Total Cost of Ownership of Sensor Faucets in Commercial and Healthcare Construction

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Abstract. Owners who are pursing the construction of new commercial and healthcare buildings are very interested in the sustainability, energy efficiency, life cycle costs and cleanliness of their proposed projects. Owners are requiring designers and construction companies to develop innovative strategies to lower their utility use and total cost in their projects. One area of opportunity to meet this owner need is the decision to use either battery-powered or hardwired restroom faucets. Several construction projects of various types and locations were analyzed to determine the total cost of ownership of both types of faucets over a 12-year and 25-year timeframe. The results of the unit cost calculation showed that the battery-powered faucets had a lower cost of ownership at 12 years, while hardwired fixtures installed in intervals of six had the lower cost of ownership over 25 years. Although, when researching actual construction projects, where installation of multiple faucets in a row isn't realistic, battery-powered faucets had the lower cost of ownership over the hardwired options in both the 12-year and 25-year timeframes in all building types.

Key Words: Sustainability, Life Cycle Cost, Energy Efficiency, Water Efficiency, Plumbing.
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1. Introduction

Owners who are engaged in building new commercial and healthcare projects have many different requirements and expectations for their projects. These requirements and expectations must be met if the project is to be successful for both the owner and the designers. As owners are the key stakeholder for construction projects in this market, it is critical to identify their ultimate needs within the building (Alshubbak, Pellicer, Catala, & Teixeira, 2015). Many owners are concerned about energy efficiency and interested in strategies to reduce their operational costs. A study by Gliedt and Hoicka in 2015 showed that many owners/property managers were motivated by economic return and made technology and funding decisions based at least in part on the expectation of direct or indirect economic returns.

The commercial building sector in the United States consists of 93 billion square feet of real estate and accounts for 18% of U.S. primary energy use (U.S. Energy Information Administration, 2020). Based on the building size, the decisions owner's make during the design stage can have substantial impacts on energy use, and their maintenance costs after construction. Depending on the building type and expected occupants, different buildings have different needs to be met. In recent years owners have become more knowledgeable in the sustainability, energy efficiency, life cycle costs, and ease of maintenance of their buildings. The increased prevalence of rating systems such as Leadership in Energy and Environmental Design (LEED), Energy Star, and American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Building Energy Quotient (bEQ) have shown that owners are making energy and water efficiency a requirement of their projects more common.

One option that is often investigated in commercial and healthcare projects is the decision to use faucets with sensing technology with either battery-powered or hardwired power supplies. Faucets with sensing technology allow for water savings as the faucets automatically shut-off the flow of water while the faucet is not in demand. In addition to water saving technology, faucets with sensors also provide a hands-free operation, which helps reduce the spread of disease and viruses (Sloan, 2011), especially important in healthcare.

William Sloan patented his flushometer style toilet flush valve in 1906, which revolutionized the plumbing industry by reducing water and energy without the need of a tank. Plumbing manufacturing companies have continued to improve and introduce new technical innovations in their products. Companies such as Sloan Valve Company (Sloan), Delta Faucet Company, and Kohler Company offer a variety of products such as faucets with hands-free sensing technology with battery-powered operation and power-harvesting technologies, such as solar and inline water turbine products. The variety of products give designers of new construction projects many options in function, aesthetics, upfront cost, energy efficiency, and water efficiency.

Sensing faucets require some form of power supply, typically battery or hardwired, to operate an internal solenoid valve to turn on and off the flow of water. Each option has its advantages and disadvantages, and each is prevalent in projects worldwide. Battery-powered faucets reduce the up-front cost of coordination and installation by eliminating the electrical wiring to the device. Battery technology is constantly evolving which has led to improved battery life, extending the time between battery replacement, therefore lowering the maintenance cost of these systems. Many owners continue to prefer the hardwired faucets because of the reliability, reduced maintenance, and perception that this will lead to lower maintenance expenses. This study investigated which of these two options had the lower total cost of ownership over the estimated lifespan of the faucet to help owners make more informed decisions.

One of the key benefits of sensing faucets according to manufacturers is the water efficiency achieved (Sloan, 2011). Non-sensing faucets are turned on manually by the occupant while starting to wash one's hands, while continue to run while lathering, when the water is not in demand. Sensing faucets automatically sense an individual's hand placement and turn the water on and off based on the integrated sensor. While each use may save only a small amount of water, when this is multiplied by multiple faucets uses each day per occupant, over many days, the amount of water saved can be substantial.

However, studies have been done to determine if sensor faucets are actually more efficient than manually operated faucets. One such study by the ASHRAE that investigated the energy efficiency of photovoltaic water heaters showed that when the researchers switched their faucet configuration from a manual faucet to a sensor faucet, average daily hot water volume increased 58% (Fanney, Dougherty, & Richardson, 2002). Another study at the Millennium Dome in London over a one-year period showed that the manual faucets used significantly less water, roughly half, than an infrared sensor faucet (Koeller, 2012). Both studies indicate a water and energy savings by using a manual faucet, contradicting manufacturer's claims.

Another key benefit of sensing faucets is the hands-free benefit that decreases the transmission of disease and viruses (Sloan, 2011), especially of importance during recent pandemics. Although users often believe flush handles are the dirtiest touch point in a restroom, sink areas are usually more germ-laden, as this is where bacteria are shed from hands during washing (Lozier, 2016). This was further studied by Kurgat et al. (2019) that showed in an office building the most contaminated areas of the building were the refrigerator, drawer handles, sink faucets, the push bar on the main exit of the building, and the soap dispensers in the women's restroom.

When analyzing the faucet's life cycle, the estimated life of the products installed must be taken into consideration. Product life cycle cost includes three primary phases: production, use and final disposal (Kalbusch & Ghisi, 2016; Gnoatto, Kalbusch, & Henning, 2019). For production, the analysis should involve the manufacturing of the faucets in both scenarios, and the amount of conduit and wiring compared to battery production. For the use phase, the analysis should include maintenance and operation (evaluated as part of this study), in addition to the energy use and battery cost. For the disposal phase, the analysis should include disassembly and recycling of the electrical wire and conduit compared to battery disposal. Batteries, depending on the type, can be easily recycled, or taken to a manufacturer for recycling. All phases would ultimately include the evaluation of water consumption, energy consumption and global warming potential for all manufactured components (Gnoatto et al., 2019).

The total cost of ownership of different construction materials relates to the interest of owners in energy efficiency. There have been studies on individual components, such as a 2014 study by Mader and Madani, that showed the total cost of ownership of various control systems for an air-water heat pump. Manufacturers of plumbing fixtures list varying advantages of their products, such as ease of use, reduced maintenance, as well as energy efficiency. But after reviewing the literature there are no peer reviewed studies on the total cost of ownership of battery-powered vs. hardwired faucets.

2. Research Methods

The researchers partnered with Sloan Valve Company to evaluate their faucets for the purpose of comparing different faucet power applications in order to identify any significant differences in installation costs and applications. The goal of this research is to help clients make informed decisions on the best products for their building projects in terms of the total cost of ownership.

Sloan Valve Company identified which models of faucets were most popular in terms of use and provided the product data sheets on these items. Sloan Valve Company also provided the preventative maintenance frequency for individual components, replacement part costs, typical life span, and recommended battery replacement. The researchers and Sloan determined that the following products would be used for this study based the popularity of use based on historic sales for the corresponding building types of the study:

- Sloan Optima Sensor Faucet EBF-425 AA battery-powered (optional turbine) with underdeck mounted manifold
- Sloan Optima Sensor Faucet EAF-350 6V battery-powered with integral temperature mixer
- Sloan Optima Sensor Faucet ETF-420 wired
    - Hardwired with transformer
    - Hardwired for plug-in
- Sloan Basys Sensor Faucet EFX-275 solar-powered

The researchers evaluated the total cost of ownership in common types of buildings that Sloan faucets were often installed, commercial office and healthcare buildings. In order to gather the project information, the researchers enlisted a variety of construction firms, including General and Mechanical Contracting companies in the United States to participate in the data collection for this research. Companies were recruited from different geographic areas of the United States in order to get a cross-section of projects. The firms that participated in the study were Turner Construction Company, Mortenson Construction Company, DPR Construction Company, JF Ahern Company, and Southland Industries.

Each company was asked via email to participate in the study, and a conference call was followed up to confirm the request and to discuss timeline expectations and project deliverables. The firms were asked to provide the researchers at least two projects in both a commercial and healthcare category for evaluation. They were asked to provide the design drawings and documents and upload through a cloud-based folder structure. The researchers requested a variety of projects in terms of size, scope and geographic location, but no other parameters were given. The construction documents were received, and the researchers then evaluated each project submitted for inclusion in the study.

For the installation costs, the installation instructions provided by Sloan were reviewed, and the researchers consulted with the mechanical and electrical contracting firms to develop the steps and materials necessary for installation. The labor hours were then calculated from the installation steps to ensure the total cost of installation was captured. Since the plumbing of hot and cold-water supply was the same for all faucets, the labor and material cost was not included in the researchers study. Table 1 shows the installation steps necessary between the different types of faucets evaluated.

The installation of all battery-powered faucets included the labor for plumbing skilled trades' people for the installation of the faucet and activation of the sensor. No electrical hours are included, as an electrician is not required for the installation of battery-powered faucets.

The installation of all hardwired faucets required electrical tradespeople for the rough-in electrical work, including running conduit and wire from the closest electrical panel to near the location of the faucet. The electrician also had finish work to complete once the drywall was completed to complete the hardwiring for the transformer model or install the electrical outlet for the plug-in model. For the transformer wired faucets there is the opportunity to power up to six faucets from one transformer, reducing the per faucet installation costs when intervals of six faucets were installed. For the plug-in faucets there is also the opportunity to daisy-chain up to six faucets together to plug into one outlet, also reducing the cost per fixture. The plumbing trade also was required to set the faucet and sensor activation unit.

For the maintenance costs, the data provided by Sloan identified the timeframes, parts, and costs for the recommended maintenance of the faucets. The recommended battery replacement was every three years for normal-use restrooms for battery-powered faucets; every six years for the solar-powered faucets; and every ten years for hardwired fixtures that had a battery backup. Each faucet was evaluated over a 12-year and 25-year maintenance period to determine if length of operation affected the total cost of ownership.

The labor hour durations for installation and maintenance requirements were estimated by the mechanical and electrical contracting firms. The U.S. national average labor rates were used as provided by the Mechanical Contractors Association of America (MCAA) and the National Electrical Contractors Association (NECA). Union plumbers were assumed for installation of the faucets, activation of the sensors, plug-in of wired faucets, and all preventative maintenance and repair items.

Tab. 1 - Installation steps of primary faucet types

Installation Steps	Battery Deck Mount and Solis	Battery Underdeck Mount	Hardwired Transformer	Hardwired Plug-In
Install conduit and wiring from panel to transformer	-	-	X	X
Install transformer and wiring to faucets	-	-	X	X
Surface mount control box and connect faucet wires	-	X	X	X
Connect control box cable to faucet	-	X	X	X
Install battery pack	X	X	-	-
Activate sensor	X	X	X	X

Union electricians were assumed for the installation of all conduits, wiring, and transformers required for the hardwired option. The battery replacement was assumed to be by custodians. There was no shared time savings to perform maintenance and battery replacement simultaneously as it was determined that these are typically different maintenance tasks performed by different trades.

Material costs were provided by the electrical contractors based on large project pricing and battery costs were provided by Amazon. Maintenance and labor costs did not take into account inflation, escalation or wage rate increases. Sloan provided the faucet and replacement part costs.

The researchers then calculated the total cost of ownership of the various faucets in both an individual analysis to determine unit cost, as well as cost per each building project. This allowed for total and average costs per building type for comparison purposes. For the quantity take off the researchers used a PDF reader and excel spreadsheet to keep track of each restroom and faucet. Electronic dots were used to mark each item as taken off. Different colors of dots were used to identify gender counts; red for women, blue for men, and lavender for individual or unisex restrooms. Each project had quantities taken off calculating the total number of restrooms for both women, men and unisex, and also the number of faucets in each women's restrooms, men's restrooms, and individual unisex restrooms. For the wired fixtures, if there were two restrooms that shared a wall with one another, and the faucets were both on either side of the wall, similar to shown in Figure 1, those faucets were identified as sharing a transformer or outlet to identify installation costs savings; instead of individually wired faucets. Figure 1 also shows one of the ideal layouts for a restroom to maximize the installation efficiency of the hardwired faucets. The preferred restroom would either be three faucets back-to-back as shown, or six faucets in a row.

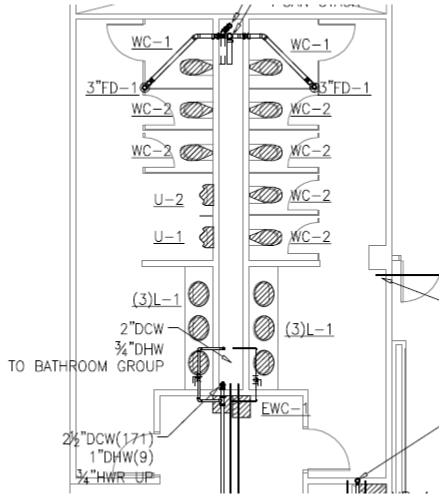

Fig. 1 - Ideal restroom of three faucets back-to-back to maximize hardwire configuration.

3. Results

A total of thirteen projects were submitted by the partnering contracting firms for use in this study. There were seven healthcare buildings and six office buildings submitted and all were included in this study. Of the healthcare buildings, four are located in Wisconsin, two in California, and one in Illinois. For the office buildings, four are located in Wisconsin and two in California.

While evaluating the installation steps, it was discovered that for both battery-powered and hardwired faucets, there were multiple installation options that could affect the cost. For the battery-powered faucets the battery pack could be either deck mounted (above the countertop) or underdeck mounted (under the countertop). Both options were evaluated. For the battery-powered faucets there is an option for an internal turbine that can be used to generate power and that option was also evaluated.

For the hardwired faucets, each faucet could be wired using a plug-in power connector that could be daisy chained together, or a bank of up to six faucets could be hardwired together in series with a transformer. Both of the options varied the electrical installation and were therefore evaluated. There was also the option to have hardwired faucets include a battery back-up, or not. Owners may want this option to have an additional power source in the event of a power outage. After consulting with Sloan, they stated that most owners want the battery back-up as a safety measure. The only way to offset this issue would be to make sure that the circuit the faucets were connected to were tied to an emergency generator, or other form of back-up power. Based on this discussion, the unit rate cost for hardwired with no battery-backup was calculated and found to be most advantageous over 25 years, but the estimated installed costs still did not outperform the battery-powered faucets.

The quantity take-offs for each building were completed and all maintenance costs were tabulated for each option on each project. Table 2 shows the results of the total cost of ownership for each faucet option in a 12-year timeframe as well as a 25-year timeframe for office building projects. Table 3 shows the total cost of ownership for healthcare buildings.

The data shown in Table 2 shows that the total cost of ownership is lowest for deck mounted, battery-powered faucets compared to all other styles. Generally speaking; the traditional battery-powered faucets are the most cost effective in all applications except for the SOLIS solar-powered faucet and the SOLIS turbine option. It is interesting to note that the two SOLIS faucets become the most expensive option at the end of the 25-year period. This is due to the high cost of replacement parts for the solar components and turbine at the end of the maintenance period.

Tab. 2 - Total cost of ownership for faucets in office building projects.

Faucet	Average Count per Project	12-Year Total	25-Year Total	Percent Increase 12-Year	Percent Increase 25-Year
Battery – AA Deck Mount	38	$39,420.82	$62,089.34	-	-
Battery – AA Underdeck	38	$39,873.78	$62,542.30	1.011	1.007
Battery – SOLIS	38	$43,903.68	$68,073.96	1.114	1.096
Battery – Turbine (SOLIS)	38	$43,980.06	$68,150.34	1.116	1.098
Hardwired – Transformer	38	$45,601.16	$65,032.08	1.157	1.047
Hardwired – Plug-in	38	$45,743.38	$65,174.30	1.160	1.050

Tab. 3 - Total cost of ownership for faucets in healthcare building projects.

Faucet	Average Count per Project	12-Year Total	25-Year Total	Percent Increase 12-Year	Percent Increase 25-Year
Battery – AA Deck Mount	70	$72,172.70	$113,674.84	-	-
Battery – AA Underdeck	70	$73,002.00	$114,504.14	1.011	1.007
Battery – SOLIS	70	$80,380.05	$124,631.65	1.114	1.096
Battery – Turbine (SOLIS)	70	$80,519.88	$124,771.49	1.116	1.098
Hardwired – Transformer	70	$90,856.05	$126,430.70	1.259	1.112
Hardwired – Plug-in	70	$92,861.00	$128,435.65	1.287	1.130

For healthcare projects as shown in Table 3, the total cost of ownership for deck mounted battery-powered faucets is lower than that of other battery and hardwired applications when compared during both the 12-year and 25-year timeframe, which is the same as what was found for the office building projects. Also, the same phenomenon of having the SOLIS faucets become the most expensive at the end of the 25-year period also presents itself in this building type. But when comparing the two building types, the total ownership cost per faucet is almost identical within each faucet type.

Results show that over a 25-year timeframe that hardwired sensors showed a total cost of ownership of less than 1.047-1.287% from the lowest battery-powered faucet.

4. Conclusions

The results show that the deck mounted and underdeck battery-powered faucets have a slightly lower cost of ownership over the life of the product compared to hardwired faucets and the SOLIS faucets. There are significant up-front costs for installation for the hardwired faucets because of the electrical conduit and wiring, which is not present in the battery-powered fixtures. The overall maintenance cost for the battery faucets is not significantly more than that of the hardwired faucets, with the exception of the SOLIS units, and over the life of the faucet this is not enough to overcome the additional upfront installation costs of the wiring.

Ultimately, it is up to the owner to determine their project needs and communicate them to the designers and contractors. They should understand the potential use requirements as to whether battery-powered or hardwired is more beneficial based on the use of their building and intended occupants. The estimated life of the building is critical component of the analysis and, additionally, whether the initial additional costs are worth the reduced maintenance and inconvenience after construction is complete.

Owners of healthcare and commercial construction projects can be well informed by the results of this study to allow them to make informed decisions about which types of faucets will produce the lowest total cost of ownership. There are many owners, architects, and construction firms that may intuitively believe the total cost would be lower by selecting the hardwired options, and they may be giving inaccurate advice believing that the maintenance costs of the battery-powered and specifically the battery replacement would eventually have a higher total price. The results of this study indicate that owners of these types of projects should select a deck mounted, battery-powered faucet for all of their bathrooms to achieve the lowest cost of ownership. Based on the unit cost, owners wishing for hardwired fixtures should coordinate and request designers to maximize the installation of six, or multiple, faucets to minimize the installation costs as much as possible.

One item that was raised during the research was the variability in how owner's facilities staff monitor the battery-powered faucets for maintenance during the life of the product. After further research, it was found that sensors on the faucets have an indicator light to notify facilities staff that a battery is weakening and needs to be replaced. This is up to the staff proactively monitor the fixtures so that batteries are replaced before failure. This will require additional training for the custodial staff to not only monitor the faucets, but also how to properly replace the batteries. This study assumed all custodial staff were trained, followed the recommended replacement procedures and did so in a timely manner. Failure to do so could result in non-operational faucets, increase total costs, and may change the results of the study. Future research can be conducted to study the level of understanding of custodial staff in these procedures as well as their effectiveness and associated costs in how they are currently maintaining their faucets.

Another area of possible future research would be to investigate the actual use of the faucets to determine if the recommended maintenance schedules and battery replacement provided by the manufacturer are indeed accurate. The methodology used in this study did not account for actual use, and some buildings may be high-use, or low-use and that could cause the maintenance and battery life to increase or decrease accordingly. Future research could also be conducted on various other building types such as educational facilities, and athletic facilities to see if the conclusions of this study are valid for those building types. Remodel projects also were not investigated as part of this research, and future research on these types of projects may indicate different results because of the unique constraints of those projects.

A final item that could be investigated is the life cycle analysis and costs of the faucets. This project only investigated the total cost of ownership to the owner of the building project, but life cycle costs include additional costs of the product that could have impact to the client as well as to the community. A study could be done to determine these additional costs as well as the environmental impacts to determine the true overall impact of these devices.

5. Acknowledgement

Sloan Valve Company provided manufacturing data and costs. The general, mechanical and electrical contracting companies listed in the report provided installation and maintenance costs and methodologies.

6. Data Access Statement

The datasets generated during and/or analysed during the current study are not available because of privacy restrictions from building project owners but the authors will make every reasonable effort to publish them in near future.

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