A Framework for Reducing Water Demand in Multi-Storey and Detached Dwellings in the United Arab Emirates

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ABSTRACT
The United Arab Emirates (UAE) is highly dependent on desalination for water supply in urban areas, which comes at significant financial and environmental costs. Therefore, reducing the demand for water is a strategic objective of water authorities in the UAE. The concentration of the UAE population in multi-story buildings in urban areas makes residential water conservation, including greywater recycling, a highly attractive option for reducing water demand and wastewater generation. However, the unique composition of the UAE population poses challenge to adopting water conservation policies that are suitable for the UAE national and expatriate sectors of the population. Furthermore, the current water recycling policies and legal framework do not encourage greywater recycling for internal use in residential buildings. In this study, a framework for assessing the potential and feasibility of water conservation, including greywater recycling, in multi-storey and detached dwellings in the UAE was developed and discussed. The results confirmed that significant potential existed for reducing the residential water demand in the UAE through adopting simple water conservation measures and greywater recycling in multi-story buildings. The discussion was extended to proposing greywater recycling systems suitable for multi-story buildings in the UAE. Such systems involve partial greywater recycling from the higher floors of multi-storey buildings to serve the toilet flushing needs of the whole building and locating greywater treatment systems on the roofs of buildings.

KEYWORDS
Domestic Water Use; Water Conservation; On-Site Greywater Treatment and Recycling; Cost Benefit Analysis

INTRODUCTION
The United Arab Emirates (UAE) is a relatively young country that has modern cities. The country experienced unprecedented expansion and development since its establishment, especially during the last two decades. The massive oil resources in the country, beside its strategic location and forward-looking policies, enabled extended periods of economic development and rapid population growth. According to the World Bank (2011), the population of the UAE was about 200,000 in 1970, which grew to about one million in 1980. In 2011, the population of the UAE was estimated to be above eight million. Less than 15% of the UAE population is UAE nationals, with the rest being expatriates from around the world. Most of the UAE population lives in modern coastal cities, with modern commercial centers, multi-storey buildings, comfortable suburbs, and sophisticated transportation networks.

The UAE is mostly a desert (about 80%), with a long coastal zone and mountains in the Eastern side. The arid climate, limited renewable water resources, rapid population growth, expansion of economic activity, and continuous improvement in the standards of living pose several challenges to

meeting the ever increasing water demand in the country. Agricultural activity is the main consumer of water in the UAE followed by domestic use. The major water sources include groundwater and desalinated sea and brackish ground waters. Despite the scarcity of renewable water resources and the high cost and environmental impacts of desalination, the per capita water consumption in the UAE is among the highest in the world, with total water consumption rate in Dubai estimated to be 550 liters per capita per day (DEWA, 2012).

Management of water resources in the UAE requires careful reconsideration of the agricultural demand for water in a country with scarce renewable water resources. However, there are demographic, legal, policy and planning challenges that currently limit the ability of the country to achieve a high level of water conservation. In terms of domestic water demand, the UAE population has not yet developed a strong culture of water conservation in residential dwellings. Therefore, significant water conservation can be achieved in residential dwellings through education and adopting appropriate water conservation measures. Water consumed in homes is transformed into wastewater, which can be classified into two categories: (1) greywater, which originates from baths, showers, hand basins and washing machines; and (2) blackwater, which originates from toilets and kitchen sinks. Greywater recycling for internal reuse in buildings has not yet received adequate attention in the UAE. Many studies have demonstrated the technical, economic and environmental benefits of greywater recycling for flushing toilets and irrigation in residential dwellings (Friedler and Hadari, 2006; Wong and Mui, 2007; Cheng, 2003; Nolde, 2000; Surendran and Wheatley, 1998). In the UAE, water consumed in residential dwellings in urban areas is collected as wastewater and treated. The treated wastewater is either discharged into the sea or recycled and reused for landscape irrigation (mostly for grass lawns irrigation). Irrigation in urban areas helps in mitigating the heat island effect as plants cool themselves and the surrounding air through transpiration. However, the excessive need for water to maintain plants with high transpiration rates in a desert environment of the UAE may not be a feasible alternative.

In this study, a framework for assessing the potential and feasibility of water conservation, including greywater recycling, in multi-storey and detached dwellings in the UAE was developed and discussed. The discussion was extended to proposing greywater recycling systems suitable for multi-story buildings in the UAE.

A FRAMEWORK FOR REDUCING WATER DEMAND IN RESIDENTIAL BUILDINGS

In the following discussion, a framework for reducing water demand in residential buildings in the UAE is presented and discussed. The various elements of the framework are identified and the feasibility of a variety of water conservation and greywater recycling schemes are assessed.

UAE residential buildings and opportunities for reducing water demand

There are three major types of residential buildings in the UAE: multi-storey buildings, including mixed-use buildings; detached dwellings; and clustered dwellings or dwellings in a row. Multi-storey buildings are characterized by high population density and limited, if any, green space that requires irrigation. Multi-storey buildings offer significant potential for installing shared greywater recycling systems. On the other hand, detached dwellings neighbourhoods have low population densities. Detached dwellings in the UAE usually have large residential gardens that consume significant amounts of water for irrigation, especially in the hot summer months.

Most of the UAE population lives in multi-storey residential buildings. Therefore, significant potential exists for reducing the domestic water demand in the UAE through water conservation, including water use reduction, water waste minimization and greywater recycling and reuse.

Domestic water conservation can be practically achieved using measures, such as: education; installation of water saving devices; and use of proper landscaping practices. Furthermore, greywater can be used in multi-storey buildings for flushing toilets and irrigation. However, most multi-storey residential buildings in the UAE have limited or no green spaces that require irrigation.

Water use in residential dwellings in the UAE

Water in residential buildings is used for a variety of purposes. To assess the potential for greywater recycling in residential buildings in the UAE, data on water use in residential dwellings are required. Unfortunately, reliable studies on water use in residential buildings in the UAE may not be available. Furthermore, the water use patterns of the different socioeconomic groups of the UAE population vary considerably. The data in Table 1 summarize the accessible data on domestic water use in the UAE. The Dubai Electricity and Water Authority (DEWA, 2011) provides data on the water use in Dubai (Table 1), which are consistent with data reported by Meyer et al. (1999) for domestic water use in the USA (Table 1). However, it is not clear whether the Dubai (DEWA, 2011) data were based on actual studies. The results of a study reported by the Dubai School of Government (DSG, 2011) on residential water use are also reported in Table 1. Furthermore, a limited survey generated by 23 university students on water use in their homes produced highly scattered results (Table 1). As such, and for purposes of assessing the potential for water conservation and greywater recycling in this study, the water use data reported by the DEWA (2011), or by Meyer et al. (1999), were used.

Table 1. Water use and water quality requirements by fixture or appliance in residential dwellings.

Water Use	Minimum Quality Required	Wastewater Generated	Water Use DEWA[1] (%)	Water Use in USA[2] (%)	Water Use DSG[3] (%)	Water Use Survey[4] (%)
Toilet Flushing	Grey	Black	27	27	10	13-32[*]
Shower	Fresh	Grey	17	17	60	10-29
Washing Basin	Fresh	Grey	8	8[$]	13	6-12
Bath	Fresh	Grey	2	2	7	0-22
Laundry	Fresh	Grey	45[**]	22	4	2-20
Kitchen Use	Grey	None		9[$]	5	3-11
Water Leaks	---	---		14	---	---

[1]DEWA, Dubia Electricity and water Authority (2011)
[2,$]Based on Mayer et al. (1999), with redistribution of "faucets" water use on toilets and kitchen basins.
[3]DSG, Dubai School of Government (2011)
[4]This study, based on 23 water use surveys conducted by engineering students.
[*]Including cleaning off after toilet use.
[**] Laundry, kitchen use and water leaks combined.

Inspection of the data in Table 1 suggests that fresh water is required for use in most appliances and fixtures in residential dwellings, with most of generated wastewater being greywater. On the other hand, greywater can only be used for flushing toilets and possibly for landscape irrigation.

The planning guidelines for new development projects in Dubai (DEWA, 2011a) state that the average domestic water use should be 250-350 l/(c.d). The indoor water use, estimated based on the survey conducted in this study, was in the range of 150 - 350 l/(ca.d). The indoor water demand used for assessing the potential for water demand reduction in this study was 300 l/(ca.d). In terms of water use for landscape irrigation, a moderate irrigation rate of 0.004 m^3/d per m^2 was used, or 250 l/(c.d) for a villa of 8 people with 500 m^2 green space.

Current water tariff in the UAE

The feasibility of water conservation and greywater recycling to consumers is determined by water consumption as well as the cost of water supply and wastewater discharge. The UAE water authorities subsidize water and wastewater for UAE nationals, who effectively get free water for domestic use. For expatriates, the water charges vary with consumption and reflect the high cost of water desalination and conveyance, as shown in Table 2.

The relatively high cost of water in the UAE provides an incentive to save water for both, consumers and water authorities. Furthermore, the high cost of water makes water conservation and greywater recycling attractive options, as discussed in the following sections.

Table 2. Current cost of water and sewerage for expatriates in Dubai.

Item	Monthly Water Use (m^3/month)	Tariff (US$/$m^3$)
Water Supply	0-27.2	2.1
	27.2-54.5	2.4
	>54.5	2.8
Sewerage Collection		0.35

Feasibility of water conservation in the UAE residential dwellings

Water conservation is a logical and quite feasible option for reducing residential water demand in the UAE. Water conservation is technically achievable; however the level of awareness as well as the cost and convenience of conservation determine the level of community participation. Example water conservation measures that can practically be implemented in UAE homes are listed in Table 3, together with their relative costs (EnviroWise, 2011). The cost of implementing some of the measures in Table 3 can be recovered within relatively short periods of time. For example, assuming a 20% reduction in water consumption can save up to approximately US$500/year on water and sewerage charges per household with 6 people in a multi-storey building.

Table 3. Data for assessing the feasibility water conservation measures for expatriate UAE residents.

Water Use	Water Saving Measure	Potential Water Saving (%)	Items per Dwelling		Assumed Cost ($) per Item
			Flat	Detached Dwelling	
Toilets	Cistern volume adjustor/dual system	15-30	3	4	L-M
Washing Basin	Flow rate restriction/ reduction	15-30	3	4	L
Kitchen Use	Flow restriction/ Efficient dishwasher	15-30	1	1	L
Bath	Education	15-30	2	3	L
Shower	Flow rate restriction/ reduction	15-30	2	3	L
Washing Machine	Water efficient washing machine	15-30	1	1	M
Green Parts of Garden	Native plants and drip irrigation	25-50	---	500 m^2 Detached	M-H

Water Leaks	Pressure reduction, detection & repair	25-80	---	---	M-H

*L=Low <US$100, M=Medium <US$1000, H=High > US$1000

Feasibility of greywater recycling in the UAE residential dwellings

While simple water conservation devices and appliances have low to medium costs, greywater recycling systems can have high capital, operation and maintenance costs. In this discussion, the cost of greywater recycling was based on the estimates provided by Friedler and Hadari (2006) for a relatively high-cost membrane biological reactor (MBR) treatment system with several treatment steps, including disinfection. The cost estimates provided by Friedler and Hadari (2006) accounted for materials, installation, and operation and maintenance of the treatment and conveyance systems. Compared to the costs reported by Friedler and Hadari (2006), the local cost of power consumption and an additional fee (US$200/flat in a multi-storey building) were used to account for cost variations. The water conservation costs were based on the data provided in Table 3, with the annual maintenance cost for conservation measures assumed to be 5% of the cost of the conservation measures.

Most multi-storey residential buildings in the UAE typically have no green areas that require watering. Therefore, only a fraction of available greywater requires recycling for flushing toilets. As such, satisfying the water demand for flushing toilets does not require recycling grewater from all dwellings, or from all greywater sources in multi-storey buildings. Based on the water consumption data reported in Table 1, the number of floors needed to generate enough greywater to satisfy the toilet flushing needs of multi-storey buildings (with six flats per floor) is depicted in Figure 1. The data in Figure 1 show that for a 30 storey building, greywater needs to be recycled from 14 floors to serve the toilet flushing needs of the whole building.

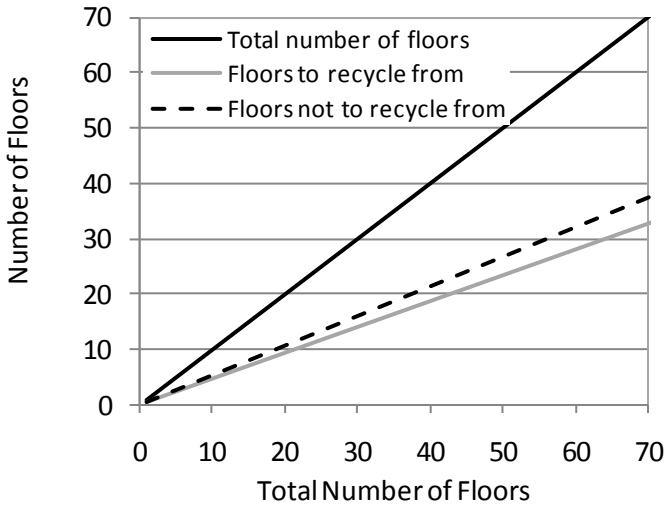

Figure 1. Number of floors in a multi-storey building from which greywater needs recycling to satisfy the toilet flushing needs of the whole building.

Partial recycling can be achieved through collecting greywater only from the higher floors, which allows locating the treatment and pumping systems higher up in the building, preferably on the roof, thus reducing the cost of pumping. Locating greywater recycling systems on the roofs of multi-storey buildings, rather than in basements, reduces the need for indoor space, and also reduces the need for expensive odor control systems.

The possibility of collecting greywater only from the higher floors in a multi-storey building to serve the needs of the whole building suggests four greywater recycling schemes, as presented in Figure 2. The four schemes differ in the location of greywater treatment systems. In scheme (a), the treatment system is located in the basement, while in scheme (b) the system is located at the roof. In scheme (c), which is suitable for partial recycling, the treatment system is located within the building, just below the floor from which greywater needs to be recycled. The preferred option for partial recycling is presented in scheme (d) in which the treatment system is located at the roof. Schemes (a and b) can be used for full or partial recycling of greywater, while schemes (c and d) can be used for partial greywater recycling.

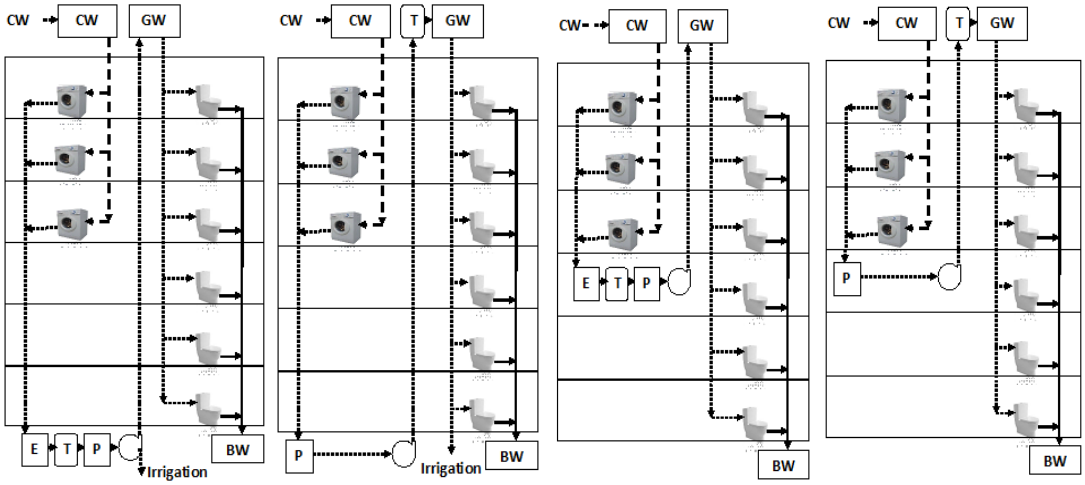

Figure 2. Greywater collection and treatment schemes; (a) basement recycling system; (b and d) roof recycling systems; and (c) middle recycling system. CW=clean water; T=treatment; GW=greywater; BW=blackwater; P=pumping; E=equalization tank.

The feasibility of greywater recycling depends on the cost of water and sewerage, as well as on the demand for and availability of greywater. To assess the feasibility of greywater recycling in the UAE, the following three recycling scenarios were considered:

1. Partial recycling of available greywater for flushing toilets in multi-storey buildings;
2. Full recycling of greywater in multi-storey building for flushing toilets and other uses that can consume available greywater; and
3. Full recycling of greywater in detached dwellings for flushing toilets and watering gardens.

Case 1. Partial greywater recycling in multi-storey buildings

Partial recycling of available greywater to satisfy the toilet flushing needs in multi-storey buildings requires collecting greywater from about half of the total number of floors in the building. Partial recycling can be achieved using any of the schemes shown in Figure 2, with scheme (d) being the recommended option.

In terms of economic feasibility, the data in Figure 3 show that partial recycling of greywater can be quite feasible due to the relatively high cost of water (US$2.4/m^3) in the UAE. The cost recovery in Figure 3 is achieved through the savings made on water and sewerage charges. The data in Figure 3 suggest that the cost recovery periods can be less than 10 years, even for building with limited number of floors, declining to less than five years for building with more than 10 floors.

The data in Figure 3 show the cost recovery periods for three water demand reduction schemes in multi-storey buildings: partial greywater recycling alone; water conservation alone; and conservation and partial greywater recycling combined. The data suggest that for buildings with less that about 10 levels, water conservation is the most economical option. Above about 10 levels, greywater recycling alone and combined greywater recycling and water conservation become more economical than conservation alone.

In addition to cost recovery, the annual water and sewerage savings from multi-storey buildings are significant. In this case, the water savings are: 27% from greywater recycling alone; 23% from conservation alone; and 45% from greywater recycling and conservation combined. In terms of public benefits, water conservation and wastewater reduction delay the need for investing in additional water and sewerage infrastructure, which provides significant economic benefits to the concerned water authorities.

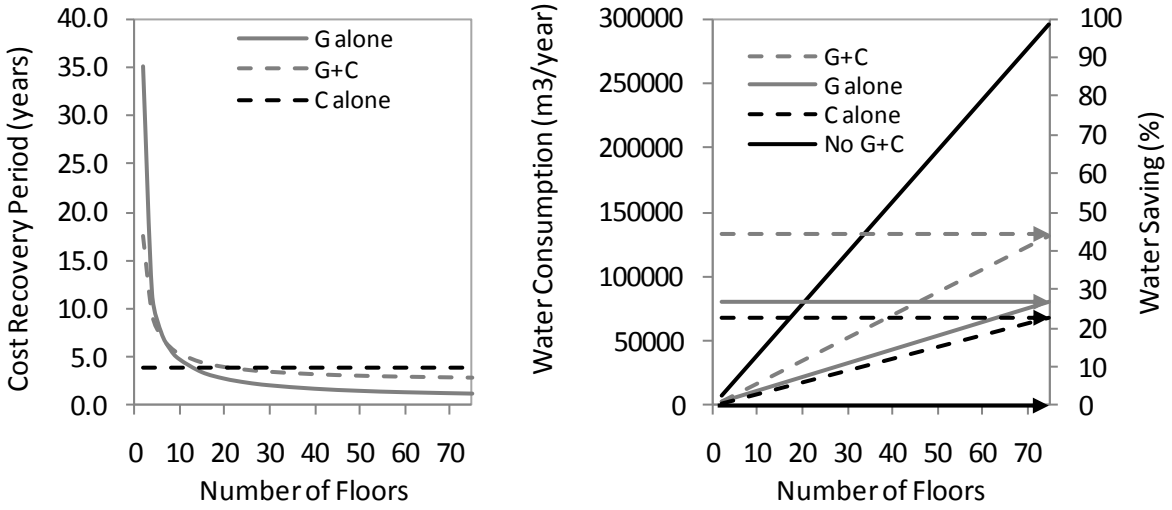

Figure 3. Partial recycling for toilet flushing - installation cost recovery and water savings. (G=greywater recycling alone; C= conservation alone; and G+C=conservation + greywater recycling. Arrows identify relevant axis)

Case 2. Full greywater recycling in multi-storey buildings

Multi-storey buildings in the UAE generate significant quantities of greywater that exceed the internal toilet flushing needs. However, the analysis presented in this section assumes that the demand for greywater recycling matches greywater generation. In this case, and due to the relatively high cost of water in the UAE, recycling can be feasible whenever freshwater can be replaced by recycled water even in multi-storey buildings with a limited number of floors. For example, the data in Figure 4 show that full greywater recycling in multi-storey buildings is highly feasible, with short cost recovery periods below five years for buildings with few floors.

The data in Figure 4 show that for buildings with less that about five levels, water conservation is the most economical option. Above five levels, greywater recycling alone and combined greywater recycling and water conservation become more economical than conservation alone. In addition, greywater recycling alone is more economically feasible than combined greywater recycling and conservation.

Full greywater recycling results in significant annual water and sewerage saving from multi-storey buildings. In this case, the water savings are 43% from greywater recycling alone; 28% from conservation alone; and 61% from greywater recycling and conservation combined. Clearly, when

the demand for greywater is high, the water savings achievable by greywater recycling can be highly significant.

The data in Figure 4 show that the cost recovery period exhibits a minimum value for skyscrapers. For example, above 70 floors, the cost recovery period starts to increase due to the excessive cost of pumping. The excessive cost of pumping can significantly reduce the feasibility of full greywater recycling, especially when the cost of water is low.

Case 3. Full greywater recycling in detached dwellings

Detached dwellings in the UAE typically have gardens with trees and green lawns. During the hot summer months, the plants typically require watering once or twice daily. Watering plants consumes significant amounts of water, which makes greywater recycling for irrigation a reasonable alternative from a technical point of view.

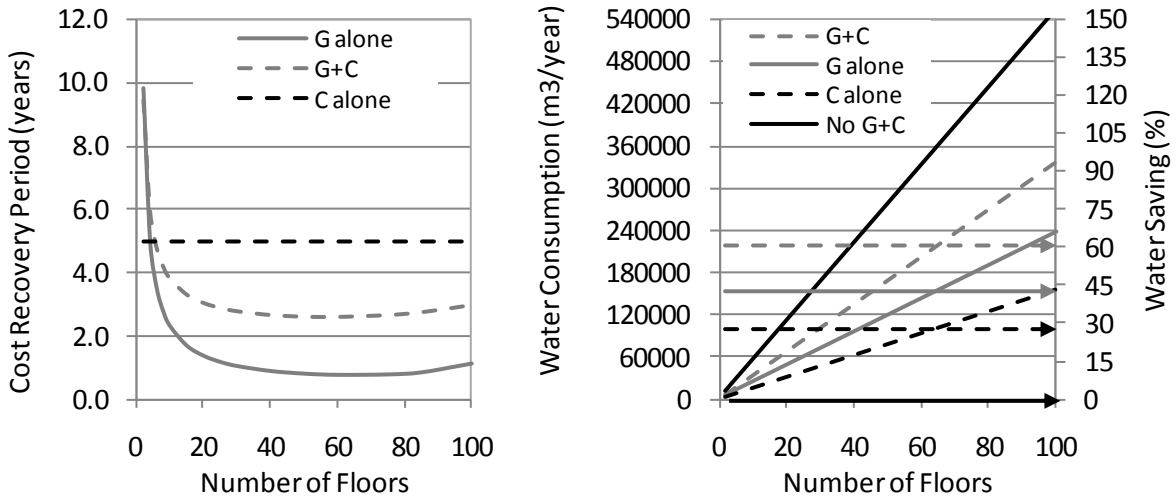

Figure 4. Full recycling of available greywater: installation cost recovery and water savings. (G=greywater recycling alone; C= conservation alone; and G+C=conservation + greywater recycling. Arrows identify relevant axis)

Given the high cost of water in the UAE, the choice of the greywater treatment system determines the economic feasibility of greywater recycling for individual dwellings. For example, the MBR system chosen in this study is economically infeasible for a single dwelling. An important factor relates to the convenience of greywater recycling for individual dwellings. Subsidies and other incentives can help make individual installations more attractive to consumers; however the issues of risk (actual or perceived) and convenience remain as limitations.

Compared to greywater recycling in multi-storey buildings, shared greywater recycling systems for a number of detached dwellings is complicated by the need for greywater collection and distribution systems that extend beyond the boundaries of individual buildings. In addition, shared greywater recycling require land space for installing such systems. However, with proper incentives, shared greywater recycling systems can be feasible for clustered dwellings.

Based on the above discussion, effective water conservation offers the most economical option for detached dwellings, especially in terms of minimizing the need for irrigation water through the use of native plant species and drip irrigation systems. For UAE nationals who typically live in detached dwellings and who effectively get free water, the government can minimize water

consumption through demanding effective water conservation measures in exchange for free or highly subsidized water supply.

Public and environmental benefits

It is clear from the analysis presented in the above sections that significant water savings can be achieved in the UAE through combing water conservation and greywater recycling. In addition, both water conservation and greywater recycling are economically feasible options in multi-storey residential buildings in the UAE.

The benefits of combining water conservation and greywater recycling in buildings extend beyond the consumers to the community and the concerned government authorities. Water conservation and greywater recycling, and therefore reduced water supply and wastewater generation, delay the need for expanding water and wastewater treatment and conveyance infrastructure and save associated water subsidies. With the cost of water desalination and conveyance exceeding US$2/m^3 in the UAE, the annual savings to the water provider, in terms of delayed investment, can be significant. The savings suggest that the water authorities should encourage conservation and greywater recycling through alternatives such as providing subsidies and adopting proper policies, including water pricing, to encourage water conservation and greywater recycling.

In addition to the economic benefits both to consumer and government authorities, greywater recycling and the associated reduced water demand and wastewater generation have positive impacts on the environment and natural water resources. All of these benefits confirm that conservation and recycling should be essential features of water management in the UAE.

Limitations to water conservation and greywater recycling in the UAE

It is clear from the analysis presented in the above sections that both water conservation and greywater recycling can be feasible alternatives for reducing water demand and wastewater generation for domestic consumers in the UAE. The feasibility of water conservation is a critical factor in determining the level of participation in water conservation or greywater recycling. However, there are other considerations that can limit the level of participation in water conservation and greywater recycling in the UAE.

With less than 15% of the population being UAE nationals who effectively receive free or highly subsidized water, implementation of water saving measures for this sector of the population is not economically feasible unless such measures and their implementation are highly subsidized by the government. The remaining more than 85% of the UAE population are expatriates who mostly do not own their own homes. Consequently, the incentive for landlords to provide the infrastructure necessary for water conservation and greywater recycling, especially with regards to retrofitting existing buildings, is currently limited or non-existent. Recently, some UAE government bodies required developers to achieve a certain level of "sustainability" in new buildings as a condition for obtaining permits.

The water charges paid by expatriate consumers are significant, which makes water conservation and greywater recycling highly desirable and feasible. However, the water authorities and concerned government bodies should adopt policies and provide incentives to make water conservation and greywater recycling attractive for landlords as well as their tenants. Currently, the law in the UAE does not directly address greywater recycling for internal reuse (i.e., flushing toilets) and the collection and treatment of wastewater or greywater is considered a regulated activity that cannot be undertaken without a licence or exception. The UAE Regulation and Supervision Beaurue (2011) suggested that greywater recycling solely for external purposes such as irrigation would be facilitated by the government on a development-wide scale rather than

individual property, mainly due to risk-related factors. However, consideration of greywater recycling for toilet flushing is relatively new in the country and it is expected that with time current restrictions will be eased.

CONCLUSIONS

The high cost of desalination, and therefore the high cost of water, make water conservation and greywater recycling feasible alternatives for reducing water demand and wastewater generation in the UAE. The benefits of water conservation and greywater recycling extend beyond the consumers to the concerned water authorities and the environment.

The unique composition of the population in the UAE poses challenges to adopting water conservation and greywater recycling in the country. With the majority of the population being expatriates who do not own their own homes, the incentive for landlords to provide the necessary infrastructure for water conservation and greywater recycling is currently limited or nonexistent. Furthermore, the current requirements of the law may not permit greywater recycling for internal reuse in buildings. Therefore, the water authorities and concerned government bodies should adopt appropriate policies and provide incentives to make water conservation and greywater recycling possible and attractive for landlords, as well as their tenants.

In this study, partial greywater recycling is proposed to reduce the costs of pumping and installation whenever the demand for greywater is less than the potentially available greywater. In multi-storey buildings, partial recycling can be achieved by collecting greywater from the higher floors to serve the needs of the whole building. Furthermore, it is proposed that greywater treatment systems be located on the roofs of multi-storey buildings to reduce the need for indoor space and the need for extra odor control systems.

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