Indoor and Built Environment

A pilot study on the impact of a first-time central heating intervention on resident mental wellbeing

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Abstract

Fuel poverty affects around 34% of European homes, representing a considerable burden to society and healthcare systems. This pilot study assesses the impact of an intervention to install a new first time central heating system in order to reduce fuel poverty on household satisfaction with indoor temperatures/environment, ability to pay bills and mental wellbeing.

In Cornwall, 183 households received the intervention and a further 374 went onto a waiting list control. A post-intervention postal questionnaires and follow up phone calls were undertaken (N=557) to collect data on household demographics, resident satisfaction with indoor environment, finances and mental wellbeing (using the Short Warwick-Edinburgh Mental Wellbeing scale). We compared responses between the waiting list control and intervention group to assess the effectiveness of the intervention.

A total of 31% of participants responded, 83 from the waiting list control and 71 from the intervention group. The intervention group reported improvements in the indoor environment, finances and mental wellbeing. However, these benefits were not expressed by all participants, which may result from diverse resident behaviours, lifestyles and housing characteristics. Future policies need to consider whole house approaches alongside resident training and other behaviour change techniques that can account for complex interactions between behaviours and the built environment.

Key words

Fuel poverty, Energy efficiency, Health, Mental wellbeing, Community

Introduction

Fuel poverty represents a significant burden to society and healthcare systems, and affects around 34% of European homes [1, 2]. The severity and/or time spent in fuel poverty depends on a complex interaction between household income, cost of energy, levels of energy efficiency of the home and resident behaviours [3, 4]. Living in fuel poverty increases the risk of a range of physical (cardiovascular and respiratory conditions) and mental health illnesses [1, 5, 6], particularly among older adults [7]. Cold homes increase the risk of cold related morbidity and mortality [8] with a large proportion of winter deaths resulting from cardiovascular (40%) and respiratory (35%) diseases [9]. Reducing energy inefficient housing [10] and the impact of excess cold on health could save the UK National Health Service (NHS) more than £800m per year [11].

Fuel poverty policies can lead to improvements in thermal comfort (i.e. achieving the recommended indoor temperature of 18-24 °C), reduced energy costs [12] and improvements in health [13] and wellbeing [14], particularly when targeted at those with a chronic illness [15], which has the potential to reduce hospital admissions [16]. Wider benefits include reduced carbon monoxide poisoning, risk of falling [17], exposure to dampness-related agents (resulting from increased condensation) such as the proliferation of house dust mites, mould and volatile organic compounds (e.g. degradation of building materials) [18, 19] and risk of allergic/non-allergic diseases [19-23]. Other co-benefits include reducing the carbon footprint of the domestic housing sector, which amounts to 25% of total UK CO_2 emissions [24]. Analyses using energy efficiency data between 2000 and 2007 showed that these co-benefits have led to around 40% of the UK's housing stock receiving home energy efficiency improvements [24] such as improved heating, insulation, glazing and draft proofing to prevent heat loss [25].

Despite a range of policy and fiscal incentives to eradicate fuel poverty, the public health impact of cold homes remains an enduring policy problem in the UK [4]. Consequently, fuel poverty interventions will continue to play a key role in reducing cold-related mortality and morbidity [26]. The success of fuel poverty policies depends

on the ability to identify those most in need, which is problematic due to the unknown nature of the interrelated social, cultural and economic factors influencing fuel poverty [27]. This has led to a fundamental change in national fuel poverty policy. In 2016, the Department of Energy & Climate Change [28] consulted on proposed changes to the UK's key fuel poverty policy; the Energy Company Obligation (ECO). The policy change required a focus on low-income and vulnerable households, and was delivered through a 'transition period' between April 2017 and October 2018 [29].

The transition period raised a number of challenges. This included the ability to effectively identify/target fuel poor households and the definition used, which have been widely contested in the UK [30-33]. As a result of the Hills Review, the UK Government changed the definition used for fuel poverty in England (i.e. from the 10% criteria to the Low-Income High Cost (LIHC) criteria). The Government also introduced a policy change [28] allowing local authorities to target funding towards householders meeting the Low Income Vulnerable to Cold (LIVC) classification through their ECO Flexible Eligibility criteria, (ECO Flex programme) [34]. The ECO Flex programme allows a broader eligibility criteria to be applied, recognising that the knowledge of local circumstances held by Local authorities and other key stakeholders, may identify those households that fail to meet the basic qualifications for support through the ECO but are in need of this assistance.

In 2017/18, this policy change was piloted in Cornwall to assess the effectiveness of the ECO Flex programme and the ability to target fuel poor households. In order to receive an intervention (i.e. in this case a 'first time heating system'), qualifying households had to apply and receive a valid Local Authority (LA) Declaration (i.e. ECO Flex qualifying certificate). Receiving this LA declaration meant that according to the LA eligibility criteria, these qualifying households met either the 10% criteria, LIHC and/or LIVC classification [35]. This study aimed to assess whether this policy change helped improve indoor living environments and mental wellbeing outcomes and reduce fuel poverty.

Methods

Study population

Cornwall is home to some of Europe's most deprived communities [36]. Following ethical approval (Cornwall Council, reference RGF002), this pilot study focused on a lower income population residing across Cornwall in the South West of England who had applied for an LA Declaration to receive support from the ECO Flex programme [34]. Targeted households were primarily home owners (70.3%) and those living within the private rental sector (PRS). A high proportion of homes receiving an intervention; were unable to heat the home (51.7%); experienced difficulty in paying energy bills (57.2%); and lived in a home without central heating (85.9%) [35].

Heating Intervention

Of the 557 households applying for an ECO Flex LA Declaration, 183 received a new heating system intervention during 2017/18 (i.e. the intervention group). The 374 households with an LA Declaration who did not receive an intervention went onto a waiting list for the 2019/20 programme (i.e. a 'waiting list control' group). All 557 households were invited to participate into this study.

Qualifying households received support and funding towards a new first time heating system under the new ECO Flex programme [34]. Rather than replacing an old central heating system, the funding allowed the installation of a new central heating system in homes reliant on a single source of heating in one room or those using electric heating for example. Applications were reviewed by Cornwall Council, and a surveyor assessed the heating needs of individual properties. The survey report stipulated the type and location of the new heating system. Due to the different needs of individual properties and geographic location (e.g. properties not on mains gas), a variety of new heating systems were installed. These included new gas (53.6%), LPG (Liquid Petroleum Gas, 26.0%) and oil (11.1%) central heating; with the remaining 9.3% receiving new quantum electric storage heaters. After installation, households were contacted by Community Energy Plus (CEP) [37] and Cornwall Rural Community Charity (CRCC) [38] to ensure installations had been completed and to resolve any further queries from households.

Questionnaire

The questionnaire was designed using prior surveys [25, 39, 40] and in collaboration with CEP [37] and CRCC [38]. Questionnaires were designed using a structured closed questioning technique to collect data on the household, which included a range of demographic (e.g. age and sex) and household (e.g. tenure and presence of damp/mould) questions.

Participants were asked whether they were satisfied with the indoor temperature; suffered from the presence of damp, mould and mouldy odour; had problems paying bills; and avoided heating due to cost. The Short Warwick Edinburgh Mental Wellbeing Scale (SWEMWBS) © [41] was used to assess participants mental wellbeing [42]. The total SWEMWBS (ranging from 7 to 35 as the highest possible mental wellbeing) [43] were transformed into mental wellbeing scores [44].

Due to delays in delivery of the ECO Flex programme, postal questionnaires were sent out in two phases during July and August 2019 along with consent forms and information sheets. To improve response rates, CEP and CRCC contacted each of the 557 target households.

BEIS eligibility criteria

As described above, the original aim of the change in policy was to improve the targeting of ECO towards fuel poor households. Participating households were compared against the Department for Business, Energy & Industrial Strategy (BEIS) Energy Company Obligation Flexible Eligibility Guidance [34] to assess the eligibility of each household under the ECO Flex scheme and whether the householders awarded LA Declarations met the guideline LIHC eligibility criteria. To enable this, data was linked with household income information from the original household applications and reviewed against BEIS' proposed eligibility criteria for identifying fuel poor households.

All participating households had a LA declaration, which meant they met the eligibility criteria set by Cornwall Council. This required the home to be deemed expensive to run or the household to contain someone vulnerable to cold, and/or be low income

defined by having an annual household income of less than £30,000. A small number of households receiving a LA Declaration had a higher annual household salary but were deemed vulnerable to cold following a local authority review panel [35, 45]. These criteria differed slightly to the BEIS definition of fuel poverty and vulnerable to cold.

To assess the proportion of households with a LA Declaration, who received an intervention and those meeting the BEIS eligibility criteria, we compared household information against the policy guidance [34]. Low income households were identified through a process of assessing the applicant households' self-declared disposable income (i.e. income after they have paid for their rent or mortgage) against BEIS' recommended household composition equivalised disposable income eligibility thresholds. These thresholds range from an annual household income of £8,900 (for one adult) up to £25,700 (for two adults and four or more children) [34].

Households in receipt of qualifying benefits (i.e. those set by the Home Heating Cost Reduction Obligation (HHCRO) scheme) were also assessed using self-reported declarations and consequently assessed as having been eligible for ECO under the standard eligibility criteria. As such they were not considered to be deemed eligible for the ECO Flex scheme under either the Cornwall Council or the BEIS criteria. We were unable to reliably assess whether households met the BEIS 'high cost' eligibility criteria (i.e. LIHC) [46] as this would have required the original household application records to have been reprocessed which was beyond the scope of this project.

Statistical analyses

Households were categorised into the intervention group (i.e. those receiving a new heating system) and waiting list control group. Descriptive statistics were used to describe and compare participant and housing characteristics of each group. To assess whether receiving a new heating system led participants to adequately heat their home and improved the indoor environment, we compared questions that are indicative of fuel poverty [47]. These included;

- How satisfied are you with your house regarding indoor temperature? For the purposes of these analyses, answers were grouped according to; “Not at all” to “Slightly”; “Somewhat” and “Very” to “Extremely” satisfied.

- Compared to this time last year have you had problems with damp, mould and condensation? Answers were again grouped according to; “Worsened a lot” to “Worsened a little”; “Not changed”; “Improved a little” to “Improved a lot” and “No problems”.

- Compared to this time last year have you had problems with paying your bills? These were again groups; “Worsened a lot” to “Worsened a little”; “Not changed”; “Improved a little” to “Improved a lot”.

- Do you avoid turning on the heating because of cost? Defined as Yes or No.

We compared mean SWEMWBS scores between both groups. SWEMWBS scores were dichotomised to indicate low scores as being greater than 1 standard deviation (SD) below participant mean scores (mean 21.76, SD = 5.13, low mental wellbeing <16) [43]. Chi-squared and two-tailed t-tests were used to assess differences in the categorical and continuous variables respectively between the waiting list control and the intervention group. To assess the potential interactions with the above four questions, we used multivariable regression models and two-way ANOVA to test interactions with participant SWEMWBS scores. P Values are provided for each of the tests presented in the below results tables. All analyses were undertaken in Stata version 15.0 (Stata Corp., College Station, US).

Results

Participant and housing characteristics

A total of 173 participants completed the questionnaire (response rate of 31%) but 19 failed to clearly report that their new heating systems was provided by the ECO Flex programme. We excluded these responses and included 71 households in the intervention group and 83 into the waiting list control (Table 1). With the exception of

age and type of heating system, participant and housing characteristics were broadly similar across the waiting list control and intervention group (Table 1).

Less than 50% of participants were men in the waiting list control (48.72%) and intervention (39.71%). Around half of participants lived with a partner in both groups (46.05% in the waiting list control versus 56.25% in the intervention group). Participating adults in the waiting list control were slightly older (65.95±1.47 years) than those in the intervention group (60.54±1.92 years). Nearly half of participating adults self-declared their employment status as being retired in both groups (48.05% versus 46.15%), and participants had lived at their current home address for around 20 years on average (20.59±1.69 versus 18.39±1.85 years).

Table 1 Participant & housing characteristics

Participant demographics, including partners	Waiting list control (n=83)		Intervention (n=71)		P value†
	% (n)*	Mean, SD (n)	% (n)*	Mean, SD (n)	
Proportion of men	48.72 (38/78)		39.71 (27/68)		0.27
Participant lives with a partner	46.05 (35/76)		56.25 (36/64)		0.23
Mean age		**65.95, 1.47 (75)**		**60.54, 1.92 (68)**	**<0.05**
Mean BMI		27.93, 0.91 (63)		27.19, 0.68 (50)	0.54
Mean occupancy		1.83, 0.12 (81)		2.06, 0.13 (69)	0.19
Time spent at current home		20.59, 1.69 (78)		18.39, 1.85 (68)	0.38
Annual household income		£16,213.31, £7,881.9 (55)		£18,681.2, £10,621.7 (45)	0.19
Employed part or full time Unemployed Retired Looking after the home Permanently sick / illness Other	28.57 (22/77) 3.90 (3/77) 48.05 (37/77) 2.60 (2/77) 12.99 (10/77) 3.90 (3/77)		29.23 (19/65) 4.62 (3/65) 46.15 (30/65) 6.15 (4/65) 12.31 (8/65) 1.54 (1/95)		0.87
Currently smokes	11.54 (9/78)		11.76 (8/68)		0.96
Currently vapes	1.41 (1/71)		8.06 (5/62)		0.07
Homeowner Renting Other	76.25 (61/80) 22.50 (18/80) 1.25 (1/80)		79.41 (54/68) 17.65 (12/68) 2.94 (2/68)		0.61
Detached house Semi-detached house End-terraced house Terraced House Bungalow Flat Other	21.79 (17/78) 20.51 (16/78) 8.97 (7/78) 23.08 (18/78) 15.38 (12/78) 8.97 (7/78) 1.28 (1/78)		10.00 (7) 25.71 (18) 22.86 (16) 21.43 (15) 10.00 (7) 7.14 (5) 2.86 (2)		0.14
Fuel mainly used for heating; Mains gas LPG Oil Electric Open fire / wood burner	 **7.79 (6/77)** **3.90 (3/77)** **14.29 (11/77)** **62.34 (48/77)** **11.69 (9/77)**		 **57.35 (39/68)** **27.94 (19/68)** **5.88 (4/68)** **7.35 (5/68)** **1.47 (1/68)**		**<0.01**
Moderately to extremely satisfied with standard housing	86.30 (63/73)		93.85 (61/65)		0.14

**** proportions may not add up to 100% due to rounding up of values***

†P values based on two-tailed t-tests for continuous measures and chi-squared test for categorical measures

Due to the nature of the funding criteria, participating households were predominantly from those who owned their own home (76.3% versus 79.4%). Over half of households were benefit claimants (60.0% versus 65.2%) and the mean annual household incomes

were similar across both groups (£16,213.31 and £18,681.20, in the waiting list control and intervention group, respectively). Also corresponding to the nature of the intervention and as anticipated, the main fuel used for heating the home differed significantly between both groups because the waiting list control received no intervention. This reflects a shift towards more mains gas and LPG in the intervention group. Lastly, a majority of households said that they were moderately to extremely satisfied with the standard of their housing in the intervention group (86.3% versus 93.9%).

Adequate heating of participant households and home satisfaction

We were not able to assess potential indicators of fuel poverty before the intervention because this retrospective study was designed to assess the reported impact of the policy change once the interventions had been installed. To assess this further we compared indicators of satisfaction of the indoor environment temperature and ability to heat the home in the waiting list control versus the intervention group (Table 2). The results indicate that the number of households satisfied with the indoor temperatures and able to heat the home was higher among those receiving an intervention in comparison to those in the waiting list control (as described below).

Households who received an intervention were more satisfied with their living environment and experienced less fuel poverty. Significantly more participants in the intervention group were very to extremely satisfied with the indoor temperature (70.77%) of their home when compared to the waiting list control (22.37%). There were also fewer participants who were unsatisfied with the indoor temperature (60.53% waiting list control versus 6.15% intervention group). Given the correlation between indoor temperature and condensation, more participants in the intervention group (70.91%) said that the presence of damp, mould and condensation had improved compared to this time last year when compared with the control (11.48%). However, 9.09% of those receiving the intervention said that problems with damp, mould and condensation had worsened. More households (50.75%) in the intervention group reported that there had been an improvement in their ability to pay their bills compared to the control (28.21%). Whilst fewer households in the intervention group

261 (58.21%) avoided turning the heating on due to the cost of fuel when compared to the
262 waiting list control (83.54%), over half still had problems with affordability (Table 2).
263 This means that some households still experience unsatisfactory indoor environments
264 (i.e. cold and problems with damp and mould) and fuel poverty (i.e. paying bills and
265 avoiding heating the home) after receiving the intervention.

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Table 2 The indoor environment and indoor temperature

Questions indicative of fuel poverty	Waiting list control (n=83)	Intervention (n=71)	P value*
	% (n)	% (n)	
How satisfied with the indoor temperature;			**<0.01**
Not at all to slightly	**60.53 (46/76)**	**6.15 (4/65)**	
Somewhat	**17.11 (13/76)**	**23.08 (15/65)**	
Very to extremely satisfied	**22.37 (17/76)**	**70.77 (46/65)**	
Compared to this time last year, problems with damp, mould and condensation;			**<0.01**
Worsened a lot to a little	**37.70 (23/61)**	**9.09 (5/55)**	
No change	**50.82 (31/61)**	**20.00 (11/55)**	
Improved	**11.48 (7/61)**	**70.91 (39/55)**	
Compared to this time last year, had problems with paying bills;			**<0.01**
Worsened a lot to a little	**30.77 (24/78)**	**8.96 (6/67)**	
No change	**41.03 (32/78)**	**40.30 (27/67)**	
Improved	**28.21 (22/78)**	**50.75 (34/67)**	
Avoid turning on the heating because of cost;			**<0.01**
No	**16.46 (13/79)**	**41.79 (29/67)**	
Yes	**83.54 (66/79)**	**58.21 (39/67)**	

**** P values based on chi-squared test for categorical measures***

Resident mental wellbeing

Mean SWEMWBS scores were not significantly different between those within the waiting list control and intervention groups (Table 3). However, the proportion of people with low mental wellbeing was statistically significantly lower in the group receiving the intervention. In households with a new heating system there were fewer participants with a low mental wellbeing (4.23% when compared to the control (18.07%)).

Table 3 Potential of new heating system on mental wellbeing

Mental wellbeing	Waiting list control (n=83)		Intervention (n=71)		P value*
	% (n)	Mean, SD (n)	% (n)	Mean, SD (n)	
Mean SWEMWBS		21.50, 0.65 (69)		21.48, 0.55 (58)	0.99
Low SWEMWBS score;					**<0.01**
Low mental wellbeing	**18.07 (15/83)**		**4.23 (3/71)**		
High --- “” ---	**81.93 (68/83)**		**95.77 (68/71)**		

****P values based on two-tailed t-tests for continuous measures and chi-squared test for categorical measures***

These findings indicate that the intervention had some form of effect, but not for everyone who received a new heating system. Without a randomised controlled trial, it is not possible to determine whether the intervention directly influenced the indoor environment and participant mental wellbeing. However, if those who reported improvements in the indoor environment and/or ability to adequately heat the home also had higher mental wellbeing this might indicate that the differences in wellbeing resulted from the intervention. In order to explore this further, we ran statistical models to examine the associations adjusted for change in indoor environment and/or ability to adequately heat the home. We also added to these models an interaction to assess the additive impact of receiving the intervention and change in indoor environment and/or ability to adequately heat the home. These models have the potential to indicate whether the intervention needed to result in certain changes in indoor environment and/or ability to adequately heat the home to result in changes in mental wellbeing.

Experiencing improved satisfaction with indoor temperature, or not avoiding heating because of cost were associated with statistically significantly higher mental wellbeing regardless of whether participants received an intervention (Tables 4 and 4a). Whereas, those whose problems paying bills worsened also experience lower mental wellbeing adjusted for whether they received an intervention (Table 4). In the model adjusted for satisfaction with indoor temperature, there was a statistically significant intervention effect, however it was in the opposite direction to what would be hoped for (Coefficient -2.08 95% CI -4.03 to -0.12, p = 0.038). Although not statistically significant, the direction of the coefficient of intervention was the same in the models adjusted for problems paying bills and avoiding heating due to cost. None of the assessed interactions between each of the situations were significant (Tables 5 and 5a), which may be due to the small sample size.

The three situations which were statistically significant in the non-interaction model remained significant, but the intervention coefficient in the model adjusted for satisfaction with indoor temperature became non-significant. Reviewing the coefficients in the models with interactions (Table 4a and 5a) reveals some potential

that if the intervention was received and households observed positive improvements (i.e. financially and/or in the indoor environment) then participant mental wellbeing was not as low as it would have been if no intervention was received. Whereas, if an intervention was installed and the participant became less satisfied with indoor temperature, then this could adversely impact participant mental wellbeing. These results could indicate that just altering a home's heating system is not always sufficient to improve the indoor environment or finances, and broader interventions may be required. Participants might have received an intervention which failed to deliver the expected improvements in indoor environment or finances, which might have reduced mental wellbeing.

322 **Table 4: Multivariate regression**

		Satisfaction with indoor temperature			Damp and mould			Problems paying bills		
		Coefficient	95% CI	P value*	Coefficient	95% CI	P value*	Coefficient	95% CI	P value*
Intercept (i.e. no intervention and no change in situation)		21.13	19.01 to 23.24		21.91	20.24 to 23.59		23.01	21.57 to 24.45	
Warm and well intervention	No	(ref)	(ref)	**0.038**	(ref)	(ref)	0.613	(ref)	(ref)	0.161
	Yes	-2.08	-4.03 to -0.12		0.60	-1.75 to 2.95		-1.25	-3.01 to 0.51	
Situation	Worsened	-0.33	-2.78 to 2.12	**0.002**	-2.49	-4.98 to -0.01	0.129	-3.61	-5.61 to -1.61	**0.002**
	No change	(ref)	(ref)		(ref)	(ref)		(ref)	(ref)	
	Improved	3.14	0.92 to 5.35		-1.29	-3.77 to 1.19		-1.33	-3.44 to 0.77	
N		121			99			98		

323 * P-values based on two-way ANOVA tests

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Table 5: Adding interactions

		Satisfaction with indoor temperature			Damp and mould			Problems paying bills		
		Coefficient	95% CI	P value*	Coefficient	95% CI	P value*	Coefficient	95% CI	P value*
Intercept (i.e. no intervention and no change in situation)		19.55	16.86 to 22.23		21.89	20.06 to 23.72		23.15	21.51 to 24.79	
Warm and well intervention	No	(ref)	(ref)	0.097	(ref)	(ref)	0.715	(ref)	(ref)	0.253
	Yes	0.84	-2.81 to 4.48		0.67	-2.69 to 4.03		-1.54	-3.91 to 0.82	
Situation	Worsened	1.34	-1.71 to 4.39	**0.001**	-2.38	-5.16 to 0.39	0.234	-3.68	-6.05 to -1.32	**0.008**
	No change	(ref)	(ref)		(ref)	(ref)		(ref)	(ref)	
	Improved	5.59	2.10 to 9.07		-1.46	-5.69 to 2.77		-2.09	-5.41 to 1.23	
Interaction	Situation worsened and received intervention	-3.85	-9.78 to 2.08	0.177	-0.72	-7.41 to 5.96	0.969	-0.06	-4.74 to 4.62	0.830
	No change in situation but received intervention	(ref)	(ref)		(ref)	(ref)		(ref)	(ref)	
	Situation improved and received intervention	-4.14	-8.65 to 0.36		0.15	-5.18 to 5.49		1.26	-3.07 to 5.59	
N		121			99			98		

* P-values based on two-way ANOVA tests

Table 4a: Multivariate regression – avoid heating to save money

		Avoid turning on the heating because of cost		
		Coefficient	95% CI	P-value*
Intercept (i.e. no intervention and does not avoid heating because of cost)		23.29	21.35 to 25.23	
Warm and well intervention	No	(ref)	(ref)	0.581
	Yes	-0.49	-2.22 to 1.25	
Avoid heating to save money	No	(ref)	(ref)	**0.031**
	Yes	-2.13	-4.06 to -0.20	
N		126		

* P-values based on two-way ANOVA tests

Table 5a: Adding interactions – avoid heating to save money

		Avoid turning on the heating because of cost		
		Coefficient	95% CI	P-value*
Intercept (i.e. no intervention and does not avoid heating because of cost)		25.53	20.89 to 26.17	
Warm and well intervention	No	(ref)	(ref)	0.542
	Yes	-0.87	-4.20 to 2.47	
Avoid heating to save money	No	(ref)	(ref)	**0.030**
	Yes	-2.43	-5.36 to 0.51	
Interaction	Does not avoid heating because of cost and received intervention	(ref)	(ref)	0.791
	Avoids heating because of cost and received intervention	0.52	-3.38 to 4.43	
N		126		

* P-values based on two-way ANOVA tests

Comparison with BEIS eligibility criteria

We compared the proportion of households with a qualifying health condition, those in receipt of ECO qualifying benefits and those meeting the BEIS Income threshold (Table 6) to assess whether the targeting of the programme influenced mental wellbeing outcomes. Due to the nature of the eligibility criteria, a high proportion of households had someone with a chronic health condition such as a range of physical long-term conditions and psychological or emotional problems, which could influence our above findings. However, with the exception of joint pain/arthritis and falling or having an accident in the home, the proportion of these physical and mental health conditions were similar across both groups.

Table 6 Participant & housing characteristics

Participant demographics, including partners	Waiting list control (n=83)	Intervention (n=71)	P value
	% (n)	% (n)	
Household has someone with a physical or mental health condition;			
Psychological / emotional conditions	53.85 (35/65)	58.18 (32/55)	0.63
Asthma, breathlessness, wheeze and/or allergy	54.69 (35/64)	50.00 (28/56)	0.61
Chronic obstructive pulmonary disorder	16.95 (40/59)	21.15 (11/52)	0.57
Circulatory and/or cardiovascular disease	60.61 (40/66)	48.28 (28/58)	0.17
Persistent flu symptoms, headaches	31.15 (19/61)	26.53 (13/49)	0.60
Joint pain, arthritis	**90.14 (64/71)**	**77.05 (47/61)**	**0.04**
Experienced falls or accident in the home	**46.88 (30/64)**	**22.00 (11/50)**	**0.01**
Household benefit claimants	60.00 (48/80)	65.22 (45/69)	0.51
Household meeting BEIS financial eligibility criteria and not on qualifying benefits	8.64 (7/81)	10.00 (7/70)	0.77

**** P values based on chi-squared test for categorical measures***

Around 60% of households were in receipt of HHCRO qualifying benefits and should have received support from the Affordable Warmth programme (i.e. not the ECO Flex programme), but the proportion of homes were similar across both groups. When applying the BEIS income threshold, only around 10% met the eligibility criteria and would be strictly deemed appropriately targeted via the ECO Flex programme according to the BEIS guidance for local authorities. The targeting effectiveness of the ECO Flex programme did not modify participant mental wellbeing outcomes (data not

shown). Due to the reduction in sample size when removing those not strictly eligible when compared against the BEIS criteria, we did not further explore the experiences of those receiving an intervention and those eligible and not eligible.

Discussion

To our knowledge this is the first study to assess the potential impact of the new ECO Flex policy change and installation of a 'first time' central heating system on participants perceptions of the indoor environment, finances and their mental wellbeing. The results further support the need for future interventions to address the complex interaction between resident behaviours/lifestyles, housing characteristics and health outcomes (Figure 1). Participants who reported positive improvements to the indoor environment and were better able to heat the home as a result of their new heating system reported better mental wellbeing. However, some households receiving an intervention still experienced indoor environment problems (e.g. persisting cold and damp) and continued to be at risk of fuel poverty. Whilst is it not possible to attribute these changes directly to the intervention, the findings may suggest that the mental wellbeing of participants worsened in households where the intervention did not have a positive effect on the indoor environment and finances.

Figure 1 Interaction between housing/behavioural characteristics and mental wellbeing, adapted from Sharpe, Machray [5]

Synthesis with existing literature

Our findings are generally in support of the conclusion that improved indoor temperatures and other benefits of energy efficiency interventions can lead to reduced fuel poverty, improvements in the indoor environment and health when targeting low income and vulnerable households [13, 48-50]. Consequently, this policy change provides an approach to support homeowners who may be reluctant to invest in energy efficiency measures [51] and help motivate private rental landlords to improve their housing stock [52]. However, we also found that not all households receiving an intervention experience positive outcome. Previous research has found evidence of short term benefits [53, 54], but reduced indoor air quality and increased the risk of cardiovascular diseases from household energy interventions [5, 25].

Prior concerns resulting from energy efficiency improvements have resulted from potential reductions in indoor air quality and/or overheating [55]. There are a range of unintended consequences that could affect residents physical and mental health. These include increased air tightness that could impact mental wellbeing resulting from a reduction in noise or sound [56]. Our inconsistent findings may be a result of poorly designed interventions or resident behaviours such as heating and ventilation patterns [5, 57, 58]. Also, some low income households may remain in fuel poverty [58, 59] despite making homes more affordable to heat [59, 60]. This means that some households still have to make stark choices [57] on how to spend their income, leading to different mental health stressors, including persistent worry about debt and affordability [6]. While area level interventions may conceal potential health benefits [5], other household characteristics such as being a single parent or remaining out of work [4] and differences in subjective mental wellbeing [14] may explain our findings.

Our findings may be influenced by a higher proportion of older participants who may be less likely to be aware of appropriate heating practices to achieve adequate warmth [61]. For example, the use of instruction in home heating [62] or simple telemetry [63] have been found to help maintain adequate indoor temperatures to improve health and wellbeing outcomes. Having a long-term condition and poor mental wellbeing or cognitive decline in older age may also be a contributory factor [64] because these can

have a profound effect on resilience and susceptibility to disease [65, 66]. This impacts on an individual's sense of security, comfort, ability to undertake day-to-day activities, reach ambitions, and create family and financial strains [67]. However, the vulnerability of households was similar in both the waiting list control and intervention group.

Nearly 10% of the intervention group experienced worsened problems with damp and mould, which is consistent with Richardson, Barton [53] who found that these indoor environment problems returned within 12 months following energy efficiency improvements. This may result from increased damp and mould problems across Cornwall (due to a wetter/milder climate and older/poorly maintained housing stock) despite resident awareness and risk perceptions [47, 68]. Indoor dampness/mould is exacerbated by poor heating and ventilation practices [5] and can lead to poor health outcomes [23, 69, 70]. These indoor environmental problems can affect a household's satisfaction with their home, which is an important factor influencing mental wellbeing [50].

Only around 50% of households said that the intervention reduced problems with paying bills, which may be a contributory factor influencing home satisfaction and mental wellbeing. Living in different settings will be another important factor because while urban areas may experience more persistent fuel poverty, rural households may be more vulnerable to fluctuations in energy prices. Living in private accommodation or a flat increases the probability of remaining fuel poor [71], which relates to societal factors such as employment and social isolation [4]. Kearns, Whitley [4] found that home improvements had no effect upon the experience of fuel poverty, which supports the need for additional policy measures when supporting vulnerable households [4, 72].

The current phase of the Energy Company Obligation (ECO3 Help to Heat) has removed the elements in previous ECO schemes that aimed to reduce carbon emissions. This reflects the finding by academics and scheme managers that interventions designed to alleviate fuel poverty may increase energy consumption in households that had been previously rationing their energy expenditure [73]. Where households have managed their fuel expenditure in the context of wider constraints on their household budgets, improved energy efficiency can enable increased levels of heating and thus potentially

437 higher emissions. With the recent renewed emphasis on achieving low or zero
438 emissions, this has yet to work through into application in ECO and related policies and
439 may give rise to conflicting priorities.

440 Future policy mechanisms should consider short to long-term impacts on those
441 receiving an intervention and adopt wider community engagement and
442 communication to be more effective [14, 54, 59]. This must be undertaken alongside a
443 better understanding of more comprehensive 'whole house' interventions [27]. These
444 need to build on more sustainable approaches such as those in the UK [74] and US [75-77]
445 that incorporate improved heating, ventilation with heat recovery, resident
446 training/advice and follow-up visits [75-78]. Training may help raise awareness, build on
447 motivations and coping strategies [51, 58, 79, 80], which may vary both temporarily and
448 spatially across Europe [81]. In addition, these policies, need to account for potential
449 increases in the carbon footprint in the domestic sector, which includes raising the
450 emissions associated with previously under-heated homes, particularly important in
451 more rural areas. Alternative options for housing retrofits are needed but current low
452 carbon technologies are expensive to retrofit [82].

453 Our findings may be due to a range of limitations. Due to the funding criteria, all
454 qualifying households received a new heating system. This meant that households
455 relying on an open fire or electric heating in a single room for example received a new
456 central heating system. Whilst this may enable households to adequately heat their
457 home, it may inadvertently increase the cost of heating a house. Heating more rooms
458 and/or heating a home to a high level may off set some of the benefits of the
459 programme.

460 While study participant and housing characteristics of participating households in the
461 waiting list control and intervention group were similar, there is likely to be the
462 inclusion of bias. This includes our response rate of 31% and the timing of the
463 questionnaire, which was conducted in July and August. This meant that all households
464 receiving an intervention benefited from a new heating system during the winter
465 months. While this response rate was higher than previous postal questionnaires
466 undertaken within the social housing sector [25], there is the potential for differences

between participating and non-participating households, which we could not fully account for. Also, the questionnaire took place after the intervention had taken place, which means we were unable to attribute any changes directly to the intervention due to the lack of baseline pre-intervention data. To overcome this limitation, we were able to compare responses from the waiting list control (i.e. those not receiving an intervention) and those receiving a new heating system (i.e. the intervention group). Relying on self-reported information and the response rate is likely to introduce an element of bias [25]. Due to the nature of the programme and survey, it is possible that those more likely to respond were those households either having a greater positive or negative experience of the programme (i.e. missing the views of those in between both extremes). We were unable to fully account for any negative experiences of the ECO Flex programme. These may result from administration problems, a lack of satisfaction with the new heating system or the upheaval of the installation process. Future studies should consider the adoption of a randomised control trial or repeated measures to further explore the impact of an energy efficiency intervention on the built environment and health. The potential ethical problems associated with delaying making homes of vulnerable fuel poor households more affordable to heat need to be considered and future trials should monitor adverse events as well as beneficial outcomes.

Conclusion

Whilst households in receipt of a new heating system experienced improvements in the indoor environment, finances and mental wellbeing, this was not consistent across all households receiving an intervention. There is a real need to identify and follow-up households who experienced problems with the delivery of an intervention and/or worsened problems with the indoor environment and finances following the intervention. To overcome the potential negative impact of some energy efficiency measures, future interventions must retrofit the whole house and put in place behavioural training to ensure the maintenance of indoor temperatures and ventilation. These need to consider the potential impact of additional techniques such as simple telemetry to help residents, particularly in older age to maintain adequate

497 indoor temperatures. As well as taking into account the potential differences in
498 lifestyles, cultures and behaviours, along with effective community engagement and
499 communication. More sustainable interventions are needed along with incorporating a
500 randomised control trial evaluation to assess the true effects of measures put in place.

501

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Author contributions

All authors contributed equally to the development of this manuscript with Dr Sharpe as the corresponding author.

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Declaration of Conflicting interest

Authors declare that there are no conflict of interest.

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