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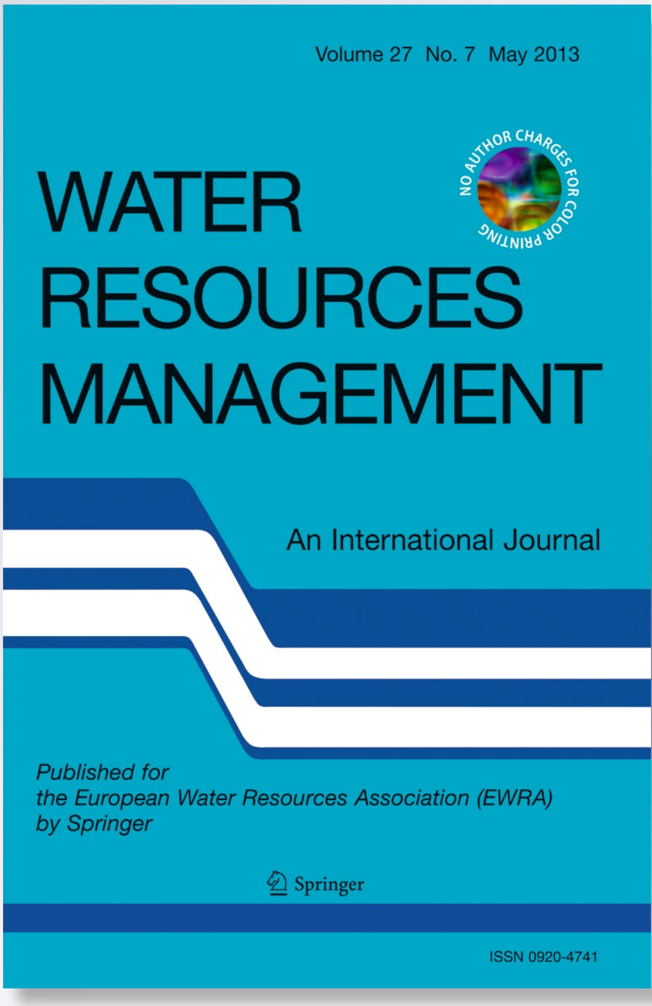

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Urban Sustainability Incentives for Residential Water Conservation: Adoption of Multiple High Efficiency Appliances

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Abstract Effects of multiple types of water use efficiency appliances on long term water savings and water use trend shifts were analyzed. The study group included senior and low income families in the urban areas of Miami-Dade County, Florida, USA. The participants in the study group experienced continuous and significant water savings within 3 years of the implementation of the water conservation incentives. Water savings were observed at approximately 200 l per household per day, which is about 31 % reduction in household water demand in comparison to the average residential water demand within the County. The water use profile of participants showed noticeable shifts over time in water demand frequency curves toward lower water consumption rates. The cost-saving analysis showed that adoption of multiple water efficiency appliances contributed to the highest annual monetary savings (i.e., high water savings and moderate product costs). Future conservation program planning efforts should take both water savings and product cost into account in order to achieve the greatest benefits.

Keywords Water conservation · High efficiency appliances · Residential water demand · Urban areas

1 Introduction

Population increase, economic growth, climate and lifestyle changes have increased global water stress (Arnell et al. 2011; Mohamed 2000; Postel et al. 1996). Environmentalists are directing water demand management towards sustainable environmental practices to provide solutions to water related issues (Wong and Brown 2009). This implies that aggressive and

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continuous developments for sustainable water demand management should be defined, refined and adapted environmental sustainability. Water demand management strategies can be broadly divided into three major categories as economic, technological and behavioral (Saurií 2003). Capacity building can be used to enable water conservation efforts by providing information about current use and potential savings as well as options for the water efficiency practices to achieve target water reduction goals (Reed 2012). Successful implementation of water conservation practices have been reported in the USA (Mayer et al. 2004) and Australia (Turner et al. 2004; Willis et al. 2010). The participants experienced more than 35 % of indoor water savings from replacement of high efficiency appliances (showerheads, faucets, aerators, toilets and clothes washers). These appliances were high water intensive fixtures for indoor water use. Showers accounted for 16.8 %, toilets accounted for 26.7 %, and clothes washers accounted for 21.7 % of indoor per capita water use (Mayer et al. 1999).

The potential water savings by implementation of efficiency appliances is well acknowledged (Ahmad and Prashar 2010; Baumann et al. 1998; Fidar et al. 2010; Kenney et al. 2008; Lee et al. 2011; Millock and Nauges 2010; Olmstead and Stavins 2009) in literatures. Practical incentives (i.e., rebate or exchange of high efficiency type appliances) are considered to be more acceptable by the public in comparison to other water management policies such as price increase or water restrictions (Millock and Nauges 2010; Polycarpou and Zacharizdis 2013; Randolph and Troy 2008). Studies on the estimated water savings after adoption of high water efficiency appliances are summarized in Table 1. However, the water savings were estimated by certain assumptions using aggregated data. Therefore, estimation of actual water savings for adoption of water conservation practices is needed for water demand management. Moreover, the impacts on water consumption change from adoption of multiple high efficiency appliances still remains unclear.

This study aims to evaluate the impacts on change of residential water consumption from adoption of multiple high efficiency appliances in senior and low income households who participated in the water conservation incentive program in Miami-Dade County, Florida, USA. Water demand trend shifts and frequency diagrams were analyzed to quantify the water savings over time. Effects of water conservation practices on water demand for customers with low and high water demands as well as customers with average water usage were analyzed. In addition, a cost-saving analysis was conducted to evaluable the feasibility of each practices from economic point of view.

Table 1 Estimated water savings from residential water conservation appliances

Water conservation practice	Estimated water savings (LPHD)[c]	Reference
Low-flow toilet[a]	90.1–111.3	Mayer et al. (2004); Reidy and Tejral 2008; Cooley et al. 2010
High efficiency showerhead[b]	35.6–45.8	Reidy and Tejral (2008); Cooley et al. (2010); Beal et al. (2011)
Faucet with efficiency aerator, sensor and hand free controller	35.2	Mayer et al. (2004)

[a] 6.1 per flush or less

[b] 9.5 per minute or less

[c] Liters per household per day

2 Program Description

Miami-Dade County is an urban area located in the southeastern part of the Florida State in the USA. It was named as second largest county in Florida State in terms of land area and eighth most populous county in the USA. The current population in Miami-Dade County is about 2.8 million as recorded in 2010. The Miami-Dade Water and Sewer Department (MDWASD) promoted several water conservation practices in assisting end-users to reduce household demand by implementation of efficiency measures. Water conservation practices from MDWASD included senior and low income family full retrofit program (SLIFR), high efficiency showerhead (SH) exchange program, high efficiency toilet (HET), and high efficiency cloth washer (HEW) rebate programs. The participants in the REBATE programs (i.e., SH, HET, HEW) were required to purchase eligible high efficiency appliances approved by the US EPA Water Sense program and submitted their receipts to MDWASD for rebate redemption. Participants in the REBATE programs were not limited to apply for multiple rebates within the water conservation program in MDWASD; however, participants with multiple applications have been excluded from the study database since this study aims to compare single and multiple effects from adoption of water efficiency appliances.

This study includes water consumption profiles from customers participated in SLIFR program to assess the effects of adoption of multiple high efficiency appliances The selected program participants are customers with low income or under senior residential household category as reflected in their property tax exemptions. This study only evaluates the water use characteristics of the SLIFR participants who reside in single family homes. The water consumption profiles of the households were extracted from qualified applicants who have sent their applications to MDWASD. The SLIFR participants were retrofitted with up to two high efficiency toilets and up to two high efficiency showerheads. A retrofit kit with two high efficiency aerators is included in the showerhead exchange package. All the appliances were customized and retrofitted by MDWASD at free of charge.

The SLIFR program started in late 2006 and has been continuing. The SLIFR participants have household characteristics of 2.3 occupants, 2.7 bedrooms, 1.5 bathrooms, adjusted building footage of 130 m^2, and building age of 63.2 years. These data on household characteristics were available from the Office of The Property Appraiser in Miami Dade County (2010). Lower household water demand was found for the SLIFR participants (570 to 770 l per household per day, LPHD) comparing to the demand for regular family (780 to 1000 LPHD). This is majorly due to the family composition of lower occupancy. Since the participants in this group were narrowed to seniors or low income families, they may be more conscientious in using water or water-energy intensive appliances (e.g., dish washer) and rely on faucets to maintain lower water use rates.

Characteristics of the water intensive appliances used in the SLIFR program are listed in Table 2. The table also provides detailed water use information and general water use pattern for residential customers for both standard and efficiency type water intensive appliances. The efficient type water intensive appliances (i.e., certified Water Sense products) must be at least 20 % more efficient than the other standard products. This can be achieved by providing added force to water during use. In SLIFR, the qualified high efficiency toilets have low flow rate of 4.8 l per flush (lower than a conventional toilet with 13.2 LPF). The high efficiency showerheads have flow rates of 5.7 l per minute (lower than a conventional showerhead with 9.8 LPM) and equipped with on/off valve and swivel head for user comfort and convenience. Among all the proposed efficiency type water intensive appliances, toilets had the highest potential in water saving (109.8 LPMD as estimated and 131.4 LPMD as observed) as compared to that for showerheads and aerators. The fractions of residential water use affected by implementation of toilet, showerhead and aerator are 20.2 %, 16.3 %

Table 2 Characteristics of water intensive appliances proposed in this study

Appliance	Maximum quantity (unit)	Average quantity (unit)	Efficiency water use (L/unit)	Standard water use (L/unit)	Water use (LPHD)[a]	Potential estimated water savings (LPMD)[b]	Potential observed water savings (LPMD)[c]	Fraction to total household consumption (%)[d]
Toilet	2	1.5	4.8 lpf[e]	11.4 lpf[e]	56.4[f]	109.8	131.4	20.2
Showerhead	2	1.4	5.7 lpm[g]	9.8 lpm[g]	83.6[h]	87.1	106.0	16.3
Aerator	3	2.0	5.7 lpm	9.8 lpm	196.1	45.4	N/A	7.0[i]
Total						242.3	237.4	43.5

[a] Liters per household per day (average occupants per household: 2.3 people), as for efficiency type water intensive appliances

[b] Liters per measurement per day (measurement is only associated to type of appliances, it is not correlated to quantity of appliance)

[c] Average value from a 4 year longitudinal study (Lee et al. 2011)

[d] Use the average household consumption from 2006 to 2009 (650.2 L/household), as for efficiency type water intensive appliances

[e] Liters per flush

[f] Assume 5.05 flush per capita per day

[g] Liters per minute

[h] Assume 0.75 times of shower per capita per day; 6.8 min shower for standard, 8.5 min for efficiency. (Lee and Tansel 2012)

[i] Use estimated water savings

and 7.0 %; respectively. These values were calculated using the potential observed water savings divided by the average household consumption from 2006 to 2009 (650.2 L/household). Based on the information provided, implementation of high efficiency toilets would be an effective method to reach the water conservation goals.

3 Results and Discussions

3.1 Reduction in Household Water Demand and Per Capita Water Use

The changes in household water demand for SLIFR program participants are included in Table 3. The average household water demand for the study group ranged from 570 to 770

Table 3 Household water demand changes in SLIFR program (n=271). The number in parenthesis stands for present reduction as compared to water consumption in previous year

Parameter (LPHD[a])	Base year[b] 2005	1st year 2006	2nd year 2007	3rd year 2008	4th year 2009
Mean	771.8	747.2 (−3.2)	699.9 (−6.3)	587.1 (−16.1)	566.7 (−3.5)
High user[c]	1969.5	1940.8 (−1.4)	1815.5 (−6.5)	1639.5 (−9.7)	1646.6 (0.4)
Low user[d]	206.3	195.3 (−5.3)	184.3 (−5.7)	142.3 (−22.6)	122.3 (−14.1)

[a] LPHD stands for liter per household per day

[b] Base year stands for 1 year prior to first year of implementation

[c] High user stands for consumers in higher 10 % of water use range

[d] Low user stands for consumers in lower 10 % of water use range

LPHD, which is lower than that for regular families (780 to 1000 LPHD, Lee et al. 2011). The difference and variation in household water demand were mainly due to the differences in family composition (i.e., number of occupants) and life style. The declining trends in household water demand could be interpreted by the success of implementation of water conservation practices. All of the SLIFR participants included in this study have retrofitted with at least one of each type of high efficiency appliance (i.e., toilet, showerhead and aerator). The water savings not only were due to the use of appliances, but also from the elimination of leakages during installation, especially from toilets (Inman and Jeffrey 2006; Lee et al. 2011).

For the SLIFR program participants, the average household water demand was reduced from 771.8 LPHD in 2005 (base year) to 566.7 LPHD in 2009 (fourth year). As shown in Table 3, high users (the customers who constitute the top 10 % of the highest water demand) in this group have reduced their average household water demand from of 1969.5 LPHD to 1646.6 LPHD. Low users (the customers representing the 10 % lowest water demand) also reduced their average household water demand from 206.3 LPHD to 122.3 LPHD. The high water demand for high users can be partially due to larger lot size in the group (878 m^2, greater than average lot size of 706 m^2). In comparison to the household water demand in base year (2005, 1 year prior to the implementation), the overall household water demand decreased by 3.2 % in the first year and by 16.1 % in the third year of retrofit. The data exhibited that the insignificant water savings in the first year of retrofit (2006) may be due to the customers adjusting to new appliances and change their water use habits (Balbin et al. 2010). The findings suggested that the customers may have developed offsetting behavior during the first 2 years while adjusting to the new appliances. However, after the first 2 years, significant savings in water use were observed. This finding can be partly due to offsetting effects over time as people became accustomed to the water efficiency units. This finding also confirmed the rebound effects discussed by Campbell et al. (2004) that water demand declining by regulating installation of low-flow fixtures but inclining by giving free retrofit device kits. Several factors such as attitudes and opinions relative to the use of efficiency measure may affect the amount of water reduction in many ways. Corral-Verdugo et al. (2003) reported that older people were most likely to develop more utilitarian water beliefs than that in younger people, which suggests that adults would invest more time in water consuming activities than younger people. According to the theory of planned behavior (studying the relationship between attitudes and actions); people were more likely to engage in water conservation behaviors if they have positive attitudes toward water conservation (Russell and Fielding, 2010). Positive attitudes for water conservation lead to strong intentions to engage in water conservation behaviors (Russell and Fielding, 2010).

Per capita water use data, on the other hand, was used to study the water use trends within the REBATE and SLIFR programs. This would eliminate the bias on water consumption data caused by differences in residential occupancy, as water use opportunity was correlated with the family size and composition. The data for REBATE program represents average of water consumption records in both HET, HEW and SH program participants, as extracted from the previous study by Lee et al. (2011).

The per capita water use for SLIFR customers is higher than that for the rebate program customers from 2002 to 2007, as shown in Fig. 1. Water consumption data in the years prior to the implementation year could be used as baseline data as the water conservation programs started in 2006 for SLIFR, 2004 for SH and 2005 for HET. The use of historical water consumption data form the same group of participants as the baseline minimized the impacts from other water-use-related factors (e.g., family composition and household characteristics) on change of water demand. The lower per capita water use found in rebate programs was due to higher number of occupants averages out the shared water demand in a

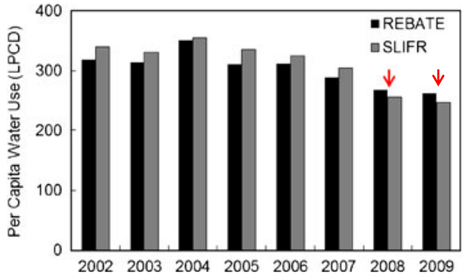

Fig. 1 Comparison of per capita water use in REBATE and SLIFR program. These values were calculated using aggregated occupancy data of 3.1 and 2.3 for REBATE and SLIFR programs, respectively. *Arrow* indicates observation of advance water reduction in SLIFR

household. This observation implied that the impacts of water conservation practices may not be significant during the early stage of implementation (2006 to 2007). However, during 2008 to 2009, per capita water use in SLIFR participants dropped significantly and reduced to values lower than those observed for the participants in the rebate programs. This finding matched the significant change (16.1 %) in water demand in the third year of retrofit (as shown in Table 3).

3.2 Water Use Trend Shifts

Water savings can also be analyzed in terms of the shifts in water demand trend curves. Figure 2 presents water use profile of the customers in the SLIFR and rebate programs. The water use profile for SLIFR customers displayed distributions with a peak water demand at 800 LPHD in the first year of retrofit, with the peak shifting to peak water demand of about 400 to 600 LPHD in the third year of retrofit. For the customers in the rebate programs, a fraction of the participants shifted from the high water demand range (1500 to 3000 LPHD) to lower water demand range (750 to 1100 LPHD); however, the shift was less significant than that observed for the SLIFR program.

The overlapping curves (in the first and second year) could be explained by the similar water demand observed during these years, as presented in Table 3. Water savings for the SLIFR customers was more significant in the third year of implementation. The trend shift implied that both of the program participants have continued to reduce their water demand over time, as observed in Fig. 1. This also suggested that the impacts from adoption of multiple types of high efficiency appliances were more significant than that from adoption of single type of high efficiency appliance.

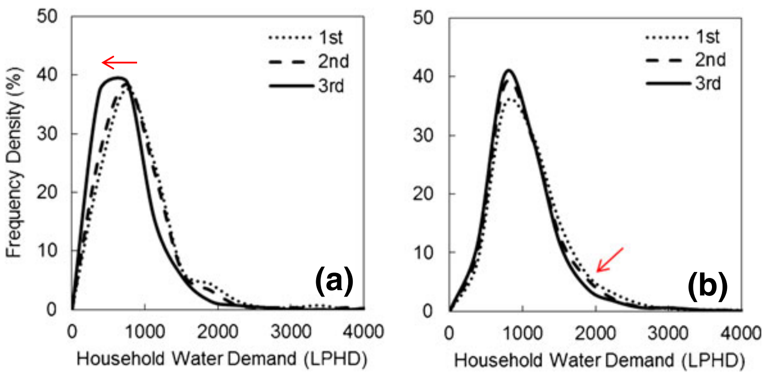

Fig. 2 Frequency trend shifts in household water demand for **a** SLIFR and **b** REBATE programs customers. Both of the programs have experienced continuous water reduction over time

The significant trend shifts for the SLIFR program participants corresponded to approximately 201.8 LPHD of water savings, which was slightly lower than the maximum potential water savings (242.3 LPHD) as listed in Table 2. The differences in water savings can be explained by the offsetting behaviors developed among the users.

3.3 Efficient and Inefficient Water Use

The Water Sense Program of the United States Environmental Protection Agency (USEPA) estimated 265 LPCD (approximately to 70 gal per capita per day) as the defining water demand for efficient and inefficient water usage. Customers with efficient water use rates usually have any kinds of water efficiency appliances installed or are more aware of the benefits of conserving water.

Figure 3 compares the percentage distribution of customers, who are in the water conservation incentive programs, with efficient and inefficient water demand in year 2009. As shown in the figure, the percentage of customers within efficient water use range in SLIFR program (24 %) was significantly higher than that in the rebate program (5 %). Adoption of multiple high efficiency appliances greatly improved the household water savings. The gap in the water demand for customers with multiple types of high efficiency appliances can be as high as 200.6 LPHD, and it is higher than that for customers only own one type of high efficiency appliance (maximum of 131.4 LPHD; Lee et al. 2011).

Number of residents joining the high efficiency appliance rebate programs (1000 in SLIFR, 3478 in HET, 938 in HEW and 4293 in SH as in 2009) are increasing with years. Lifestyle changes may also facilitate these residents becoming more aware of the benefits of water conservation and high efficiency appliances.

3.4 Cost-Savings Analysis

Cost-savings analysis is one of the preferred economic analyses which has been widely used for comparison of alternatives to identify the most economically efficient measures while addressing the current and future water needs (Berbel et al. 2011). It is generally aimed at choosing the least costly or the most beneficial option to achieve a given objective. In this work, the output of the cost-savings analysis was defined as the annual monetary savings (AMS), which can be determined by the following equation:

$$AMS\left(\frac{\$}{yr}\right) = \sum_{i=1}^{n} n \times (AWS - LC) \quad i = 1, 2 \ldots n \tag{1}$$

where, AWS is the annual water saving ($USD/year) due to potential observed water saving (WS, L/day) as described in Table 2 or Table 3 (for SLIFR) and the average water price

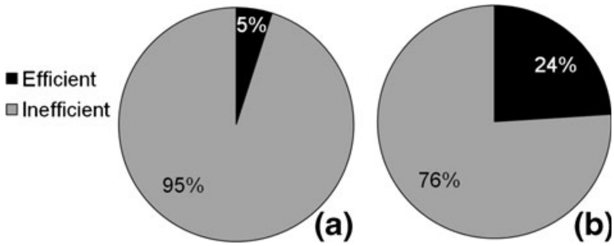

Fig. 3 Percentage distribution of participants with efficient and inefficient per capita water use in 2009 (**a**: REBATE program; **b**: SLIFR program). Higher rate of efficient water usage was found in SLIFR than that found in REBATE

(exclude sewer charge) in Miami-Dade County (MDWASD 2013), which can be expressed as the following formula:

$$\mathrm{AWS}\left(\frac{\$}{\mathrm{yr}}\right) = \frac{\mathrm{WS}\left(\frac{\mathrm{L}}{\mathrm{day}}\right) \times 365\left(\frac{\mathrm{day}}{\mathrm{yr}}\right)}{0.913\left(\frac{\$}{1000\mathrm{L}}\right)} \tag{2}$$

Where, LC stands for products' life cycle cost as determined by the ratio of product cost ($220 for toilet, $35 for showerhead and $10 for aerator) and its lifespan (20.7 years for toilet, 8.2 years for both showerhead and aerator, Lee and Tansel 2012), which can be obtained from the following relationship:

$$\mathrm{LC}\left(\frac{\$}{\mathrm{yr}}\right) = \frac{\mathrm{Product\ cost}(\$)}{\mathrm{Lifespan}(\mathrm{yr})} \tag{3}$$

As presented in Fig. 4, the AMS increased with year of implementation of the water efficiency appliances. It was expected that the AMS would increase over time of ownership of the water conserving appliances. Comparison of the trends between different appliances suggests that AMS was correlated with the potential water savings while single water efficiency appliance was adopted, as toilet posed the highest AMS increment (highest AWS of $43.8/year). Showerheads had a similar degree of AMS rate in comparison to that of toilets, as they have a significant water saving rate at relative lower product cost. For the customers in the SLIFR, the highest AMS increment rates were observed. This can be partly due to the high level of water savings and lower installation costs. It is recommended that SLIFR presents the most economically efficient measure within the MDWASD water conservation program, as it provides the highest AMS at a moderate cost.

4 Conclusions

The water conservation programs promoted in Miami-Dade County, Florida have made significant impacts in reducing residential water demand for programs' participants. Adoption of multiple types of high efficiency appliances has shown significant improvements in water savings within the households, as the household water demand gradually decreased with years of incentives. This suggested a continuous influence from the water conservation program which may have increased their environmental awareness on water conservation and reported positive attitudes on the benefits of the practice. The water use profile has showed noticeable shifts over time in water demand frequency curves moved toward lower water consumption rates. The shifts also validated that adoption of multiple high efficiency appliances increased the number of customers within efficient water use range. Based on the

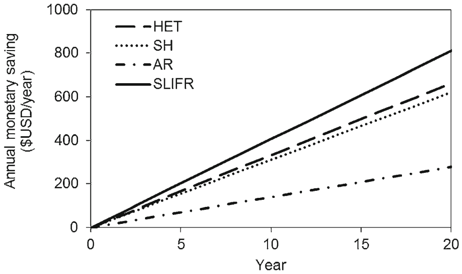

Fig. 4 Cost-saving analysis with increasing annual monetary saving over time for types of water conservation program in MDWASD. Practice with higher increment rate implis that is a more economic measure

cost-savings analyses, adoption of multiple water efficiency appliances had the highest annual monetary savings (i.e., high water savings and moderate product costs). Incentive strategies for replacing or retrofitting of water efficiency appliances can be provided to the consumers for achieving sustainable water demand management and economic development benefits. In addition, with respect to the environmental sustainability concerns, the reduction in overall water demand can also affect the associated environmental impacts, such as energy demand and greenhouse gas emissions. Future conservation planning efforts should take into account both water savings and product costs to achieve the most beneficial overall savings.

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