Reducing Building Water Use Intensity (WUI): Tools for Academia and Practice

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Abstract

Recent prolonged droughts have increased water awareness worldwide, yet limited progress has been made to expand integrated building solutions. This paper investigates the critical tools needed by architectural practice and academia to support water efficient pedagogy and design. A water auditing protocol was developed, tested, and standardized during an undergraduate/graduate architecture water efficiency course over 2017-19. This paper presents the case study implementation of this tool for water use reduction in a commercial building in Tucson, Arizona. The paper ultimately evaluates the success of this new tool through four outcomes from the case study. First, a cutting-edge, service-learning pedagogical model was developed to teach water efficient design to architecture students. Second, the local water service provider was given a new tool for future commercial building owner compliance in the case of a Level 2 Drought declaration. Third, the water audit provided the building owner with cost-effective strategies to accomplish use reduction. Finally, the architectural professional community received a new tool for water efficient design and retrofit. The paper presents a tool for architecture students and professionals to expand integrated water efficient design for commercial buildings.

Introduction

Water awareness has increased with prolonged droughts in arid regions worldwide. Yet, the building profession has limited post-occupancy protocols and tools to evaluate advancements in integrated building solutions. Unlike energy, there are no certified, comprehensive auditing protocols for water. The apparent barrier had been expensive and invasive water metering technology. Using new, inexpensive electromagnetic metering technology, this research developed, tested, and standardized a water auditing protocol for commercial buildings. This study was conducted in Tucson, Arizona, a desert city in the Southwestern United States that has been under drought advisories since 1990. The city's water utility, Tucson Water, currently uses national use percentages to estimate fixture-level water use. This study provides a protocol and tool for architecture students to collect and analyze data to evaluate local water use at the fixture-level. Auditing and analysis is particularly important in drought prone cities to provide the data to determine the most efficacious water efficient building strategies for municipal investments.

In order to successfully understand and implement water efficient design and retrofit, the architectural profession needs standardized and accessible protocols and tools. To address this critical academic and professional need, a partnership was formed in 2017 between a regional architecture and engineering firm, a district member of a national energy and water efficiency organization (the 2030 District), local building owners signatories of that organization, and a undergraduate/graduate architecture water efficiency course. This public-private-academic partnership mobilized unique and complementary skills toward developing, testing, and disseminating a water auditing protocol. The district partner identified building owners and oversaw final efficiency measure implementation. The professional partners provided critical, detailed feedback to ensure usability of the protocol for national practice. The architecture course developed and tested the auditing process during 2017-19. Research findings were analyzed by the author with the integral involvement of professional partners.

This paper examines this new water auditing protocol through four goals: educate the next generation of architects to address water efficiency through design, expand community capacity, reduce commercial building water use, and increase professional tools. The paper begins with a discussion of past obstacles and new promising technology for water auditing. Next, the context of Southwestern drought and commercial building use is provided. Then, the methodology of the four module water auditing protocol is outlined. A case study audit of the Community Food Bank of Southern Arizona is provided to illustrate to auditing process. Findings from the testing of the protocol are analyzed. Finally, conclusions are shared for the new auditing tool to be used by the architectural profession and academy.

Past Obstacles and New Promise in Water Auditing Technology

The Need for Fixture-Level Auditing to Determine Regional Use Behavior

Currently, building water consumption by type of use is almost exclusively examined through self-reporting behavior methods, most commonly in residential settings.[1] [2] [3] [4] [5] Several pragmatic barriers have made the more precise method of fixture-level data collection costly, invasive, and rare. Unlike energy, water infrastructure is difficult to access and modify once a building is constructed. Water sub-metering technology has required in-pipe installation, usually during construction when pipes are exposed and empty. Today, most buildings have one water meter with no differentiation between indoor/outdoor use or fixtures. As a result of this technology barrier and scant data, no comprehensive, standardize auditing protocol exists for water.[6]

A new suite of inexpensive electromagnetic water metering technology has recently provided new promise for fixture data collection. The FLUID Water Meter clamps onto pipes and reads individual fixtures through flow signatures (e.g. a toilet flush registers as a different flow velocity and amount than handwashing). This project used this new technology to develop, test, and standardize a water auditing protocol for commercial buildings through an undergraduate / graduate architecture water efficiency course.

Existing Water Assessment Programs: National and Local

Programs like Architecture 2030 and the 2030 District set goals for water (and energy) reduction. However, few tools are provided to support subscribers to reach these targets. The Environmental Protection Agency (EPA) created an “Energy Portfolio Manager” with a short section on overall water consumption.[7] The United States Green Building Council (USGBC)’s Leadership in Energy and Environmental Design (LEED) provides water reduction goals broken into indoor, outdoor, and process water use. The required calculations to obtain “Water Efficiency” points in the LEED system, are based on projected national averages and occupancy numbers under the Environmental Protection Act (EPAct).[8] [9] Greater precision in average water use by the variations of building type and regional climate is needed.

In Tucson, the water utility, Tucson Water, conducts self-reporting audits with residential customers whose water bills have experienced unexpected spikes. During these audits, no fixture-level data is collected – rather estimates are made on national averages. Tucson does not currently have data specific to regional use by fixture.[10]

The Challenge: Decreasing Commercial Building Potable Water Use in the Face of Increasing Drought

The United States Southwest is experiencing what some believe to be the worst drought in 500 years.[11] Studies have projected a more arid climate and higher risk of water shortages in the region over the coming century.[12] While water resources become scarce, population in the region has grown considerably in the past decades and the growth is expected to continue. In Arizona, the population is anticipated to increase by 25% between the years 2012 and 2030, with a 30% growth in Phoenix Metro region and a 17% increase in Tucson Metro. The Arizona Department of Water Resources (ADWR) determined that in 25 years Arizona will need an additional 900k acre feet of water to meet projected shortages. In 100 years, Arizona's water demand will outpace supply by about 3.2 million acre feet.[13] Having a reliable source of water is key for enabling sustainable and equitable development. In this context, this study seeks to standardize a method to evaluate success in building water efficiency implementations.

In response to these water realities Tucson Water devised a 2012 Drought Preparedness and Response Plan.[14] The plan is structured in four drought responsive levels beginning with Stage 1 and increasing in severity to Stage 4. Currently, Tucson is at a Stage 1 drought and has been at this rating for several years. Declaration of Stage 2 drought depends on Colorado River conditions and is made by the Tucson City Manager with advice by the Director of Tucson Water.

The plan states that if Stage 2 is declared, all commercial and industrial customers using an average of over 325 centrum cubic feet per month (or 2.5 million gallons per year) need to conduct a self-audit of water use at the facility and develop a conservation plan. Nationally, commercial buildings represent 29% of water use compared with a slightly lower 25% in Tucson.[15] [16] Overall, commercial buildings rank as the highest single users of water in Tucson. Although numerous studies exist at the scale of broad urban water management and narrow residential behavior, little research has examined water use at a fixture-level, particularly for commercial buildings.[17] [18] Due to their large occupancy and square footage, thus usage, these buildings provide one of the greatest opportunities for water reductions.

Tucson Water has begun to offer free commercial water audits in preparation for the Stage 2 declaration.[19] Currently, these audits estimate fixture-level use by using national estimated ratios. This project worked with Tucson Water to enhance this program through a systematic water auditing procedure that measures fixture-level use. Students worked with volunteer commercial buildings to hone the process and technological use by lay people. The water auditing protocol discussed in this article was planned with Tucson Water to be one piece of Tucson's ongoing efforts to ensure that the growing metropolitan area has a long-term reliable source of water for its expanding populations.

Methods: A Comprehensive Water Auditing Protocol for Commercial Buildings in Four Modules

The water auditing protocol has four modules: (1) conservation, (2) passive systems, (3) active systems, and (4) integrated strategy implementation (*Figure 1*). Each of the first three modules are composed of a baseline assessment, a quantitative and qualitative auditing process, and strategy recommendations. In the fourth module, a comprehensive strategy implementation plan is provided to the building owner. All steps were carried out through the Water Efficiency in Buildings course (ARCH 461/561) at University of Arizona. In the process of testing and refining this water auditing protocol, students learned the building fixtures with the greatest average demands, daily and seasonal variations in these fixtures use, regional variations in use, and building owner and users' perception of their use. Students devised comprehensive strategies to reduce indoor and outdoor building water use together. They then worked with owners and occupants to create a feasible and measureable plan for immediate implementation. Before the project began, the professor conducted a one month pilot study to ensure that the water meters were appropriately placed and correctly transmitting data. Additionally, written consent from the commercial building owner was acquired to release their hourly water meter data from Tucson Water to the professor for educational purposes. The four modules are outlined below using the case study audit of the Community Food Bank of Southern Arizona.

	TIME	**FOCUS OF AUDIT**	**DESIGN APPLICATION**
Module 1	Month 1	Indoor Water Use	Conservation Design
Module 2	Month 2	Outdoor Water Use	Passive Design
Module 3	Month 3	Process Water Use	Active Design
Module 4	Month 4	Integrated Strategies	Technology and Energy-Water Nexus

Fig. 1. Water Auditing Protocol with Four Modules

Module 1: Indoor Water Audit / Conservation Design

The first step of the water auditing protocol is to establish a baseline use by which future efficiency gains can be measured. The baseline contains both quantitative numbers and qualitative behaviors. In the first month of the course, students visit the commercial building to interview owners and users on occupancy patterns and use behavior and count and obtain flow rate specifications for all building fixtures. The main learning objective during the baseline step is for students to understand how to measure each type of fixture use, average user behaviors by fixture use, and the impact of basic conservation measures.

Demand Calculation: Students hold an interview with the building manager and key occupants. During this interview, occupancy hours are recorded for the average workday and over a year with holidays and seasonal use patterns. A fulltime occupancy equivalent (FTE) and visitor occupancy hours are computed with this information. During this interview, floor plans are used by the building manager to identify all indoor fixtures for the students. Students then record the installed flow rates of these fixtures either through time testing or through written specifications. With this information, the LEED indoor water prerequisite procedures are followed to calculate baseline water demand for the building (indoor) based on the national averages under the Environmental Protection Act (EPAct).[20]

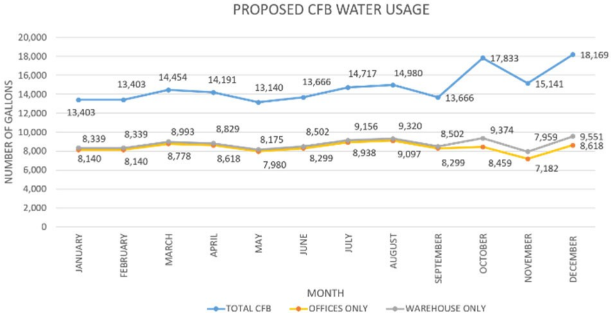

Fig. 2. Module 1: Indoor Water Budget (Credit students: T. Alaqtum, S. Ghaemi, M. Wilke, K. Chaikunpon, M. Torres)

Strategy Formation: The calculated LEED and EPAct baseline is then compared with current fixtures and then higher efficiency fixtures to project total baseline, current, and potential potable water use reduction. Total percentage reductions are calculated between baseline, current use, and potential reduction. In the case study example of the Community Food Bank of Southern Arizona (*Figure 2)*, students recommend that compost toilets be built for visitors to the garden. Other suggested conservation measures included installing more efficient-fixtures and using the Tucson Water rebate to exchange the current inefficient top-loading washing machine for a front loading machine. The strategies led to an overall 67% baseline reduction.

Module 2: Outdoor Water Audit / Passive Systems Design

In the second month of the course, students completed a site water audit for outdoor uses and consider passive measures to decrease potable water use. Passive rainwater harvesting systems are designed to retain water until it can be naturally absorbed into the land (swales and pervious pavers are common passive strategies). Water harvested passively offsets irrigation demands, whereas the water harvested through active systems can be stored and employed to meet non-potable and potable demands, depending on the treatment level achieved.

Demand Calculation: For this module, students complete a site plan, locating various vegetation species throughout the site. To calculate outdoor water demand, the students then use species factors, microclimate factors, and density factors to project vegetation demand. Students fill out LEED credits for outdoor water use with these numbers.

Fig. 3. Module 2: Passive Water Design Baseline and New (Credit students: T. Alaqtum, S. Ghaemi, M. Wilke, K. Chaikunpon, M. Torres)

Strategy Formation: To calculate potential new sources of water (through passive strategies), students then use the site plan, average monthly precipitation, and impervious and pervious material run-off coefficients to calculate possible water collection volumes. Students consider both rainwater harvesting and native and adaptive species as strategies to passively reduce water use outdoors. Students complete a water budget for outside supply and demand to determine water reduction percentage. In the case study, student used the water budget to maximize passive water harvesting via a retrofit to the existing parking lot for flood mitigation and heat island reduction (*Figure 3)*.

Module 3: Process Water Audit / Active Systems Design

In the third month of the course, students complete a process water audit with qualitative and quantitative tools. Active measures were considered as means to reduce water use. Active systems to decrease potable water use include rainwater harvesting, gray water use, and condensate recovery. Active rainwater harvesting collects, cleans, and stores rainwater for reuse (tanks and cisterns are prevalent elements of active harvesting). In this module, student build on their knowledge of indoor fixture use and outdoor use by adding a specific understanding of process water and determining how active systems can address these potable water demands.

Demand Calculation: The students examine process water systems. The students create a water budget based on this data. Students also complete calculations to determine the amount of water that can be actively harvested from the process water systems for reuse (e.g. condensate recovery from air handling units and bleed-off from evaporative coolers).

Strategy Formation: Then, students identify the indoor, outdoor, and process water demands (calculations form Module 1, 2, and 3) where active systems could be employed to replace potable water use. Active measures, along with the previously applied passive and conservation measures are applied. From this water budget, a total potential reduction is calculated.

Students compare the FLUID real-time water meter fixture-level data, the Tucson Water hourly water meter data, and their demand calculations from module 1, 2, and 3. Students reflect on the discrepancies and accuracies of these datasets. Student reflect on the challenges of designing a building to preform in a predictive manner and what they can do as designers to decrease this uncertainty. Disparities between total predicted use and actual use are usually found. This comparison gives students an important first-hand lesson in the margin of error between predicted use and operational use over time – a pitfall in designing sustainable buildings to perform for average populations in average situations.

In the case study, students aimed to size the active harvesting system so that the garden survived on rainwater only (*Figure 4)*. They recommended both expanding the roof catchment given their analysis that the cistern was never full. Students also recommended both turning garden beds fallow in the summer and reducing the number of beds so that the garden demand matched the available active system rainwater supply.

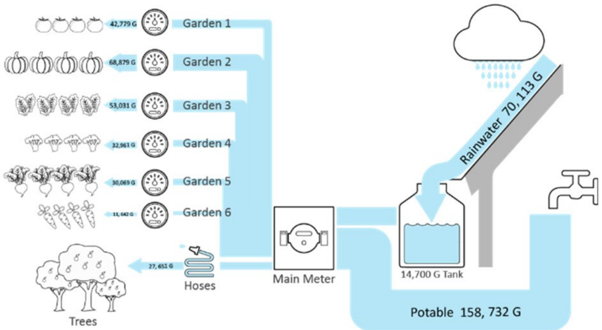

Fig. 4. Module 3: Baseline Active Water System Calculation (Credit students: T. Alaqtum, S. Ghaemi, M. Wilke, K. Chaikunpon, M. Torres)

Module 4: Final Report / Strategy Implementation

In the final month of the audit, students look holistically at data and recommendations from Module 1, 2, and 3. In Module 4 students add research on new technologies that had also been shown to be successful – particularly at the nexus of energy and water. Students meet with the building owner and manager to go over the complete water budget and the conservation, passive, and active strategy recommendations. Building owners and managers provide students with feedback on the feasibility of the selected measures and which are financially and operationally practical for short and long-term implementation plans. Students complete a full report for final presentation to the building owner, manager, and key occupants. In the case study, the owner plans to adopt composting toilets, parking lot modifications, and garden bad reduction with gutter expansion.

Discussion: Analysis, Applications, and Impact of Protocol

This section analyzes real and potential outcomes from the use of the water auditing protocol based on the testing that occurred from 2017-19. The protocol outlined in this article has the potential to directly impact four populations: (1) architecture students, (2) water service providers in drought prone areas, (3) commercial building owners, and (4) the professional architecture community. The analyses, applications, and impacts of the auditing protocol for each of the four populations are discussed below.

Pedagogical Learning Outcomes: the Next Generation of Architects

A model service-learning pedagogy was developed to teach future architects water efficient design – and push the boundaries of the former understanding of architect's responsibility in integrating water savings through design. The author's Water Efficiency in Buildings (ARCH 461/561) course engages undergraduate (Bachelors of Architecture) and graduate (Masters of Architecture, Masters of Science in Architecture, and Masters in Water, Society, and Policy) students each spring semester. Students enrolled in ARCH 461/561 learned water auditing, water budgeting, and key trends in use by occupant, fixture, and program type. Education promoting water efficiency is a key priority for federal funding institutions and programs such as the EPA and DOE due to increasing professional importance. Students will enter the profession with this new, marketable skill. Through the case study, students gained confidence as future professionals able to take on the growing water challenges in the built environment.

Local Community Outcomes: Tucson Water Commercial Water Auditing for Level 2 Drought for Building Owners

Unlike energy, no national, standardized water auditing protocol exists. The absence of these tools presents a major barrier to municipalities and water utilities seeking to successfully reduce community water use. This is particularly pertinent in drought prone areas, like Tucson. Under Tucson Water's 2012 Drought Contingency Plan, all commercial and industrial customers using an average of over 325 centrum cubic feet per month (or 2.5 million gallons per year) need to conduct a self-audit of water use at the facility and develop a conservation plan once a Level 2 drought is declared. However, no standardized protocol exists to guide commercial building owners and managers through a self-auditing process to comply with this requirement. The protocol outlined in this article was planned with Tucson Water for this ultimate purpose. Now that the protocol has been piloted form 2017-19, the intension is for Tucson Water to use the four module spreadsheets as a platform and tool for commercial self-audits when Level 2 drought is declared. In the case study, the Community Food Bank of Southern Arizona was projected to decrease overall potable water use if the auditing recommendations were adopted.

National Outcomes: 2030 District National Application

Nationwide, the 2030 District organization has the goal to reduce energy and water consumption by 50% by 2030.[21] Over fifteen national districts have successfully pursued the energy goal through the Energy Star portfolio manager tool, the national Commercial Building Energy Consumption Survey (CBECS) database, and ASHRAE standardized auditing protocols. However, an integrative approach to the water goal has been largely unaddressed due to the absence of protocols and tools for professionals. The new water auditing protocol supports the community partners to reduce water use in current district signatory buildings by 50% by 2030. The auditing tool provides greater clarity to building owners and managers on the actual impact of implementations on their volume of use and financial payback of water savings investments.

Professional Outcomes: Changing Architecture's Approach to Water Efficient Design

Finally, the created water auditing protocol serves the architectural professional community through the creation of new, currently unavailable, critical tools for water efficient design and retrofit. Unlike energy, no national standardized water auditing protocol or database currently exists. The discipline will be served with a cutting-edge, service-learning pedagogical model to teach water efficiency. With further testing, an online platform will be created. On this platform, the new standardized water auditing protocol will be easily accessible to building owners in the fifteen other efficiency district cities.

Conclusion

This paper argues that building water efficient design will advance if accessible, fixture-level tools are made available to professionals, building owners and operators, and students. Ultimately, to address this resource gap, a standardize auditing protocol was developed and evaluated for commercial buildings. The protocol is composed of four modules: (1) conservation / indoor use, (2) passive design / outdoor use, (3) active design / process use, and (4) holistic strategy implementation. Qualitative and quantitative research methods are used throughout all four modules. The protocol was developed and then tested from 2017-19 in an undergraduate and graduate co-convened architecture course in collaboration with the local public and private sectors in Tucson, Arizona.

In future work, the developed protocol will be placed on an assessable online platform for use by the 2030 districts across the county. Architects need to receive training in school to design for a water efficient future. The auditing protocol provides architecture students with a systematic tool to apply to each future building they design. The real world experience of auditing the presented commercial building case study developed student s' confidence to take on current and future challenges of water with an integrated process of measurement, analysis, and design.

Notes

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