	2	2222	No change – warm
No	No	Yes	Yes		
1000	100	20	2	1122	Become warm
No	Yes	No	Yes		
1000	200	10	2	1212	Fluctuated
Missing	No	Missing	Missing		
9000	100	90	9	9199	Missing

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Software and code

Policy information about availability of computer code

Data collection	Data used in this article were collected through online questionnaires, issued to participants by email or completed with the support of a research assistant. Questionnaire responses were uploaded into SPSS data files and securely stored in the WELLBASED repository, operated by INCLIVA (Project Lead).
Data analysis	IBM SPSS Statistics 28.0.0.0

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

The dataset that we have used for this analysis is not publicly available. This was decided at the end of the project based on participant anonymity. The Project Ethics Lead concluded the data could not be fully anonymised, only pseudonymised. If the data were made available at a level to be of scientific relevance there

remained a risk of reidentification. The data are therefore held in a secure repository by the Erasmus Medical Centre, which is open for researchers who were involved in the original project only.

Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	Participants self-reported sex. The distribution of sex is reported in Table E1. The unit of analysis for this research is household, sex is therefore not reported separately. .
Reporting on race, ethnicity, or other socially relevant groupings	Questions on migrant status were asked in the questionnaire, but are not included in this analysis.
Population characteristics	See below
Recruitment	Recruitment was self-selecting, convenience sampling. Recruitment was challenging due to the Ukraine was and rising energy prices. Many eligible households had other challenges on their minds and were hesitant to commit to a long-term project. Households facing the biggest challenges are mostly likely under represented in the sample. This groups are potentially more likely to benefit from energy poverty interventions, meaning the results are most likely an under-estimation.
Ethics oversight	Ethics Approval was received by all project partners. The names of the review boards and the approval references are: Valencia, Spain: Ethics committee for research with medicines of the university clinical hospital of Valencia, ref. no. 2021/316; Heerlen, The Netherlands: Medical Ethical Committee (MEC) – Erasmus University Medical Centre Rotterdam, ref. no. MEC-2022–0150; Leeds, United Kingdom: Ethics committee University of Leeds—AREA (Faculties of Business, Environment and Social Sciences), ref. no. 21–070; Edirne, Turkey: Trakya University Edirne Clinical Studies Ethical Committee, ref. no. 07/01; Obuda, Hungary: Scientific and Research Ethics Committee of the Medical Research Council of Hungary, ref. no. 332/2022, and; Jelgava, Latvia: Central Medical Ethics committee of Latvia, ref. no. 01–29.1.2/2267. Informed consent was collected on paper by a research assistant.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☒ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	WELLBASED addresses Horizon 2020 Call: SC1-BHC-29-2020 – Innovative actions for improving urban health and well-being – addressing environment, climate and socioeconomic factors. The project aimed to design, implement, and evaluate a novel, comprehensive urban programme, based on the social ecological model, to significantly reduce energy poverty and its effects on the citizen's health and well-being. WELLBASED is a mix-methods study using quantitative (self-completion questionnaires; health monitoring; indoor air quality monitoring) and qualitative (interviews) methods.
Research sample	WELLBASED used non-probabilistic sampling. In total 1235 participants provided informed consent. The average age of participants is 50. Overall, 65% of the sample are female, 39% are home owners, 68% are lower income households, 34% are households with children, 21% are migrants, 5% belong to an ethnic minority and 18% have moderate, severe or extreme health related quality of life problems.
Sampling strategy	The WELLBASED study sample is based on convenience sampling with a control (CG) and intervention group (IG) in each pilot study site. Participants could be included if they were considered vulnerable to energy poverty. Please note that 'intervention group' referred to only those receiving a WELLBASED intervention. The 'control group' may have received other interventions privately. For the purposes of the analysis presented in this article participants were identified as having received an intervention or not, irrespective of whether this was a WELLBASED intervention (IG) or privately organised (CG).
Data collection	The analysis reported in this article uses data from Self-reported questionnaire at baseline (T0) 6-month (T1), 12-month (T2) and 15-18 month (T3) follow-up, the latter depending on the month of recruitment. Other data collection (not analysed here): Self-monitoring or research assistant monitoring or peak flow, oxygen saturation, blood pressure and heart rate, every month. Self-reported sleep quality, every 3 months. Indoor air quality (temperature, CO2 and humidity) near real-time.
Timing	September 2022 to September 2024
Data exclusions	people were not eligible to participate if they had been beneficiaries of a previous similar intervention, when they had limitations

Data exclusions	preventing the adequate participation in the intervention actions proposed in the pilots (e.g., intellectual disabilities, unable to attend to workshops, training, meetings; very poor health conditions, severe language limitations preventing the minimum communication), or when their household was illegally connected to the electricity grid.
Non-participation	No information was collected on people who did not wish to be participants. Of the 1235 participant 1004 (81%) completed questionnaires at 6-month follow up, 988 (80%) at 12-month follow up, and 948 (77%) at 15/18 month follow up.
Randomization	Participants were not allocated into experimental groups.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Plants

Seed stocks	N/A
Novel plant genotypes	N/A
Authentication	N/A