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Co-Designed Interventions Yield Significant Electricity Savings among Low-Income Households in Makhanda South Africa

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Abstract: Human practices are at the centre of unsustainable electricity use at the household level, which means behaviour change strategies can form pathways towards electricity conservation. Although behaviour change interventions are useful in promoting electricity savings at the household level, they are rarely inclusive and informed by the users of electricity. Using a field-based experiment, this study examines the impact of co-designed interventions on household electricity consumption among low-income households in Makhanda, South Africa. The results show that co-designed interventions yielded significantly more electricity savings (5%) than prescriptive interventions (2%) over the intervention period. Participant households exposed to the co-designed interventions showed electricity savings of up to 14% post the intervention period, suggestive of positive persistent effects. Household size and employment status had a significant negative effect on electricity consumption while age, employment status, and baseline electricity consumption yielded positive effects. Electricity savings were positively correlated with involvement and trust, perceived behavioural control, and the intention to act pro-environmentally. The results highlight that co-designed interventions can yield significant electricity savings, which can in turn, result in grid stability, and reduced electricity expenditures and carbon emissions. A key contribution of this study lies in advancing our understanding of the effects of user-driven approaches in yielding persistent electricity-saving behaviour, which to date has not been a focus of intervention studies. In particular, the findings lend support to notions of supporting the agency of electricity users in co-developing solutions for local sustainability challenges.

Keywords: electricity use; urban sustainability; co-designed interventions; behaviour

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1. Introduction

Globally, ensuring energy security remains a major urban sustainability challenge particularly among low-income households. Meanwhile, the residential sector remains a major consumer of energy. For example, the global share of household electricity consumption stands at approximately 20% [1], making the household sector a major player in urban sustainability debates. Promoting electricity savings through behavioural interventions has long been considered a promising pathway to sustainable cities, and a growing body of literature interrogates the effectiveness of electricity-saving interventions [2–4]. Behavioural interventions such as the provision of electricity-saving information in the form of stickers and pamphlets, goal setting, and feedback on electricity-saving performance have been applied in household settings with varying effects. For example, Kua and Wong [5] showed that the use of stickers with electricity-saving information on the use of household appliances, such as refrigerators, resulted in electricity reductions of up to 2% in Singapore. The eco-living programme in Singapore also highlights the effectiveness of combining stickers and leaflets, with an approximate 16% reduction in electricity consumption among households [6]. Mi et al. [7] found that coupling environmental education information and feedback yielded about 21% in electricity savings among Chinese households.

However, these interventions are often externally driven and unsustainable as they are seldom designed with input from key stakeholders, such as electricity suppliers, providers, and users [8–10]. The outcome is that behavioural interventions tend to be prescriptive and not reflective of local contexts, needs, and priorities, which could undermine persistent electricity-saving behaviour, as shown by He and Kua [6] where prescriptive interventions on the Partial Treatment group (PT) yielded less savings than the Full Treatment (FT) group which participated in designing the interventions. Consideration of local people's views is important for developing a common understanding of the sustainability challenge and for co-designing electricity-saving interventions [8,9]. User-driven interventions are characterised by collective problem formulation and the involvement of households as key partners in designing solutions for local sustainability challenges [10]. Processes that engender co-generation and the sharing of knowledge and creation of trust between actors are likely to yield persistent effects [8,11]. Further, co-designing interventions can result in increased agency for electricity users, decision-making capacity, and ownership of the project [12]. Thus, co-designing is gaining traction globally for designing locally relevant solutions to local sustainability challenges [9,10,13,14].

In South Africa, investment in behavioural change interventions for promoting household electricity saving is important for several reasons. First, South Africa generates 70% of its electricity from low quality coal and is the only African country among the top 20 carbon emitters in the world [15]. South Africa's CO_2 emission per capita is about 7.5 t CO_2/capita (2018 levels), more than the global average of 4.79 t CO_2/capita [16]. Further, despite a comparatively high rate of access to electricity [17], the country is faced with energy insecurity with persistent load shedding. Therefore, technical solutions such as improving electricity generation capacity by building more power generation plants and energy efficient technologies can address electricity availability, but they might be prohibitive due to high implementation and maintenance costs. For instance, South Africa has endured power cuts since 2008 attributed to insufficient electricity generating capacity, operational failures and poorly maintained infrastructure due to a lack of financial investments. ESKOM, the country's power utility is in a financial crisis and cannot afford to construct new or maintain existing electricity infrastructure [18]. Further, technical interventions alone might be insufficient to (i) meet the growing electricity demand due to population growth, and (ii) address energy poverty among poor households because of the prohibitive costs of purchasing electricity and energy-efficient technologies [19,20]. Third, co-designing interventions can engender agency, that is, the ability to act in one's interest [21]. Therefore, investing in behavioural interventions can contribute to efforts aimed at promoting electricity conservation in the country [22,23].

Transdisciplinary approaches can be central in steering positive behaviour change because collaborative processes can result in trust and capacity building, feelings of inclusivity and representation of views, and feelings of control over one's situation [9,14]. Transdisciplinary approaches can support established theories for studying human behaviour. One of the commonly used theories is the Theory of Planned Behaviour (TPB) (Figure 1). The TPB suggests that people's behaviour is determined by intentions that emanate from personal attitudes, perceived behavioural control (PBC) and subjective norms [24]. Attitudes measure the favourability of certain behaviours for individuals [24]. For example, [25] found a positive correlation between people who have a positive attitude towards switching off appliances when leaving the room and actual electricity-saving behaviour. Heaslip and Fahy [26] found transdisciplinary approaches had a positive effect on attitude towards community energy transitions in Ireland, which can, arguably, result in pro-environmental behaviour. Thus, it is plausible to argue that the involvement of electricity users in problem formulation can ensure alignment of research project goals with electricity users' needs, and activate electricity users' agency, which can engender positive attitudes towards electricity saving [27,28]. However, Albarracín et al. [29] argue that attitudes do not always translate into pro-environmental behaviour, especially when there are external constraints such as structural barriers which can make it difficult to undertake a desired behaviour. Therefore, while transdisciplinary approaches can foster positive attitudes towards electricity use, other factors might shape behavioural responses.

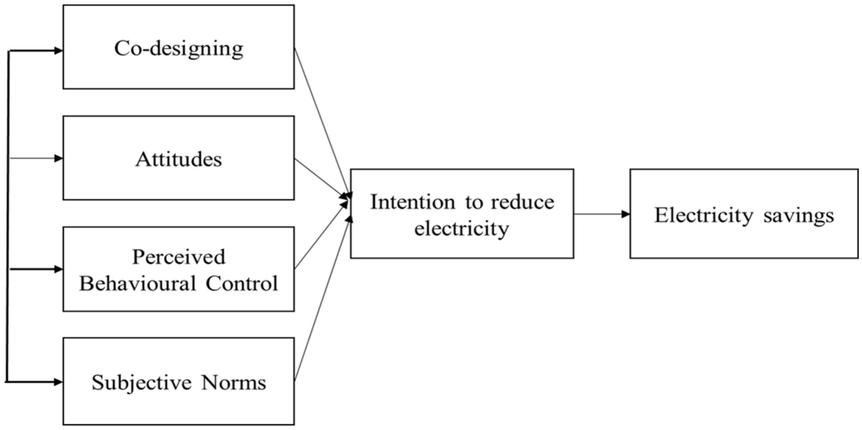

Figure 1. Determinants of electricity-use behaviour.

Perceived behavioural control (PBC) is the extent to which one believes has the means, opportunity, and ability to control an outcome [24]. It is determined by how easy or difficult performing a behaviour is perceived to be [30]. People who perceive switching off-lights or electrical appliances completely or unplugging chargers as easy to do are more likely to engage in electricity-saving actions than those who do not. Ru et al. [31] show that a high level of PBC resulted in electricity savings among Chinese households. Based on the literature, we hypothesise that co-designing electricity-saving interventions can allow households the opportunity to learn and share information about electricity-saving measures, which can in turn, result in a high level of PBC. A high level of PBC can translate into substantial electricity savings among households.

Subjective norms refer to the expectations of significant others [24]. Ajzen [24] suggests that the perception of significant figures such as respected members of the society and family members has a very strong influence on individual behaviour. Dixon et al. [32] found a positive correlation between subjective norms and intention to save electricity in the workplace. However, it is argued the influence of subjective norms is more applicable to visible (e.g., waste dumping) than non-visible behaviour [33] such as electricity use. Based on the literature [34–36], this study hypothesises that co-designing interventions can engender a collective understanding of the sustainability challenge and the responsibility of everyone in addressing the challenge. Thus, people's perceptions of how others expect them to act pro-environmentally can result in electricity savings.

However, relative to technical interventions, studies on behavioural interventions in the household sector are limited in South Africa [37]. Further, available studies on behavioural interventions, for example, Thondhlana and Kua [2] and Williams et al. [38], show that interventions are mainly externally initiated and researcher-driven, undertaken over short periods, and do not measure the persistent effects of the interventions [37,38].

Within this context, this study examined the effects of co-designing electricity-saving interventions on electricity consumption among low-income households in Makhanda, South Africa. To the best of our knowledge, this is the first study in South Africa that examines electricity consumption among households over a relatively long period of time (about two years), and that integrates transdisciplinary approaches with behavioural theories in designing interventions. A key contribution of this study lies in advancing our understanding of the effects of user-driven approaches in yielding persistent electricity-saving behaviour, which is arguably underrepresented in the literature. From a practical perspective, this paper builds on the value of collective problem formulation as a basis for co-designing socially relevant and meaningful electricity-saving interventions which can enable the alignment of local needs, interests, and priorities with research goals.

2. Materials and Methods

2.1. Study Participants

The study was undertaken among low-income households in Makhanda, a medium-sized town located in the Eastern Cape Province of South Africa (33°18′36″ S; 26°31′36″ E). The study is part of the Leading Integrated Research for Agenda 2030 in Africa (LIRA2030), a five-year programme aimed at supporting the production of "high-quality, inter- and transdisciplinary, solution-oriented research on global sustainability by early career scientists in Africa" (https://council.science/what-we-do/funding-programmes/lira2030/ (accessed on 11 February 2022)). The population of Makhanda is about 70,000 people [39] The Eastern Cape province is one of the poorest provinces in South Africa, characterised by high levels of illiteracy and unemployment (33%) [40]. Owing to high levels of poverty and unemployment, over 40% of the province's population receive government social grants [40], a common characteristic in many South African towns. Consistent with many South African towns, Makhanda is characterised by some colonial-era spatial arrangements [41]. The town is divided into two main areas, the western side and the eastern side. The western side is characterised by high-income households, good educational facilities including state and private schools and a university, and good basic social amenities. The eastern side is characterised by low- to medium-income households and consists of three types of housing, namely privately built blockhouses, state-built houses, and informal houses (locally known as shacks). Like most towns in South Africa, though many low-income households are connected to the national grid, they are energy poor and insecure [18], and receive Free Basic Electricity units of 50 kWh per month.

2.2. Study Design

The study was conducted between August 2019 and June 2021. Participant households were selected from Tantyi, Joza, Pumlani, Vukani, and Fingo suburbs using a convenience sampling approach via social hubs such as churches and local societies with the assistance of local volunteers (champions). Within each participant household, household heads and, in their absence, the eldest adult member of the family with a fair understanding of electricity use practices in the household were targeted for the study. In convenience sampling, participants are selected based on location and willingness to participate in the study [42]. The limitation of this approach is that the findings cannot be generalised. However, the study acquired transferrable insights [42] which can advance our understanding of complex research questions relating to behavioural responses to varied interventions. Champions were selected to facilitate community engagements based on their positions in the communities (e.g., ward councillor, youth leader, and church leader). Prior to commencement of the project, all champions received advanced scientific training on project facilitation, data collection tools, interpretation of electricity-saving interventions, and collection of electricity consumption data. The champions were instrumental in the designing of data collection instruments by acting as conduits between the researchers and participant households, particularly in making data collection instruments reflective of and meaningful to the local context.

For an accurate estimation of the experimental effect of treatment factors (behavioural interventions), the study dealt with non-experimental factors, such as weather, that are difficult to control using multiple treatment groups experiencing the same conditions at the same time [7]. By conducting the study over two years, all four seasons of the year were considered. The coldest months in Makhanda are in austral winter months between June and July, which represent the peak period for electricity usage for heating, cooking, and entertainment as people spend more time indoors. Thus, the effects of the intervention strategies on electricity saving can be better tested during this period. The experiment had three stages.

2.2.1. Stage 1: Baseline Data

A total of 297 households selected from Tantyi, Joza, Pumlani, Vukani, and Fingo suburbs participated in the first stage of the project. Socio-demographic information of the participant households, electricity-use behaviour and electricity consumption data were collected using a household questionnaire. Following problem formulation and co-design of data collection instruments, electricity consumption data were collected between October 2019 and January 2020.

2.2.2. Stage 2: Intervention Period

Participant households were allocated into three groups: Full Treatment (FT), Partial Treatment (PT), and Control (C) through volitional choice. All households were informed by the champions about the length of the electricity-saving programme, the various activities of the project, and participants' roles in each of the treatment groups and, based on this information, households were invited to join the respective groups. The champions also used their experience of working with participant households during the problem formulation stage to measure the level of engagement and interest, which was used to allocate undecided households to treatment groups. In the second stage, 56.6% of participant households pulled out of the study for various reasons including loss of interest, research fatigue, incomplete data and work commitments. Subsequently, only 132 households (44.4%) with complete data were considered in the analysis. Electricity-saving interventions were applied for 11 months between February 2019 and December 2019. The electricity-saving tips such as switching off lights and home appliances completely when not in use, unplugging chargers from sockets, not overloading refrigerators, placing refrigerators from heat sources and boiling just enough water for coffee or tea were drafted following Eskom Demand Side Management [43] but adjusted to suit the study context. Households in the FT group received a full set of interventions, including pamphlets and stickers with co-developed electricity-saving tips, monthly discussions on the benefits of electricity saving, challenges faced in implementing the interventions and performance feedback. A workshop with all the FT households was conducted in the month of October 2020 for a reflective exercise on the usefulness of electricity-saving interventions, challenges encountered, and potential solutions. Throughout the intervention period, the champions played a key role in the learning process, including monthly visits to participant households and in facilitating small group meetings and reflective workshops. During monthly visits to participant households in the FT group, discussions facilitated by the champions centred on participant households' electricity consumption relative to previous months' consumption as a basis for encouraging electricity-saving behaviour. This approach also enabled identification and understanding of household specific barriers to electricity saving and designing appropriate responses.

Households in the PT group received pamphlets and stickers with electricity-saving information exclusively designed by the researchers. No further interventions such as monthly meetings with champions and performance feedback were applied. Participant households were asked to record their monthly electricity consumption. Households in the Control group did not receive any interventions but knew about the project. In the seventh month (September 2020) of the intervention period, households in the FT and PT groups were asked to evaluate the usefulness of the programme and electricity-saving guidelines based on their experiences.

2.2.3. Stage 3: Post-Intervention Electricity Consumption

Active application of electricity-saving interventions through discussions and feedback ended in December 2020. To test the persistent effect of interventions, electricity consumption was recorded for six months between January 2021 and June 2021 across the three treatment groups. The respondents were selected to participate based on their willingness to participate further in the study. A total of 67 households participated in the post-intervention experiment, consisting of 21, 22, and 24 households in the FT, PT, and

Control group, respectively. During the post-intervention period, the champions collected electricity consumption data only.

2.3. Measures

2.3.1. Socio-Demographic Factors

A questionnaire was used to collect the socio-demographic profile of all the participant households including gender, age, level of education, employment status, household size, number of rooms, and social grant and Free Basic Electricity status. The respondents were asked to indicate all the electric appliances they owned.

2.3.2. Electricity Consumption Data

All participant households had prepaid electricity meters. The amount of monthly electricity consumption was calculated from the reported electricity expenditure divided by the average cost (R0.58) per kWh. For households that received Free Basic Electricity, 50 kWh was added to the recorded monthly consumption.

2.3.3. Perceived Behavioural Control (PBC)

To measure PBC, the participants in the FT and PT groups were asked questions such as: "How much control do you have over reducing electricity consumption in your household?" (1 = no control, 2 = little control, 3 = neutral, 4 = some control, 5 = great control); How difficult is it for you to reduce electricity consumption in the household?" (1 = very difficult; 2 = difficult; 3 = neutral; 4 = easy; 5 = very easy); and "It is my choice whether I reduce household electricity consumption" (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree). "The amount of electricity saved is determined by family members"; "I have full control over the amount of electricity that I use"; again, these were rated on a 5-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

2.3.4. Subjective Norms

To measure subjective norms, participants were asked about their perception of the approval of the significant others on electricity saving. For example, participants were asked to respond to the question, "If I save electricity, the people significant to me would ... " (1 = completely disapprove, 2 = partially disapprove, 3 = neutral, 4 = approve, 5 = completely approve). In the second stage, the participants were asked to evaluate their perception of the significant others on electricity saving. For example, "Most people who are significant to me think that electricity saving is ... " (1 = very undesirable, 2 = undesirable, 3 = neutral, 4 = desirable, 5 = very desirable).

2.3.5. Motivation

The questionnaire measured motivation to ascertain consumer involvement with the electricity-saving interventions. The questionnaire asked questions such as, "Do you think reducing household electricity consumption is good for the environment?" (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree). To measure the effect of feedback on behaviour we asked the question, "Knowledge about your previous month's electricity savings encouraged you to implement interventions" (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

2.3.6. Ability

To capture the extent of knowledge possessed by the householders (how much householders feel they know about electricity saving) the questionnaire included questions such as "Electricity saving measures are easy to do", with responses on a 5-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

2.3.7. Intentions

The questionnaire included questions aimed at measuring the participants' intention to save electricity, including "My intention to save electricity in my home is ... " (1 = very weak, 2 = weak, 3 = neutral, 4 = strong, 5 = very strong), and "How likely are you to save electricity in your home in the next months?" (1 = very unlikely, 2 = unlikely, 3 = neutral, 4 = likely, 5 = very likely).

2.3.8. Perceived Importance of the Intervention Programme

Questions aimed at assessing perceptions on the effects of the interventions and the co-design processes (collective problem formulation and involvement) included "We have provided you with useful information about electricity reduction", with responses on a five-point Likert scale (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree). To check if co-design processes resulted in the development of a common interest and shared vision in the FT group, the FT participants were asked if they felt there was general agreement on the sustainability challenge (electricity wastage), and the benefits of collective problem solving. To gauge trust-building, the participants were asked to indicate if decision making was perceived as open and fair, and if information was shared and understood by all participants. The participants were also asked to indicate if they were informed about the project (processes, activities, and expectations), and if they felt their views and opinions were considered), with responses on a scale of 1–5 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree). The participants were also asked to provide explanations for their answers to provide meaning to their experiences of the project.

2.4. Data Analysis

Mean monthly electricity consumption per household over the intervention period (baseline, intervention, and post-intervention) was calculated. Non-parametric tests were used for statistical analyses because electricity consumption data failed normality and homogeneity of variance after Levene's tests. Comparison of electricity between and within groups, before, during, and post-intervention were conducted using the Difference-in-Difference (DID) approach following Mi et al. [7]. The basic standard of the DID estimator is to measure the actual outcome of an intervention by comparing the differences between the treatment groups and the control, before and after treatment [7]. The DID standard estimator eliminates interfering factors on the results, including primary (permanent) factors (e.g., socio-demographic factors and residential area) and secondary (dynamic) factors (e.g., changes in electricity prices and weather). The differences in reduction in electricity between months for each of the three groups were determined through Wilcoxon matched pairs tests, and the results are presented in the form of tables. Kruskal–Wallis tests were conducted to see if there were significant differences between groups. Comparisons of monthly electricity consumption between the three groups, FT and PT and Control, were performed using the Mann–Whitney U tests. The influence of socio-demographic factors on electricity consumption was examined through a generalised linear regression model. A correlation analysis was performed to examine the relationship between electricity consumption and socio-demographic and psychological factors, including personal values and subjective norms. All statistical analyses were conducted using Statistica version 14.0.

3. Results

3.1. Baseline Characteristics of Participant Households

The results showed more male representation (65%) than female (35%) across the total sample and in all the treatment groups, with the biggest proportion in the Full Treatment (FT), followed by the Control and the Partial Treatment group (PT) (Table 1). The mean age for the total sample was about 50 years, and the mean household size was 4.4 persons. The average number of rooms was roughly 4.4 across the sample. The educational level across the sample was generally low, with most of the respondents (60%) having attained secondary education only (Table 1).

Table 1. Socio-demographic features of households.

Variable	Treatment Group FT	PT	Control	Total	Kruskal–Wallis (H)/χ^2 Test
Gender (%) of participants					
Female	28	41	38	35	χ^2 = 1.83;
Male	72	59	62	65	p = 0.40
Mean age of participant	50.9 ± 16.0	48.5 ± 17.2	49.5 ± 16.7	49.8 ± 16.4	H = 0.665; p = 0.717
Mean household size	4.7 ± 2.2	4.4 ± 2.4	4 ± 1.9	4.4 ± 2.2	H = 2.583; p = 0.275
Mean number of rooms	4.6 ± 1.4	4.3 ± 1.4	4.2 ± 1.4	4.4 ± 1.4	H = 3.114; p = 0.211
Proportion (%) of households receiving social grants	92	92	73	86	χ^2 = 8.68 **; p = 0.013
Education level (%)					
No education	5	3	11	6	χ^2 = 4.89;
Primary	22	21	17	18	p = 0.56
Secondary	59	67	50	60	
Tertiary	14	9	22	16	
Mean number of people employed	0.5 ± 0.75	0.9 ± 1.18	0.8 ± 0.7	0.8 ± 0.87	H = 3.019; p = 0.221
Employment status of Participant (%)					
Full time	55	63	53	57	χ^2 = 5.70;
Part time	36	34	36	35	p = 0.68
Unemployed	9	3	9	7	
Other	-	-	2	1	
Income group (%)					
0–10,000	54	63	50	55	χ^2 = 5.47;
10,001–30,000	37	34	39	37	p = 0.71
30,000 and above	9	3	11	8	
Proportion (%) receiving Free Basic Electricity)	58	38	48	49	χ^2 = 3.53; p = 0.17
Proportion (%) of homesteads with separate units	64	57	67	63	χ^2 = 1.03; p = 0.60
Proportion (%) of houses with separate meters	51	48	39	46	χ^2 = 1.03; p = 0.60

** = $p < 0.01$ representing significant differences.

Less than a quarter of the participants had tertiary education. About 86% of the participant households across the treatment groups were recipients of social grants. A substantial proportion of the household members were not formally employed, and more than 50% of those who were employed received an income of less than ZAR 10,000 (USD 668) per annum across all the treatment groups. Moreover, a substantial proportion of households were recipients of the government's Free Basic Electricity (50 kWh/month), which is a token for supporting poor households. Generally, the socio-demographic profile of the households shows that the society under study had a relatively low standard of living.

About 63% of the participant households had separate housing units, while less than half (46%) had separate meters. Overall, there were no significant differences in socio-demographic characteristics between the treatment groups except for the proportion of households receiving social grants (Table 1). There were significantly more households that received government social grants in both the FT and PT groups (92%) than the Control (73%). Taken together, the results suggest that most household characteristics are comparable and similar between the treatment groups.

3.2. The Effects of Interventions on Electricity Consumption

The average baseline electricity consumption (before intervention) per capita was significantly higher for the Control group than for the FT and PT (Table 2). Significant differences in monthly electricity consumption before application of interventions were recorded in the months of October and November (2019) but not in December (2019) and January (2020). There were general but marginal electricity savings for the FT group and Control between February and August, following initialisation of electricity-saving interventions. The PT group showed an increase in electricity consumption (Table 2, Figure 2). In comparison, the FT group saved electricity about four and six times more than the PT and Control groups, respectively, during the last five months of active interventions (August–December 2020). While there was an expected increase in electricity consumption in the winter months of May and June, the FT group recorded the lowest rate of increase in electricity consumption. Interestingly, both the FT (2.3%) and the PT (1.26%) groups recorded electricity savings in the coldest month of July while the Control showed an increase. Overall, the FT group showed the highest electricity saving (5.45%) during the intervention period, compared to about 1% for Control and PT groups. When electricity savings were disaggregated by months, the FT group recorded the highest month-on-month increase in electricity savings, ranging from 2% in July 2020 to 22% in December 2020 (Table 2; Figure 2). The FT group also recorded savings in 9 out of 11 months compared to the PT (5) and Control (4) groups. Taken together, the findings suggest that FT group saved more electricity than the PT and Control groups.

Table 2. Mean (±SD) monthly household electricity consumption (in kWh) changes before and after interventions. Reductions (electricity saving) and increases in consumption are represented by positive and negative values (%) in brackets. Letters [a, b] represent significant differences between treatment groups.

Month/Year	Treatment Group			Kruskal–Wallis (*H*)-Test
	FT (kWh)	PT (kWh)	Control (kWh)	
October 2019	37.68 ± 13.32 [a]	31.31 ± 11.37 [a]	47.60 ± 26.42 [b]	$H = 15.359$ $p = 0.0001$ ***
November 2019	36.94 ± 14.56 [a]	30.06 ± 10.75 [a]	41.26 ± 17.71 [b]	$H = 9.730$ $p = 0.008$ **
December 2019	37.28 ± 19.59	33.93 ± 12.90	40.70 ± 21.73	$H = 1.4342$ $p = 0.488$
January 2020	34.28 ± 15.99	32.06 ± 12.29	37.77 ± 18.70	$H = 2.560$ $p = 0.278$
Average Baseline	36.55	31.84	41.83	
February 2020	35.00 ± 14.88 (4.24%)	34.58 ± 12.94 (−8.61%)	37.65 ± 17.90 (9.99%)	$H = 0.883$ $p = 0.643$
March 2020	35.7 ± 16.24 [a] (2.33%)	29.61 ± 9.43 [a] (7%)	39.60 ± 16.47 [b] (5.33%)	$H = 7.493$ $p = 0.024$ *
April 2020	35.88 ± 15.68 (1.83)	33.27 ± 10.96 (−4.49%)	40.48 ± 16.20 (3.23%)	$H = 4.579$ $p = 0.101$
May 2020	37.26 ± 17.11 (−0.47%)	34.27 ± 9.93 (−7.63%)	42.87 ± 15.69 (−2.49%)	$H = 4.203$ $p = 0.122$
June 2020	38.72 ± 20.21 (−5.93%)	34.50 ± 9.64 (−8.35%)	45.44 ± 17.81 (−8.63%)	$H = 6.531$ $p = 0.038$ *
July 2020	35.71 ± 17.65 [a] (2.30%)	31.44 ± 11.27 [a] (1.26%)	42.79 ± 19.14 [b] (−2.30%)	$H = 7.032428$ $p = 0.030$ *
August 2020	35.49 ± 17.66 (2.90%)	32.09 ± 12.66 (−0.79%)	40.59 ± 18.18 (0.57%)	$H = 4.808$ $p = 0.090$
September 2020	32.28 ± 14.17 [a] (11.68%)	29.66 ± 9.66 [a] (6.85%)	40.50 ± 19.07 [b] (2.96%)	$H = 9.116$ $p = 0.011$ **
October 2020	32.76 ± 13.84 [a] (10.37%)	31.54 ± 9.80 [a] (0.94%)	41.37 ± 17.11 [b] (1.10)	$H = 9.854$ $p = 0.007$ **

Table 2. *Cont.*

Month/Year	Treatment Group FT (kWh)	PT (kWh)	Control (kWh)	Kruskal–Wallis (*H*)-Test
November 2020	33.46± 13.60 [a] (8.45%)	31.53 10.30 [a] (0.97%)	42.02 ± 14.95 [b] (−0.45%)	$H = 11.1522$ $p = 0.004$ **
December 2020	28.41 ± 15.43 [a] (22.27%)	31.21 ± 9.35 [b] (1.98%)	40.42 ± 17.38 [b] (3.37%)	$H = 11.014$ $p = 0.004$ **
Mean electricity savings (%)	5.45	−0.98	1.15	

* = $p < 0.05$, ** = $p < 0.01$, and *** = $p < 0.001$ representing significant differences.

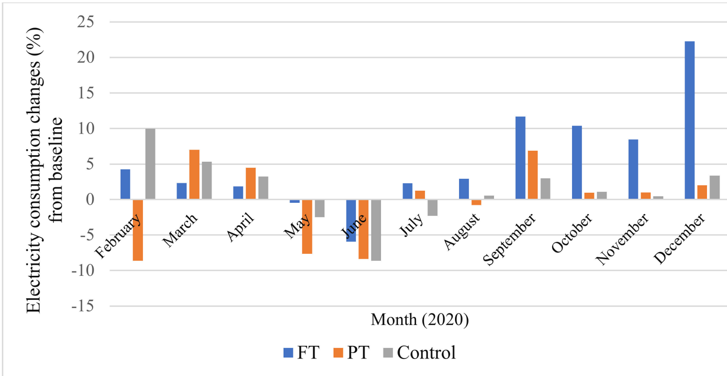

Figure 2. Household electricity consumption (kWh) changes from baseline for the Full Treatment, Partial Treatment and Control between February 2020 and December 2020.

3.3. Post-Intervention Electricity Consumption

To evaluate the persistent effects of co-designed electricity-saving interventions, the study measured monthly electricity consumption between January 2021 and June 2021 (after the intervention period) for all the three treatment groups. Significant differences in mean monthly household electricity consumption were noted between the treatment groups for all the months (Table 3). The results showed a significant reduction in electricity consumption ranging from 9.7% to 19.2% for the FT and 7% to 11% for the PT group (Table 3; Figure 3). Though both groups recorded electricity savings in the winter months of May and June, the FT group showed more savings than the PT (Table 3; Figure 3). On average, electricity savings for the FT was about twofold higher than that of the PT group over the post-intervention period. In contrast, the Control group showed a constant increase in electricity consumption of at least 10% during the same period.

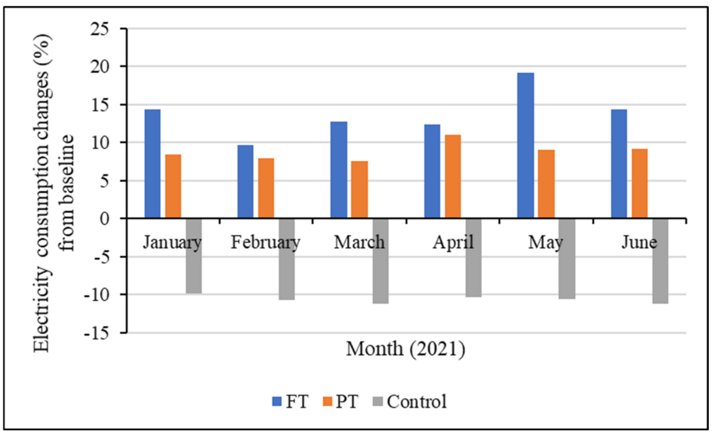

Figure 3. Household electricity consumption (kWh) changes from baseline for the Full Treatment, Partial Treatment, and Control.

Table 3. Post-intervention monthly mean electricity consumption. Electricity savings (reductions) and increases in consumption are represented by positive and negative values (%) in bracket. Letters [a, b] represent significant differences between treatment groups.

Month	Treatment Group FT	PT	Control	Kruskal–Wallis (*H*)-Test
Baseline consumption (kWh)	36.55	31.84	41.83	
January 2021	31.32 ± 13.02 [a] (14.3%)	29.17 ± 8.07 [a] (8.4%)	45.93 ± 15.72 [b] (−9.8%)	$H = 10.028$ $p = 0.007$ **
February 2021	33.02 ± 13.93 [a] (9.7%)	29.31 ± 8.45 [a] (7.9%)	46.32 ± 15.15 [b] (−10.7%)	$H = 10.749$ $p = 0.005$ **
March 2021	31.87 ± 13.98 [a] (12.8%)	29.44 ± 8.85 [a] (7.5%)	46.52 ± 15.76 [b] (−11.2%)	$H = 10.257$ $p = 0.006$ **
April 2021	32.00 ± 12.85 [a] (12.4%)	28.34 ± 10.14 [a] (11%)	46.12 ± 14.52 [b] (−10.3%)	$H = 13.242$ $p = 0.001$ ***
May 2021	29.53 ± 12.88 [a] (19.2%)	28.98 ± 8.26 [a] (9%)	46.26 ± 14.97 [b] (−10.6%)	$H = 11.851$ $p = 0.003$ **
June 2021	31.23 ± 13.30 [a] (14.3%)	28.92 ± 7.95 [a] (9.2%)	46.52± 15.21 [b] (−11.2%)	$H = 12.891$ $p = 0.002$ **
Mean (%) electricity savings between January and June 2021	13.8	8.8	−10.63	

** = $p < 0.01$ and *** = $p < 0.001$ representing significant relationship.

3.4. Factors Influencing Electricity Consumption

The results showed that household size and employment status had significant negative effects on electricity consumption, while age (6–17 years age group) and baseline electricity consumption yielded positive effects (Table 4).

Table 4. Determinants of electricity consumption for FT households.

Variable	Coef. Estimate	Std. Error	Wald. Stat.	*p*
Intercept	2.4770	0.1646	226.4229	0.000
Gender (1 = female; 0 = male)	−0.0280	0.0246	1.2895	0.256
Age of respondent	−0.0002	0.0015	0.0231	0.879
Household size	−0.0638	0.0190	11.2351	0.001 ***
Number of rooms	−0.0016	0.0151	0.0116	0.914
Employment status (1 = fulltime; 0 = Other)	−0.1343	0.0465	8.3295	0.004 **
Number of people above 65 years	−0.0679	0.0445	2.3332	0.127
Number of people between 6 to 17 years	0.0678	0.0298	5.1654	0.023 *
Baseline electricity consumption	0.0301	0.0019	229.6501	0.000 ***
Access to Basic Free Electricity (1 = Recipient; 2 = non-recipient)	−0.0290	0.0235	1.5136	0.219
Social grants (1 = Recipient; 2 = non-recipient)	−0.0012	0.0306	0.0017	0.967
Homestead has separate units	−0.0461	0.0285	2.6292	0.105

* = $p < 0.05$, ** = $p < 0.01$, and *** = $p < 0.001$ representing significant relationship.

3.5. Relationship between Electricity Saving and Socio-Psychological Variables

The results showed that all the considered factors, except for one, yielded a positive relationship with electricity-savings, though only four factors yielded significant differences (Table 5). Having feelings that views were considered, having control over one's situation, ease of implementation of electricity-saving interventions, and the intention to save electricity in the future were all significantly positively related to electricity savings.

Table 5. Spearman correlation coefficient between electricity savings and socio-psychological variables.

Socio-Psychological Variables	Valid N	Spearman R (Rho)	T(N-2)	*p*-Value
Concern				
Increased concern about the negative impacts of wasting electricity	37	0.138	0.822	0.042
Encouragement and satisfaction				
Encouragement	37	0.298	1.846	0.073
Sense of satisfaction	36	0.167	0.986	0.331
Feedback encourages	37	0.245	1.495	0.144
Involvement and trust				
You feel involved	37	0.097	0.577	0.568
Champions listen	36	0.119	0.700	0.489
My views are considered	37	0.341	2.143	0.039 *
Information is from a trusted source	37	0.127	0.759	0.453
Communities have power to control their situation	37	0.151	0.901	0.373
Subjective norms				
If I save electricity, the people significant to me would approve	36	0.231	1.390	0.174
Electricity saving is the responsibility of everyone	36	0.0164	0.096	0.924
Perceived Behaviour Control				
Having control over the situation	35	0.355	2.181	0.036 *
Ease of use of electricity-saving interventions	36	0.397	2.520	0.017 *
It is my choice whether I reduce household electricity consumption	36	0.060	0.351	0.726
Intention				
Likely to save electricity in the future	37	0.349	2.203	0.034 *

* = $p < 0.05$ representing significant relationship.

About 60% of respondents in the FT group shared electricity-saving information with household members compared to 36% in the PT group. About 82.5% of respondents in the FT group either agreed or strongly agreed that they changed their old wasteful electricity practices, compared to 57% in the PT. A slightly higher proportion of respondents in the FT (82%) than in the PT group (76%) said they were more concerned about saving electricity than before. More respondents in the FT (72%) than in the PT (47%) group reported a sense of satisfaction after implementing co-designed electricity-saving interventions. Marginal differences were recorded between the FT and PT groups regarding the motivations for electricity conservation, including saving electricity to save money and to stop power cuts. About 60% of respondents in the FT group either agreed or strongly agreed that electricity-saving measures were easy to do, compared to 36% in the PT group. Lastly, approximately 80% of participant households in the FT group said they felt involved in the electricity savings in their homes compared to 57% in the PT group.

4. Discussion

4.1. The Effects of Interventions on Electricity Consumption

The findings showed that the rate of electricity savings recorded was higher for the FT group than for the PT and Control groups. The differences in electricity savings can be attributed to the differential treatment between the FT group (which received a full package of electricity-saving information via discussions, electricity-saving stickers, and pamphlets) and the PT and Control groups who received the prescribed interventions and no interventions, respectively. The rate of electricity savings for the PT group (3%) with prescribed interventions is comparable to similar studies by Kua and Wong [5] (2%) and [38] but the electricity saving in the FT group (5%) is comparatively higher. The 11% electricity savings recorded for the FT group in the last five months of the intervention is also higher than the other two groups. The high rate of electricity conservation in the FT relative to the PT and Control can be attributed to the inclusive nature of the designing behavioural interventions. Remarkably, electricity savings increased for the FT group following a reflective workshop with participant households on the effectiveness of interventions. This implies that if users of electricity are involved not only in designing interventions but also in reflective processes on the ease and challenges of implementation, they can adjust electricity-use practices and respond to challenges. A central point in co-designing activities is providing a platform for electricity users to actively participate in decisions that directly affect them, which can engender positive attitudes towards electricity saving. Engendering positive attitudes is confirmed in this study because participant households in the FT group felt their voices were included in designing electricity-saving interventions, and that the interventions were easy to implement hence they were arguably likely to implement the interventions. Therefore, it is plausible to suggest that an inclusive approach to electricity savings employed in this study can explain the differences in savings between the three groups. These results provide a useful empirical basis for supporting principles of transdisciplinary approaches to encourage electricity conservation in households, which view users of electricity as principal stakeholders in crafting solutions needed to steer behaviour change [8,9].

Further, the 14% electricity savings recorded during the post intervention period highlights the potential persistent effects of co-designed interventions. The savings recorded in the PT group post the intervention period is also very high (8%). This can be explained by the fact that PT households still engaged with the champions post the intervention period. It might also be that participants in the PT households realised the benefits of behaviour change over time and were motivated to reduce electricity consumption. The electricity savings translate to marginal but important financial savings for households already struggling to meet daily basic needs such as food, water and electricity. These findings on the persistent effects of interventions represent a new dimension to the electricity use behaviour literature, which can advance sustainability debates. The persistent effects of interventions suggest that households felt they co-owned the interventions, consistent with the principles of co-designing on the value of collective interventions in engendering acceptance and long-lasting solutions to environmental issues [8,9]. Elsewhere, co-designed interventions have been shown to yield pro-environmental electricity use behaviour. For instance, a co-designed intervention study conducted in Monte Carlo showed average electricity savings of about 12% [44], while Cellina et al. [45] found a 20% average electricity savings among Swiss households. Though the savings recorded among Swiss households is higher than this study's savings of 14%, this must be considered in the context of our study, where most participant households are marginalised and energy poor meaning there is a limit to which they can reduce electricity consumption, beyond which their lifestyles might be adversely affected. Overall, the findings suggest that promoting environmentally friendly pathways to electricity use in households requires a culture of inclusiveness in identifying local sustainability challenges, and co-developing solutions. In the context of South Africa, calls for behaviour change approaches to addressing rolling power black outs are timely and needed, but arguably, insufficient to yield significant electricity gains if households are not part of these initiatives.

4.2. Determinants of Electricity Consumption

The generalised linear regression model showed important insights salient to our understanding of household electricity consumption. The results showed counter-intuitive results regarding the relationship between household size and electricity reduction, consistent with Huang [46]. This can be explained by the fact that bigger households might not always translate into high electricity consumption if they consist of working adult members who spend most of their daytime at work or if the household has few electrical gadgets to use. Households with employed people are likely to reduce electricity consumption possibly because they bear the costs of electricity use, hence they are bound to minimise consumption to minimise costs. This is consistent with classical economic theories. For instance, in the "labour theory of value", Kurz [47] states that the economic value of a service is determined by the effort invested in acquiring it. Huang [46] found similar trends among Taiwanese households, arguing that employed people may consume less electricity because of the limited time they spend at home and the economic costs associated with high electricity consumption.

Consistent with findings elsewhere [38,48], households with a high number of members between 6–17 years of age group were likely to consume more electricity. This might be explained by the fact that this age group often spends more time on activities that consume a lot of electricity, including watching TV overnight and gaming [38]. In an Irish case study, [43] households with children and middle-aged adults consumed more electricity because of the number of active people during the night. It could also be argued that young members of households do not incur the costs of wasteful electricity practices, hence they might have less interest in saving electricity. For example, Trotta [49] showed that UK households with people aged 24 years and below had a lower chance (13%) of engaging in electricity-saving behaviour than households with members aged 25 years and above who have up to 55% chance of doing so. Baseline electricity consumption is likely to result in high electricity consumption because of a potentially high saving threshold for high electricity consumers, beyond which lifestyles become negatively affected. Therefore, electricity saving goals should consider the effects of variability in baseline electricity consumption.

Taken together, these results imply that consideration of socio-demographic variables is very important when crafting interventions for promoting sustainable electricity use. For example, interventions that target young to middle-aged groups and the unemployed might be effective because these are the people who spend most time at home and might potentially use more electricity. Further, households who consume more electricity should be specifically targeted when designing saving goals and thresholds.

4.3. Relationship between Electricity Savings and Psychological Variables

The results showed that people who felt that their views were represented were likely to engage with the electricity-saving interventions. This suggests that involving people in interventions for sustainable electricity use is important because it can engender feelings of inclusiveness which can trigger positive attitudes needed to change behaviour. Beckman and Barry [27] found that the involvement of employees in company design resulted in employee satisfaction and willingness to act in the interest of the environment. Nevens et al. [28] found the importance of collective problem formulation and co-designing of electricity-saving in promoting positive attitudes towards electricity-saving in Dutch cities. Mauser et al. [36] also suggest that including civil societies in the discussions and crafting of interventions enables them to reflect on their ideas, which changes their attitudes positively. Thus, our findings align with the goals of transdisciplinary research, i.e., establishing relationships and shared understanding for designing interventions that are relevant to society [9,50].

Similarly, having control over one's situation yielded electricity savings in line with findings by Ru et al. [31] among Chinese households. Ajzen [24] suggests that a high perceived behavioural control boosts the intention to act positively, which results in pro-environmental behaviour. A positive correlation between the ease of implementing electricity interventions and electricity savings also implies that the structure of interventions is an important determinant of whether people will perform the desired behaviour. This is comparable to a study by Botetzagias [51] which showed that high levels perceived behavioural control resulted in high electricity savings among Greek households. Lin et al. [48] found that perceived behavioural control helps people to evaluate how much effort they will need to perform a given task and whether they should persist in doing the task in the face of difficulties. In this study, it is plausible to argue that collective problem formulation with participant household helped households in the FT group understand the sustainability challenge and interventions, and how these related to their respective contexts, which empowered them to engage actively in the project.

The results also showed a positive significant correlation between people with strong intentions to save electricity in the future and actual electricity savings. Findings by Wang et al. [52] among Beijing residents similarly showed that households with strong intentions to save electricity saved more electricity than those with weak intentions. However, behaviour intention does not always translate into behaviour [24]. For instance, in a Canadian study, Kennedy [53] found negative correlations between behavioural intentions and behaviour, implying that the influence of intentions is not absolute. A key aspect to note is the linkage between co-designed electricity-saving interventions and socio-psychological constructs needed to improve behaviour. Interventions that promote awareness of the impacts of wasteful electricity use practices, trust, agency, involvement, feeling of control, ability, concern for the environment, and good intentions may encourage and sustain environmentally friendly electricity use behaviour. Arguably, for developing countries, often faced with scarce financial resources, investing in behavioural approaches can offer cheap and sustainable pathways to sustainability.

5. Conclusions

The study investigated the effectiveness of co-designed interventions on electricity consumption among low-income households. Overall, the results advance our understanding of the effects of behavioural interventions in promoting electricity conservation in households. In particular, the results highlight the importance of active involvement of electricity users in designing interventions, including problem formulation, drafting of interventions, and reflective activities on the experiences of implementing interventions in engendering a sense of inclusion, trust, and having control over one's situation needed for triggering the intention to save electricity. These findings also imply that users make conscious decisions to realise electricity savings, and the extent to which such savings are realised depends on the constraints and opportunities surrounding daily household consumption. The insights from this work are important but are based on a single study hence they are insufficient to leverage responsiveness from policy makers and related practitioners. Therefore, there is a need for further empirical studies on the subject to allow generalisations and conclusive judgements on the effects of co-designed interventions on promoting electricity conservation in households.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of Rhodes University (Review Reference Number 2019-0720-730—23 September 2019) for studies involving humans.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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