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ORIGINAL ARTICLE

Beyond energy savings: comfort and health effects of white goods schemes

Arianne J. van der Wal · Queena K. Qian · Elham Maghsoudi Nia · Joris Hoekstra

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Abstract The energy crisis, that began in 2021 has exacerbated energy poverty throughout Europe. Households with lower incomes, higher energy requirements, and less efficient homes and appliances are disproportionately affected by this crisis. These households often lack the financial capacity to upgrade outdated and inefficient appliances, such as refrigerators and washing machines. This then leads to increased energy costs or necessitates cutbacks in other energy uses such as heating, which in turn diminishes their residential comfort. In response to this issue, the Dutch government has implemented various strategies to mitigate energy poverty, including the 'White Goods Scheme'. The term 'White Goods Schemes' usually refers to a governmental initiative that offers financial incentives or assistance to consumers to encourage the purchase of new, energy-efficient household appliances. Despite such initiatives, there is hardly any research evaluating their effectiveness. This study examined the impact of the 'White Goods Scheme' in two regions of the Netherlands, by means of a questionnaire among residents (N = 541), comparing households that have made use of a white goods scheme (intervention group; N = 310) with households that have not yet made use of a white goods scheme (control group; N = 231). The findings show that the white goods schemes have the potential to improve residential comfort conditions, enhance physical health and reduce energy costs and financial concerns, yield better mental health. Yet, the causal mechanisms behind these connections need to be further scrutinised. While the scheme has demonstrated positive outcomes in terms of comfort, financial well-being and health, it is suggested that combining improvements like shallow retrofits and appliance schemes with other local support initiatives like energy advice is essential to address energy poverty, effectively.

Keywords Energy poverty · White goods scheme · Appliance scheme · Energy consumption · Residential comfort · Mental and physical health · Social innovation

Introduction

The building sector continues to be the largest energy consumer in Europe, accounting for approximately 40% of the EU's energy consumption and 36% of greenhouse gas emissions (European Union, 2024). Among these, residential buildings play a significant role, with their operational phase contributing the most

A. J. van der Wal (✉)
TNO, Motion Building, Radarweg 60,
1043 NT Amsterdam, The Netherlands
e-mail: arianne.vanderwal@tno.nl

Q. K. Qian · E. Maghsoudi Nia · J. Hoekstra
Faculty of Architecture and the Built Environment, Delft University of Technology, Julianalaan 134, 2628BL Delft, The Netherlands

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to their overall environmental impact (Ürge-Vorsatz et al., 2012). Eurostat data further reveals that household energy consumption in the EU- 27 constituted 26% of the final energy consumption in 2022. The breakdown of this consumption shows that approximately 64% was attributed to space heating, 15% to water heating, 14% to lighting and household appliances, and 6% to cooking (Eurostat, 2021). These statistics highlight the significant energy demand and environmental impact related to residential buildings, emphasising the importance of implementing energy-efficient measures in this sector (Gaspari et al., 2021). However, household energy usage varies significantly by country, influenced by factors such as climate, building characteristics (age, type, size), heating/cooling systems, appliance types, and usage patterns, as well as occupants'demographics (age, income, ownership) and behaviours (EEA, 2018, Delzendeh et al., 2017, Economidou et al., 2011). A recent report from the European Environmental Agency (EEA) highlights habits related to space heating, electrical appliance use, and other domestic behaviours as key determinants of household energy demand (EEA, 2018, Gaspari et al., 2021). According to the International Energy Agency (IEA), the appliances and equipment category includes major electrical devices like refrigerators, washing machines, dishwashers, dryers, and televisions (note that appliances such as air conditioners, heaters, and stoves are considered separately). Despite developments in efficiency, energy consumption by these devices is still rising, particularly in emerging economies. To align with the Net Zero Emissions by 2050 Scenario, most appliances and equipment sold in 2035 should match the efficiency levels of today's best available technologies. Although stricter minimum energy performance standards in many regions have improved efficiency, further enhancements are necessary. These improvements should be accompanied by changes in behaviour to reduce household electricity consumption (IEA, 2023). Commonly highlighted occupant behaviours in the literature include adjustments to comfort temperature settings (for heating and cooling), patterns of window usage, management of lighting, optimisation of device and appliance efficiency, and hot water usage (Delzendeh et al., 2017; Gaspari et al., 2021; Sun & Hong, 2017). Scholars broadly define"behavioural change"as various actions that impact household energy consumption patterns (D'oca, 2014; Delzendeh et al., 2017; Dubois et al., 2019; Faber, et al., 2012; Gill et al., 2010; Huebner et al., 2013; Lucon, et al., 2014; Stern, 2020; Stevenson and Leaman, 2010; Sun & Hong, 2017; Williamson, et al., 2018). Niamir et al. (2020) further categorises behavioural changes into investment (e.g., purchasing efficient appliances), conservation (e.g., reducing household temperatures), or switching (e.g., transitioning to green energy) (Gaspari et al., 2021; Niamir et al., 2020). Following the importance of behaviour change and in response to the rise in energy prices across Europe in 2021, governments are considering investments in different programmes such as the 'White Goods Scheme' (or appliance scheme) to reduce energy consumption. This approach is explained completely in the following section. The study aims to evaluate the impact of 'white goods scheme' approaches on perceived comfort, health, energy cost, and sustainability behaviours by analysing the results of an extensive survey conducted in 2023 within an intervention group and a control group, supplemented with detailed household characteristics.

Energy poverty

Energy poverty refers to a household lacking sufficient access to adequate energy provisions at home (Mulder et al., 2023). This may relate to the affordability of the energy bill. It also refers to the energy quality of a dwelling; homes with a low energy label are often poorly insulated, leading to an unhealthy indoor environment with issues like mould, moisture, and draught (Balfour et al., 2014; Liddell & Morris, 2010). However, not every household can address this issue. Some households depend on their landlord to make their homes more sustainable, putting them at risk of falling behind in the energy transition (Mulder et al., 2023). Addressing energy poverty requires a balanced approach involving increased financial resources, price incentives, and home insulation standards. Following the significant increase in energy prices, the Dutch government has allocated more funds to municipalities to specifically support households, in addition to measures such as implementing a price ceiling. These municipalities could choose their approach to address the issue, with different strategies emerging. The first involved shallow retrofitting measures, a group of trained professionals installing minor energy-saving measures in homes. The second strategy involved

energy coaching, predominantly volunteers offering advice on sustainable energy behaviour. The third is the 'White Goods Schemes' (van der Wal et al., 2023). The white goods scheme typically refers to a government program or initiative aimed at providing financial assistance or incentives to consumers to purchase new, energy-efficient household appliances such as refrigerators, washing machines, dishwashers, and other major appliances finished in white enamel. It is anticipated that support for energy-poor households will be necessary for an extended period, given the likelihood that energy prices will remain uncertain for a prolonged period and may not return to stable low levels before the energy crisis. This study explores the municipal support through the provision of white goods, that can be served as a Social Innovation initiative, promote residents'perceived comfort and health (Cunha & Benneworth, 2020; Mulgan et al., 2007; Singh & Majumdar, 2015; Wittmayer et al., 2019).

Negative consequences of energy poverty

Physical and mental health issues. Different European studies indicate that households living in poorly insulated homes, experiencing (extreme) cold, heat, moisture, draught, and mould, are more likely to face physical and mental health problems (Evans et al., 2000; Hernández, 2016; Jessel et al., 2019; Kose, 2019; Lacroix & Chaton, 2015; Pan et al., 2021). Physical health issues are more common among energy-poor households, including respiratory complaints, asthma, arthritis, and cardiovascular diseases (Balfour et al., 2014; Jessel et al., 2019; Platt et al., 1989). A European review also suggests that children are more vulnerable than adults to physical health effects (Liddell & Morris, 2010). Examples of mental health problems that are more prevalent among energy-poor households include (financial) stress, anxiety, sadness, and depression (Balfour et al., 2014; Hernández, 2016; Jessel et al., 2019; Platt et al., 1989). Studies additionally show that healthcare costs for energy-poor households are higher than for non-energy-poor households (Nicol et al., 2015; Scheer, 2013). A recent report on "Health costs and energy poverty" by the Netherlands Organisation for Applied Scientific Research (TNO) in the Dutch context revealed particularly high healthcare costs for children and young people up to 18 years old in households living in poorly insulated homes with inadequate heating (Van Maurik et al., 2023).

Social issues. Furthermore, households experiencing energy poverty are more likely to be socially isolated. These households invite fewer guests to their homes due to shame about the cold conditions or the state of their homes (Baudaux & Bartiaux, 2020). The cold conditions in the home can result from both the low energy quality of the dwelling and the unaffordability of the energy bill. Some households lack the financial means to heat their homes adequately. In addition, an increase in energy poverty will likely have negative implications for public support for the energy transition. In essence, the negative impact of energy poverty on individual households may extend to influence broader attitudes and public support for societal changes in energy use and production. If these households feel they are lagging in the transition and bearing the burdens of the energy transition while others benefit (e.g., from cheaper energy through solar panels or financial gains from wind farms) (Straver et al., 2020); it undermines support for the transition. Public support is a crucial element in achieving the energy transition (Bayulgen, 2020; Biresselioglu et al., 2020).

White goods schemes to alleviate energy poverty

Households with lower incomes generally own less energy-efficient appliances than those with higher incomes, as Schleich (2019) found a consistent trend in adoption rates of energy-efficient technologies based on income across various European countries. Moreover, energy-poor households, in particular, often own old, energy-consuming, or malfunctioning appliances (Bartiaux et al., 2021; Simcock et al., 2016). This observation applies to various household devices, including LED lights, refrigerators, combined fridge-freezers, freezers, dishwashers, and washing machines. In terms of household appliance replacement, there are mixed results in different countries. For instance, a study by Baldini et al. (2018) suggested that income is a less significant predictor of the selection of energy-efficient appliances in Denmark compared to factors such as housing type, the number of occupants, age, and end-use behaviours. However, a study by Young (2008) on Canadian households indicates that the patterns of appliance

replacement are influenced by having a low income. Moreover, the latter paper suggests that targeted policy measures aimed at encouraging the earlier replacement of outdated appliances with newer, more energy-efficient models among low-income households might be effective.

Although we have not found actual research on energy savings and potential other improvements resulting from replacing old appliances, it is known that, for instance, old refrigerators or freezers consume significantly more energy than newer, more efficient models. A 15-year-old fridge-freezer, for example, consumes approximately 380 kWh per year, while a new fridge-freezer with energy label C uses around 150 kWh per year, which saves 50 to 160 euros per year (MilieuCentraal, 2023). These data, combined with the results from European studies showing that energy-poor households often own old, energy-consuming, and/or malfunctioning appliances, suggest that replacing old appliances might alleviate energy poverty by reducing the energy bill of these households (van der Wal et al. 2023) (Fig. 1). Hence, in this research, we are exploring the effect of the 'white goods scheme' on people's residential comfort and physical health, energy costs, financial concerns, and mental health, and the sustainable energy use behaviours of residents.

It can be concluded that 'white goods scheme' or 'appliance subsidy' programs can support energy-poor households. However, it is still unclear to which household aspects (e.g., residential comfort, energy costs, health) this type of intervention yields effects and to what extent. In the current research, two white goods schemes were implemented by municipalities and made available to households with low incomes. The following question is central to this research: How do white goods schemes affect residential comfort (subsequently physical and mental health), energy costs (subsequently financial concerns and mental health), and sustainability behaviour? To identify the possible relationships between the variables, the study conducted a survey. The subsequent sections of the study outline the details of this survey design, including data collection methods and analytical approach. Through this survey design, the study aimed to gather empirical evidence and analyse it to identify the relationships between variables, and draw meaningful conclusions regarding the research questions.

Methodology

Case descriptions

For this exploratory study, two different municipalities that implemented an appliance scheme were willing to assist in the execution of the research. In both cases, an executive organisation was used to provide gift cards with the amount specified by the municipality to purchase new, more energy-efficient appliances. Both schemes target households with a low (minimum) income. The case descriptions of the different support measures can be used to interpret the possible findings, as the implementation method of a support measure might influence its effects. The case descriptions have been formulated based on interviews with municipalities regarding appliance schemes.

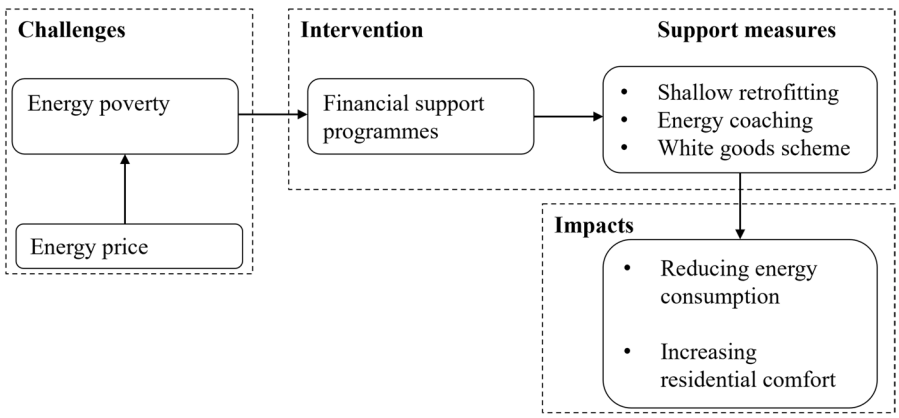


Fig. 1 Impacts of the financial support programmes by governments, Van der Wal et al., 2023

White Goods Scheme 1: is a scheme from the municipality of The Hague, where households can choose from five different types of appliances: refrigerator, freezer, washing machine, vacuum cleaner, or a refurbished iPad. Depending on the appliance choice, the resident received a discount of €50 to €250, with a maximum of €750 per household. Households with a low (minimum) income could apply for the gift card with the help of their Ooievaarspas (a free pass for people with a low income to do some activities for free or at a discount), which they could then redeem at physical stores participating in the scheme.

White Goods Scheme 2: is a scheme from the municipality of Leiden, where households could only purchase a new refrigerator. This was a decision made by the municipality, as older refrigerators, in particular, can consume a lot of energy. For the purchase of a new refrigerator, the resident received €300. With this amount, a small (energy-efficient) refrigerator could, in principle, be purchased. Residents covered the remaining costs for more expensive refrigerators. Households with a low (minimum) income entitled to the energy allowance received an appliance voucher by mail, allowing them to activate the gift card. They could then use the gift card at physical stores participating in the scheme (Table 1 and Fig. 2).

Study design

For both white goods schemes, we were able to compare households that participated in the support measure (intervention group) with households that had not yet participated in this support measure (control group). This creates a between-subjects design, allowing for a statistical comparison between the intervention and control groups to demonstrate the effects of the support measures on the energy poverty-related aspects. The intervention group of the two white goods schemes included households that had already used the gift card to replace their old appliances. The control group included households that had applied for the necessary gift card to use the program but had not yet used it. The questionnaire was conducted from January 22, 2023, to March 3, 2023 in collaboration with the involved municipalities. Filling out the questionnaire took approximately 5 min, and participation was voluntary and without compensation. An invitation email with a link to the questionnaire was used to recruit households in the two white goods schemes. Households eligible for the white goods schemes and who had enrolled for it were invited to the questionnaire. The questionnaire included whether the participant had used the appliance subsidy program and which device was purchased through it. Households were asked to indicate their experiences in residential comfort, physical and mental health, energy costs, concerns about payment of energy bills, and sustainability behaviour.

Participants

In total, 541 households filled in the questionnaire, of which 310 households had already made use of the white goods scheme (intervention group), and 231 households had not yet cashed in their gift card to replace their old appliances (control group) (Tables 2 and 3). The questionnaire was offered in five languages: Dutch, English, Turkish, Arabic, and Polish. The questions were designed to explore participants'experiences regarding residential comfort, physical health, financial concerns, mental health, and sustainable behaviour. Examples of the questions are as follows: *Residential comfort*: Do you suffer from dampness and/or mould in your home?; *Physical health*: How often do you suffer from your respiratory tract? (e.g. coughing, cold, shortness of breath, tightness in the chest); *Financial concern*: e.g. How many euros do you pay monthly for your energy bill?; *Mental health*: e.g. How often do you feel depressed? (e.g. not feeling like doing anything, not seeing a way out); *Sustainable behaviour*: e.g. What temperature do you set the thermostat to during the day?

The response options"never, rarely, sometimes, regularly, often, and always"were used as a 6-point Likert scale for all questions in the survey (Table 4). The questionnaire was completed by 488 households in Dutch, 12 households in English, 12 households in Turkish, 4 households in Arabic, and 2 participants in Polish during the period from January 22, 2023, to March 3, 2023.

Data analysis

To test for differences between the control and intervention groups, a General Linear Model was used. This statistical model examines whether participation

Table 1 The details of two white goods schemes provided by two municipalities

	White Goods Scheme 1	White Goods Scheme 2
Starting year	2021	2023
Municipality implementing the white goods scheme	The Hague	Leiden
Research location	Municipality of The Hague	Municipality of Leiden
Target audience	Households in The Hague in possession of an Ooievaarspas. This is a pass for residents with a low income. With the pass, they can do fun things(e.g., sports, cultural, workshops) for free or at a discount	Households with a low (minimum) income were entitled to the energy allowance (allowance for low-income households to pay for the increased energy bills)
Household recruitment	Households in possession of the Ooievaarspas can register via the website https://denhaag.duurzame-cadeaukaart.nl/ to obtain a gift card	Households that are listed in the municipal files as minima received a letter from the municipality containing a white goods voucher, with which they can activate the gift card
Procedure	Residents can apply for a gift card themselves via the website. The gift card gives residents a discount on a white goods appliance of their choice. Depending on the choice of white goods (fridge, freezer, washing machine, vacuum cleaner or refurbished iPad), the resident receives a €50 to €250 discount, with a maximum of €750 per household	Recipients of the white goods voucher activate the gift card themselves via a QR code, website or telephone. In principle, the amount of €300 can be used to purchase a small (economical) refrigerator. With more expensive refrigerators, residents pay the remaining costs
Prerequisites for white goods voucher	The gift card can be used physically at one of the affiliated white goods providers. The card entitles the household to a discount on one device of their choice. The white goods provider is responsible for collecting the old appliance	The card can be used at one of the affiliated physical stores. The refrigerator that is purchased must have at least label D. The white goods provider is responsible for collecting the old appliance

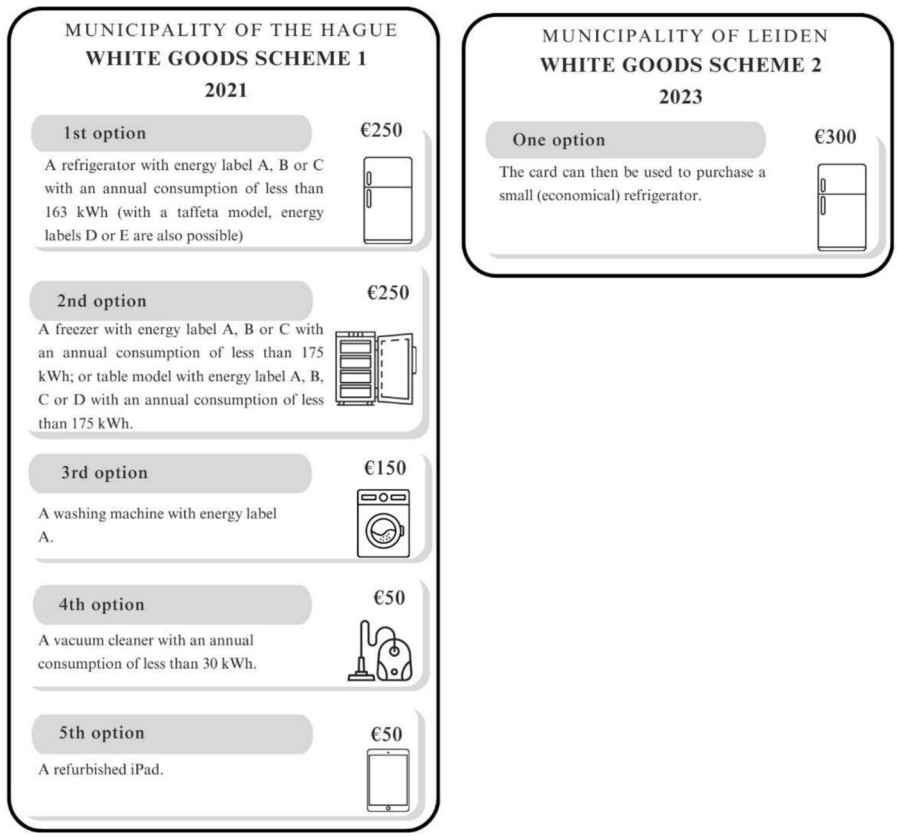


Fig. 2 Provided gift cards by municipalities for two white goods schemes

Table 2 The number of white goods vouchers provided

	Control group: did not yet make use of the white goods scheme	Intervention group: did make use of the white goods scheme	Total
White Goods Scheme 1	206	261	467
White Goods Scheme 2	25	49	74
Total	231	310	541

in the white goods scheme significantly affected the variables, including Residential comfort, Physical health, Mental health, and Sustainable energy use behaviour. The independent factor was participation in the white goods scheme (intervention type, group type, and their interaction). The dependent variables included: *Residential comfort* (dampness and mould); *Physical health* (respiratory problems); *Mental health* (energy bills, financial concerns, and mental well-being); *Sustainable behaviour* (indoor temperature setting, extra clothing, lighting, and shower duration).

Additionally, to capture any differences due to the spread in the date participants completed the questionnaire, daily precipitation, mean temperature, sunshine duration, and maximum hourly mean wind speed were included from the Dutch national weather service as co-variables in the model for each participant based on date of participation and place of residence.[1] Including weather variables in the model allows us to control for these environmental factors. This helps ensure that any differences in the outcome are not merely due to variations in weather conditions

[1] This data came from KNMI (https://www.knmi.nl/nederland-nu/klimatologie/geografische-overzichten).

Table 3 Statistical summary of responses

Variable	Survey question	N	Share (%)
Perceived comfort	Do you experience issues with moisture and/or mould in your home?	541	100
Physical health	How often do you experience issues with your respiratory system? (e.g., coughing, cold, shortness of breath, wheezing)	541	100
Energy costs and financial concerns	How many euros do you pay monthly for your energy bill?	475	88
	Are you worried about paying your energy bill?	541	100
Mental health	How often do you experience stress?	541	100
	How often do you feel angry?	541	100
	How often do you feel gloomy?	541	100
Sustainability behaviour	At what temperature do you set the thermostat during the day?	395	73
	Do you wear a warm sweater or take a blanket if you feel cold at home?	539	99.6
	Do you turn off the lights in rooms where no one is present?	541	100
	Do you take showers shorter than 5 min?	541	100

but are instead attributable to the primary variables in the study. None of these co-variables had a statistically significant effect on the perceived comfort, physical health, financial concerns and mental health (all p-values > 0.05).

Results

The results are described in the following sections. For all findings, the p-values related to the weather co-variables (> 0.05) show that they do not affect the dependent variable.

Perceived comfort and physical health

We explored the effect of white goods schemes on residents'comfort in reducing mould and, as a result, reducing inspiratory problems. Two questions of Q1-Perceived comfort: Do you suffer from dampness and mould in your home?; and Q2-Physical health: How often do you have problems with your respiratory tract? (e.g., coughing, cold, shortness of breath, shortness of breath) are addressed. Table 5 shows the results of analysing the impact of intervention type, group type, and their interaction on the dependent variable dampness and/or mould, and respiratory problems. The explanation of the model is as follows:

Perceived residential comfort by the residents. The descriptive statistical results of perceived comfort are shown in Table 6 for the two groups and two schemes. The results of tests of between-subjects effects, specifically analysing the impact of intervention type, group type, and their interaction on the dependent Variables 'dampness and mould'. It shows that the model has limited explanatory power (adjusted R-squared $= 0.003$), and none of the individual predictors significantly predict the outcome variable, except for group type, with F-value of 3.88 ($p = 0.05$). The interaction between intervention and group types also does not significantly impact the dependent variable. Therefore, the findings show that in both white goods schemes, those who renewed their appliances (intervention group) suffered less from the moisture. It can be concluded that living conditions have been enhanced due to the reduction of moisture by replacing efficient appliances such as washing machines.

While the explained variance is limited, it is important to consider the broader context of this finding. First, this small effect size highlights that many factors beyond the scope of the intervention, such as building characteristics and individual preferences, influence residential comfort. Hence, the white goods scheme alone cannot be expected to impact comfort levels. Second, although the direct effect on residential comfort appears minimal, the scheme may have indirect benefits, such as improving financial concerns, sustainable behaviour, or mental health. These secondary effects could contribute to overall well-being and justify the scheme's implementation as

Table 4 Questions per section of the questionnaire

	Never	Rarely	Sometimes	Regularly	Often	Always
Residential comfort: Do you suffer from dampness and/or mould in your home?	☐	☐	☐	☐	☐	☐
Physical health: How often do you suffer from your respiratory tract? (e.g. coughing, cold, shortness of breath, tightness in the chest)	☐	☐	☐	☐	☐	☐
Financial concern 1: How many euros do you pay monthly for your energy bill?	Response					
Financial concern 2: Are you worried about paying your energy bill?	☐	☐	☐	☐	☐	☐
Mental health 1: How often do you feel depressed? (e.g. not feeling like doing anything, not seeing a way out)	☐	☐	☐	☐	☐	☐
Mental health 2: How often do you experience stress? (e.g. being anxious, brooding, having worries)	☐	☐	☐	☐	☐	☐
Mental health 3: How often are you angry? (e.g. irritation, frustration, anger, aggression)	☐	☐	☐	☐	☐	☐
Sustainable behaviour 1: What temperature do you set the thermostat to during the day?	Response					
Sustainable behaviour 2: Do you put on a warm sweater or grab a blanket when you are cold at home?	☐	☐	☐	☐	☐	☐
Sustainable behaviour 3: Do you turn off the lights in rooms that are unoccupied?	☐	☐	☐	☐	☐	☐
Sustainable behaviour 4: Do you shower for less than 5 min?	☐	☐	☐	☐	☐	☐

Table 5 Testing two models of group and intervention-type effects on the perceived comfort and health of the residents

Tests of Between-Subjects Effects							
Model	Dependent Variable: Residential comfort (1) and respiratory problems (2)						
	Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
(1) Perceived comfort	Corrected Model	26.79[a]	7	3.83	1.25	0.27	0.016
	Intercept	250.85	1	250.85	82.06	0.00	0.13
	Intervention type	1.18	1	1.18	0.39	0.54	0.001
	Group type	11.87	1	11.87	3.88	0.05	0.007
	Intervention type * Group type	1.03	1	1.03	0.34	0.56	0.001
	a. R Squared = 0.016 (Adjusted R Squared = 0.003)						
(2) Perceived improved physical health	Corrected Model	22.94[a]	7	3.27	1.65	0.12	0.02
	Intercept	284.86	1	284.86	142.99	0.00	0.21
	Intervention type	2.02	1	2.01	1.01	0.32	0.002
	Group type	0.81	1	0.81	0.41	0.52	0.001
	Intervention type * Group type	8.54	1	8.54	4.29	0.04	0.008
	Corrected Model	22.94[a]	7	3.27	1.65	0.12	0.02
	Intercept	284.86	1	284.86	142.99	0.00	0.21
	a. R Squared = 0.021 (Adjusted R Squared = 0.008)						

Table 6 Descriptive analysis of perceived comfort

Descriptive Statistics				
Dependent Variable: Dampness and/or mould				
Intervention type	Group type	Mean	Std. Deviation	N
White goods scheme 1	Control group	3.31	1.75	206
	Intervention group	3.00	1.76	261
	Total	3.13	1.76	467
White goods scheme 2	Control group	3.24	1.80	25
	Intervention group	2.63	1.56	49
	Total	2.84	1.66	74
Total	Control group	3.30	1.75	231
	Intervention group	2.94	1.73	310
	Total	3.09	1.75	541

part of a broader strategy. Finally, this finding highlights the need for municipalities to adopt a holistic approach, integrating white goods schemes with other interventions to improve residential comfort (Croon et al., 2025).

Perceived physical health of the residents. Table 7 shows the descriptive statistical results related to the respiratory problems. We explored whether the provided scheme can decrease respiratory issues due to reduced moisture in the house. As Fig. 3 shows, the perceived respiratory problem is improved only in Scheme 1, which can be due to the type of replaced efficient appliances such, as the washing machine, and subsequently the moisture reduction. The results of the between-subjects effects on the dependent variable 'respiratory issues' show that the overall model, which includes intervention type, group type, and their interaction, does not effectively explain or predict variations in respiratory issues among the subjects. The Adjusted R-squared value, which measures the proportion of variance in the dependent variable (respiratory issues) explained by the independent variables (intervention type, group type, and their interaction), is very low at 0.008. This indicates that only around 0.8% of the variability in respiratory issues can be accounted for by the predictors in the model. Furthermore, neither predictor shows a statistically significant association when examining the individual effects of intervention type and group type on respiratory issues. This means that on their own, intervention type and group type do not reliably predict changes in respiratory issues among the subjects.

While there is a statistically significant interaction effect between intervention and group types, with F-value of 4.29 ($p = 0.04$), the explained variance in respiratory issues is minimal. This suggests that, although some relationship exists, the practical impact of these factors on respiratory issues is limited and requires further investigation to confirm. This indicates that the impact of white goods schemes on respiratory health varies depending on the characteristics of the intervention being studied (e.g., the type of appliances offered for replacement). Furthermore, the lower levels of respiratory problems are related to the perceived residential comfort ($r(541) = 0.44$; $p < 0.001$). Although the renewal of energy appliances may contribute to reducing dampness and mould, the observed effects on physical health are limited. This highlights the potential for intervention programs to improve residential comfort, but further research is needed to evidence their impact on health outcomes.

Energy costs and mental health

The results is assessed with responses to 'How many euros do you pay monthly for your energy bill?' and 'Are you worried about paying your energy bill?'. The two models of interaction between the dependent (energy bills, financial concern, and mental well-being) and independent variables (group and intervention types) are shown in Table 8, and the description is as follows:

Energy bill. The results of tests of between-subjects effects for the dependent variable 'Energy bill' are

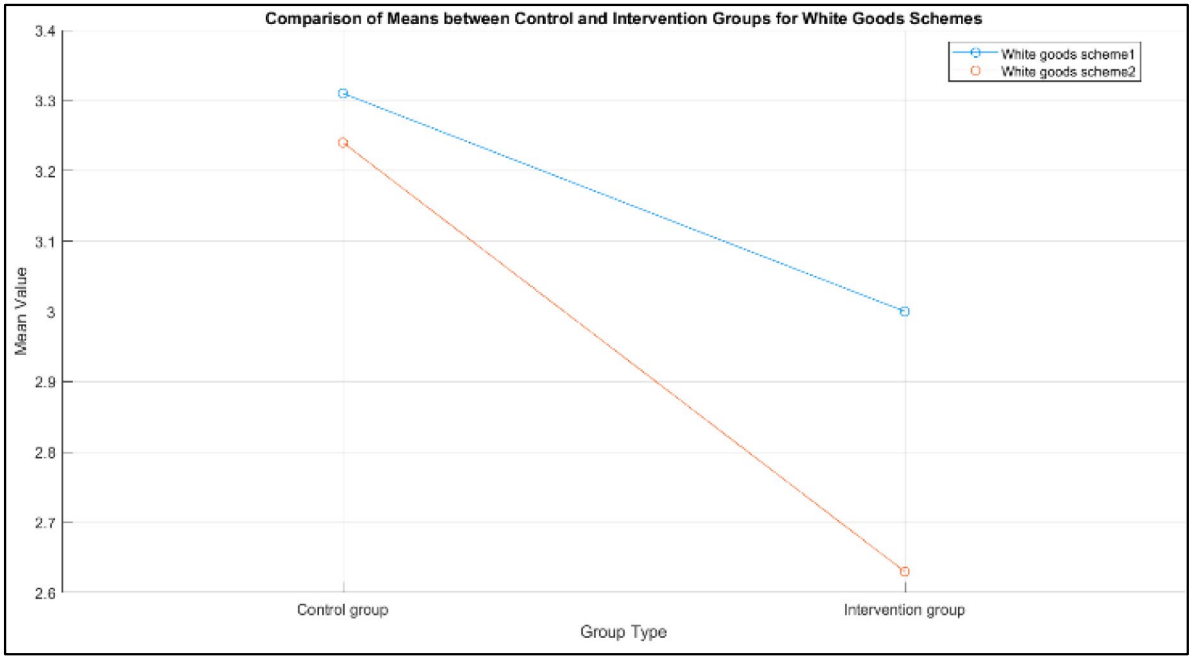
Table 7 Descriptive analysis of perceived improved health through the white goods schemes

Descriptive Statistics					
Dependent Variable: Respiratory problems					
Intervention type	Group type	Mean	Std. Deviation	N	
White goods scheme1	Control group	3.78	1.43	206	
	Intervention group	3.54	1.43	261	
	Total	3.65	1.43	467	
White goods scheme 2	Control group	3.08	1.35	25	
	Intervention group	3.53	1.26	49	
	Total	3.38	1.30	74	
Total	Control group	3.71	1.44	231	
	Intervention group	3.54	1.40	310	
	Total	3.61	1.42	541	

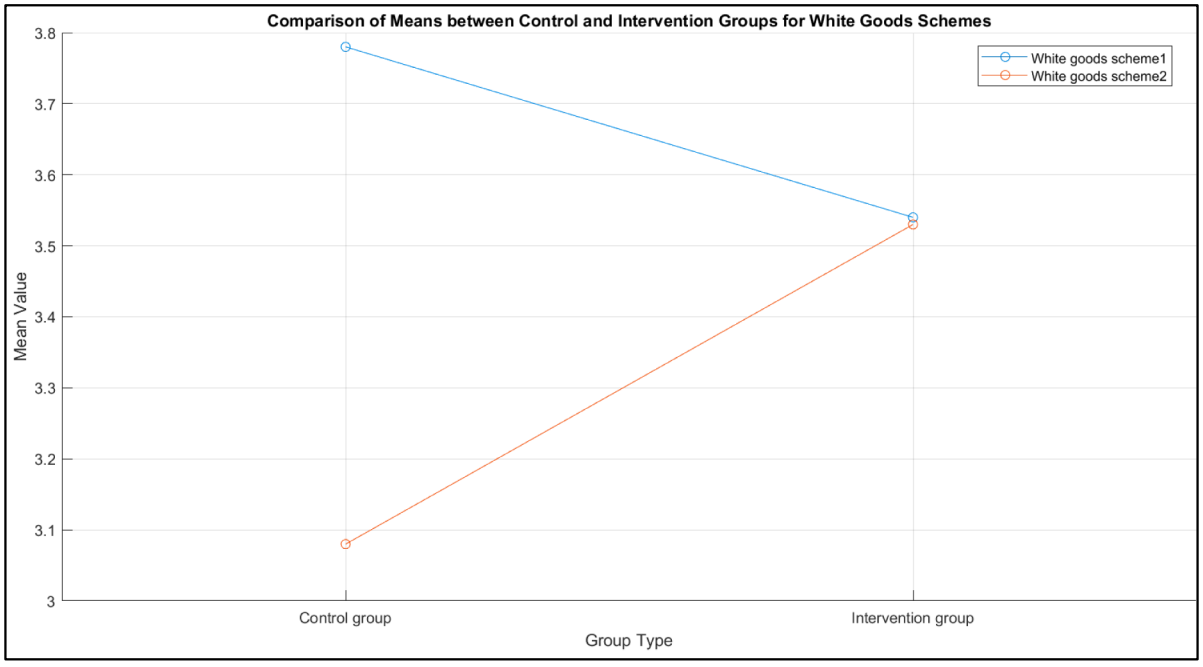
shown in Table 9. The model has some explanatory power, as indicated by the Adjusted R-squared value of 0.026. The test model shows that intervention type and group type significantly predict the energy bill, with F-values of 6.05 ($p = 0.014$) and 4.24 ($p = 0.04$), respectively. However, the interaction effect between intervention and group types is not statistically significant. The findings show that the energy bill has been reduced in both schemes; however, in the white goods scheme 2, the energy bill is less than in scheme 1 due to the type of replaced appliances. This can be referred to as the higher amount offered in scheme 2 for buying a refrigerator. This cannot be solely interpreted to the provided energy-efficient appliance since many factors, such as demographic features, residents'profiles, and dwelling characteristics, can influence energy bills. In summary, the intervention group in the first scheme could save 7.9 euros per month, while people using the white goods scheme 2 could save a total of 41.02 euros per month through this scheme.

Perceived financial concerns of the residents. In response to the question 'Are you worried about paying your energy bill?', the intervention groups in both schemes had lower financial concerns than the control group (Table 10). It can be expected that this is due to the renewal of the appliances and reduced energy costs ($r(475) = 0.36$; $p < 0.001$). The test model shows that intervention type and group type significantly affect financial concerns, with F-values of 4.42 ($p = 0.04$) and 3.47 ($p = 0.06$), respectively. However, the effect size is relatively small, as indicated by the partial eta squared values (0.008 and 0.006, respectively). While intervention and group types have some influence on financial concerns, other factors not included in the analysis may also play a significant role. Overall, these analyses suggest that intervention programs aimed at reducing energy bills may have a limited positive effect on residents'mental health. However, further research is necessary to confirm and better understand this relationship. It also underlines the need to consider other factors that may contribute to these concerns.

Perceived mental well-being of the residents. In response to the mental health, the participants responded to three questions: 'How often do you experience stress?'; 'How often do you feel angry?'; and 'How often do you feel gloomy?'. The results



a. The comparison between the perceived comfort (suffering from dampness)



b. The comparison between the perceived improved health (respiratory problems)

Fig. 3 The comparison between the perceived comfort and physical health-related variables between two groups and schemes

Table 8 Testing the model of different schemes and groups on the energy bills, financial concerns and mental health of the residents

Tests of Between-Subjects Effects								
Dependent Variable: Energy bill (1), financial concerns (2) and mental health (gloom, stress, and anger level) (3)								
Model		Source	Type III Sum of Squares	df	Mean Square	F	Sig	Partial Eta Squared
(1) Energy bill		Corrected Model	140906.31[a]	7	20129.47	2.78	0.008	0.040
		Intercept	479467.58	1	479467.52	66.18	0.000	0.124
		Intervention type	43792.38	1	43792.38	6.05	0.014	0.013
		Group type	30708.42	1	30708.42	4.24	0.040	0.009
		Intervention type * Group type	14681.35	1	14681.35	2.03	0.155	0.004
		a. R Squared = 0.040 (Adjusted R Squared = 0.026)						
(2) Financial concerns		Corrected Model	60.38[a]	7	8.63	3.92	0.00	0.049
		Intercept	491.29	1	491.29	223.01	0.00	0.295
		Intervention type	9.73	1	9.73	4.42	0.04	0.008
		Group type	7.64	1	7.64	3.47	0.06	0.006
		Intervention type * Group type	0.05	1	0.05	0.02	0.88	0.00
		a. R Squared = 0.049 (Adjusted R Squared = 0.036)						
(3) Mental health	Gloom level	Corrected Model	19.12[a]	7	2.73	1.42	0.196	0.018
		Intercept	320.23	1	320.23	166.21	< 0.001	0.238
		Intervention type	2.89	1	2.89	1.51	0.22	0.003
		Group type	7.19	1	7.19	3.73	0.054	0.007
		Intervention type * Group type	0.93	1	0.93	0.481	0.49	0.001
		a. R Squared = 0.018 (Adjusted R Squared = 0.005)						
	Stress level	Corrected Model	22.80[a]	7	3.26	1.61	0.13	0.021
		Intercept	367.79	1	367.79	181.78	< 0.001	0.25
		Intervention type	0.237	1	0.24	0.12	0.732	0.00
		Group type	10.49	1	10.49	5.18	0.023	0.01
		Intervention type * Group type	1.18	1	1.18	0.58	0.45	0.001
		a. R Squared = 0.021 (Adjusted R Squared = 0.008)						
	Anger level	Corrected Model	34.66[a]	7	4.95	2.84	0.006	0.04
		Intercept	291.30	1	291.30	167.32	< 0.001	0.24
		Intervention type	2.18	1	2.18	1.25	0.263	0.002
		Group type	14.18	1	14.18	8.15	0.004	0.015
		Intervention type * Group type	4.74	1	4.74	2.72	0.099	0.005
		a. R Squared = 0.021 (Adjusted R Squared = 0.008)						

show that the intervention groups in both schemes had lower levels of negative emotions (stress, anger, and gloom) than the control group (Table 11). The test model shows that group type significantly affects mental health, with an F-value of 3.73 (p = 0.054) for gloom level, an F-value of 5.18 (p = 0.023) for stress level, and an F-value of 8.15 (p = 0.004) for anger level. The findings illustrate that the levels of gloom, stress, and anger are lower in the intervention groups. When comparing the two schemes, these levels are significantly reduced in Scheme 2. Additionally, within the intervention groups of both schemes, the results show that participants experienced less anger compared to stress and gloom. Moreover, the lower levels of negative emotions are related to the energy costs ($r(475) = 0.23$; $p < 0.001$) as well as the financial concerns ($r(541) = 0.50$; $p < 0.001$). This indicates that due to the renewal of the appliances, energy

Table 9 Descriptive analysis of the energy bills through the white goods schemes

Descriptive Statistics				
Dependent Variable: Energy bill				
Intervention type	Group type	Mean	Std. Deviation	N
White goods scheme 1	Control group	184.55	84.63	183
	Intervention group	176.68	89.54	230
	Total	180.17	87.38	413
White goods scheme 2	Control group	171.82	83.44	22
	Intervention group	130.80	60.54	40
	Total	145.35	71.64	62
Total	Control group	183.19	84.39	205
	Intervention group	169.88	87.31	270
	Total	175.62	86.23	475

Table 10 Descriptive analysis of the financial concerns through the white goods schemes

Descriptive Statistics				
Dependent Variable: Financial concerns				
Intervention type	Group type	Mean	Std. Deviation	N
White goods scheme 1	Control group	4.56	1.35	206
	Intervention group	4.20	1.55	261
	Total	4.36	1.47	467
White goods scheme 2	Control group	3.96	1.81	25
	Intervention group	3.61	1.58	49
	Total	3.73	1.66	74
Total	Control group	4.49	1.41	231
	Intervention group	4.10	1.57	310
	Total	4.27	1.51	541

costs and financial concerns are reduced, which subsequently yields better mental health. In addition, there is a noticeable difference in Scheme 2 between the control and intervention groups for all levels of negative emotions. In contrast, there is little difference between the control and intervention groups in Scheme 1. This shows that the intervention group in Scheme 2 experienced significantly greater improvements in mental health compared to Scheme 1. Overall, these analyses highlight the importance of intervention programs that reduce energy bills, as they also improve residents'mental health (Figs. 4 and 5).

Making sustainable energy use behaviour

In the following assessment, we explored how introducing this kind of energy support measure can affect people's behaviour regarding energy efficiency activities. Therefore, we asked for related questions and analysed them accordingly (Table 12).

Indoor temperature setting: What temperature do you set the thermostat to during the day?

The results show that the average temperature setting is 17.56 °C for both groups, and there is no significant difference between them in both schemes. In summary, the analysis examines the effects of different factors (intervention and group types) on indoor temperature. However, none of the factors appear to have a significant effect, as indicated by their non-significant p-values. Additionally, the Adjusted R-squared value suggests that the model does not explain much of the variance in the dependent variable.

Table 11 Descriptive analysis of mental health through the white goods schemes

Descriptive Statistics				
Dependent Variable: Gloom level				
Intervention type	Group type	Mean	Std. Deviation	N
White goods scheme 1	Control group	3.51	1.30	206
	Intervention group	3.28	1.40	261
	Total	3.38	1.39	467
White goods scheme 2	Control group	3.40	1.55	25
	Intervention group	2.94	1.30	49
	Total	3.09	1.40	74
Total	Control group	3.50	1.35	231
	Intervention group	3.23	1.40	310
	Total	3.34	1.39	541
Dependent Variable: Stress level				
White goods scheme1	Control group	3.92	1.37	206
	Intervention group	3.65	1.40	261
	Total	3.77	1.40	467
White goods scheme 2	Control group	3.92	1.70	25
	Intervention group	3.33	1.38	49
	Total	3.53	1.50	74
Total	Control group	3.92	1.40	231
	Intervention group	3.60	1.40	310
	Total	3.74	1.40	541
Dependent Variable: Anger level				
White goods scheme1	Control group	3.30	1.36	206
	Intervention group	3.10	1.30	261
	Total	3.19	1.30	467
White goods scheme 2	Control group	3.36	1.20	25
	Intervention group	2.55	1.19	49
	Total	2.82	1.25	74
Total	Control group	3.31	1.30	231
	Intervention group	3.01	1.30	310
	Total	3.14	1.30	541

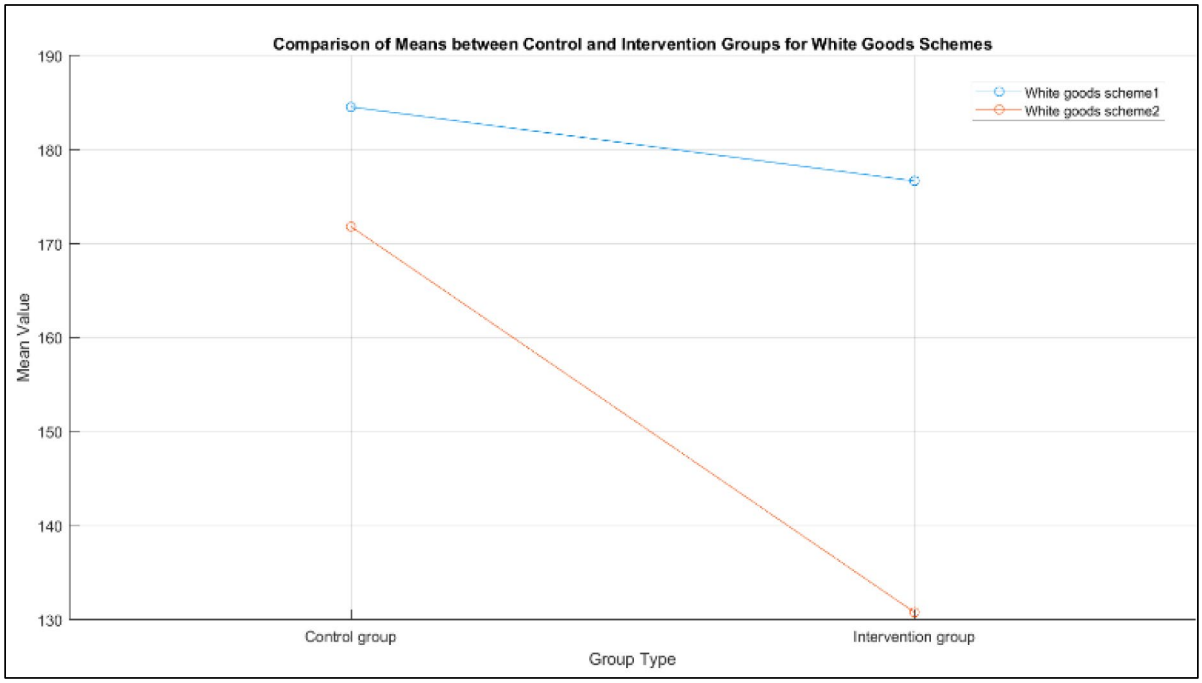
Extra clothing: Do you put on a warm sweater or take a blanket when you are cold at home?

In response to this question, both groups often put on a warm cloth or use a blanket in cold indoor air. The different schemes do not affect people's choices. The statistical analysis examines the relationship between two groups and schemes and how people respond to feeling cold at home. The analysis suggests that the factors examined (group type and intervention type) do not have a significant impact on people's behaviour when feeling cold at home. The model's ability to predict behaviour is limited, indicating that other factors not included in the analysis may play a more substantial role.

Lighting: Do you turn off the lights in rooms where no one is there?

The average response for both groups and both intervention types was often turning the lights off when they were not used. The statistical analysis explores the relationship between different types and schemes factors and whether individuals turn off lights in rooms where no one is present. The

a. The comparison be tween the energy bills



b. The comparison between the financial concerns

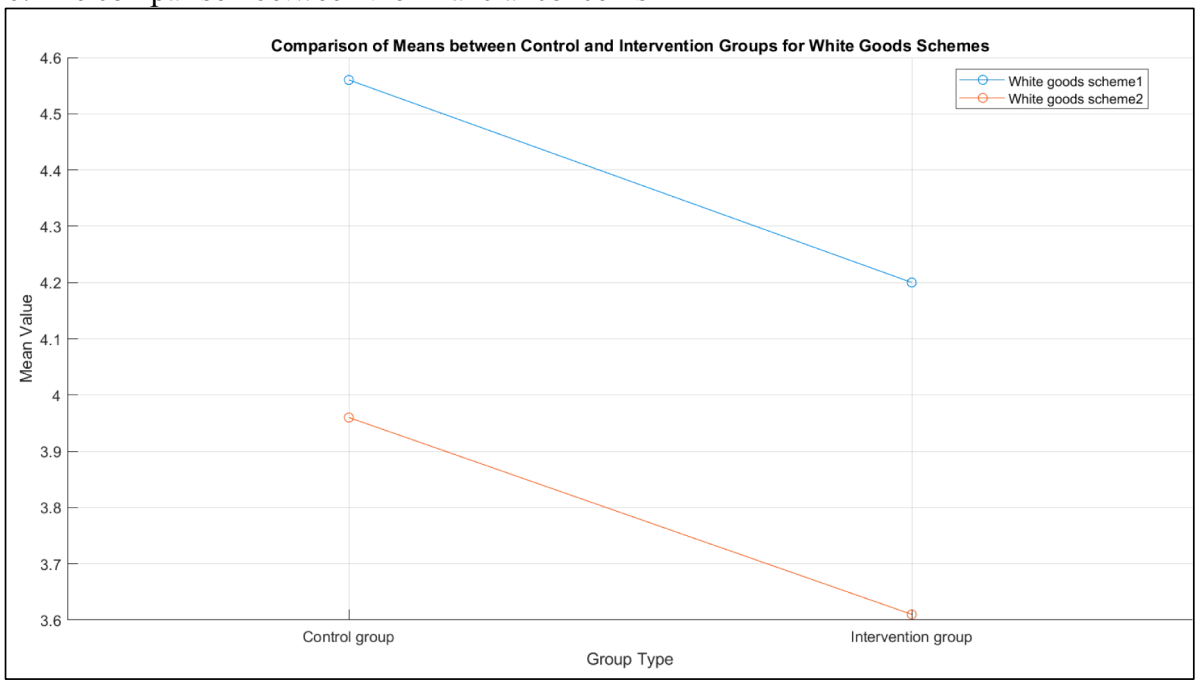
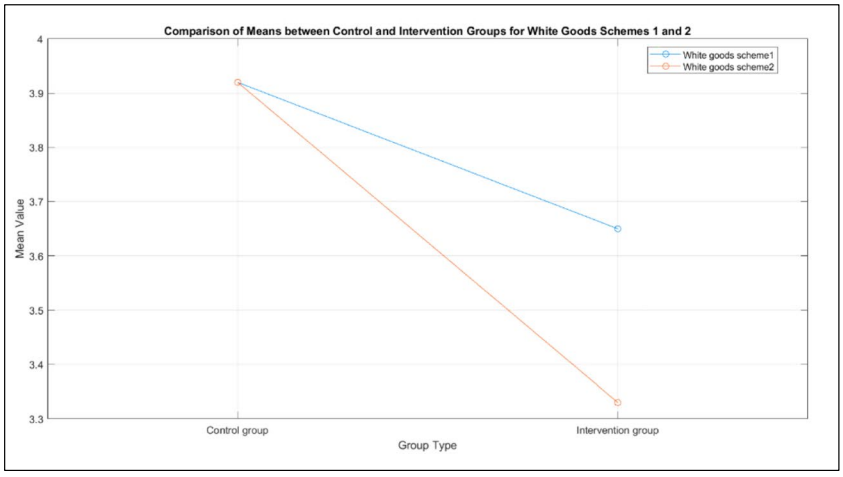


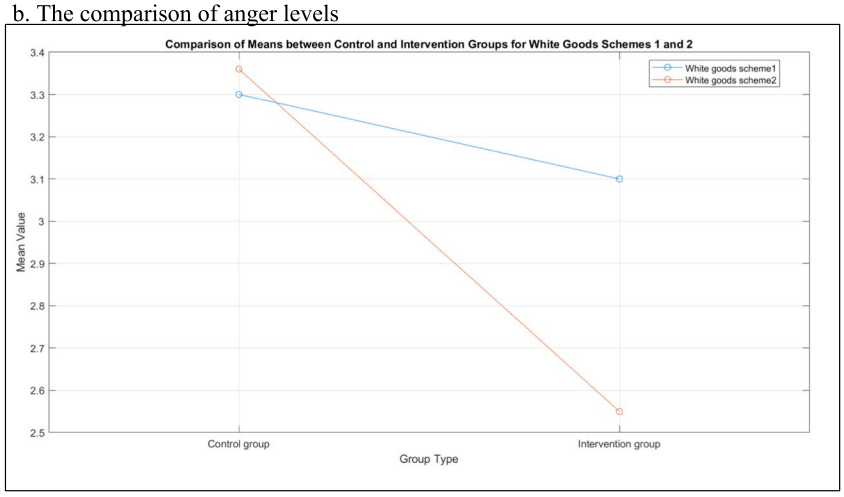
Fig. 4 The comparison of energy costs, financial concerns variables between two groups and schemes

Fig. 5 The comparison of perceived mental health-related variables between two groups and schemes

a. The comparison of stress levels



b. The comparison of anger levels



c. The comparison of gloom levels

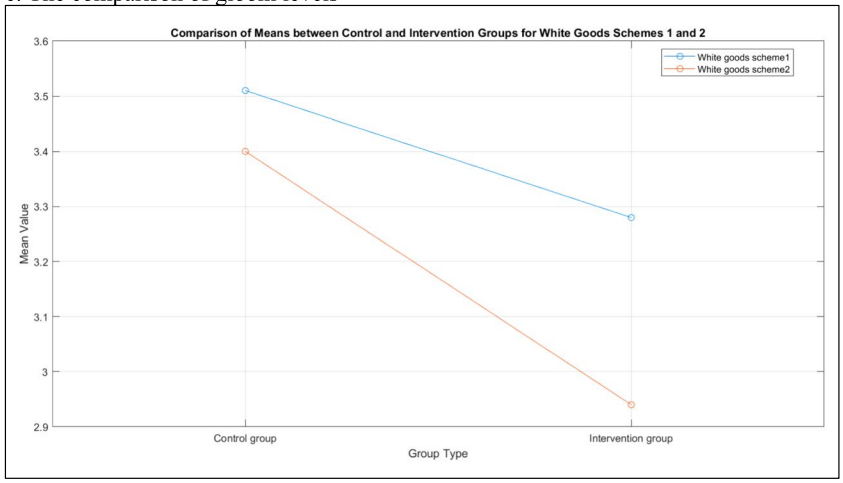


Table 12 Testing the model of different schemes and groups on the sustainability behaviour of the residents

Tests of Between-Subjects Effects							
Dependent Variable: indoor temperature, extra clothing, lighting, showering duration							
Model	Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
(1) Indoor temperature setting	Intervention type	15.20	1	15.201	2.69	0.10	0.007
	Group type	0.42	1	0.42	0.07	0.79	0.00
	Intervention type * Group type	0.07	1	0.07	0.01	0.91	0.00
	a. R Squared = 0.018 (Adjusted R Squared = 0.00)						
(2) Extra clothing (Wearing warm clothes)	Intervention type	2.02	1	2.02	1.74	0.19	0.003
	Group type	0.35	1	0.35	0.30	0.58	0.001
	Intervention type * Group type	2.507E- 6	1	2.507E- 6	0.00	0.99	0.00
	a. R Squared = 0.006 (Adjusted R Squared = −0.007)						
(3) Lighting (Turning unused light off)	Intervention type	0.67	1	0.67	0.99	0.32	0.002
	Group type	1.76	1	1.76	2.60	0.11	0.005
	Intervention type * Group type	2.18	1	2.18	3.23	0.07	0.006
	a. R Squared = 0.009 (Adjusted R Squared = −0.004)						
(4) Shower duration	Intervention type	0.001	1	0.001	0.00	0.99	0.00
	Group type	1.71	1	1.71	0.68	0.41	0.001
	Intervention type * Group type	0.003	1	0.003	0.001	0.97	0.00
	a. R Squared = 0.012 (Adjusted R Squared = −0.001)						

analysis indicates that the factors considered do not significantly impact individuals'behaviour regarding turning off lights in unoccupied rooms. However, other factors may not be included in the analysis that could influence this behaviour.

Showing duration: Do you shower for less than 5 minutes?

Regularly, people shower for less than five minutes and consequently consume less water in both groups and schemes. There is no significant difference between them. Therefore, it can be more related to their habit and lifestyle than the effect of the schemes. The overall model has a partial eta squared of 0.012, indicating that the predictors collectively explain 1.2% of the variance in shower duration. None of the predictors (intervention and group types and their interaction) have statistically significant effects on shower duration, as indicated by their non-significant p-values (all above 0.05). The intercept (representing the average shower duration when all predictors are zero) is statistically significant, with a large F-value and a small p-value. Therefore, the predictors included in the model do not significantly predict shower duration, and the model explains only a small proportion of the variance in shower duration.

Discussion

We have investigated the effects of the two types of white goods schemes on residential comfort, physical and mental health, energy costs, financial concerns, and sustainable energy use behaviour. The limitations of the study primarily include its cross-sectional design instead of a longitudinal approach and potential differences in socio-economic and housing characteristics, such as energy poverty, between the control and intervention groups.. The following sub-section summarises the findings.

White goods scheme enhances the perceived comfort of residents

The analyses indicate that white goods schemes, particularly those that involve replacing old or inefficient appliances with new ones, positively impact residents'perceived comfort concerning moisture and mould in their homes. We assume that this effect can be attributed to replacing old or faulty appliances, such as washing machines, with newer models that are more effective at removing moisture from laundry during the spin cycle. By effectively removing excess moisture from laundry during the spin cycle, these newer appliances result in less damp clothing hanging on drying racks within the home. Reducing moisture levels in the home has several additional benefits beyond improving comfort (Bornehag et al., 2005; Peat et al., 1998; Sun & Sundell, 2013; Sun et al., 2018; Zhang et al., 2019). One significant advantage is the potential reduction of respiratory problems associated with damp indoor environments. Excessive moisture can contribute to the growth of mould and fungus, which can exacerbate respiratory conditions such as asthma and allergies. By addressing moisture issues through appliance replacement schemes, residents may experience improvements in respiratory health and indoor air quality. However, further research into this issue is needed since the causal mechanisms through which white goods schemes affect physical health outcomes fall beyond the scope of this study.

White goods scheme reduces energy cost and subsequently enhances perceived mental health

The findings suggest that appliance schemes are likely highly energy-efficient, and have a positive impact on reducing energy bills and, consequently, alleviating financial concerns among residents. Specifically, the results indicate that residents could save approximately 156 euros annually from using these energy-efficient appliances. This significant cost-saving potential is attributed to the energy efficiency of the appliances, which leads to lower energy consumption and, consequently, reduced energy costs for households. By alleviating financial concerns associated with high energy bills, residents are likely to experience decreased stress and anxiety related to financial strain. This, in turn, can contribute to improved mental health. However, also here, follow-up research is needed to unravel further the causal mechanisms through which white good schemes may impact mental health. These benefits emphasise the importance of implementing energy-efficient appliance schemes to promote financial stability and overall well-being within communities.

Additional interventions or schemes are necessary to encourage sustainable energy use behaviours among households

The data indicates that households generally show a high level of awareness and conscientiousness regarding energy conservation practices. Even among households that have not yet made use of the white goods scheme, there is evidence of environmentally friendly behaviours, such as setting the thermostat at relatively low temperatures (averaging 17.5 °C) during the autumn/winter period. Additionally, many households use extra clothing, such as sweaters or blankets, to stay warm instead of relying solely on heating. Similarly, these households frequently engage in energy-saving habits like turning off lights in unoccupied rooms and taking shorter showers (less than 5 minutes). This proactive approach to energy conservation may have been influenced by the energy crisis that occurred during the winter of 2022/2023, prompting households to adopt more sustainable practices in response to rising energy costs and supply shortages. Interestingly, the analysis indicates that implementing white goods schemes did not significantly alter these already-established sustainable behaviours due to the so-called spillover effect. This effect entails that sustainable actions increase awareness and could foster other sustainable actions (Thøgersen & Ölander, 2003). This could be attributed to the fact that households were already practising energy-saving habits to a considerable extent, leaving little room for improvement. On the other hand, no rebound effect (Vivanco et al., 2016), an increase in energy consumption following the savings provided by the white goods scheme, did occur either. Consequently, while the appliance schemes did not lead to noticeable behavioural changes, they also did not uncover any significant discrepancies in sustainable practices among participating households. Overall, the findings highlight the commendable efforts of households in proactively managing energy consumption and embracing sustainable behaviours, even without formal support measures. Additionally, they highlight the challenges of promoting further energy conservation improvements among households already highly engaged in environmentally friendly practices.

In conclusion, the white goods scheme can efficiently reduce energy consumption. However, the way of using appliances and residents' behaviours is also essential in terms of energy consumption. For instance, in terms of lighting, the UN ActNow platform suggests simple yet impactful actions (Nations, n.d). Unplugging appliances when not in use can save more than 3.5 kWh of electricity per year per person (equivalent to around 1.5 kg of CO_2 emissions). Similarly, turning off a 60 W light bulb for 4 h can save 0.24 kWh of electricity and approximately 100 g of CO_2 emissions. Abrahamse and Steg (2009) demonstrate that mindful usage of household appliances can also reduce energy demand. For example, opting to launder clothes at 40 °C instead of 90 °C or 60 °C or running the dishwasher only when it's fully loaded can lead to significant energy savings (Gaspari et al., 2021). Figure 6 shows the effect size between the provision of the white goods scheme and perceived

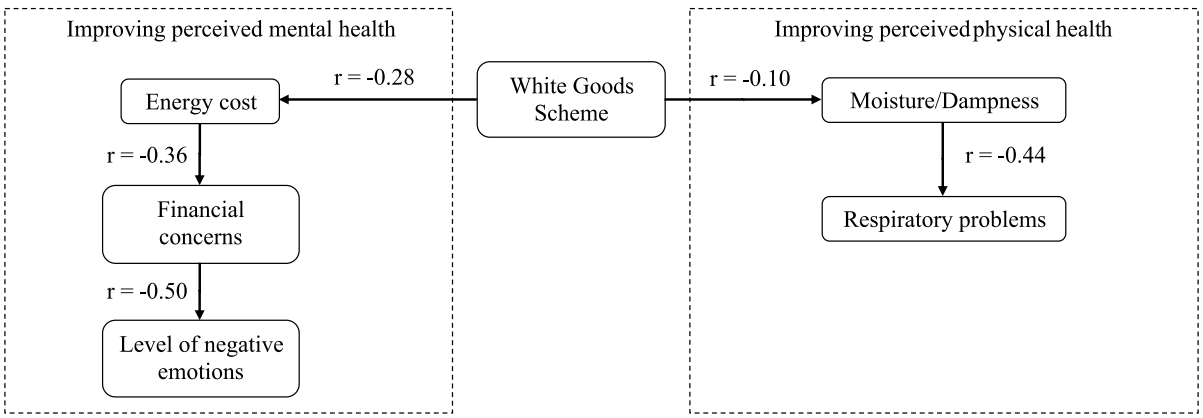


Fig. 6 The effect size between the white goods scheme and residents' perceived comfort and health

comfort and health by the households, as indicated by the correlation coefficient. However, the effect depends on the type of the scheme and provided appliance. However, there is no relationship between improving the sustainability behaviour of the residents and the support measures.

Conclusion

This study addressed the question of 'How do white goods schemes affect residential comfort (subsequently physical and mental health), energy costs (subsequently financial concerns and mental health), and sustainability behaviour?'. It highlights the resilience and proactive approach adopted by households in managing their energy consumption, particularly in response to the challenges posed by high energy prices. Throughout the fall and winter seasons of 2022/2023, participants showed commendable energy-saving behaviours, including keeping indoor temperatures at an average of 17.5 °C, increasing warmth with additional clothing, restricting shower durations to less than 5 min, and conscientiously switching off lights in unoccupied rooms. Despite these efforts, due to the poor condition of the homes, many households encountered challenges related to residential comfort through moisture and mould within their living spaces, which had detrimental effects on their physical health and well-being. Implementing the'White Goods Scheme' support measure yielded positive outcomes and contributed to an overall enhancement in living conditions. The study concludes:

1. Participation in the white goods scheme enhances residents'perceived comfort by reducing moisture and dampness indoors, leading to fewer reported respiratory problems, depending on the type of replaced appliance.
2. Participation in the white goods scheme reduces energy costs, subsequently enhancing perceived mental health by alleviating financial concerns, thereby decreasing residents'stress and anxiety related to financial strain.
3. A combination of interventions or schemes is necessary to encourage sustainable energy use behaviours among households.

Therefore, depending on the type of appliance offered for replacement, the white goods schemes seem to improve health in two ways. Firstly, increasing residential comfort conditions yields better physical health. Secondly, reducing energy costs and financial concerns yields better mental health. Yet, the causal mechanisms behind these connections need to be further scrutinised. Overall, this research shows how government/local financial support can indirectly enhance the well-being of the people by implementing a combination of interventions and schemes. The study recommends a further comprehensive strategy, including a combination of renovations, energy coaching, white goods schemes, and collaborative efforts in sustainable energy generation and pricing to tackle the challenges of energy transition, effectively. By integrating diverse support and policy interventions, stakeholders can work towards a more inclusive and sustainable solution to accelerate transition, alleviate energy poverty, and enhance the overall well-being of vulnerable households. Last but not least, to achieve an inclusive program, it is suggested to consider all aspects of sustainability, including offering and replacing refurbished, reused, and recycled options, along with providing infrastructure for the end-of-life management of old appliances.

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Author contributions Methodology: Arianne J. van der Wal, Data visualisation: Elham Maghsoudi Nia, Investigation: Arianne J. van der Wal, Writing – Initial draft: Elham Maghsoudi Nia, Writing – Review: Arianne J. van der Wal, Queena K. Qian, Joris Hoekstra, Funding Acquisition: TNO, Supervision: Queena K. Qian, Joris Hoekstra.

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Data availability Supporting data is available in the TNO publication at https://publications.tno.nl/publication/34640993/1EDZiA/TNO-2023-effecten.pdf

Declarations

Ethical approval and consent to participate Informed consent was obtained from all participants involved in the study.

Human ethics This study was reviewed and approved by the ethics committee of TNO, under reference number 2022–097.

Consent for publication All authors have provided consent for publication.

Competing interests The authors declare that they have no competing interests.

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