Influence of residential water use efficiency measures on household water demand: A four year longitudinal study

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ABSTRACT

In response to increasing water demand, Miami-Dade County, FL, USA implemented water conservation incentives for the residential customers. These incentives include rebates and unit exchange programs for showerheads, toilets and clothes washers. In this study, impacts of the water conservation incentives on water demand were analyzed. Water savings and water use trend shifts of the customers were evaluated during the first four years after the implementation of water conservation practices. About 6–14% reduction in water demand has been observed during the first and second years. The water savings continued during the third and fourth years at a lower percentage. Water savings for water use efficiency measures were about 28 (10.9%), 34.7 (13.3%) and 39.7 (14.5%) gallons per household per day for the showerhead, toilet, and clothes washer programs; respectively. Adoption of more than one type of water efficiency appliance contributed to additional saving in residential water use.

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1. Introduction

Sustainability of water supply in urban settings is a major concern from environmental, social and economic perspectives. Water utilities are facing challenges for providing water services while reducing water demand (Hildebrand et al., 2009). Implementation of new technologies or practices require experiments and frameworks to address the complexity and uncertainty of acceptance and social impacts of water conservation practices (Farrelly and Brown, 2011). Population increase, economic growth and lifestyle changes can adversely impact the water demand (Mohamed, 2000; Postel et al., 1996). Hence, environmentalists have been directing the water sectors toward sustainable management practices (Wong and Brown, 2009).

Water conservation practices have been implemented in developed countries and regions to achieve sustainable water demand management. The residential water conservation practices include the use of water use efficiency appliances (i.e., showers, toilets, clothes washers) in residential units. Water conservation by residential customers can be effective from several aspects: (1) residential customers account for the majority of the water demand in urban areas, (2) residential appliances such as showers, toilets, clothes washers constitute the majority of household water demand, and (3) the potential water savings by water efficiency appliances have been well acknowledged (Balbin et al., 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 addition, incentives for switching to water efficient units (i.e., rebates or unit exchange programs) 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; Randolph and Troy, 2008).

Location, function, and personal preferences are major factors in determining water demand. Residential water demand can be classified as indoor and outdoor water use. Approximately 50 percent of the residential water demand is for indoor use. The top three water consuming indoor fixtures include toilets, showerheads and washers, which account for 26.7%, 16.8% and 21.7% of total indoor water demand, respectively (Mayer et al., 1999). Residential water demand is affected by demand management strategies such as water metering, water restrictions and installation of water efficiency appliances. Table 1 summarizes the estimated water savings reported for water conservation appliances. The water savings in water were estimated by certain assumptions using aggregated data. Estimation of actual water savings for each water conservation practice is needed for estimation and management of future water needs.

This paper aims to fill the gap (estimates versus observations) for implementation of effective water conservation practices by analysis of water demand data from individual households over time. Water demand trend shifts and water use frequency diagrams were developed to quantify the impact of water conservation

Table 1
Estimated water savings from residential water conservation appliances.

Study	Water conservation practice	Water savings (GPHD)[a]
Beal et al. (2011)	Water-efficient washing machine (front loaders)	8.0
	High-efficient showerheads	9.4
Tsai et al. (2011)	Low water demand toilet	11.4
	Low water demand clothes washer	15.6
Cooley et al. (2010)	Low-flow toilet (1.28 GPF)	23.8
	Low-flow showerhead (1.5 GPM)	12.1
	Front-loading clothes washer	27.9
	Faucet aerator (1.5 GPM)	1.7
Willis et al. (2010)	Alarming visual display shower monitor	4.1
Clarke et al. (2009)	Efficient model of toilet	17.3
	Mixer shower (1.58 GPM) replace bath and shorter duration (5 min per use)	12.3
Davis (2008)	High efficiency clothes washer	19.6
Reidy and Tejral (2011)	Low-flow toilet (1.6 GPF or less)	26.2
	High efficiency clothes washer	30.9
Mayer et al. (1999)	Ultra low flush toilet (1.6 GPF or less)	29.4
	High efficiency showerhead (2.5 GPM or less)	10.2
	Front loading horizontal axis clothes washer	20.1
	Faucet with efficiency aerator, sensor and hand free controllers	9.3
Turner et al. (2004)	Efficient showerheads, tap water flow regulators, toilet cistern flush arrestors, and leakage repairs	16.9

[a] GPHD, gallons per household per day.

practices. Variability in water consumption data of customers (i.e., low and high end users) and due to seasonal changes were evaluated. Impacts of different types of residential water conservation appliances on water demand were analyzed individually.

2. Program descriptions

Miami-Dade County (MDC) is an urban area located in the southeastern part of the State of Florida in the USA. It is the second largest county in Florida in terms of land area and eighth most populous county in the USA (U.S. Census Bureau, 2011). Water conservation practices promoted by Miami-Dade Water and Sewer Department (MDWASD) assist end-users to implement efficiency measures to reduce water demand. Water conservation practices promoted by MDWASD include projects such as senior and low income family full retrofit program, high efficiency showerhead (SH) exchange program, high efficiency toilet (HET) rebate program, and high efficiency clothes washer (HEW) rebate program. For the rebate programs (HET and HEW), consumers have purchased the high efficiency appliances approved by either the EPA Water Sense program (for SH and HET) or the Energy Star program (for HEW). The certified Water Sense or Energy Star products must be at least 20 percent more efficient than the other conventional products. For the HET rebate program, the qualified toilets have flow rates less than 1.6 gallons per flush (GPF), which is lower than that for a conventional toilet (3.5–7 GPF). For the SH exchange program, MDWASD offers low flow showerheads (1.5 gallons per min, GPM) and equipped with on/off valve and swivel head for user comfort and convenience. A retrofit kit with two high efficiency aerators is included in the SH exchange package. With respect to HEW rebate program, the certified HEW products are usually frontloader designs which can reduce the total water volume during washing. These programs were promoted in different years, starting in 2005 for SH, 2006 for HET and 2007 for HEW.

Table 2 provides the basic characteristics for each water conservation program studied. The total number of participating households is 1829 units. All the households are single family homes. Senior or low income families have been excluded for this study. The average number of occupants in the households is only available for HET customers, which is 3.1 people. This number is slightly higher than the average number of occupants in the US which is 2.6 people according to U.S. Census Bureau (2011). The maximum amount of incentives which can be received per household is two for SH and HET and one for HEW. The HET participants have average of 1.2 toilets, the SH participants have average of 1.3 showerheads, and the HEW participants have average of 1.0 clothes washer.

3. Methods

For the long term analysis, only the participants who joined the program during the first year of implementation were considered. The participants were recruited through the MDWASD water conservation website (MDWASD, 2011). Water use data were extracted from the water bills. Variation in the number of households for different programs was due to the differences in the number of customers participating in different programs. The seasonal/monthly household water demand data from January 2006 to December 2009 were used for the analyses. This period covered the implementation period for different programs. The control group was defined as the study group one year prior to the implementation of the programs, which was considered as the base year (Table 2). Analyses were conducted for the SH, HET and HEW programs individually with the corresponding control groups. The analyses compared with control groups intended to minimize the effects of socio-demographic factors on household water use profile.

The following water demand determinates were used to differentiate the water demand and/or degree of water savings for each water conservation incentive:

1. Household water demand: water consumption in the household expressed as gallons per household per day (GPHD).
2. Mean household water demand: average of daily household water demand.
3. Per capita water use: water use in gallons per capita per day (GPCD), using household size in HET program (3.1 people per household).
4. Low user water demand: average water demand for the 10% of consumers with the lowest water demand.
5. High user water demand: average of water demand for the 10% of consumers with highest water demand.
6. Percent change or water savings in water demand: ratio of water demand difference between target year and base year to water demand in base year.

Table 2
Characteristics of the program participants.

Program	Number of households	Average household size (people)[a]	Average number of appliances (unit)	Maximum number of appliances (unit)	Implementation year	Base year
SH	421	N.A.	1.3	2.0	2005	2004
HET	744	3.1	1.2	2.0	2006	2005
HEW	664	N.A.	1.0	1.0	2007	2006
Multiple	85	N.A.	2.0[b]	3.0[b]	N.A.	N.A.

[a] Average household occupants in the US is 2.6 people (U.S. Census Bureau, 2011).
[b] Type of appliances (in any combination of SH, HET and HEW).

4. Results and discussions

Significant reduction in water demand was been starting 2005. This reduction may be partly due to the effectiveness of water conservation education and publicity efforts. Fig. 1 presents the historical water demand for the participants in different water conservation programs (HET, HEW and SH). Household water demand ranges from 200 to 310 GPHD, which correspond to per capita water use of 65–100 GPCD. The household water demand in MDC is significantly lower than the typical value reported in the literature (400 GPHD) based on the average data compiled from 12 cities in the US (Mayer et al., 1999). The water demand trends for the customers in the three programs were almost parallel during the early stages (before 2006); however, the demand for the customers in the HET program showed a significant reduction after 2007, indicating that the participants in the HET program have experienced relatively higher water savings.

Climate variables can also influence water demand by altering soil water availability and evaporation rate (Fox et al., 2009; Goodchild, 2003). Rainfall events reduce the need for watering and other outdoor activities resulting in temporary reduction in water demand (Miaou, 1990). Temperate is positively correlated with the water demand (i.e., water demand increases as temperature raises) (Gato et al., 2007; Lee et al., 2011). The subtropical climate in South Florida has two major climate periods as dry and wet seasons. The wet season is from May to October which includes the months with warmer temperatures with significant rainfall. The dry season is from November to April with mild to cool temperatures and low precipitation. Seasonal effects on household water demand for all program participants are presented in Fig. 2. During the four year study period, significant differences in water demand between dry and wet seasons were observed at 95% confidence level. In 2006, the South Florida Water Management District initiated water restrictions during the wet season, hence, the water demand during wet season dropped significantly from 2006 to 2007. The drop in water demand could also be explained by the higher number of rainy days in 2007 (118 days in 2006 and 149 days in 2007). Combination of water restrictions for outdoor irrigation systems and indoor water efficiency programs significantly

reduced the household water demand starting 2006. However, the differences in water demand between seasons were less significant. This implies that the impacts of water efficiency appliances overcome the effects of climate variables.

4.1. Effects of high efficiency appliances

High water use efficiency appliances have been well acknowledged for their impact on reducing residential water demand. Pressure-assisted flow is the key mechanism for HET and SH that higher flush velocity. Detailed household water demand changes for the participants in each water conservation program are presented in Table 3. The numbers in parenthesis are percent changes in water demand from the base year. The high and low users are defined as the 10% of customers that are in the high and low water use range of the customer water demand distribution, respectively. A series of paired sample *t*-tests (assuming equal variance) were performed to determine if the changes in water demand were statistically significant at the 95 percent confidence level. An asterisk sign after parenthesis indicates that there is no statistically significant difference in water demand between the present year and the previous year at the 95 percent confidence level. The base year was set as the year before the first year of retrofitting appliances. The average water demand for both programs (HET and SH) were between 250 and 270 GPHD in the base year and between 200 and 255 GPHD in the subsequent years. The water demand for the high and low water users were in the range from 500 to 600 GPHD and from 55 to 90 GPHD, respectively. The water demand curves indicate significant decrease during the first two years of implementation with additional savings during the third or fourth years of implementation. It is likely that after 2 years, as the customers become used to the water use efficiency appliances, additional savings in subsequent years become less significant (Lee et al., 2011).

In general, about 6–14% water could be saved in the first or second year of retrofit. With the installation of high efficiency appliances, the water demand could be potentially reduced to less than 210 GPHD (approximately 70 GPCD). Similar water savings could be accomplished by both high and low water use consumers. For example, high users could reduce their water demand from over 222 GPCD (base year) to 188 GPCD (first year) by installing SH. The
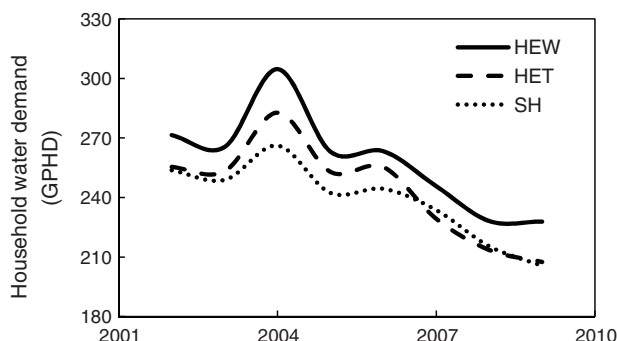

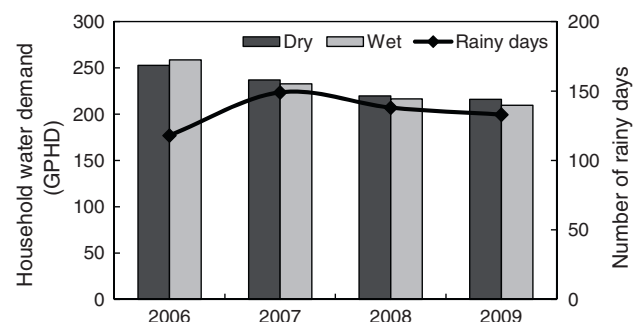**Fig. 1.** Household water demand for water conservation program participants.

Fig. 2. Differences of household water demand during dry and wet season.

Table 3
Household water demand in water conservation practice rebate programs (number in parenthesis is percent change comparing to base year).

Water conservation practice	Base year[d]	1st year	2nd year	3rd year	4th year
SH (n = 421)					
Mean (GPHD[a])	266.1	242.3 (−9.0)	244.3 (−8.2)[*]	233.6 (−12.2)	215.4 (−19.1)
High user[b] (GPHD)	687.5	582.1 (−15.3)	593.0 (−13.7)	562.5 (−18.2)	525.5 (−23.6)
Low user[c] (GPHD)	70.3	61.6 (−12.4)	70.6 (0.4)	60.8 (−13.5)	54.7 (−22.1)
HET (n = 744)					
Mean (GPHD[a])	252.9	255.3 (1.0)[*]	229.2 (−9.4)	213.6 (−15.6)	207.5 (−18.0)
High user[b] (GPHD)	554.4	562.6 (1.5)[*]	493.1 (−11.1)	477.9 (−13.8)	460.0 (−17.0)[*]
Low user[c] (GPHD)	81.6	79.9 (−2.1)[*]	69.4 (−15.0)	64.7 (−20.7)	64.8 (−20.6)[*]
HEW (n = 664)					
Mean (GPHD[a])	262.8	245.8 (−6.5)	225.5 (−14.2)	224.1 (−14.7)[*]	N/A
High user[b] (GPHD)	583.3	565.2 (−3.1)[*]	507.5 (−13.0)	499.7 (−14.3)	N/A
Low user[c] (GPHD)	87.2	78.5 (−9.9)	76.8 (−12.0)[*]	87.2 (0.1)[*]	N/A

[a] GPHD stands for gallon per household per day.
[b] Consumers in the higher 10% of water use range.
[c] Consumers in the lower 10% of water use range.
[d] One year prior to the first year of implementation (2004 for SH, 2005 for HET and 2006 for HEW).
[*] Not a statistically significant difference from the previous year at the 95 percent confidence level.

variations in household water demands could be explained by the differences in family composition (i.e., number and age of occupants) and their life style (i.e., frequency of use of water-demanding appliances or activities).

Among the three programs, the customers in the HET program had the lowest water demand. The water demand did not change significantly during the first year of retrofit, however, significant savings (about 15.6%) were observed in the third year of retrofit. This can be explained by the fact that water use for toilets accounts for the highest percentage of in indoor water use. Also, toilets are considered as likely source of water leaks due to faulty installation. Replacement of the older toilets with HET not only saves water during each use but also reduces the water loss due to reduction of leaks (Inman and Jeffrey, 2006).

The average annual laundry wash cycle per household in the USA is estimated as 289 times (Pakula and Stamminger, 2010). Therefore, use of HEW has the potential to save significant amount of water with each cycle. For the HEW program, the water savings in the first and second years of retrofit were 6.5% and 14.2%, respectively. The relatively low water savings in the first year indicates that the participants were getting used to the new appliances. For example, higher total washing frequency have been reported after receiving a new machine (i.e., washer) (Davis, 2008). Significant differences in the water demand was observed in the second year of retrofit, however, the water demand remained stable in the third year. This suggests that the effect of HEW on conserving water was stabilized after two years.

Water use for showering may have the lowest variation since people take showers regularly (Domene and Sauri, 2006). For the SH program, the water savings fluctuated during the study period (9.0% in the first year, 8.2% in the second year and increased to 12.2% in the third year) (Table 4). Offsetting behaviors such as awareness of the water conservation but using more water could be seen in the SH program participants (Inman and Jeffrey, 2006). The water savings for the SH program has additional environmental impacts due to reduction in energy consumption and greenhouse gas emissions from water heating (Fidar et al., 2010; Willis et al., 2010).

Comparison of the water demand and water savings for the participants in different water conservation programs is listed in Table 4. The water savings were the highest for the participants in the HEW (39.7 GPHD) program, followed by HET (34.7 GPHD) and SH (28.0 GPHD) programs. The observed water savings are in same order as the estimated savings reported by other studies as presented in Table 1, however, with higher magnitudes. In urban areas, higher household density and number of occupants can create opportunities for conserving water. As presented in Table 4, the results are similar to the water savings observed by other studies (Inman and Jeffrey, 2006; Proença and Ghisi, 2010) which show that toilets and washers have the highest potential for conserving water. In a life cycle assessment study of various types of HETs, the low flush system toilets was considered to be an effective option from investment and environmental performance perspectives (Anand and Apul, 2011). HEWs have also been valued as potential household goods that reduce water and energy consumption significantly (Davis, 2008). Table 4 provides the estimated annual water savings for 1000 participants in each program as 10.2, 12.7 and 14.5 million gallons for SH, HET and HEW programs, respectively.

Relative frequency diagrams of water demand for participants in the three programs are illustrated in Fig. 3.The frequency distribution curves for HET and HEW programs show that the either the water demand distribution curve or the peak shifted toward lower water use values. This suggests that participants in these programs have continued to reduce their water demand over the years. Meanwhile, the distribution curves are wide and overlapping form the first to the second years in the SH program. The overlapping curves can be due to similar water demand observed during these years (Table 3). Effects of SH on water savings was observed to be more significant after the third year of implementation as the frequency curve shifted toward lower demand levels (Fig. 3). This observation suggests offsetting behavior for the participants in the SH program in the first two years of implementation. However, these offsetting effects decrease over time as people become accustomed to the new units.

Table 4
Differences of water demand and savings with and without conservation practices.

Parameter	SH	HET	HEW
Mean water demand (GPHD)			
Without water conservation practices	256.2[a]	261.1[b]	273.6[c]
With water conservation practices	228.2[d]	226.4[e]	233.9[f]
Water savings (gallons per household per day)	28.0	34.7	39.7
Water savings (%)	10.9	13.3	14.5
Water savings (million gallons per year)[g]	10.2	12.7	14.5

[a] 2002–2004.
[b] 2002–2005.
[c] 2002–2006.
[d] 2005–2009.
[e] 2006–2009.
[f] 2007–2009.
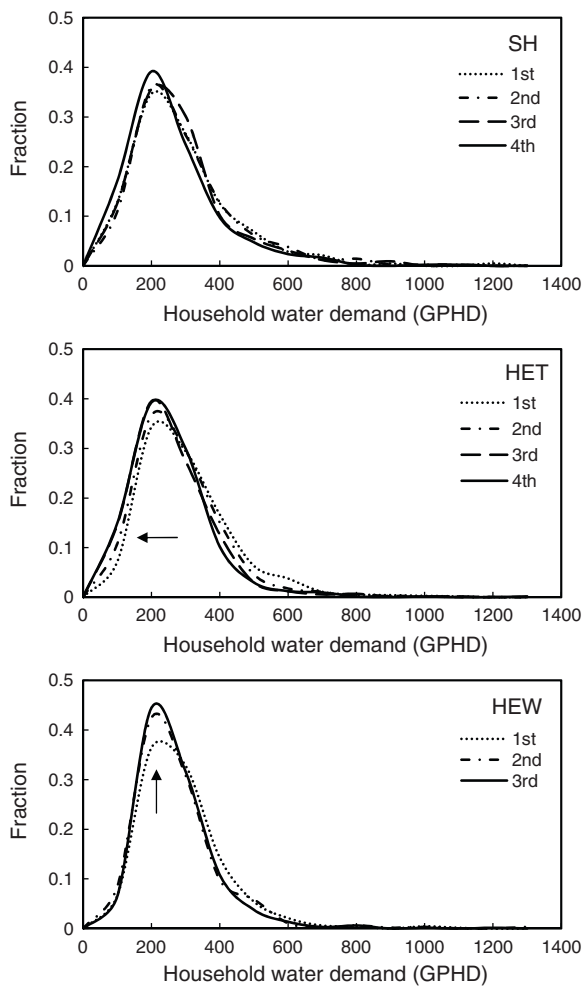[g] Based on 1000 customers.

Fig. 3. Shifts in residential household water demand distribution curves after implementation of high efficiency appliance programs.

4.2. Effect of type and number of appliances

Approximately 4.6% (85 out of 1829) of the customers participated in more than one type of water conservation program (i.e., multiple type participants). The group of multiple type participants comes from the same study group described in Section 4.1, with the participants who have any combination of two or three types of water efficiency appliances (i.e., SH and HET or HET and HEW or SH and HEW or SH, HET and HEW). Fig. 4 compares the household water demand for the participants with one type and multiple types of water efficiency appliances. Significant
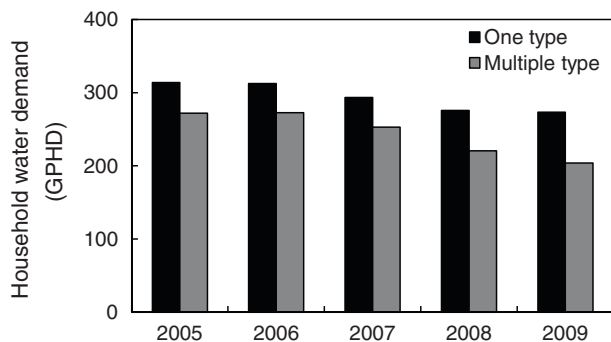

Fig. 4. Comparison of water demand of participants with only one type and multiple types of water conservation appliances.
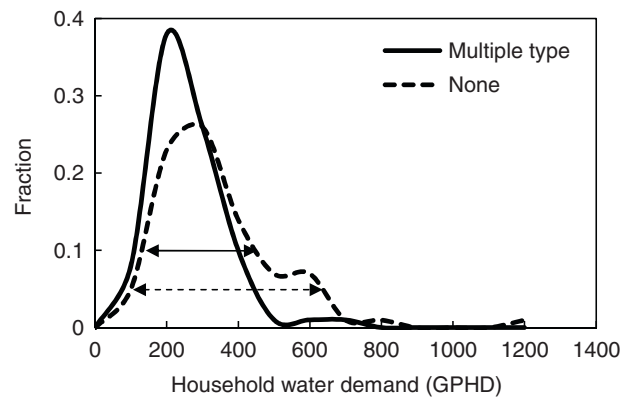

Fig. 5. Frequency density curve for customers with no (dashed line) and multiple types (solid line) of appliances.

differences in water demand was observed between the participants who had one type and multiple types of high efficiency appliances. Household water demand remained stable from 2005 to 2006 and followed by a decrease in 2007 (for both one type and multiple type participants). The first two years (2005 and 2006) is the transition stage when the customers are adjusting to the water conservation appliances. Preferences for either the water-intensive or water-conserving practices depend on individual lifestyles (Gottdiener, 2000).

The differences in water demand between the customers who had one type and multiple types of high efficiency appliances increased over time (Fig. 4). The water demand difference was 40 GPHD in 2005 and increased to 70 GPHD in 2009. The gap for customers with multiple types of high efficiency appliances is much larger than those customers with one type high efficiency appliance (maximum of 25 GPHD, Table 3). This suggests that customers with more than one type of high efficiency appliance can significantly reduce their household water demand. This result was also validated by the frequency density curves (Fig. 5). The distribution for customers with no high efficiency appliances (i.e., control group) is wide extending to high demand ranges. On the other hand, the trend for the customers with had multiple high efficiency appliances show a sharp distribution curve which is shifted toward the lower demand ranges.

Tsai et al. (2011) observed no statistically significant water savings for the participants who joined in both HET and HEW programs. This finding is different from the results in this study. The impact of adopting multiple types of water savings appliances can have long term effects that may not be quantifiable within a short time period.

With the increasing number of residents participating in the high efficiency appliance rebate programs (3478 in HET, 938 in HEW and 4293 in SH as in 2009), it is expected to see higher number of residents with multiple types of high efficiency appliances. Urban lifestyle may also facilitate these residents to be more aware of the benefits of water conservation and high efficiency measures for creation of sustainable communities.

5. Conclusions

Four year longitudinal study was conducted to evaluate the potential water savings from residential water use efficiency measures. Statistically significant changes in water demand were observed for SH, HET and HEW program participants. The residential water demand for all the rebate program participants shifted to lower demand levels over time. The household water demand significantly decreased during the first two years after

implementation, and there were additional less significant savings during the third or fourth years.

The analyses show that HET and HEW had the highest potential in conserving water based on their observed impact on water savings. The customers who had more than one type of water efficiency appliance experienced higher water savings. The water savings observed by the participants in this study were more significant than the values reported in the literature from similar studies. The results indicated that participants became more aware of the benefits of conserving water over time.

Acknowledgements

References

Anand C, Apul DS. Economic and environmental analysis of standard, high efficiency, rainwater flushed, and composting toilets. Journal of Environmental Management 2011;92:419–28.

Balbin M, Tansel B, Lee M. Effectiveness of Miami-Dade water use efficiency program senior retrofit project: comparative analysis of water consumption rates and savings. The Florida Water Resources Journal 2010(August):14–5.

Baumann DD, Boland JJ, Hanemann WM. Urban water demand management and planning. New York: McGraw-Hill; 1998.

Beal C, Steward RA, Huang T, Rey E. SEQ residential end use study. AWA Water Journal 2011(March):92–6.

Clarke A, Grant N, Thornton J. Quantifying the energy and carbon effects of water saving. London, UK: Elemental Solutions; 2009. p. 1–121.

Cooley H, Christian-Smith J, Gleick PH, Cohen MJ, Heberger M.Ross N, Luu P, editors. California's next million acre-feet: saving water, energy, and money. Pacific Institute; 2010.

Davis LW. Durable goods and residential demand for energy and water: evidence from a field trial. Rand Journal of Economics 2008;39:530–46.

Domene E, Sauri D. Urbanisation and water consumption: influencing factors in the Metropolitan Region of Barcelona. Urban Studies 2006;43:1605–23.

Farrelly M, Brown R. Rethinking urban water management: experimentation as a way forward? Global Environmental Change 2011;21(2):721–32.

Fidar A, Memon FA, Butler D. Environmental implications of water efficient microcomponents in residential buildings. Science of the Total Environment 2010;408:5828–35.

Fox C, McIntosh BS, Jeffrey P. Classifying households for water demand forecasting using physical property characteristics. Land Use Policy 2009;26:558–68.

Gato S, Jayasuriya N, Roberts P. Temperature and rainfall thresholds for base use urban water demand modelling. Journal of Hydrology 2007;337:364–76.

Goodchild CW. Modeling the impact of climate change on domestic water demand. Water and Environment Journal 2003;17:8–12.

Gottdiener M. New forms of consumption. Lanham, MD: Rowman & Littlefield Publishers, Inc; 2000.

Hildebrand M, Guar S, Salt KJ. Water conservation made legal: water budgets and California law. American Water Works Association Journal 2009;101:85–9.

Inman D, Jeffrey P. A review of residential water conservation tool performance and influences on implementation effectiveness. Urban Water Journal 2006;3:127–43.

Kenney DS, Goemans C, Klein R, Lowrey J, Reidy K. Residential water demand management: lessons from Aurora, Colorado. Journal of the American Water Resources Association 2008;44:192–207.

Lee M, Tansel B, Balbin M. Goal based water conservation projections based on historical water use data and trends in Miami-Dade County. Sustainable Cities and Society 2011;1:97–103.

Mayer PW, deOreo WB, Opitz EM, Kiefer JC, Davis WY, Dziegielewski B, et al. Residential end uses of water. Dever, CO: American Water Works Research Association Foundation and American Water Works Association; 1999.

Miami-Dade Water and Sewer Department. Water conservation program; 2011, http://www.miamidade.gov/conservation/2011 [last access August 2nd, 2011].

Miaou S-P. A class of time series urban water demand models with nonlinear climatic effects. Water Resources Research 1990;26:169–78.

Millock K, Nauges C. Household adoption of water-efficient equipment: the role of socio-economic factors, environmental attitudes and policy. Environmental and Resource Economics 2010;46:539–65.

Mohamed AS. Water demand management in Egypt: policy objectives and strategy measures. Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere 2000;25:243–9.

Olmstead SM, Stavins RN. Comparing price and nonprice approaches to urban water conservation. Water Resources Research 2009:45.

Pakula C, Stamminger R. Electricity and water consumption for laundry washing by washing machine worldwide. Energy Efficiency 2010;3:365–82.

Postel SL, Daily GC, Ehrlich PR. Human appropriation of renewable fresh water. Science 1996;271:785–8.

Proença LC, Ghisi E. Water end-uses in Brazilian office buildings. Resources, Conservation and Recycling 2010;54:489–500.

Randolph B, Troy P. Attitudes to conservation and water consumption. Environmental Science and Policy 2008;11:441–55.

Reidy K, Tejral J. Aurora water 2008 conservation annual report. City of Aurora Government; 2011, https://www.auroragov.org/stellent/groups/public/documents/article-publication/035857.pdf 2008 [last accessed 11th April, 2011].

Tsai Y, Cohen S, Vogel RM. The impacts of water conservation strategies on water use: four case studies. JAWRA Journal of the American Water Resources Association 2011;47:687–701.

Turner A, White S, Beatty K, Gregory A. Results of the largest residential demand management program in Australia. Marrakech, Morocco: Biennial World Water Congress; 2004.

U.S. Census Bureau. State & County Quickfacts; 2011, http://quickfacts.census.gov/qfd/states/00000.html 2010 [last access August 2nd, 2011].

Willis RM, Stewart RA, Panuwatwanich K, Jones S, Kyriakides A. Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. Resources, Conservation and Recycling 2010;54:1117–27.

Wong THF, Brown RB. The water sensitive city: principles for practice. Water Science and Technology 2009;60:673–82.