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Evaluating the Effectiveness of Residential Water Efficiency Initiatives in England: Influencing Factors and Policy Implications

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Abstract

Providers of municipal water supply services worldwide are facing pressure from climate change and increasing water demand due to growing populations and lifestyle changes. With finite global freshwater supplies, there is need for water service providers to consider water demand management as an option for closing the supply-demand gap. Several water utilities in the UK are implementing residential water efficiency initiatives, but to-date, the effectiveness of these programmes have not been comprehensively evaluated. The present study uses statistical analysis to evaluate the effectiveness of a domestic water efficiency programme, initiated by a major water supply company in South East England. Using multilevel regression, water consumption, weather and demographic data, the study analysed water savings achieved through the efficiency programme and defined the factors that affect a household's potential to save water. Analysis showed that households that participated in the programme reduced their per capita consumption by approximately 15%. Importantly, research findings provide strong evidence that single resident and financially stretched households have a bigger potential to conserve water than wealthier and larger households do. This study also highlights the robustness of multilevel analysis, even in cases of data limitations. The findings generate implications for policy and practice, which are useful for water companies involved in implementing water efficiency programmes, as well as their evaluation.

Keywords Demand management · Household water use · Multilevel models · Water conservation · Water efficiency

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1 Introduction

Global freshwater supplies may be adequate to meet global demand for the near future – however, the world's freshwater is poorly distributed across countries, within countries and between seasons while global population and therefore demand for safe potable water is rising rapidly (Kayaga et al. 2007; Emenike et al. 2017). For instance, the Eastern and South Eastern parts of the United Kingdom are highly populated regions where annual rainfall levels are significantly lower than the national average, hence they are experiencing a significant deficiency in water resources in the immediate and long term. In such cases, the traditional way of fulfilling the growing demand-supply gap by only exploiting new freshwater resources and investing in the expansion of infrastructure is no longer environmentally sustainable or economically viable. During drought periods, water providers usually impose temporary use bans on external water uses and promote water saving practices at the household level (Water UK 2016; Manouseli et al. 2018) and increasingly, they are exploring water demand management to reduce water stress (Arup 2015).

The corporatisation of the UK water industry led two of its regulatory authorities, the Office of Water Services (Ofwat) and the UK Environment Agency (EA 2015) to establish procedures to make sure that water utilities manage demand as well as supply. In response, several water companies in the UK have taken major steps towards residential water efficiency by installing smart water meters and launching information campaigns in an effort to promote more water efficient behaviours (Watson 2017), but also by limiting leakage levels, and promoting installation of water-saving devices and fixtures at the customers' homes. Conservation is a concept that consumers seem to embrace in general, but agreement over certain water conservation practices such as price increases, can prove to be very difficult to accomplish (Randolph and Troy 2008). Applying non-price water demand management measures in the domestic sector (public information and school education programs, retrofit and permanent or temporary ordinances) has been characterized as a 'low regret' option (Parker 2013).

Pilot efficiency initiatives are being launched in the UK since the past decade. However, literature on water demand management programmes evaluation is limited, especially in the UK. As a result, little information is publicly available as to the magnitude of water savings that were achieved in the context of each water efficiency initiative and the need for establishing a robust water savings evaluation framework is imperative. On the other hand, the lack of results points out that it is often hard and costly to gather the large amount of different data needed to complete robust programme evaluation.

This paper contributes to addressing this gap by applying multilevel regression analysis to evaluate the effectiveness of a domestic water efficiency programme, initiated by a UK water company. It further quantifies the effect of social status and household size on the achieved water savings, enabling more detailed policy recommendations.

2 Literature Review

2.1 Factors of Influence to Domestic Demand

Researchers (Gaudin 2006; Foster 2011) suggest that per capita consumption (pcc) decreases with an increase in household size. Most studies indicate that there are some economies of scale with many residents in a house, where food preparation, dishwashing, gardening and other activities take place regardless of household size and are capitalized on a shared living environment (Foster 2011; Willis et al. 2013). However, these economies of scale diminish, thus causing pcc to be less than proportional to household size beyond a household size threshold. Moreover, as far as water-conserving habits are concerned, research by Gilg and Barr (2006) showed that households of fewer residents are more likely than the rest to be committed environmentalists; therefore, they are more likely to achieve larger water savings. Similarly, Sadr et al. (2015) found that the increasing number of small family households and of people living alone aggravates the inefficient use problem.

The effects of household income on user demand have also been explored (Mieno and Braden 2011; Ahmad et al. 2016) and despite the climatic variations across the UK, urban water demand appears to be mainly a function of income, which influences the acquisition of water-using goods and household composition (Clarke et al. 1997). However, data on household income are not usually readily available for UK water systems. Geodemographic systems are commonly used in the UK domestic demand literature instead. One of these is Acorn (A Classification Of Residential Neighborhoods), which was developed in the UK and it has been used as a proxy variable for income and social status in several UK studies. It ranges from class 1 (Affluent Achievers) to class 5 (Urban Adversity).

Water demand appears to be linked to water use habits and attitudes towards conservation (Syme et al. 2004; Willis et al. 2011; Hoolohan and Browne 2016). Lam (2006) found that beliefs about how neighbours would act on water conservation had a positive effect on water saving intentions. However, there is not enough evidence of whether conservation intentions translate into actions (Fielding et al. 2012).

2.2 Evaluation of Domestic Water Efficiency Programmes

In most cases, efficiency initiatives in the UK are set up without accounting for each population's characteristics and habits, rather they are formed based on an average consumer. As Medd and Shove (2006) point out, there should be a move away from analysis that is based on averages and a shift towards disaggregated analysis, so that the dynamics of real-life demand can be understood. Detailed information on local residential consumption is essential for the appropriate implementation of such programmes and for achieving larger water savings. Specifically, water companies usually do not investigate the effect that their water efficiency programmes had in households of different characteristics although this information would provide useful insights on the local population's water use. Also, such data would be invaluable for future water efficiency initiatives as they would set the right direction for effective implementation on suitable population samples, thus potentially enabling larger water savings.

Technological changes such as retrofit programmes and other non-price policies have gained little research attention, mainly because of the lack of adequate data (Millock and Nauges 2010). Australia, a country in great danger of water scarcity, is the leader in the implementation of residential non-price water efficiency programmes (Lindsay et al. 2017). Even in the case of Australian research, the publicly available information about achieved water savings is limited. In most instances, research relies on engineering assumptions of the expected demand reductions (Kenney et al. 2008). Furthermore, there is no thorough and robust evaluation framework for water conservation programmes yet and as Jorgensen et al. (2009) point out, the theoretical underpinnings of evaluation attempts are mainly adopted from theories of environmental and consumer behaviour developed in non-water contexts such as household energy conservation and consumption of private goods.

Renwick and Green (2000) show that stringent mandatory non-price efforts were more successful in reducing residential demand than voluntary measures in urban California; but further research is needed to study the impact of each single demand reduction initiative on overall demand reduction. Kenney et al. (2008) showed that water saving devices installed in homes in Colorado reduced consumption by 10%. In California, Renwick and Archibald (1998) used a six year panel dataset to assess the influence of different demand side management policies. Water allocation reduced consumption by 28.2% while irrigation restrictions reduced it by 16%. The authors suggest that to achieve the required demand decrease efficiently, regional demand should be disaggregated based on the specific characteristics of a community. Mayer et al. (2003) explored the relationship between retrofit programmes and indoor water demand and concluded that the biggest potential for water conservation resulted from the retrofit of toilets and washing machines. Showing similar results, in New Mexico, Price et al. (2014) observed large reductions in water use (controlling for weather conditions and water price) after installing low flow toilets and efficient washing machines in 43,000 and 19,000 homes in Albuquerque respectively.

Some researchers warn that ‘offsetting behaviour’ can negate conservation efforts by altering the effectiveness of a water saving devices. ‘Offsetting behaviour’ is a situation where residents know that water-conserving devices are in place and end up using more water than usual (Campbell et al. 2004). Hills et al. (2002) revealed that voluntary participation, the awareness of being monitored and lack of representative samples negatively influences the assessment.

In Arizona, Campbell et al. (2004) found that regulation forcing the installation of efficiency products resulted in a 3.5% demand reduction. However, in the case of free water saving kits distributed to people’s homes, demand appeared to increase, indicating a possible rebound effect. Stewart et al. (2012) showed that although beeping shower display monitors initially reduced a shower’s duration by almost 30%, shower use returned to pre-installation levels after 4 mo.

The study of Lee et al. (2011) is among the few ones that evaluate water savings from each water efficiency programme individually. They assessed the effectiveness of three programmes in Florida, which involved the use of efficient showers, toilets and clothes washers. Although no significant change in consumption was observed for the first year of the programme’s implementation, there were substantial savings for the second and third year (15.6% for a toilets retrofit programme). For a high efficiency washing machines programme and a high efficiency showerheads programme, savings were 14.2% and 8.2% for the second year respectively. Fyfe et al. (2009) documented savings of between 8.5 and 12.4 KL/hh/yr. for a showerhead exchange initiative in Melbourne while Turner et al. (2012) observed approximately the same savings for another showerhead exchange programme and savings of approximately 20 KL/hh/yr. for a toilet retrofit programme.

Tsai et al. (2011) showed that weather-sensitive irrigation controller switches reduced the variability of water use among domestic participants, mainly via reducing demand of the highest water users. On the other hand, reduction in water use caused by rainwater harvesting could not be discerned while audits and appliance rebates programmes showed statistically significant but modest reductions in consumption.

In an experimental study in Australia, three methods for residential water conservation were trialed: instructions on how to save water in the household, descriptive norms and water end-use feedback. All measures were effective in reducing demand, even under abundant rainfall conditions (Fielding et al. 2012). However, demand returned to pre-intervention levels a year after the implementation, suggesting that long-term effectiveness of such voluntary programmes might depend on continued implementation of conservation strategies.

Polebitski and Palmer (2010) used a 12-year panel dataset on the census tract level developing three regression models (pooled, fixed and random effects), establishing that demand within small spatial resolutions can be accurately predicted using these methods. Their research also showed that mandatory and voluntary water curtailments (without water pricing components) were effective in decreasing pcc by 27% and 12% respectively and that as income, lot size and household size increase, the effectiveness of the measures decreases.

Research by Kemmelmeier et al. (2002) demonstrated that wealthier and educated consumers were more likely to adopt water saving habits, mainly because they could afford buying more efficient devices. Income has been used in a plethora of water conservation studies (e.g. Tinker et al. 2005; Harlan et al. 2009) pointing out that sometimes the effect of high income outweighs the effect of water conserving appliances. Thus, household conservation programmes should be best targeted to lower income homes, as they are more likely to produce much bigger savings, provided that the demand management strategies are offered free-of charge (Inman and Jeffrey 2006; Manouseli et al. 2017).

Over the past 20 years, UK water companies have embarked on several domestic water efficiency projects and trials. Anglian Water's WEM Trial in 2007 involved free water audits and installation of water efficient devices. The participants completed a questionnaire, providing water use and demographic information. However, the 90% confidence intervals resulting from t-tests showed that there was between a 50% reduction and a 21% increase in water use - a very broad band of savings. The use of a control group was not feasible for this study. A more recent project carried out by Anglian Water, called 'Love every drop' which involved free household water audits and retrofits between 2013 and 2015, is reported to have saved approximately 9.9 l/hh/d (Ashton et al. 2015). Savings calculations incorporated before-after tests and control groups. Severn Trent's (STW) Residential Efficiency trial in 2007, involved installing dual-flush conversion and cistern displacement devices and tap inserts in 717 metered properties that volunteered to participate. No control group was used; therefore, external influencing factors could not be excluded. According to Waterwise (2010), 65% of the participating properties reduced their consumption after the trial. However, the exact proportion of demand reduction that can be attributed to the trial itself could not be accurately measured.

3 Research Objectives and Methodology

The overall aim of the study was to evaluate the effectiveness of residential water efficiency initiatives in South East England. The specific objectives were:

- Identify the factors that influence domestic single-family water demand
- Determine the water savings attributed to the efficiency programme and explore the causal relationships among achieved water savings and household specific characteristics.
- Explore the implications of the research findings.

3.1 Study Area

Although the misconceived belief that the UK is a wet country is very common, parts of the South East experience the lowest levels of rainfall across the country and face increased risk of droughts. According to UK's Met Office, some parts of East Anglia and Essex are classified as semi-arid (less than 600 mm of rain every year) while southern and south-eastern England are the warmest areas in the UK. This study focuses on a residential water efficiency programme, launched by Essex & Suffolk Water (ESW), which provides water services to customers in Essex and Suffolk, England. This area's water stress is projected to be further aggravated in the near future due to expected population growth. In the light of these challenges, the company is continuing to deliver industry-leading demand management projects and maintaining one of the lowest leakage levels in the UK water industry (60.9 Ml/day in 2015).

3.2 Data Sets

3.2.1 Background to the H_2eco Project

The H_2eco project (Essex and Suffolk Water 2018) is one of the largest ongoing household water efficiency initiatives in the UK. The project, which was launched in 2007 in South Essex, involves home visits by a plumber who installed a wide range of water saving products to both metered and un-metered residential customers. Since the programme's inception, 22,511 full retrofit efficiency audits have been undertaken and around 106,000 products are fitted including dual flush retrofit devices, tap inserts, aerated showerheads and rainwater harvesting tanks. Each participating property received up to £110 worth of products. The programme also aims to engage customers by offering advice on how to save water, in order to promote long-term savings. The data collected and analysed in the context of the present research were part of the H_2eco initiative.

3.2.2 Water Consumption and Demographic Data

Single-family six-monthly water consumption records over a period of 10 years (2005–2015) were received from ESW for a sample of 601 households that took part in the H_2eco project. All households were located in Basildon, Essex. The sample was reduced to 451 households after omitting the 150 properties that had a meter exchanged or a change in occupancy during these 10 years. The households used in this analysis volunteered for a free efficiency audit and a water use questionnaire was filled by the head of household. Survey questions included information on household size and Acorn class, water use habits and the number of water using appliances in the household. Household size and Acorn class were the demographic variables used in this analysis. Additionally, the water company provided the programme take up dates for each household. It is important to note that data used this study were not collected by the researchers themselves – they were already collected by the water company in the context of their normal data collection procedures and as supplementary data to their implemented water efficiency programmes. Flats were omitted from the datasets. The reason behind this exclusion is the common water meter that many flats usually have, which does not allow each family's consumption to be distinguished.

3.2.3 Climate Data

Weather data were derived from the Met Office archives, the UK's national weather service. Maximum Temperature and number of days having more than 1 mm of rain for six-monthly periods for 2005 until 2015 were manually extracted from the Met Office website. The regional records for Southeast England were used, as all participating households are located in Basildon, Essex.

3.3 Data Analysis

3.3.1 Multilevel Models

Multilevel regression models were employed since they have been designed to account for the statistical dependence among sequential observations in the same group (i.e. consecutive six-monthly household consumption records). They are an extension of regression and their difference lies in the fact that parameters can be allowed to vary. Multilevel models can also ignore the assumption of homogeneity of regression slopes; they can handle missing data with greater ease than other statistical procedures; and they make use of data for each observation or time point, increasing the power of analysis (Field et al. 2012). In the context of this study, they provide the opportunity to make use of both time varying (i.e. climate variables and efficiency programme dummy) and time invariant variables (i.e. Acorn class and household size) in the same analysis, outperforming classical regression methods in predictive accuracy (Gelman 2006).

Five separate models were constructed. The first model incorporates the whole sample of households. The second and third ones employ clustering by Acorn class while the fourth and the fifth model use clustering by household size. They were formed so that the relationships among demographics and the efficiency programme effect could be explored in depth. The dependent variable in all models is daily pcc. The conceptual multilevel model is:

$$Yit = \beta 0 + \beta 1Xit, 1 + \cdots + \beta mXit, m + \beta + 1Xi, 1 + \cdots + \beta m + nXi, n + \mu i + \varepsilon it \quad (1)$$

where Y_i is the daily per capita consumption (l/c/d) on the household level and i is the index to identify each subject, t is the time period (six-months), $X_{it,\ 1}$,..., $X_{it,\ m}$ are a group of time-dependent explanatory variables (weather variables and the efficiency programme dummy), $X_{i,\ 1}$,…, $X_{i,\ n}$ are a set of time-invariant variables (demographic variables), β_0, $\beta_1 \ldots \beta_{m+1}$ are parameters indicating the fixed effects of the explanatory variables on Y_{it}, μ_i is a subject (household) specific term representing unobserved time-invariant random effects and ε_{it} is the remaining non-explained variance of Y_{it}, which is both subject specific and time-variant. $\mu_i \sim N\left(0, \sigma_\mu^2\right) + \varepsilon_{it} \sim N(0, \sigma^2)$ is the error term of Eq. (1).

The first model that was developed was an unconditional means (empty) model which is equal to a one-way analysis of variance (ANOVA), followed by a step-by-step addition of fixed effects. The fixed effects components include weather and household demographic variables as well as a dummy variable representing the water efficiency programme (takes the value of either 0 or 1 to indicate the before and after programme launch period respectively for each household). Finally, several interactions between variables of interest were added to the models, completing the formation of a two-level model with cross-scale interactions (Table 1). Random effects were not included as significant heterogeneity in the slopes for the two weather variables was not found. The level-1 unit of analysis are the separate consumption observations in time whereas the level-2 unit under which level-1 units are nested is the household.

Consumption records that were identified as extreme outliers using boxplots were removed from the sample and weather variables as well as the independent variable (pcc) were transformed to the natural logarithm so that the assumption of normality is met. Presence of heteroscedasticity and correlations between errors were not found in the dataset.

4 Results

4.1 Descriptive Statistics

More than 60% of the households in the sample belong to Acorn classes 3 to 5 (Comfortable Communities, Financially Stretched and Urban Adversity). This fact depicts the prevalence of middle to lower income residents in the sample of participants. Almost 70% of the households have one or two residents and only 86 out of 475 households have four or more people. Seven water saving devices were installed in each home on average. Average consumption was 300.6 l/hh/d before and reduced to 260 l/hh/d after programme launch as illustrated in Fig. 1.

The fact that the amount of rain gradually increased throughout the period can be the reason for the consumption decrease observed throughout the study period (see Fig. 1). It is also evident that consumption demonstrated a rapid decline after the first half of 2011. This is also the time point when the water conservation programme was initiated thus there is a strong sign that the initiative was successful in reducing water consumption. These trends are explored further in analyses presented the following sections.

4.2 Models for the Whole Sample of Participants

Table 1 shows results of the multilevel analysis conducted. The empty model was run first to investigate the proportion of the time independent variance in water demand attributed to the households. The Interclass Correlation Coefficient was 0.695 ($p < 0.001$) indicating that 69.5% of the variance in water consumption can be attributed to the between household factors and 30.5% to variations within households over time.

The first variables we entered in the model were the weather related ones, the level-1 variables. The natural logarithm (ln) of the number of days of more than 1 mm rain per half year and the maximum temperature were selected as they appeared to have a more significant effect on water consumption than other weather variables. Also, it was possible for both of them to be used in the model, as the relationship between them appeared to be weak, with a correlation coefficient of −0.314. At level-2, the dummy variable for the water efficiency programme (*Intervention*), Acorn class, the number of residents per house (*Occupants*) and the number of water saving devices installed were included in the model. Interactions between variables were also explored.

The intercept was 4.90 in the Full model, indicating the mean daily logged pcc, taking into account all the independent variables and interactions. This value equates to 134.3 L [*exp* (*4.90*)] per person per day.

Table 1 Model coefficients from multilevel analysis

	1. Unconditional Means Model	2. Level-1 fixed	3. Level-2 fixed	4. Level-2 fixed (incl. intervention)	5. Full model (incl. interactions)
Intercept	4.777	4.78	4.879	4.945	4.90
Ln-Raindays	–	−0.235***	−0.2355***	−0.032*	−0.033*
Ln-Tmax	–	0.268***	0.268***	0.031**	0.067**
Intervention	–	–	–	−0.159***	−0.056***
Acorn	–	–	−0.031**	−0.031**	−0.017
Occupants	–	–	−0.090***	−0.091***	−0.109***
Number-of-devices	–	–	0.0015	0.0001	0.009
Intervention*Occupants	–	–	–	–	0.044***
Intervention*Acorn	–	–	–	–	−0.032***
Intervention*Number-of-devices	–	–	–	–	−0.023***
Log-Tmax*Occupants	–	–	–	–	−0.058**

*$p < 0.1$. **$p < 0.05$, ***$p < 0.001$, Number of Households = 451

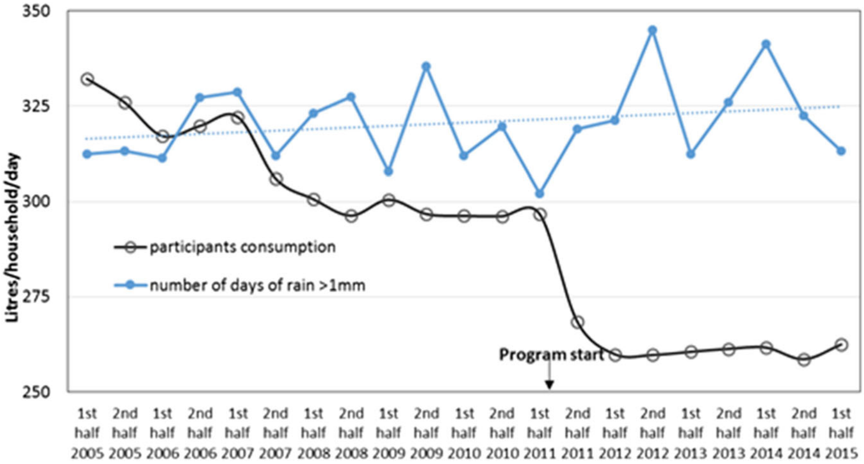

Fig. 1 Participants consumption trends and number of rainy days of more than 1 mm

As seen in Table 1 -Model 4, a 10% increase in maximum Temperature is associated with a 0.30% increase in pcc[1] ($p < 0.05$) while a 10% increase in days with rain of more than 1 mm can lead to a 0.33% decrease in pcc ($p < 0.1$). After the programme launch there was a 14.7%[2] ($p < 0.001$) decrease in consumption. Using the *intervals ()* function from the *nlme* package in R software, confidence intervals were obtained for the coefficient of the *Intervention*: [−0.171;-0.149] which translate to a range from 13.8% to 15.7% consumption decrease ($p < 0.001$).

As far as the consumption of separate Acorn classes is concerned, the model shows that moving from Acorn class 1 to Acorn class 5, pcc decreases by 3% ($p < 0.05$). In other words, an average resident of a class 1 household consumes 3% more water than an average class 5 household. In the case of number of people in the household, model 4 demonstrates that an average occupant of a household of five members consumes 8.7% less water than an average occupant who lives alone.

The interaction of the *Intervention* with *Occupants* was positive and highly significant ($p < 0.001$), showing that in households with more occupants, the water efficiency programme was less effective, as the consumption decrease that was caused by the devices became smaller. Also, the interaction of the *Intervention* with *Acorn* was negative and highly significant ($p < 0.001$). This shows that moving from Acorn class 1 to Acorn class 5, the installation of water saving devices was more effective in reducing consumption. A possible explanation for this finding is that households of higher Acorn classes are usually smaller than class 1 households and with less water consuming appliances and fixtures. Thus, if roughly the same number of water conserving devices were installed in all households, they would cover a larger proportion of water using appliances in smaller properties, making the efficiency programme more effective.

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[1] This coefficient x, as well as the remaining interpretations of x in the form: $\log(Y_1) = \beta_0 + \log(x_1)$, are calculated as: A 10% change in x_1, changes Y_1 by $(1.1^{\beta_0}–1)*100$. In the particular example, this gives: $(1.1^{0.031}–1)*100 = 0.0030*100 = 0.30$.

[2] This coefficient x, as well as the remaining interpretations of x in the form: $\log(Y_1) = \beta_0 + \beta_1 (x_1)$, are calculated as: A 1-unit change in x_1, changes Y_1 by $[\exp(\beta_1)-1]\%$. In the particular example this gives: $[\exp(-0.159)-1] = -0.147 = -14.7\%$

As shown in Table 1, the interaction of the *Intervention* with the *numberofdevices* was negative and highly significant ($p < 0.001$). Not surprisingly, this finding shows that the more water conserving devices were installed in a household the more effective the efficiency programme was in decreasing pcc. Similarly, the interaction of the lnTmax with *Occupants* was negative and significant ($p < 0.05$) showing that during periods of high temperature, a person would consume much more water than usual if he/she lives alone than if he/she lives with other people.

Multicollinearity was assessed by calculating the variance inflation factors (VIFs) of the independent variables. All VIFs were under 2.4 thus it can be assumed that there is no multicollinearity problem in the dataset (Fox 2008).

4.3 Models for Separate Acorn Classes

Using the same model structure as in the aggregated multilevel model described in Section 5.2, separate models were built for groups of households of the same Acorn classes in order to clearly observe differences between groups (Tables 2 and 3).

As seen in Tables 2 and 3, a 10% increase in maximum Temperature is associated with a 1.4% increase in pcc ($p < 0.05$) for Acorn classes 1&2 and with a 0.28% for classes 5 and 6 (non-significant result). We can conclude that after the programme launch there was a 19.7% decrease in pcc for classes 4 and 5, a value greater than that of the aggregated model and an 11.8% decrease for classes 1 and 2, a value lower than that of the aggregated model. This finding further demonstrates that the programme was much more effective for higher Acorn classes (less affluent households).

The interaction of the *Intervention* with *Occupants* was positive and highly significant for both groups of Acorn classes ($p < 0.001$) showing that in households with more occupants, the water efficiency programme was less effective. This effect is slightly stronger for classes 1 and 2. The interaction of the *Intervention* with the *Numberofdevices* was negative and highly significant ($p < 0.001$), as in the previous models. The interaction of the *logTmax* with the *Occupants* was negative and significant for classes 1 and 2 ($p < 0.05$), but insignificant for classes 4 and 5.

4.4 Models for Separate Household Sizes

Separate models were built for groups of households with the same number of residents in order to clearly observe differences between groups. Tables 4 and 5.

A 10% increase in maximum Temperature is associated with a 1.33% increase in pcc for one-person households ($p < 0.05$) while the coefficient for households of three or more people was insignificant. A 10% increase in days with rain of more than 1 mm could lead to a 0.34% (ns) and 0.65% decrease ($p < 0.05$) in pcc respectively – with the coefficient for households of a single resident being insignificant. We can conclude that after the programme launch there was an impressive 20.2% decrease in pcc for one person homes, a value greater than that of the aggregated model and a 10.8% decrease for households of three or more residents, a value lower than that of the aggregated model.

As far as the pcc of separate Acorn classes is concerned, the model for one-person households shows that moving from Acorn class 1 to Acorn class 5, pcc decreases by 3.8% (ns) while in households of more than three consumption decreases by 2.7% ($p < 0.1$). This

Table 2 Coefficients for multilevel models of Acorn classes 1 and 2 households

	1. Unconditional Means Model	2. Level-1 fixed	3. Level-2 fixed	4. Level-2 fixed (incl. intervention term)	5. Full model (incl. interactions)
Intercept	4.86	4.867	4.867	5.096	4.916
Ln.raindays	–	−0.197***	−0.197***	−0.039	−0.04
Ln.Tmax	–	0.297***	0.297***	0.144**	0.148**
Intervention	–	–	–	−0.126***	−0.125***
Occupants	–	–	−0.103***	−0.103***	−0.126***
Numberofdevices			−0.024**	−0.025**	−0.018*
Intervention*Occupants	–	–	–	–	0.057***
Intervention*Numberofdevices	–	–	–	–	−0.018***
LogTmax*Occupants	–	–	–	–	−0.07*

*p < 0.1, $^{**}p < 0.05$, $^{***}p < 0.001$, Number of Households = 143

Table 3 Coefficients for multilevel models of Acorn classes 4 and 5 households

	1. Unconditional Means Model	2. Level–1 fixed	3. Level-2 fixed	4. Level-2 fixed (incl. intervention term)	5. Full model (incl. interactions)
Intercept	4.743	4.744	4.744	4.763	4.834
Ln.graindays	–	−0.304***	−0.305***	−0.021	−0.021
Ln.Tmax	–	0.262***	0.263***	−0.028	−0.029
Intervention	–	–	–	−0.219***	−0.216***
Occupants	–	–	−0.101***	−0.103***	−0.119***
Numberofdevices			0.0127	0.011	0.024**
Intervention *Occupants	–	–	–	–	0.042***
Intervention*Numberofdevices	–	–	–	–	−0.032***
LnTmax*Occupants	–	–	–	–	−0.048

*p < 0 **p < 0.05, ***p < 0.001, Number of Households = 190

Table 4 Coefficients for multilevel models of households with a single resident

	Unconditional Means Model	Level-1 fixed	Level-2 fixed	Level-2 fixed (incl. intervention term)	Full model (incl. interactions)
Intercept	4.873	4.878	5.02	4.95	5.057
Ln.raindays	–	−0.325***	−0.325***	−0.034	−0.038
Ln.Tmax	–	0.418***	0.417***	0.133*	0.13*
Intervention	–	–	–	−0.226***	−0.108**
Acorn	–	–	−0.04	−0.038	−0.026
Numberofdevices	–	–	0.031	0.027	0.047**
Intervention*Acorn	–	–	–	–	−0.032***
Intervention*Numberofdevices	–	–	–	–	−0.045***

*$p < 0.1$, **$p < 0.05$, ***$p < 0.001$, Number of Households = 110

Table 5 Coefficients for multilevel models of households with three or more residents

	Unconditional Means Model	Level-1 fixed	Level-2 fixed	Level-2 fixed (incl. Intervention term)	Full model (incl. interactions)
Intercept	4.647	4.648	4.738	4.839	4.735
Ln.graindays	–	−0.210***	−0.210***	−0.065**	−0.067**
Ln.Tmax	–	0.147**	0.147**	0.002	−0.0005
Intervention	–	–	–	−0.114***	0.006
Acorn	–	–	−0.027*	−0.027*	−0.013
Numbercfdevices			−0.006	−0.007	−0.002
Intervention*Acorn	–	–	–	–	−0.035***
Intervention*Numberafdevices	–	–	–	–	−0.012***

**$p < 0.05$, ***$p < 0.001$, Number of Households = 142 finding suggests that a person who lives with two or more people in an Acorn class 1 household consumes 2.7% more water than an average Acorn class 5 household resident who lives with two or more people.

The interaction of the *Intervention* with *Acorn* was negative and highly significant ($p < 0.001$) and the coefficient was in the same range for both groups. This means that the installation of water saving devices is more effective in reducing pcc in Acorn class 5 homes than in class 1. This effect is slightly stronger for one-person households.

5 Discussion

In line with past research, which in its larger extent found climate variables to be significant but of low magnitude (Gato et al. 2007; Martins and Fortunato 2007; Mieno and Braden 2011), pcc was shown to be relatively insensitive to weather changes. However, a few researchers such as Gato et al. (2007) point out that there are weather thresholds under/over which consumption is not affected by weather factors.

In this study, it was also possible to examine the effects of weather on separate Acorn classes and household sizes. Based on the results we cannot conclude that there is a significant difference in the way consumption of separate Acorn classes is affected by the weather. However, there are indications that Acorn classes 1 and 2 are more sensitive to maximum Temperature in particular. As for household size, it can be inferred that pcc of people living alone is slightly more sensitive to weather than of those living with two or more people.

In this study, the difference between Acorn class 1 and 5 in terms of pcc was 3.1%. Although the Acorn class coefficient was small, the effect of the variable was highly significant ($p < 0.05$), indicating that more affluent residents consume more water than the financially stretched ones. The most likely explanation for this is that richer homes usually contain more water amenities, both indoors and outdoors and that due to their level of affluence, they might be less concerned about their water bill. This finding is also supported by relevant research which shows that suburban affluent homes use more water than other household types (Kowalski and Marshallsay 2005; Harlan et al. 2009). As Domene and Sauri (2006) point out, the effect of income and social status is more prevalent in the households that have gardens and therefore where outdoor water use exists.

The effect of Acorn class was also explored in terms of the water savings that each category achieved due to the efficiency programmes. Apparently, the more financially stretched households reduced their consumption at a larger extent because of the efficiency programme while the most affluent ones showed the least water savings. After conducting further multilevel analysis clustered by Acorn groups, it was shown that Acorn classes 1 and 2 properties decreased their pcc by 11.8% while classes 4 and 5 presented an impressive 19.7% average decrease.

An average occupant of a household of five members consumed 8.7% less water than an average occupant who lives alone, a finding that agrees with previous research, which has demonstrated that pcc decreases with household size (Gaudin 2006; Foster 2011). Results also illustrate that in households with more occupants, the water efficiency programme was less effective in reducing pcc. Specifically, it was shown that after the programme launch there was a 20.2% decrease in consumption for one-person households, reducing to a 10.8% decrease for households of three or more. It is possible that the-one-to-one engagement with the plumber during the home visit has a quite significant impact in encouraging behavior change in one-person households and that this effect becomes weaker as the messages are shared less and less in larger household sizes.

6 Conclusions

This study has contributed to the existing water efficiency literature in several ways. Firstly, dissemination of detailed findings related to implemented water efficiency programmes internationally is very rare – however it is essential for the establishment of a robust water savings evaluation framework. Water use savings that were explicitly attributed to the water efficiency programme in the present case study provide sufficient evidence that devices and appliances retrofits are effective in reducing water demand. This evidence can be used to strengthen the application of such initiatives and to encourage more extensive use of water saving devices at home, so that future programmes yield sufficient results. Sample segregation based on demographic characteristics such as social status was incorporated in the multilevel analysis, producing significant relationships among water saved through water efficiency programmes and Acorn class (social status proxy). To the best of our knowledge, no other studies have investigated the impact of social status on water savings using multilevel modelling within the UK and Europe.

Results suggest that the water efficiency programmes were more effective in reducing pcc in financially stretched and smaller households. Hence, water utility managers may wish to consider intensifying their demand management efforts in Acorn classes 4 and 5 and one-person households as they would probably achieve much greater water savings. It is highly recommended that future educational programmes and awareness campaigns in conjunction with retrofit programmes be targeted to the aforementioned types of households. Further to this, water companies are advised to invest in high frequency water use metering, as water demand studies would benefit tremendously from high quality daily consumption records or data on separate end-uses (micro components). In contrast to older research that critiques the use of population classification systems such as Acorn categorization as for their representativeness (Clarke et al. 1997; Maksimovic et al. 2003), the present research points out that Acorn class can be used as a proxy variable for income and social status, in agreement with research by Kowalski and Marshallsay (2005) and Lawson (2015).

An important finding is the potential that multilevel regression demonstrated in determining water savings without the need for a control sample of households while at the same time controlling for other influential variables such as the weather. It should be acknowledged though that multilevel statistical analysis is much more complex in its implementation and in the interpretation of the produced coefficients than simple ordinary squares regression.

Interestingly, the water efficiency programme appeared to be less effective in reducing pcc during periods of sunny and warmer weather. However, the reason behind this finding remains unclear to the researchers and it is highly recommended that future research addresses this effect.

Despite the promising findings in this study, there are a few limitations worth noting. First, no information was available on garden ownership, thus water used outdoors could not be discerned. Had these data been available, garden ownership would have contributed as a variable in the models as it is usually related to higher consumption (Fox et al. 2009). Secondly, information on any changes of water using appliances in the participating households was not available. Thus, whether old appliances were replaced with new ones or new water using features were added in the households was not known to the researchers. It is extremely rare for water companies to collect data of such detail as it would require frequent visits to the properties, thus it would be very costly and time consuming.

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Compliance with Ethical Standards

Conflict of Interest None.

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