Water Consumption in Dormitories: Insight from an Analysis in the USA

Umberto Berardi and Nakisa Alborzfard

Abstract Worldwide depletion of resources has brought many sustainability issues to the forefront including the consumption of water use for indoor purposes. Based on various studies, the third largest consumption of water occurs in buildings, mainly for flushing and personal hygiene. The United States Department of Energy and European Commission places domestic indoor water use at more than 250 L per person per day. This chapter examines the water consumption in Leadership in Energy and Environmental Design (LEED) and non-LEED-certified dormitories. LEED is a sustainability rating system providing guidance on incorporating sustainable design strategies in the design of buildings. LEED offers various rating levels including certified, silver, gold, and platinum out of a possible 100 base points. The varying levels are associated with target points achieved. Three LEED and six non-LEED dormitories, located in the northeast, serving over 2,000 students, were selected for this comparative study. Different categorization of dormitories by varied agencies and the inconsistency in water-use studies make isolating water consumption in dormitories problematic. Considering the fact that the International and Uniform Plumbing Codes do not require to calculate the water consumption in buildings, and engineers' calculations have been used to create baseline water use for the nine dormitories. The perception of water consumption behavior of occupants has also been investigated through users' surveys. Finally, a comparison among the design evaluation, actual water consumption and subjectively evaluated consumption allows highlighting water consumption in dormitories.

Keywords Dormitories · LEED · Sustainable buildings · Water consumption

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Abbreviations

AIA	American Institute of Architects
AWWA	American Water Works Association
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CNT	Center for Neighborhood Technology
EEA	European Environment Agency
EC	European Commission
EPA	Environmental Protection Agency
EU	European Union
HE	Higher education
IAMPO	International Association of Plumbing and Mechanical Officials
ICC	International Code Council
ILFI	International Living Future Institute
LBC	Living Building Challenge
LEED	Leadership in Energy and Environmental Design
LPD	Liters per person per day
LPF	Liters per flush
LPM	Liters per minute
NWS	National Weather Service
OECD	Organization for Economic Co-operation and Development
POE	Post Occupancy Evaluation
RIBA	Royal Institute of British Architects
SIU	Southern Illinois University
USGS	United States Geological Survey
US	United States
US-DOE	United States Department of Energy
WE	Water efficiency

1 Introduction

In 2050, global population, water demand, and global gross domestic product should increase by 30, 55, and 100 %, respectively (OECD 2012). Moreover, by 2050, almost 70 % of the world population is projected to live in cities, relying on public water supply (OECD 2012). As a result, future urban developments will further stress public water supply infrastructures.

Less than 1 % of the world water is freshwater and can be adapted for human use (ILFI 2011). Given this already limited resource, current and future challenges of sustainable water consumption and recharge have become ever more pressing. The current state of water extraction from groundwater and freshwater sources has resulted in dramatic negative environmental impacts, such as water depletion, quality reduction, waterlogging, salinization, annual discharge reduction, and contamination of potable water sources (OECD 2012; EEA 2012). Excessive diversion of river waters has also led to lowering of groundwater tables and saltwater infiltration in coastal areas (EEA 2012). These considerations impose to promote more sustainable water management and use. In particular, this chapter will focus on the opportunities available in a particular typology of buildings in the USA, which is the dormitory.

In the USA, the United States Geological Survey (USGS) works in collaboration with local, state, and federal agencies to collect water-use data. USGS has several goals including: (1) analyzing source, use, and disposition of water resources at local, state, and national levels; (2) replying to water-use information requests from the public; (3) documenting water-use trends; (4) cooperating with state and local agencies on projects of special interest; (5) developing water-use databases; and (6) publishing water-use data reports outlining domestic (residential) water consumption from self-supplied (i.e., wells) and public-supplied (i.e., state agencies) sources. Domestic (residential) water use typically includes drinking, food preparation, washing clothes and dishes, flushing toilets, and outdoor applications include watering lawns and washing cars (USGS 2013).

In the last decade, almost every region in the USA has experienced water shortages, and at least 36 US states have recently anticipated local, regional, or statewide water shortages under non-drought conditions (Shi et al. 2013). Researches show that due to increases in water demand and droughts, water has not been recharged at sustainable rates (Shi et al. 2013). This points to the need to promote sustainable pathways, which consider population growth, climate change, and water-use habits to decrease risks of future water shortages and challenges in our ability to source water (The National Academies 2008; Shi et al. 2013).

From the total water withdrawn for all uses in the USA, domestic water use has an estimated value of 111.3 billion L per day (LPD) (USGS 2009). The consumptions differ from 193 L per person per day in Maine to 715 LPD in Nevada, with the national average at 375 LPD (USGS 2009). The Environmental Protection Agency (EPA) WaterSense program reports a similar average value of 379 LPD, of which 70 % (265 LPD) is assumed for indoor purposes (EPA 2013).

Since this chapter focuses on water consumption in dormitories, it may be a misrepresentation to compare the residential case studies to dormitories, as they include outdoor water consumption values. A lack of uniformity in USA water-use study methods and variables results in the inability to use available reports for comparisons (SIU 2002). Categorical disparities of dormitories (commercial or domestic) by USGS and United States Department of Energy (US-DOE) further complicate isolating water use in dormitories (USGS 2009; US-DOE 2013a, b). USGS does not explicitly categorize building types, resulting in ambiguity on whether dormitories fall under the commercial or residential data set. Commercial water-use data were not collected by USGS in the 2000 and 2005 reports (USGS

2000, 2009). However, in the 1995 report, below the commercial category, the following building typologies were identified: hotels, motels, restaurants, office buildings, other commercial facilities, and civilian and military institutions (USGS 1995). These building types are very different from dormitories, and their water consumption values do not reflect the indoor water-use purposes in dormitories. Residential values suggested by USGS seem more applicable to dormitories, although they include outdoor applications (watering lawns, gardening, and washing cars).

US-DOE categorizes dormitories under lodging, a commercial category. However, the US-DOE relies on the USGS datasets for water use reporting per sector. Given the inconsistency between the USGS and US-DOE building categorization, no explicit US data on indoor water consumption of dormitories exist.

Examining water consumption in the European Union (EU) between 60 and 80 % of public supply water is used for domestic applications, of which personal hygiene and flushing account for 60 % (Mudgal and Lauranson 2009). Case studies from different member states showed domestic water consumption of 168 LPD on average (Mudgal and Lauranson 2009).

The overall withdrawals in the EU are projected to decrease by almost 11 % in 2020 (Floerke and Alcamo 2004). However, a major unknown variable of water use in EU is the domestic water consumption (Floerke and Alcamo 2004). Given the current increase in water consumption in urban area and the increasing effects of climate changes, the Mediterranean river basins are continuing to face water stress (EEA 2012). These stresses pose threats to the availability of clean potable water and might increase the need for more sophisticated wastewater treatment methods. The Environment Directorate-General European Commission (EC) carried out a water performance of buildings study (Mudgal and Lauranson 2009), which does not explicitly categorize dormitories. However, EC identifies educational buildings in the non-residential public sector, although a lack of water consumption data exists for this category.

Differences between EU and US study methodologies and building categorizations compound problems of isolating dormitory water consumption. To address the lack of available water consumption data in dormitories, this chapter assesses and compares the water consumption in some US dormitories. Different uses of water, such as washing dishes and clothing, flushing toilets, and showering, are taken into account (Vickers 2001; Schleich and Hillenbrand 2009).

Many factors influence water consumption such as geographical location, climate, culture, gender, and occupant behavior (Vickers 2001; Balling et al. 2008; Randolph and Troy 2008; Schleich and Hillenbrand 2009; Vinz 2009; Elliott 2013; Berardi 2013a). To mitigate the effect of these variables, the present study considers water-related practices in several dormitories over the last 10 years.

This chapter is structured in the following way: Sect. 2 focuses on water efficiency (WE) strategies in sustainability rating systems, Sect. 3 presents the methodology of the case study research, Sect. 4 presents the case study results, and Sect. 5 highlights main conclusions.

2 Sustainability Rating Systems and Water Efficiency Strategies

Voluntary sustainability rating systems including LEED (USGBC 2009), BRE Environmental Assessment Method (BREEAM 2008), Comprehensive Assessment System for Built Environment Efficiency (CASBEE 2010), and Living Building Challenge (LBC 2012; Green Globes 2012) recommend use of water-efficient flow fixtures to minimize water demand. Guidance is also provided for the minimization of wastewater effluent into existing treatment infrastructures by implementing onsite treatment strategies.

Some of the shared water-saving strategies recommended by the rating systems and professional associations such as the American Institute of Architects (AIA) and the Royal Institute of British Architects (RIBA) include low-flow fixtures, dual-flush toilets, ultra-low-flow or waterless urinals, infrared sensors, timed automatic shutoff faucets, low water-use washing machines and dishwashers, rainwater catchment, gray water use, and onsite wastewater treatment. Gray water is untreated wastewater which has not come in contact with toilet water, and it includes water from bathroom washbasins or laundry tubs (USGBC 2009). Onsite wastewater treatment can reduce the quantity of effluent treated in the public treatment infrastructures, reducing overall energy demands to treat and transport effluent (AIA 2007; USGBC 2009; LBC 2012). Onsite-treated water can be reused within the building for non-potable purposes such as toilet flushing, minimizing demand from public water supply infrastructures. Various strategies might be implemented to accomplish secondary- or tertiary-level treatment of wastewater including anaerobic septic tanks, anoxic reactors, closed aerobic tanks with plants to filter gases, open aerobic tanks with snails, shrimp and fish, redirection of sludge to septic tanks or composting of sludge, and redirection of polluted water to indoor wetlands for filtration (AIA 2007; ILFI 2011; LBC 2012).

Table 1 provides an overview of recommended water-saving flow fixture efficiencies in liters per flush (LPF) for toilets and liters per minute (LPM) for showerheads, lavatory, and kitchen faucets. As can be seen, difference between recommended efficiencies by rating system exists. In cases such as CASBEE and LBC, a prescriptive value is missing, and it is at the discretion of designers to select and specify the appropriate fixture technology to meet water-saving target goals.

However, water-efficient fixtures and treatment strategies alone may be insufficient to reduce consumption, as users' behavior is critical in lowering overall water consumption (Stevenson and Leaman 2010). The collection of users' feedback about WE strategies in the buildings and the education on consuming less water plays a key role in supporting WE strategies. Active participation of users and post occupancy evaluations (POEs) are significant to uphold sustainability in practice. Various researchers highlight the need to adopt education campaigns to promote more sustainable users' behaviors (Stevenson and Leaman 2010; Sterling et al. 2013; Berardi 2013a).

Table 1 Efficiencies of water-saving flow fixtures

Rating system and professional best practices	Toilet efficiency targets (LPF)	Shower efficiency targets (LPM)	Lavatory faucet targets (LPM)	Kitchen faucet targets (LPM)
LEED	≤6 LPF	≤9.5 LPM	≤8.5 LPM	≤8.5 LPM
BREEAM	Dual flush: ≤3 LPF (low) to ≤4.5 LPF (full)		≤6 LPM	Two-stage faucets with low flow for rinsing and higher flow for filling objects
CASBEE	Specific target values not provided			
LBC	Specific target values not provided			
Green Globes	≤6 LPF	≤9 LPM	≤7.5 LPM	≤7.5 LPM
AIA	≤4.9 LPF	≤6.6 LPM	≤3.8 LPM	≤7.6 LPM
	Dual flush: ≤3.6 LPF (low) to ≤5.7 LPF (full)			
RIBA	Specific target values not provided, suggested referring to other reference sources including BREEAM			

Some examples of organizations, agencies, and programs that are promoting sustainable water practices in the USA include the following: the Center for Neighborhood Technology (CNT), Nature's Voice-Our Choice, Water Use it Wisely, Save our Water, Stop the water while using me, and EPA WaterSense. These agencies and programs provide suggestions on water conservation and water-saving strategies and promote WE through behavioral changes.

Design strategies and users are hence strongly linked in the process of making sustainability a reality (Stevenson and Leaman 2010; Berardi 2013a; GhaffarianHoseini et al. 2013). A bridge between modeled design and actual outcome is represented by POEs. POEs ensure users are satisfied with their current conditions and inform future designs (Bordass et al. 2006, 2010; Stevenson and Leaman 2010; Berardi 2012). Design strategy labeling can also be developed through the collection of user feedback, further identifying which sustainable strategies to avoid and promote in practice (Bordass et al. 2006; Berardi 2013b).

3 Case Study Overview and Methodology

Three LEED and six non-LEED dormitories, varying from 3 to 62 years of age, comprise the studied dataset. The research methodology involved the collection of various specifications including number and gender split of students served, flow fixture efficiencies, actual water meter readings, and LEED documentation pertaining to WE credits in LEED-certified dormitories.

Data were gathered from designers, facilities departments, and residential life offices of the various higher education (HE) institutions. All dormitories are

Table 2 Overview of dormitories

Bldg.	Rating	Age years	No. of users	Gender split (% of female)	Location	Building zone[a]
EH	LEED-Gold	5	232	F = 31	Northeast	Cold
CSC	LEED-Gold	3	450	F = 53	Northeast	Mixed-humid
PS	LEED-Silver	3	622	F = 44	West Coast	Hot-dry
WT	Non-LEED	11	475	F = 18	Northeast	Cold
MH1	Non-LEED	62	284	F = 60	Northeast	Cold
MH2	Non-LEED	52	190	F = 49	Northeast	Cold
MH3	Non-LEED	47	190	F = 60	Northeast	Cold
HH	Non-LEED	54	163	F = 50	Northeast	Cold
KH	Non-LEED	52	191	F = 53	Northeast	Cold

[a]Based on US-DOE (2013a, b)

located in the USA with eight in the northeast and one on the West Coast. For the purposes of anonymity, acronyms designate the dormitories. Table 2 provides main building data of the selected dormitories.

Monthly actual water meter readings were collected for EH, PS, WT, MH1, MH2, MH3, HH, and KH and quarterly actual water meter readings for CSC. The average number of students served per year allowed calculating the liters per person per day (LPD) metrics and comparing water performance. Dormitories EH, CSC, WT, MH1, MH2, MH3, HH, and KH are located in the northeast, experiencing cold to mixed-humid climates, whereas dormitory PS is located on the West Coast, experiencing a hot-dry climate.

Typically, the peak water consumption occurs in summer (AWWA 1999). The weather in the USA followed typical patterns in the years from 2002 to 2009 and in 2011 and 2013; reversely, in 2010, the coldest winter was experienced, and in 2012, record summer heat and mildest winter was recorded (NWS 2013).

Flow fixture efficiency values were collected to highlight differences in technologies used in dormitories. Non-LEED flow fixture data were collected from the HE facilities departments and walkthroughs, while WE documentation was collected from designers for LEED dormitories. Dormitory age was also recorded as newer dormitories are less likely to experience plumbing leakages and may have implemented higher efficiency fixtures.

3.1 Engineer's Metrics

The International and Uniform Plumbing Codes do not require designers to calculate total water consumption of buildings (ICC 2009; IAMPO 2009); hence, engineer's metrics were calculated based on the EC report, providing European metrics (Mudgal and Lauranson 2009), and the AWWA report, providing guidance on US metrics (AWWA 1999).

The AWWA report values are based on data from over 1,000 households in 12 study sites around the USA. The data include historic billing records and detailed mail surveys, broken into two sets to capture winter and summer indoor water consumption. The AWWA water end-use findings are as follows: 70 LPD for toilet use, 57 LPD for clothes washer, 44 LPD for shower use, 41 LPD for faucet use, 36 LPD for leaks, 5 LPD for baths, 4 LPD for dishwasher, and 6 LPD for other domestic use (AWWA 1999). In calculating the comparative AWWA metric, the value applicable to dormitories was assessed to be 212 LPD (including toilet use, clothes washer, shower use, and faucet).

The EC report values are based on information collected from local case studies in different European member states, feedback from stakeholders, and a literature search. Findings in water using products of residential buildings are 41 LPD toilet use, 26 LPD clothes washer, 37 LPD showers, 29 LPD faucet use, 10 LPD dishwasher, and 11 LPD outdoor use (Mudgal and Lauranson 2009). Calculating the comparative EC metric, the value applicable to dormitories is 143 LPD.

4 Results and Discussion

4.1 Average Overall (LEED and Non-LEED) Actual Water Consumption

As indicated in Table 3, the overall range of actual LEED and non-LEED dormitory water consumption fell between 85 and 175 LPD, with an average of 144 LPD and a standard deviation of 34 LPD. Comparing the average consumption to the EC and AWWA engineer's metrics, the consumption was higher by almost 1 and 32 %, respectively.

Figure 1 depicts the actual water consumption of the nine dormitories in LPD: LEED dormitory EH is the top performer followed by non-LEED dormitories WT and HH, while LEED dormitory PS performed slightly better than the poorest performer non-LEED dormitory MH1.

4.2 Non-LEED Dormitories

The average water consumption of non-LEED dormitories was 146 LPD with a standard deviation of 30 LPD. Figure 2 provides a profile of the water consumption of the six non-LEED dormitories over the years. In the dormitory WT, the averaged consumption resulted 107 LPD with a 3 % increase in consumption over the 12 years. Although the increasing consumptions, these are lower than to the engineer's metrics by 25 and 45 %, respectively. Excluding WT from the non-LEED dataset, the average consumption resulted 154 LPD. Comparing this average to the engineer's metrics, the consumption is higher by 8 % and lower by

Table 3 Average overall water consumption results in liters per person per day (LPD)

Bldg.	Data range dates	Sample size 'N'	Actual average consumption (LPD)	Standard deviation of Bldg. Dataset (LPD)	Comparison of actual to EC engineer's metric (143 LPD) (%)	Comparison of actual to US engineer's metric (212 LPD) (%)
EH	September '08–June '12	46	85	52	−41	−60
WT	January '02–June '13	138	107	37	−25	−50
HH	July '07–May '12	59	110	74	−23	−48
MH2	July '07–June '12	60	160	104	+12	−25
KH	July '07–June '12	60	162	114	+13	−24
CSC	May '11–April '13	24	163	82	+14	−23
MH3	July '07–June '12	60	164	98	+15	−23
PS	July '11–May '13	23	172	107	+20	−19
MH1	July '07–June '12	60	175	101	+22	−18

38 %, respectively. In dormitories MH1, MH2, MH3, KH, and HH, the percent net change over the 5 years was 3 % indicating an uptick. Dormitories HH and KH showed the highest variation over the years versus steadier consumption in MH1, MH2, MH3, and WT (Fig. 2).

Factors specific to dormitories that affect the vary consumption include institutional academic schedules together with water technologies the other factors

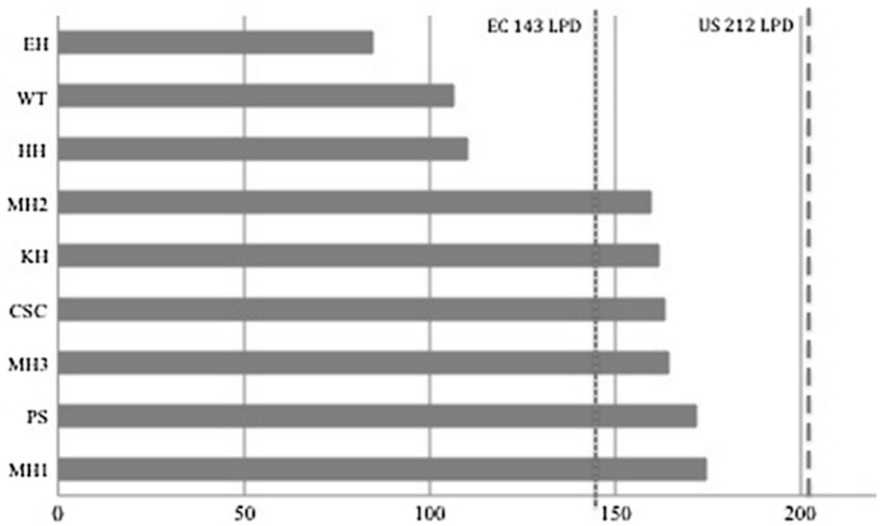

Fig. 1 Actual water consumption of the nine dormitories in LPD (compared to engineer's metrics)

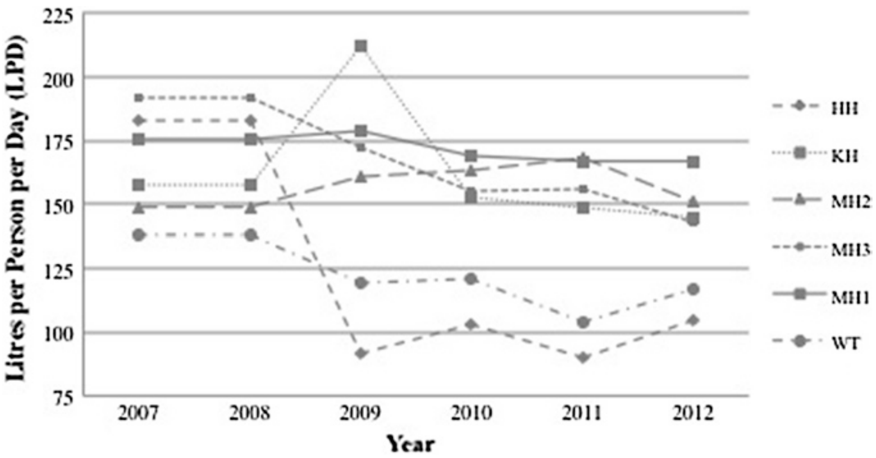

Fig. 2 Actual average yearly water consumption of non-LEED dormitories in LPD

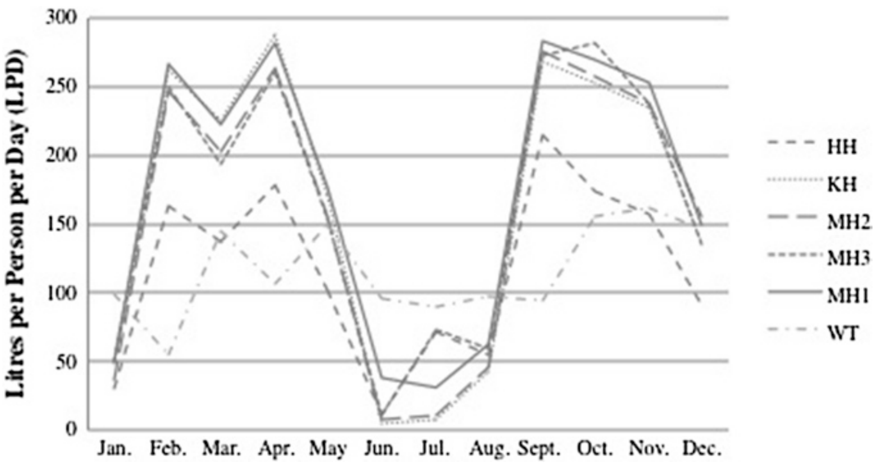

Fig. 3 Actual average (from 2007 to 2012) monthly water consumption of non-LEED dormitories in LPD

outlined in Sect. 1 (geographical location, climate, culture, gender, and occupant behavior).

In an effort to investigate the high variations, an exploration of the monthly consumption values over the years is provided in Fig. 3, showing average monthly LPD of the six non-LEED dormitories.

The months with the highest average consumption were during the fall and spring semesters for dormitories MH1, MH2, MH3, KH, and HH. The water consumption for the summer months (June, July, and August) was the lowest, followed by January winter recess. The highest consumption periods were attributed to periods of high occupancy (returning students) and the warmer months within those periods. Dormitory WT also experienced consumption during the summer months (June, July, and August) as it operates year round due to academic requirements in the summer. Reversely, dormitories MH1, MH2, MH3, KH, and HH do not have summer sessions and showed minimal summer consumption.

4.3 LEED Dormitories

4.3.1 Dormitory EH

In calculating the LEED green case, designers assume a specific number of days the dormitory will be in operation. The assumed operational days play an important part over the water performance calculation. The assumption is generally based on the information provided by owner's facilities departments according to academic schedules.

Designers of dormitory EH used 305 days and estimated a green case consumption of 89 LPD. Using the 305-day assumption, dormitory EH resulted in the lowest average water consumption when compared to all the dormitories (LEED and non-LEED). The average yearly consumption values from 2008 to 2012 were 133, 62, 68, 78, and 82 LPD, respectively. Although dormitory EH outperformed its counterparts in further dissecting the water consumption over the years, an increase resulted. If the consumption of the first (commissioning) and last years (hottest summer) is excluded, the average consumption is 69 LPD. This value is 29 % lower than the 'green' case. EH actual consumption was less than modeled consumption by 22 % over the 3-year period (2009–2011), but only by 4 % over the 5-year period (2008–2012).

To further explore the discrepancy between actual and LEED case consumption values, an online user survey was distributed to EH occupants. Since 44 % of indoor residential water end use is related to shower and toilet use (AWWA 1999), questions were developed on the shared assumptions used in LEED (USGBC 2009) and AWWA (1999) about shower duration (8 min), shower frequency (1/day/occupant), and toilet flushes (5 flushes/occupant/day). Sixty occupants answered the questionnaire in the 2 weeks following the survey distribution (November 2010), a value corresponding to 26 % of students living in the dormitory at the time. Figure 4 provides the percent breakdown of responses to the LEED and AWWA assumptions posed in the user survey.

The responses indicate shower frequency and daily toilet flushes fall within shared thresholds of AWWA and LEED design assumptions. However, the shower duration assumptions of 8 min dramatically fell short. Over 87 % of respondents indicated taking longer than 15-min showers. Such variations in actual practice versus modeled assumptions can result in large differences in water estimations and performance evaluations. These results confirm that highlight

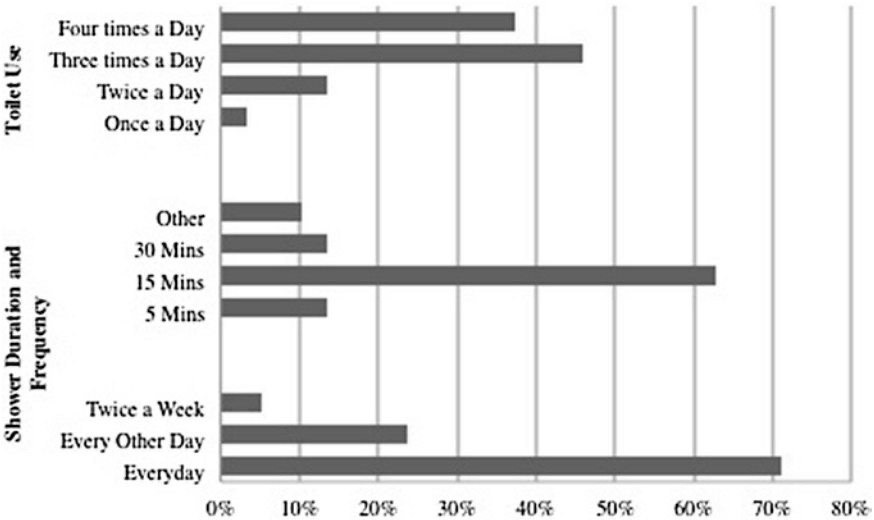

Fig. 4 Occupant responses on toilet use, shower duration, and shower frequency in dormitory EH

occupants' attitudes and behaviors have substantial impacts on promoting sustainability in practice (Barr 2003; Bamberg 2003; Hand et al. 2003; Hurlimann 2006; Alshuwaikhat and Abubakar 2008; Randolph and Troy 2008).

4.3.2 Dormitory CSC

CSC designers assumed 360 operational days, with a LEED 'green' case of 88 LPD. CSC exceeded modeled consumption by an average of 85 % over the 3-year period (2011–2013). The yearly consumption values for 2011, 2012, and 2013 were 147, 170, and 172 LPD, respectively, resulting in drastic percent increase in consumption as compared to the modeled case of 67 % higher, 93 % higher, and 95 % consumption in 2011, 2012, and 2013, respectively. As previously mentioned, part of the increase may be due to record heat in 2012. However, drastic percent increases in consumption over the years, echo the findings of other dormitories which behaved less sustainably over time.

4.3.3 Dormitory PS

PS designers assumed 250 operational days with a LEED 'green' case of 87 LPD. The yearly consumption values for 2011, 2012, and 2013 were 198, 146, and 171 LPD, respectively, resulting in differences in consumption as compared to the modeled case of 128 % higher, 68 % higher, and 97 % higher in 2011, 2012, and 2103, respectively. Dormitory PS actual consumption exceeded modeled consumption by an average of 98 % over the three-year period. It must be noted given the dormitories location that its occupants may have been better equipped to handle the heat of 2012, as consumption of PS in that year was lower than in any other year.

4.3.4 Comparison of LEED and Non-LEED Dormitories

Exploring the age and technologies employed among the dormitories, the average age of non-LEED dormitories is 46 years, while the average age of LEED dormitories is 4 years. Dormitories EH, WT, CSC, and PS were built in 2008, 2002, 2011, and 2011, respectively, where the 1992 and 2005 Federal Energy Policy Act (FEPA) were already in place. This act includes maximum consumption for fixtures of 9.5 LPM and 6.0 LPF. MH1, HH, MH2, KH, and MH3 were built in 1951, 1959, 1961, 1961 and 1966, respectively, and do not comply with the 1992 or 2005 Federal Energy Policy Act.

All non-LEED dormitories and dormitory CSC used full flush toilets, while EH and PS used dual-flush toilets (low/full). Figure 5 represents the average and standard deviation of flow fixture rates in LEED and non-LEED dormitories in LPM for lavatory, kitchen sink, and shower fixtures and in LPF for toilets.

Non-LEED dormitories used flow fixtures with 6.4, 7.9, and 7.9 LPM for shower, lavatory, and kitchen sink, respectively, with toilets using 10.9 LPF, whereas LEED dormitories used flow fixtures with 5.9, 1.9, and 8.1 LPM for shower, lavatory, and kitchen sink, respectively, with toilets using 3.6 and 5.7 LPF for low and full flush, respectively.

Even though non-LEED flow fixtures were higher on average, the dormitories outperformed LEED ones in terms of total LPD. This finding indicates sole reliance on technology to lower overall consumption which might not be the answer.

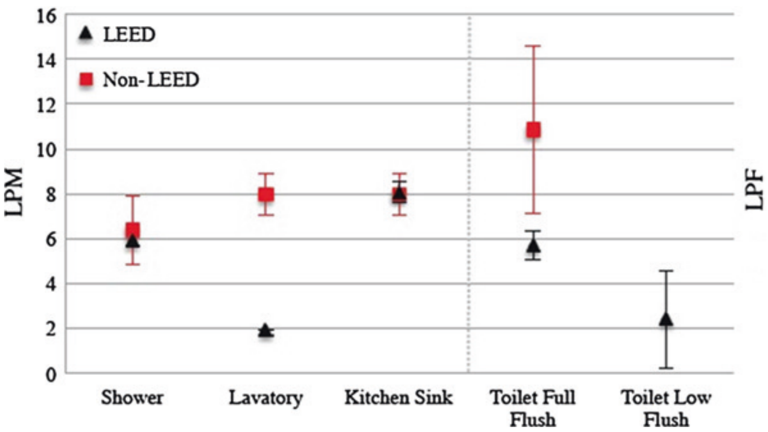

Fig. 5 Average flow fixture rates in LPM and LPF for LEED and non-LEED dormitories

Attention must be given to occupant expectations and behaviors. For example, some respondents in the EH survey commented about their frustrations with low-flow fixtures and declared they replaced low-flow showerheads with higher flow fixtures, while others indicated taking longer showers. Similar comments were provided for low-flow toilets, where respondents indicated often double and triple flushing as the toilet low flush was simply not sufficient. These results confirm the role of users as critical factors for sustainability.

To further highlight how climate impacted the consumption of the dataset, bivariate correlation analysis was carried out. The analysis tested the relationship between average monthly temperature and consumption in LPD. The bivariate correlation analysis was done using IBM SPSS Statistics software version 19. The analysis excluded summer months of all dormitories, except in the case of WT, which has summer semesters.

The results indicate a positive correlation between average monthly temperature and LPD consumption in all dormitories except PS; however, the correlations are not significant (95 % or above). It must be noted in dormitory EH, HH, MH2, MH3, and MH1 the significance surpass 90 %, supporting the work of previous researchers. Table 4 provides the bivariate correlation results per dormitory.

In the case of PS, the number of observations in the dataset was only 18; therefore, the negative correlation result may be attributed to the small sample size. In the case of WT with over 10 years of data and inclusion of the warmest months, the correlation between average monthly temperature and LPD consumption was positive yet weak. This indicates that temperature has a negligible impact on the consumption patterns. In order to dissect this weak correlation, the 12-month average monthly temperature moving average was compared to highlight variations due to seasonality. It can be seen in Fig. 6 that no variations due to seasonality exist, and average temperatures were relatively steady over the 10-year period.

Table 4 Bivariate correlation results of average monthly temperature and liters per person per day (LPD) consumption

Bldg.	Building zone[a]	Dates of data range[b]	Bivariate correlation results $R_{d.f.}$ $(N-2) = r$, ρ
EH	Cold	Sept. '08–June '12	$r(30) = 0.284$, $\rho < 0.057$
WT	Mixed-humid	Jan '02–June '13	$r(136) = 0.015$, $\rho < 0.432$
HH	Hot-dry	July '07–May '12	$r(38) = 0.237$, $\rho < 0.070$
MH2	Cold	July '07–June '12	$r(38) = 0.213$, $\rho < 0.094$
KH	Cold	July '07–June '12	$r(38) = 0.150$, $\rho < 0.177$
CSC	Cold	May'11–April 13	$r(16) = 0.217$, $\rho < 0.193$
MH3	Cold	July '07–June '12	$r(38) = 0.259$, $\rho < 0.053$
PS	Cold	July '11–May '13	$r(16) = -0.079$, $\rho < 0.378$
MH1	Cold	July '07–June '12	$r(38) = 0.248$, $\rho < 0.061$

[a]Based on United States Department of Energy (USDOE 2013a, b)
[b]Excludes summer months when students are not on campus except in the case of WT, since summer semesters are required as part of the academic program

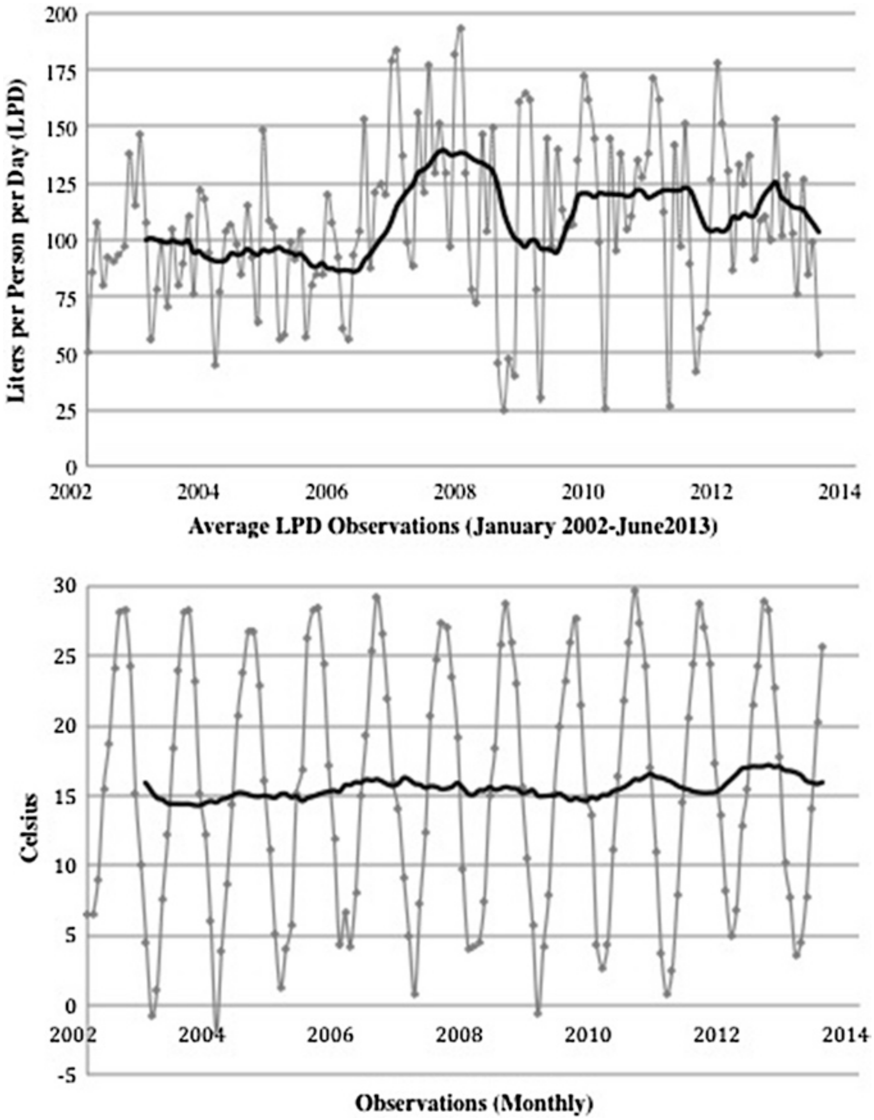

Fig. 6 Twelve-month LPD moving average and 12-month average monthly temperature moving average (January 2002–June 2013)

This indicates that other variables, such as user consumption behavior, might be the driving force behind consumption variations. Figure 6 also provides a plot of the 12-month LPD moving average over the 10-year period. As can be seen, the consumption patterns are not uniform and vary substantially from year to year.

Examining the average water consumption of LEED dormitories between years, building EH, CSC, and PS consumed 10 % more, 9 % more, and 5 % less, respectively, between yearly readings. However, compared to their LEED 'green' cases, the average yearly consumptions of EH, CSC, and PS were 4 % lower, 85 % higher, and 98 % higher, respectively. These values result in an overall percent increase in consumption of 60 % as compared to their LEED 'green' cases. Dormitory EH and CSC are LEED-Gold, while PS is LEED-Silver. Even though the LEED-Gold dormitory outperformed the LEED-Silver one, both did not provide the expected savings (Kats 2010). Moreover, LEED dormitory data indicate diminished consumption savings over time, rendering them less sustainable every year.

Non-LEED dormitories WT, MH1, MH2, MH3, KH, and HH resulted in an increase of 3 % in water consumption over the years. Based on the findings, on average, non-LEED dormitories outperformed LEED ones depicting steadier consumption profiles. It is interesting to note as the gender split equalized in dormitories, the consumption increased (Vinz 2009; Elliott 2013). Dormitories EH and WT had the highest male populations at 75 % on average, while dormitories MH1, MH2, MH3, KH, HH, PS, and CSC had average male populations of 47 %.

5 Conclusions

Water-related studies suggest we are consuming water at an unsustainable rate. Population growth, climate change, increased wealth, urban development, and mismanagement of water systems are over stressing our already fragile water infrastructures. These issues further compound the challenges faced with sustaining this necessity. As a result, we must engage new strategies to minimize consumption, pushing forth the idea of behavioral water conservation and not only fixture WE (Bennetts and Bordass 2007; Berardi 2013a). Tracking, measuring, and collecting user feedback are fundamental to understand consumptions. We can only develop conservation and management strategies, through an in-depth understanding of qualitative and quantitative feedback by implementing POEs.

In attempting to gain an understanding of dormitory water use, this chapter focused on identifying and comparing indoor water use of LEED and non-LEED certified dormitories. It addressed several scopes including identifying indoor water consumption in dormitories, comparing LEED to non-LEED dormitories, assessing LEED modeled case projections with actual water consumption, and comparing actual water consumption to developed engineer's metrics.

Evidently isolating water consumption of dormitories using US-DOE, USGS, AWWA, and EC data is problematic due to differences in the categorization of dormitories between water-use studies and a lack of available data. Different classifications of residential customers by utility companies also compound the problems in collecting published data on water consumption in dormitories.

To address this gap, actual consumption data were collected from nine dormitories, indicating indoor water ranges between 85 and 175 LPD. Overall average actual dormitory consumption was lower than values found in US-DOE (375 LPD), EPA (265 LPD), EC (168 LPD), AWWA US (212 LPD), and EC (143 LPD) engineer's metric. On average, non-LEED dormitories consumed 4 % more than LEED ones; however, the LEED buildings resulted in contrasting results with a high standard deviation of values.

On a yearly and monthly basis, non-LEED dormitories depicted steadier consumption values with an overall 3 % uptick for which the entire time data were collected. On the other hand, LEED dormitories showed an increase of 5 % over the years and, on average, higher variations in consumption patterns. The average water consumption of EH, CSC, and PS was 60 % higher when compared to the LEED 'green' cases. The data showed decreases in savings yearly, making LEED dormitories less sustainable every year. These results highlight the possibility that LEED labeling does not fully capture actual user behavior and might result in unrealistic savings expectations.

Examining assumptions of LEED and AWWA, over 87 % of respondents indicated longer than 15-min showers. Such vast differences in assumptions (8 min) and actual practice (over 15 min) must be ameliorated to ensure performance gaps are minimized. It is interesting to note as the gender differential equalized the consumption in the dormitories increased, tying to arguments made by researchers on the inequality of gender consumption. The best performing dormitories had 75 % males on average, while the poorer performing dormitories held 47 % males.

Finally, it is important to highlight technology alone may not guarantee water saving. Many factors impact water use including: geography, weather, socioeconomic factors, gender, and occupant behaviors. Larger reductions in water consumption need improved user attitudes and changes in occupant behaviors.

Further examination about the influence of previous variables on actual water consumption is needed. An in-depth understanding of users interact with designed building components is important to ensure sustainability in practice. Also, research about preferred water temperature is ongoing.

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