Energy and Buildings 80 (2014) 114–119

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

The impact of combined water and energy consumption eco-feedback on conservation

Seung Hyo Jeong [a], Rimas Gulbinas [a], Rishee K. Jain [b], John E. Taylor [a,*]

[a] Charles E. Via, Jr. Department of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA 24060, United States
[b] Center for Urban Science + Progress, New York University, Brooklyn, NY 11201, United States

ARTICLE INFO

Article history:
Received 22 February 2014
Received in revised form 30 April 2014
Accepted 9 May 2014
Available online 17 May 2014

Keywords:
Eco-feedback
Energy conservation
Water conservation
Water–energy nexus

ABSTRACT

Demand for water is increasing with buildings accounting for the large majority of increased water consumption. As such, the development of methods to effectively promote water conservation in buildings has become an important focal area for research. Specifically, providing feedback of resource consumption to residential building occupants has been demonstrated to be effective in promoting conservation. Although water and energy are inextricably connected, there is a lack of research that investigates the bridge between water and energy in the representation of feedback to promote water conservation. In this paper, we investigate the impact of two different representations of water consumption eco-feedback on water conservation (i.e., gallons and associated estimated embodied energy). We collected consumption data in 18 residential dormitories, involving nearly 4700 occupants over a period of approximately six weeks. We found that representing water consumption simultaneously in terms of gallons and associated embodied energy led to a statistically significant reduction in water consumption, while representing water consumption only in terms of gallons did not. This has significant implications for the growing body of research at the nexus between water and energy consumption and can inform future eco-feedback system designs.

1. Introduction

As the world's population increases, so will the demand for potable water. Supplies of fresh and potable water are finite and it is estimated that by 2030, only 60% of the global demand for potable water will be met [1]. In the United States, Roy et al. [2] identified many areas, e.g., California, Nevada, Texas and Florida that are at a high or extreme risk of not being able to meet potable water demand by 2050. However, despite this risk, the relative ease of access to potable water in the United States and other developed countries has resulted in misperceptions of potable water availability and its general overuse at the end-user level [3]. To curb these alarming trends in the developed world, targeted measures need to be taken to conserve water.

The built environment accounted for over 95% of water consumption growth between 1985 and 2005 in the United States [4]. As such, targeting buildings for water conservation represents a strategic approach to realizing significant overall water savings. Considerable research has examined the issue of modeling water consumption associated with buildings [5–8] and some work has begun to assess the interdependencies between water efficiency and energy efficiency in buildings [9]. In addition, occupant behavior has been shown to be a substantial factor in both energy [10–12] and water consumption [13,14] of buildings. In this paper, we examine the impact of providing eco-feedback at the nexus between water and energy consumption on water consumption in a study of 18 buildings occupied by nearly 4700 individuals.

2. Background

The challenges associated with meeting the demand for potable water are exacerbated by the inextricable link between water and energy; water distribution and consumption necessitates energy production, which itself necessitates additional water consumption. For example, Blackhurst et al. [15] reported that the power generation sector consumes nearly double the amount of water as the next biggest sector, grain farming, in the United States. The transition to renewable energy sources may help mitigate some of the water consumption associated with traditional power generation, but even these systems can require a substantial amount of water [16].

* Corresponding author. Tel.: +1 540 231 0972; fax: +1 540 231 7532.
E-mail addresses: sjeong1@vt.edu (S.H. Jeong), rimasg@vt.edu (R. Gulbinas), rishee.jain@nyu.edu (R.K. Jain), jet@vt.edu (J.E. Taylor).

http://dx.doi.org/10.1016/j.enbuild.2014.05.013
0378-7788/

An alternative approach to addressing the issue of water conservation is to direct efforts at demand-side conservation programs. Conservation programs offer an opportunity to definitively reduce both water and energy consumption. A recent analysis by Zhou et al. [17] quantified the potential of conservation programs to reduce both water and energy consumption for a major urban area in China. The analysis found that 1 Mt of water savings in the residential sector could yield over 0.4 Mt of coal equivalent energy savings. Furthermore, the household sector energy savings ratio was the highest among all other sectors (wastewater, industrial) in the study. One approach for motivating water and energy conservation in the residential sector is through behavior-based conservation campaigns, as occupant behavior has been shown to be an important driver of energy [10–12] and water usage [13,14] in buildings. Some campaigns have proven to effectively motivate conservation by providing building occupants resource consumption feedback, also referred to as "eco-feedback" [18–22]. Such energy conservation campaigns based on feedback have been shown to be effective in reducing consumption [23,24], and have resulted in the development of similar water feedback systems [25,26]. However, while feedback has been effective in motivating energy conservation, it has been shown to have little or inconsistent impact on the water conservation behavior of participants [27–29].

While targeted water-use feedback has been shown to be generally ineffective in motivating water conservation, environmental-impact attuned messaging has been shown to yield significant water savings. In a study by Kurz et al. [30], participants who understood the environmental impact of their water consumption were much more motivated than others to reduce their water consumption, and saved as much as 23% relative to normal levels. However, despite the observed impact of such message-combined water feedback, there is a dearth of research that explores the effectiveness of water–energy feedback on eliciting conservation behavior. We address this lack of understanding by conducting an empirical experiment to examine the efficacy of joint water–energy feedback. In our experiment, we convey water consumption levels as well as the "embodied energy in water"—a concept introduced by Mo et al. [31]—to residential building occupants. The primary goal of this study is to determine if providing participants with information on both water consumption and the embodied energy in that water consumed can overcome the limitations and mixed results of previous water-only feedback intervention strategies.

3. Methodology

3.1. Experimental design

The study was conducted in 18 Virginia Tech residential halls that house nearly 4700 students. Water consumption data was collected weekly at the building level. Weekly baseline readings were taken between August 27, 2012, and September 24, 2012, by Virginia Tech Electrical Services. The study period lasted six weeks, from September 24, 2012, through October 29, 2012. All of the water readings for the study were performed utilizing a handheld device that wirelessly and synchronously read water meters and ensured that the frequency and the rate of water data collection was consistent throughout the study.

Three groups were created to formulate testable hypotheses for investigating the effectiveness of water-only feedback and water–energy feedback on water conservation:

(1) *Control Group*: The control group did not receive any type of feedback or education, though water use was still monitored.
(2) *Water-Only Feedback Group*: The water-only group was provided with feedback on building level and per capita weekly, daily and cumulative water consumption in gallons. This group was also provided with education on the issues of excessive water consumption, such as decreasing freshwater sources and increasing potable water demand. General water conservation tips (e.g., turn off the faucet when brushing and shaving, take shorter showers) were also provided.
(3) *Water–Energy Feedback Group*: The water–energy group was provided with feedback on building level and per capita weekly, daily and cumulative water consumption (gallons) *as well as* the estimated embodied energy (kWh) associated with such consumption. Embodied energy was calculated by using equation (1). To provide a tangible unit for users to interpret embodied energy, it was communicated in terms of 'light bulb hours', which represent the number of hours a 100 W light bulb can stay lit utilizing the estimated embodied energy in water consumption. This group was provided with the same education and conservation tips as the water-only feedback group.

Table 1
Study groups and control group parameters.

Groups	Daily water per capita	Average # of males	Average # of females
Control	11.8	148	109
Water-only	13.4	153	119
Water–energy	12.6	146	112
Groups	**% Variance (per capita)**	**% Variance (males)**	**% Variance (females)**
Control	0	0	0
Water-only	12	3	8
Water–energy	7	−1	3

The number of residents and the distribution of males and females per residence hall were used in the formation of the study groups and the control group to ensure that they had similar demographics. Males and females have been shown to have different water consumption behaviors and different water conservation behaviors, resulting in different water conservation rates [32]. The purpose of having similar numbers of males and females for the water-only, the water–energy and the control group was to control for any group possibly conserving more water due to gender differences in the study population and to directly compare the relative effectiveness of water-only, water–energy and no feedback on water conservation. Each study group consisted of six residential halls. Study groups were selected so that the average per capita water consumption from the previous year across the groups was similar. Additionally, it should be pointed out that administrators strive to provide each residence hall with a demographically diverse population (e.g., gender, university major) when assigning students to residence halls. All study groups were located in the same geographical area (Virginia Tech, Blacksburg campus), ensuring consistent temperature and weather. Basing the study in residence halls at Virginia Tech also ensured that the residents were in similar facilities; e.g., all residence halls were confirmed to have laundry rooms and shared restrooms. Other externalities that could potentially impact relative levels of consumption were also controlled for in the analysis through the use of the control group. The summary of factors and the values of the study groups and the control group can be found in Table 1.

For the water–energy Feedback Group, the embodied energy in water consumption was estimated based on water consumption parameters presented in a report by the River Network [33]. The following equation was used to calculate the estimated embodied