RETROFITTING CONNECTIVITY FOR ENERGY BENEFITS

Prepared by:
Brendan Trimboli, Katherine Dayem, and Cat Mercier
XERGY CONSULTING

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1 EXECUTIVE SUMMARY

Previous research suggests that significant energy savings opportunities may exist through the various control and intelligence strategies that network-connected products enable. While the global market for connected products is growing rapidly, global market penetration of connected products remains small, and a vast majority of the global installed stock of existing residential products remains unconnected. Connected retrofit solutions can add connectivity at a fraction of the cost of replacing an existing product with a connected one in some cases. In this project, we examine the retrofit solutions on the market today to identify those that could be leveraged to achieve energy benefits in otherwise unconnected residential products.

Space conditioning (heating, ventilation and air conditioning or HVAC) and water heating end uses comprise the greatest energy savings opportunity for connected retrofits due to their ubiquity, relatively high annual energy consumption, high load flexibility, and long average product lifespan. Retrofits for other products such as lighting, plug loads, appliances and other end uses present moderate to minimal energy savings opportunities due to their relatively low annual energy consumption, lack of load flexibility, and, in some cases, short average product lifespan. Issues with product compatibility, device and communication interoperability, and long term viability of the manufacturers behind connected retrofit devices further complicate their feasibility as a cost effective means of achieving connectivity-based energy benefits.

2 INTRODUCTION & MOTIVATION

In recent years the adoption of network-connected consumer products has grown precipitously. This trend is expected to continue in the years ahead with the total number of network-connected devices growing to an estimated 100 billion devices by 2030 (EDNA 2019, ACEEE 2017). Much of this growth is driven by the increased availability of network-connected products — known also as “Internet of Things” (IoT) products, or “smart” products — and by demand from consumers who seek the benefits these products claim to provide: the convenience of operating a product remotely, improved security and comfort, entertainment, and environmental and health monitoring (Wilson et al 2017).

Many IoT products are also marketed on their ability to provide energy benefits. By leveraging data provided through network connectivity or collected by the IoT device itself, control strategies can be employed in a way that reduces energy use or enables demand response and demand flexibility. Energy use reduction can occur by using available information and strategically placing products in low power states or by powering down other devices when they are not needed. IoT products have the potential to provide demand flexibility since their connectivity can allow them to receive signals or information to alter their energy use, specifically by:

- Shedding load: reducing electricity use during a peak or emergency event, or
- Shifting load: shifting operation from peaks or other periods of day when electricity is expensive or scarce to those when electricity is inexpensive and plentiful, such as during solar or wind generation peaks (U.S. DOE 2019, EDNA 2020).[1]

One recent study commissioned by EDNA indicates that smart home technologies could reduce energy use in homes by 20% to 30% (EDNA 2018). The energy benefits of standalone connected products are assessed in the accompanying EDNA report, Harnessing IoT for Energy Savings.

Even as existing unconnected products are being replaced by their connected counterparts at an increasing rate, the market for IoT products remains nascent and global market penetration of

[1] Note that demand flexibility can also entail load modulation, or real-time, autonomous matching of electricity demand to supply. For the purposes of this discussion, we focus on load shedding and shifting as flexibility strategies that many consumer products are capable of today.

residential IoT products is still less than 10% (Statista 2020). A vast majority of the global installed stock of existing residential products, therefore, remains unconnected, and product categories that present some of the best energy savings opportunities are also some of the slowest to adopt connectivity.

Connected retrofit solutions can add connectivity at a fraction of the cost of replacing the existing product with a new connected product. While a range of connected retrofit devices exist and can help consumers achieve the marketed benefits of IoT products, only a relatively smaller number of retrofits have the potential to achieve energy benefits. In this project, we examine the retrofit solutions on the market today to identify those that could be leveraged to achieve energy benefits in otherwise unconnected residential products.

3 CONNECTED RETROFIT SOLUTIONS

We define a connected retrofit solution as an off-the-shelf device that enables the marketed benefits of IoT products in existing unconnected products. Energy benefits enabled by retrofit solutions are assessed in later sections, but first we explore the various characteristics that distinguish retrofit solutions from one another and factor in to their cost-effectiveness as an energy saving investment. These characteristics include: control strategies, intelligence strategies, wireless technologies, cost of retrofit, and product lifespan.

We surveyed the market of connected retrofit solutions for domestic products and identified devices that showed potential to achieve energy benefits. A sample of commercially-available retrofit solutions are shown in Table 1. Although the focus of this project is on retrofits that may be leveraged for energy benefits, we list some that do not appear to possess any energy benefit in our assessment. Each retrofit solution listed is categorized by the end use of the product to which it enables connectivity. A specific example of the retrofit device is provided, and both the retrofit strategy and marketed benefits are summarized.

3.1 Control Strategies

The control strategy is the means through which the connected retrofit device exhibits control over the existing product. It is important to understand the control strategy used in a connected retrofit because it can have implications on compatibility and capability of the retrofit solution. We identified three control strategies into which the retrofits surveyed can be categorized: electrical, mechanical, and behavioral.

Using an **electrical control** strategy, a retrofit switches or modulates an electrical signal to the existing product. In some cases, the electrical signal is the power supply to the product. For example, the smart plug strip is effectively a connected switch that controls the flow of electricity to any load plugged into it. In the case of the water heater control retrofit, the signal to an existing water heater relay used to tell the water heater when to cycle the heating element is modulated. In either case, an electrical signal is used to alter the operation of the existing product.

When **mechanical control** is exhibited, the retrofit device physically mimics an action that would've otherwise been taken by a human. One example is the automatic button pusher. This retrofit device is positioned in such a way on the existing product that, when activated, it mechanically manipulates a button or switch on the existing product. Many existing products are too sophisticated to be usefully cycled on or off by a single button push, so the applications of retrofit devices using a mechanical control strategy are typically limited.

If a retrofit relies on human intervention to complete the action, it relies on a **behavioral control** strategy. One example is the connected laundry sensor which transmits a notification to the consumer when a heat or dryness threshold is reached. It is then up to the consumer to take action based upon the information received. Behavioral control is simpler to implement than electrical or mechanical control strategies and less susceptible to compatibility limitations, but it leads to less consistent outcomes due to reliance upon human behavior.

Table 1: Sample of connected retrofit solutions for residential end uses

End Use Category	Retrofit Solution	Retrofit Device Example(s)	Retrofit Strategy	Control Strategy	Marketed Benefits
HVAC	Connected thermostat	Nest Thermostat, Ecobee Thermostat	Control central HVAC system through Wi-Fi remote control and multiple intelligence strategies	Electrical	Convenience, comfort, energy savings
	Room HVAC control	Cielo Breez Eco, Flair Puck	Utilize IR signals to control end uses from Wi-Fi enabled hub controller	Electrical	Convenience, comfort, energy savings
	Radiator control	Tado Smart Radiator Valve	Control radiator set point through 868MHz ISM band to Wi-Fi enabled hub	Mechanical	Convenience, comfort, energy savings
	Vent control	Keen Home Smart Vent, Flair Smart Vent	Control airflow to room in centralized HVAC system through 915MHz ISM band to Wi-Fi enabled hub	Mechanical	Convenience, comfort, energy savings
Water Heating	Water heater control	Aquanta Water Heater Controller	Attach Wi-Fi module to internal relays in water heater controls	Electrical	Convenience, energy savings
Plug Load / Lighting	Smart plug or strip	Wemo Mini Smart Plug	Control flow of power to plug load by routing through Wi-Fi enabled outlet or plug strip	Electrical	Convenience, security
	Automatic button pusher	Microbot Push	Wi-Fi enabled mechanical device pushes button on end use to start or stop a process	Electrical	Convenience
Appliance	Clothes dryer sensor	SmartDry Laundry Sensor	Wi-Fi enabled sensor that snaps inside clothes dryer	Behavioral	Convenience, energy savings
	Cooking thermometer	Range Dial Smart Thermometer	Sense temperature of cooking surface or food and communicate to user through Bluetooth	Behavioral	Convenience, security
Lighting	Smart bulb socket	iDevices Socket Adapter	Existing light bulb plugs into Wi-Fi enabled socket which plugs into lamp socket	Electrical	Convenience
	Smart switch plate	SimplySmart Home Switchmate	Bluetooth enabled switch plate snaps on over existing toggle-style light switch	Electrical	Convenience
Window Coverings	Window covering control	Soma Smart Shades Soma Tilt	Bluetooth enabled motor attaches to shade/blind pull and tilt mechanisms	Mechanical	Convenience, comfort
Home Security	Smart smoke alarm battery	Roost Smart Battery	WiFi enabled 9V battery sends notifications for smoke or battery depletion	Electrical	Security
	Garage door control	Tailwind iQ3 Garage Controller	Replace existing garage door controller with Wi-Fi and Bluetooth enabled control	Electrical	Convenience, security
	Smart door lock	Sesame Smart Lock	Bluetooth enabled device installs directly over deadbolt (Wi-Fi option with hub)	Mechanical	Convenience, security

3.2 Intelligence Strategies

Regardless of the control strategy employed, the benefits that network connectivity may enable can be limited by the intelligence behind the controls. The intelligence can include the different types of input put to use by the retrofit device, and the sophistication with which the inputs are utilized in determining how the controls should be operated.

Many connected retrofits rely on very simple logic. An example is the smart smoke alarm battery which relies on electrical current and voltage to determine whether the alarm is sounding or the battery itself is depleting its energy charge. This information is relayed to the consumer in a notification to a proprietary software app on their mobile device. The device is not designed to incorporate input from other sensors or devices in the house, nor can its own output be made available for other connected devices to use. While a simple intelligence strategy offers some level of robustness, it may limit the overall potential of the retrofit.

A more sophisticated retrofit uses a variety of inputs, such as: user input, sensor input, grid input, and input from other devices. A connected thermostat, for example, takes user input to establish an initial temperature setpoint. It can then process sensor input – like weather conditions, the temperature in another room, or the user's location – and grid input – like a demand curtailment signal – to adapt the setpoint to meet certain conditions. Machine learning algorithms are used to process historical data and optimize the thermostat controls in anticipation for future consumer behavior.

Total smart home systems maximize the benefits of connectivity by maximizing device intercommunication and interoperability (EDNA 2018). Simple intelligence and lack of interoperability in connected devices and retrofits may provide short-term benefits but limit the overall benefits of connectivity. Most of the retrofits surveyed in this project relied on simple intelligence and proprietary communication and control platforms.

3.3 Wireless Technologies

Connected retrofit solutions, like standalone connected products, rely on underlying wireless technologies to enable communication with the retrofit device. Depending on the application, a wireless technology is selected based on the range, frequency, bandwidth, and latency required by the connected device (EDNA 2016). Each technology also requires a certain amount of power to maintain connectivity, an important consideration when weighing the energy benefits connectivity might enable.

All retrofits examined in this project rely on a mobile app interface to enable the user to wirelessly communicate with the retrofit device. In general, two wireless technology approaches were observed: short range control directly with the retrofit device using a low power wireless technology, and long range control through a Wi-Fi enabled retrofit device or hub.

Low power Bluetooth was the most common wireless technology used when short range control is sufficient, though a few retrofits relied on alternate low power wireless technologies like Zigbee and unlicensed industrial-medical-scientific (ISM) frequencies. The advantage to these technologies is that they require only 10-100 mW of power to maintain connectivity, which is beneficial particularly when the device is battery powered.

One of the primary marketed benefits of connectivity is allowing the consumer to maintain control even when away from home. This feature is most commonly enabled by utilizing Wi-Fi, which requires 1-2 W of power to maintain connectivity. When the retrofit is hardwired, like the connected thermostat, Wi-Fi is integrated directly into the retrofit device itself. However some retrofits, like the smart laundry sensor, are battery powered and communicate by Bluetooth to a hardwired hub that relays communication from the sensor to the consumer through Wi-Fi. Some retrofits, like the window covering controls, do not use Wi-Fi at all, and thereby limit the consumer to short-range (<10 meters) control. When Wi-Fi is utilized, the retrofit device consumes 10-20 kWh per year to maintain connectivity.

3.4 Cost of Retrofit and Product Lifespan

Generally speaking, the more expensive a replacement IoT product is compared to its retrofit solution, and the longer the remaining life of the existing product being retrofitted, the better the case that can be made for retrofit cost effectiveness. A subset of retrofit solutions are presented in Table 2 along with the cost of the retrofit, the cost of replacing the existing product with an IoT product, and the ratio between the costs.

The spread of ratios illustrates the range that can be found, from relatively inexpensive retrofits in the clothes dryer sensor and water heater control, to the relatively expensive smart light bulb socket retrofit that is no less expensive than purchasing an IoT smart light bulb.

Table 2: Comparison between cost of retrofit and cost of IoT product replacement

Retrofit Solution	Retrofit Cost	IoT Product Cost	Retrofit Cost Relative to Product Cost
Clothes dryer sensor	$50	$700	7%
Water heater control	$150	$800	19%
Room AC control	$80	$375	21%
Smart light bulb socket	$20	$20	100%

The average lifespan of existing products varies by end use. Products including HVAC equipment, water heaters, window coverings, and some large appliances have an average lifespan of 10 to 20 years, and in many cases last even longer before they are replaced. Plug loads, lighting and other small products generally have a shorter average lifespan ranging from 5 to 10 years. When considering a connected retrofit solution, a greater anticipated number of years of product life remaining can provide enough time for the cumulative benefits of connectivity to pay for themselves.

4 Energy Efficiency and Demand Flexibility Potential

The two primary energy benefits considered in this project that are enabled by connected retrofits are energy efficiency and demand flexibility. Energy efficiency is the reduction in overall energy consumed by the end use product. Demand flexibility is the ability to shed load during peaks or shift load to off-peak or otherwise advantageous times of day.

There are several key factors to consider when assessing the overall energy efficiency and demand flexibility potential of a connected retrofit solution, and whether or not it is a cost effective option for the consumer. These factors include:

- Total end use product energy consumption per unit
- Extent to which the end use product load can be flexed and shifted
- Useful remaining life of the existing end use product considered for retrofit
- Procurement and installation cost of the retrofit as compared to the cost of fully replacing the existing end use product with an IoT product
- Additional product-level and upstream energy consumption introduced by the retrofit
- Compatibility limitations and operational barriers of the retrofit

A qualitative summary of energy efficiency and demand flexibility potential for a range of connected retrofit solutions is presented in Table 3 and discussed below.

4.1 Heating & Cooling

Space conditioning (heating, ventilation and air conditioning or HVAC) and water heating end uses comprise the greatest energy savings opportunity for connected retrofits due to their ubiquity, relatively high annual energy consumption, high load flexibility, and long average product lifespan. While connected thermostats have been used to retrofit central HVAC systems with connectivity and control with well documented success in achieving energy benefits, connected retrofits for water heaters and room AC units show significant potential but have not yet received the same level of attention.

According to the *IEA Energy Efficiency Indicators* report, space conditioning and water heating are responsible for 52% and 18% of global residential energy use respectively (IEA 2019). The global installed stock of domestic HVAC equipment exceeds 1 billion units, and each unit consumes an average of 1 MWh per year (IEA 2018). The installed stock of domestic tank-based water heaters exceeds 300 million in the US and the EU combined, and each unit consumes an average of 3 MWh per year (IEA 4E 2017, IEA ETSAP 2012).

4.1.1 Space Conditioning

The most prolific and well-known connected retrofit solution is probably the connected thermostat. Connected thermostats are found in at least 11% of US households, and have been found to reduce energy usage by 7-11% in central ducted HVAC systems (ACEEE 2018). The market for these devices is growing fast, and the benefits in the application of central HVAC systems have been fairly well documented. Outside the US, a large share of residential space conditioning is decentralized, and the installed stock of room AC units, ductless mini-splits, and portable space conditioning units continues to grow (IEA 2018). Therefore the connected thermostats designed specifically to retrofit decentralized space conditioning end uses deserve consideration.

Several room HVAC connected retrofit solutions exist on the market, distinguished primarily by the means through which they connect to and control the existing product. Some retrofits leverage the infrared (IR) receiver, while others function more like a smart plug in that they can cut power to the existing unit altogether.

The energy efficiency potential depends largely on climate and user preferences. However, decentralized space conditioning is inherently flexible, and achieving energy usage reduction similar to what has been shown in centralized HVAC through the use of connected thermostats is reasonable. Provided sufficient intelligence strategies are employed, HVAC units retrofitted with connectivity can precondition space, curtail load based on grid signals, and participate in demand response programs like the PeakSmart program in Australia, which compensates consumers in exchange for relinquishing a small amount of comfort (Energex 2020).

For central ducted HVAC systems, duct vents can be retrofitted with connected louvers that enable zone control within the home. While reducing heating or cooling to an unoccupied part of the house could enable more precise and efficient use of the HVAC system, studies to date have shown inconclusive results, and there are concerns around how the use of zoning might impact the performance of the central heater or AC (Urban et al 2016).

Table 3: Summary of energy savings potential and limitations of connected retrofits

End Use Category	Retrofit Solution	Energy Efficiency and Demand Flexibility Potential	Limitations
Significant Energy Savings Potential			
HVAC	Smart thermostat	Flexible load for shedding and shifting; relatively mature technology incorporates many intelligence strategies and opportunities for efficiency	Some issues with compatibility and interoperability with other connected devices may exist
HVAC	Room AC control	Flexible load for shedding and shifting; gradient of set points and control enable efficiency; large global stock of existing room AC units	IR-based retrofits require IR-enabled end use; interoperability challenges with other connected products; proprietary control app
HVAC	Radiator control	Flexible load for shedding and shifting; compatible with standalone and multiple radiator systems; gradient of set points and control enable efficiency	Specific to hydronic radiator based heating; compatibility with certain radiator models; proprietary control app
Water Heating	Water heater control	Flexible load for shedding and shifting; gradient of set points and control enable efficiency; large global stock of existing tank-based water heaters	Compatible with tank-based heaters with electronic controls only
Limited Energy Savings Potential			
HVAC	Vent control	Enables heating/cooling precision within zones; does not enhance demand flexibility	Zone control may impact furnace performance; only compatible with certain ducted HVAC systems
Plug Load, Lighting	Smart plug or strip	Limited demand flexibility dependent on end use plug load; wide range of end use plug load products	Compatible only with simple plug loads that can perform active function by power source switching
Plug Load, Lighting	Automatic button pusher	Limited demand flexibility dependent on end use plug load	Compatible only with products for which a single button-press is effective; proprietary control app; short range
Large Appliance	Clothes dryer sensor	Moderately flexible load (would require retrofit device improvements to capitalize on); efficiency based on cutting dryer cycle short	No dryer cycle interruption; efficiency reliant on user intervention
Large Appliance	Cooking thermometer	Inflexible load; efficiency based on shortening cooking duration	No cooking appliance interruption; efficiency reliant on user intervention
Lighting	Smart bulb socket	Inflexible load; small efficiency potential based on low ratio of lighting energy usage to retrofit energy usage	Compatible only with specific bulb socket types; proprietary control app
Lighting	Smart switch plate	Inflexible load; small efficiency potential based on low ratio of lighting energy usage to retrofit energy usage	Compatible only with specific toggle-style switch plates; proprietary control app
Window Coverings	Window covering control	Efficiency and demand flexibility savings associated with reducing HVAC and lighting loads	Compatible only with specific window covering types; very limited
Home Security	Smart alarm battery	No apparent energy efficiency or demand flexibility opportunity	Enhances home security only
Home Security	Garage door control	No apparent energy efficiency or demand flexibility opportunity	Enhances home security only
Home Security	Smart door lock	No apparent energy efficiency or demand flexibility opportunity	Enhances home security only

4.1.2 Water Heating

Tank-based water heaters are inherently flexible loads that can benefit from connectivity in ways similar to HVAC systems. One study points out that water heaters are essentially “pre-installed thermal batteries that are sitting idle” and a significantly untapped source of energy benefits (Hledic et al 2016).

A limited field study of connected retrofits for tank-based water heaters revealed an energy use reduction opportunity of 10% while limiting the increased risk of hot water depletion, but this depends largely on the climate and consumer preferences (GTI 2018). Connected retrofits for water heaters also enable the ability to better coincide with on-site distributed energy resources, and participation in utility demand response programs (Hledic et al 2016).

While there has been much focus on connecting HVAC products through connected thermostats, water heaters remain mostly unconnected. Most water heaters are replaced upon failure on short notice, and due to the lack of connected water heaters available, unconnected water heaters tend to be installed. An effort to standardize inclusion of a communications port in all water heaters to enable future connectivity is underway but has not been finalized (Eustis 2016). The average lifespan of a water heater is between 10 and 20 years, therefore a connected retrofit generally has plenty of time to justify its expense.

4.2 Lighting, Plug Loads and Other End Uses

Domestic lighting, plug loads, appliances and other residential end uses present moderate to minimal energy savings potential from connected retrofits due in part to the relatively small total energy usage these end uses represent, and the lack of flexibility in the way these end uses tend to be operated.

Together lighting, plug loads, and appliances comprise about 28% of global residential energy consumption (IEA 2019). Unlike HVAC and water heating products which cycle based on temperature set points, lighting, plug loads and appliances are generally active based on user discretion and are therefore inherently less flexible.

4.2.1 Lighting

The proliferation of LED lighting technology has substantially reduced energy consumption of the residential lighting end use category as a whole. Global market share of LED lighting has increased from 5% in 2013 to 40% in 2018, and is anticipated to reach 90% by 2030 (IEA 2019b). LED lights consume an order of magnitude less energy than the incandescent bulbs they generally replace, and therefore while connected retrofits for LED lights may help a consumer achieve other IoT benefits such as convenience, they yield little in the way of meaningful energy efficiency.

One pilot study found energy savings from connected lighting ranged from 7% to 27% based on reduced hours of use and dimming when deployed in high-use areas within the home (Bonn and Rivest 2016). Even so the cost of a lighting retrofit is difficult to justify. Connected retrofit solutions for lighting, like the smart switch plate or bulb socket, cost about as much as a full IoT replacement product: the connected light bulb. The increased energy needs of connectivity erode the energy savings opportunity, and consumers may encounter issues with existing light bulbs, fixtures and switches with which the retrofits are not compatible.

4.2.2 Plug Loads

Standby power consumption in plug loads has increased dramatically due to the addition of secondary functions in these products (EDNA 2019). Consumer electronics and other residential plug loads can benefit from the use of a connected retrofit – a smart plug or smart plug strip – to effectively disconnect the product from its source of power when not in use, an approach that may yield energy usage reductions of up to 50% (Urban et al. 2016). However, as with lighting, the added power consumption of the retrofit device erodes much of the potential. Further, some products may lose functionality if disconnected from the power source, such as loss of remote control programmed setting stored in memory. Additionally, the relatively short average lifespan of plug load products and the growing number of connected IoT replacement products further diminishes the practicality of a connected retrofit.

4.2.3 Appliances

Most large appliances do not receive energy benefits from connectivity because they are expected to perform at the discretion of the consumer. Any energy savings potential that connected retrofits might enable for large appliances stem from shortening the run time or scheduling the run cycle in order to shift the load.

The connected retrofits we identified for large appliances capture data that is then used to trigger notifications to the consumer, who must manually interrupt the appliance cycle to capture any energy efficiency. There are complications with implementing electrical control over a large, often high-voltage electronic product whose capabilities are substantially limited by the product's own internal controls, and for this reason connected retrofits for appliances are difficult to justify.

4.2.4 Window Coverings

Connected retrofits for window curtains, blinds and shades use wireless motors to schedule and automate the opening and closing of window coverings based on user preference and ambient conditions. Automation of window covering controls were shown to provide 10-20% reduction in HVAC energy usage by insulating windows or reflecting solar irradiation when conditions warranted (ACEEE 2018). However, the practicality of this is limited to very specific home configurations. Further, the available retrofits are not universally compatible with existing window coverings thereby reducing their potential to provide energy benefits.

4.2.5 Home Security

For existing door locks, smoke alarms, garage doors and other home security devices, the marketed benefits of connected retrofits are on the convenience and peace-of-mind that they provide. These end uses consume very little energy relative to other domestic end uses, and therefore connected retrofit solutions do not provide any measurable energy benefits, and in fact may only increase energy consumed based on the added energy requirements of the retrofit device itself.

5 Use Cases for Connected Retrofits

The energy benefits realized by a particular retrofit product depend largely on the end product it retrofits. We therefore explore energy benefits of three promising retrofit products, each applied to a major energy-using load in the home, to explore some of the best opportunities for retrofits from an energy perspective.

5.1 Use Case: Aquanta Water Heater Control

The Aquanta Smart Water Heater Controller is a retrofit device designed to add network connectivity to an existing electric or gas tank-style water heater. For electric water heaters, the retrofit device output plugs into the water heater power source, and for a gas water heater it plugs into the electronic ignition control of the heating element. A sensor is installed to measure the water temperature inside the tank. While the manufacturer claims installation can be performed by the consumer, there are risks associated with retrofitting an existing water heater an, it is recommended that a certified professional performs the retrofit. Connectivity is established through Wi-Fi, and the user communicates with the device using a proprietary mobile app.

The retail price of the Aquanta controller kit is US$150, and professional installation could cost between US$50 and US$200. For comparison, the cost of a connected electric tank-based water heater with installation would total about US$1000 to US$1300.

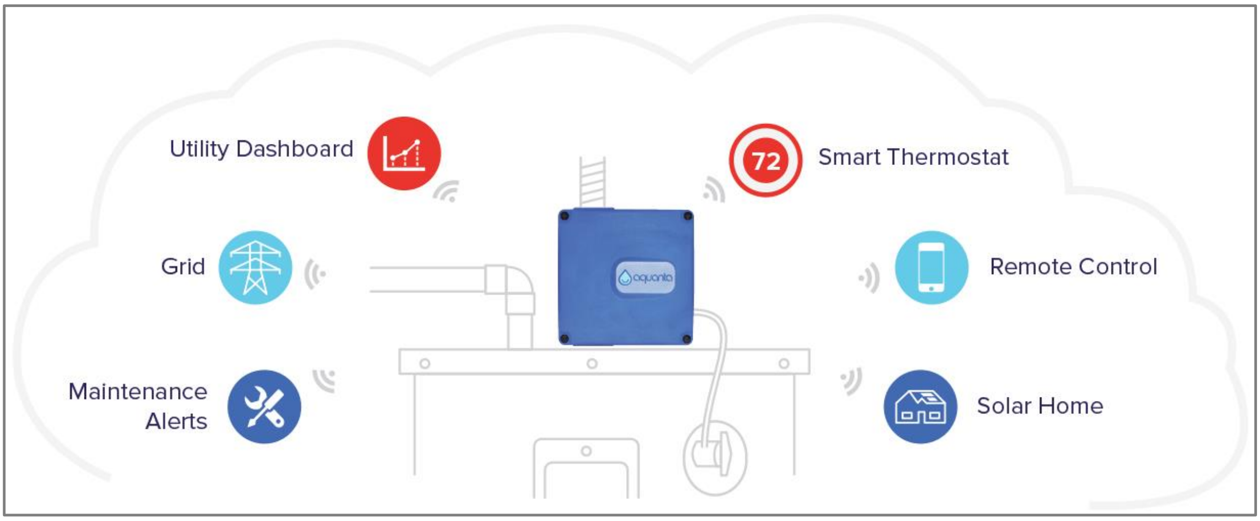

Figure 1. Overview of Aquanta Water Heater Controller. Source: aquanta.io

The Aquanta device reduces water heater energy usage by allowing the user to set a heating schedule and remotely turn off the heater when away for long periods of time, and by preventing unnecessary heating by learning and adapting to the consumer's usage patterns. The device is also equipped to receive and respond to grid signals and participate in demand response programs.

An early-stage pilot demonstrated energy savings of about 10%, or about 300 kWh per year, based on the average energy consumption a typical tank-based water heater, though optimized intelligence strategies may enable savings closer to 20% (GTI 2018). The Aquanta product brochure states that the device draws about 5W, or about 40 kWh per year, resulting in a net savings of 260 kWh per year.

A study found that the net benefits of demand response participation relying on load control strategies including peak shaving to reduce max demand, thermal storage to shift load away from peak time-of-use periods, and fast response to provide additional grid stability could range from $50 to $200 per participant per year, some of which could be shared with the consumer in the form of an incentive or subsidy program by the energy provider (Hledic et al. 2016).

Figure 2 presents the results of a simple breakeven analysis for the Aquanta retrofit. Assumptions include energy usage reduction of 5%, 10% and 15%, and annual customer demand flexibility benefits of US$0, US$50, and US$100 for the conservative, median and optimistic scenarios respectively. Constant assumptions include residential energy cost at US$0.12/kWh, and the cost of the retrofit at US$250 for parts and installation.

The breakeven analysis suggests that the Aquanta device can pay for itself in 3 to 7 years in terms of the net energy benefits provided to the consumer. At a cost of US $1000 to $1300, a fully connected tank-based water heater replacement would not pay for itself in terms of energy benefits to the consumer, further justifying the viability of a connected retrofit solution such as the Aquanta device.

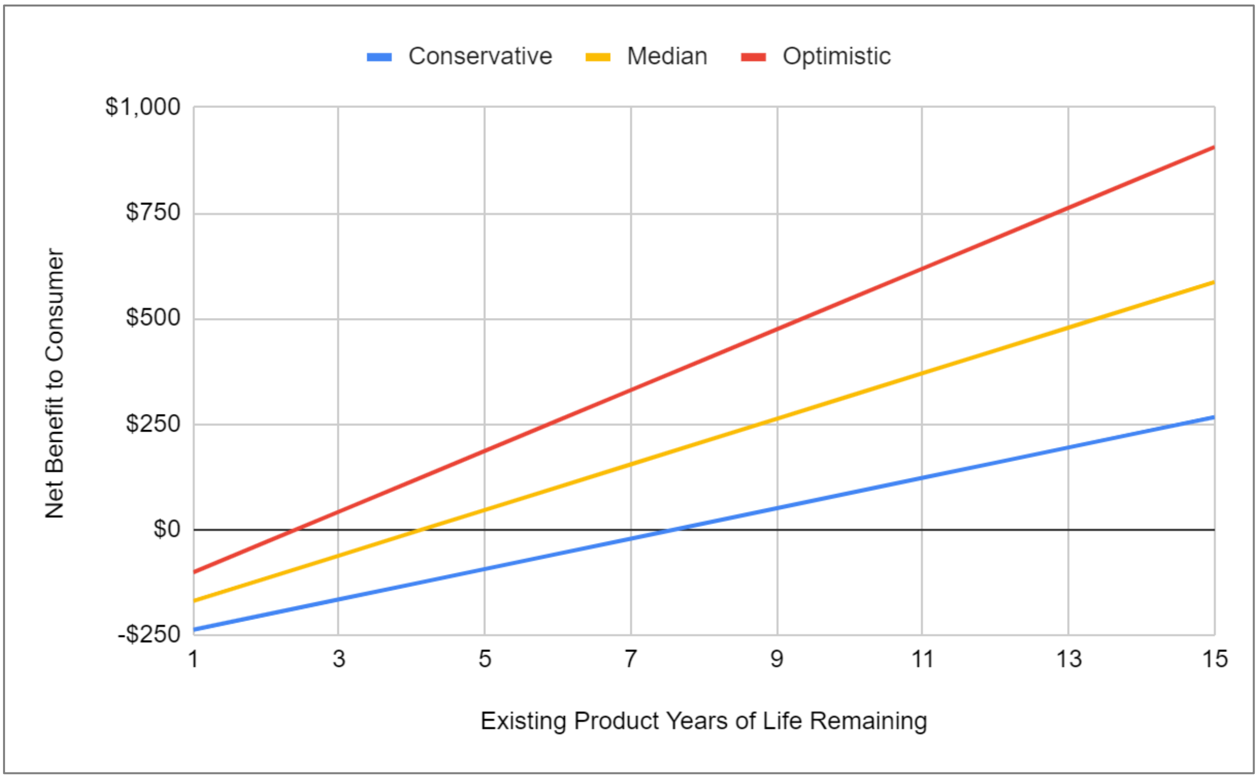

Figure 2. Energy benefit breakeven of the Aquanta water heater controller connected retrofit.

One drawback of the Aquanta device is potential incompatibility with some existing water heaters. This retrofit does not work with tankless systems, nor does it work with systems equipped with anything other than electronic controls. The manufacturer claims the product is compatible with 60-85% of installed stock of tank-based water heaters. The utility and effectiveness of the Aquanta device might be maximized by addressing compatibility limitations, reducing device energy consumption, and simplifying the installation as much as possible.

5.2 Use Case: Flair Puck Thermostat for Room AC Control

The **Flair Puck Thermostat** is a unique retrofit solution designed to add connectivity and control to a variety of decentralized HVAC end uses, including room AC units, space heaters, ductless mini-splits, and portable space conditioning products.

The Puck is installed by mounting it to a wall and plugging it in. It is then paired with an existing decentralized product through the product's IR remote control receiver, and is connected to the internet through Wi-Fi. The user uses a proprietary mobile app to configure and control the Puck as well as any additional Pucks installed to control additional devices in other rooms.

There is added value in Puck's ability to interact with other devices. Consumers can integrate the Puck with existing connected thermostats to consolidate control through a single interface. For homes with central ducted HVAC, the **Flair Smart Vent** can be used to deploy a zone control strategy, though it requires an installed Puck for connectivity and control. The retail price of a Puck is US$120. For comparison, the cost of a typical mid-range connected room AC unit is about US$375.

The Puck device enables energy savings by allowing users to schedule and remotely control their room AC units, and by allowing the AC units to respond to ambient conditions or utility-based demand response programs. One study found that energy savings in room ACs of 5-6% were possible through the use of connectivity (Sastry et al. 2010).

Figure 3. Flair Puck and Flair Smart Vent retrofit devices. Source: flair.co

Figure 4 presents the results of a simple breakeven analysis for a single Flair Puck connected thermostat retrofit of an existing room AC based. The assumptions include energy savings of 4%, 6% and 8% for the conservative, median and optimistic scenarios respectively. Constant assumptions include no demand response benefits, residential energy cost at US$0.12/kWh, and the cost of the retrofit at US$120.

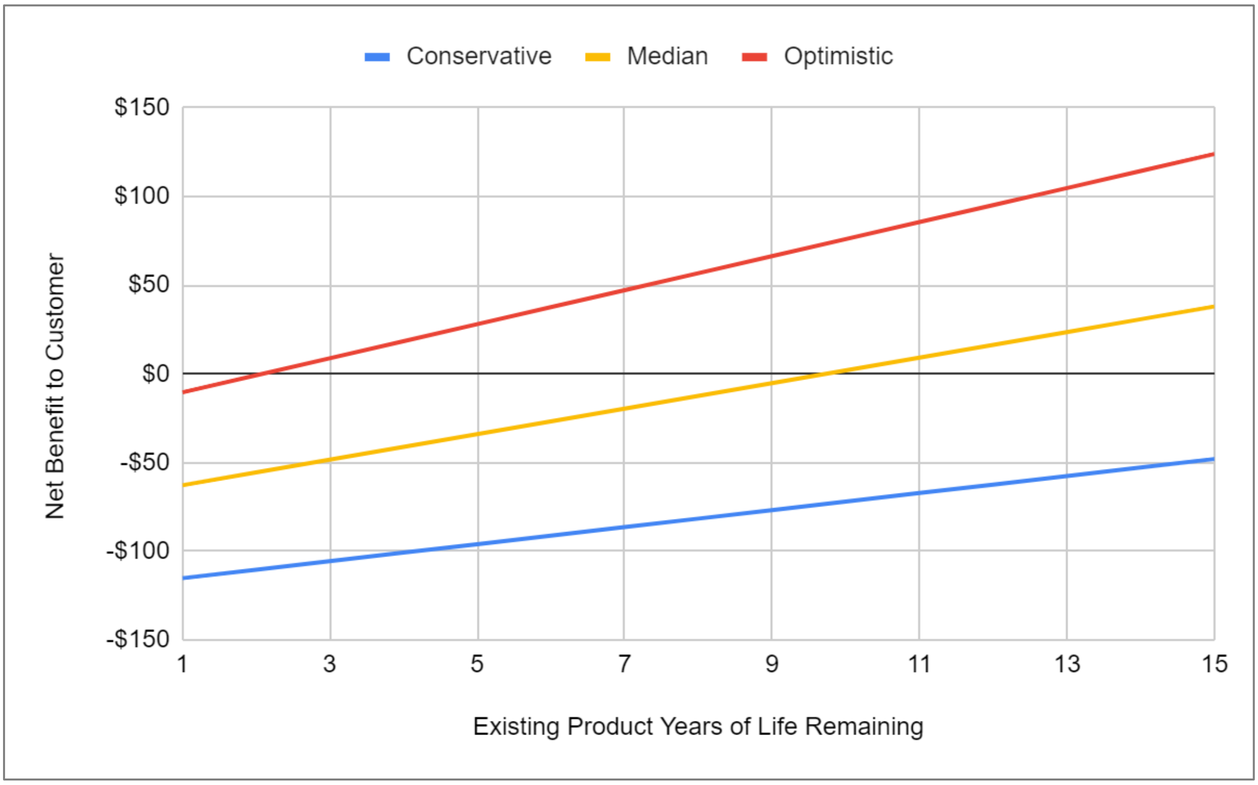

Figure 4. Energy benefit breakeven of the Flair Puck connected thermostat room AC retrofit.

The breakeven analysis suggests that the ability for the Flair Puck to pay for itself depends largely upon the number of hours per year the consumer uses the room AC, as well as the actual energy efficiency savings the consumer can achieve. Unlike the connected water heater, a standalone connected room AC can be purchased at a much lower incremental cost, and may be more cost effective for the consumer depending on the remaining useful life of the existing room AC unit.

5.3 Use Case: SmartDry Smart Laundry Sensor

The **SmartDry Laundry Sensor** is a multi-sensor device that can reduce the energy consumption of a tumble-style clothes dryer by eliminating unnecessary runtime. The SmartDry device consists of two main components. The first is a battery-powered temperature and humidity sensor that is secured inside the dryer drum using a magnet. This sensor communicates by Bluetooth to a hardwired Wi-Fi enabled hub that sits outside the dryer. The hub serves as a bridge between the sensor and the Internet.

The consumer uses a mobile app to configure the SmartDry device. By setting temperature and moisture thresholds, the SmartDry will send the user mobile notifications during each dryer cycle whenever the configured temperature and moisture thresholds are reached. Energy savings are captured when the user reacts to the notification by interrupting the dryer cycle before it would typically end based on its internal controls.[2] The retail price of the SmartDry device is US$50.

Figure 5. SmartDry smart laundry sensor and Wi-Fi hub. Source: reviewgeek.com

One reviewer claimed that the SmartDry reduced dryer run time by 15 minutes per load (Delaney 2020). Assuming a typical clothes dryer cycle lasts one hour with a power consumption of 3 kW, and the dryer is used about 100 times per year, a 25% reduction in run time would equate to energy savings of about 75 kWh per year. However, for the SmartDry Wi-Fi hub to maintain connectivity, an additional 45 kWh per year might be required, thereby offsetting more than half of the attainable energy savings.

Figure 6 presents the results of a simple breakeven analysis for the SmartDry device. Assumptions include 10 kWh per year of network standby power required by the Wi-Fi hub, and 20%, 25%, and 30% reduction in clothes dryer energy usage for the conservative, median, and optimistic scenarios respectively.

[2] Note that a dryer with this retrofit is similar to a dryer with an integrated humidity sensor that automatically turns off when the clothes are dry. The integrated product does not need connectivity to provide energy savings, and is likely to yield more savings than the retrofit because shut-off is automatic rather than dependent on user action.

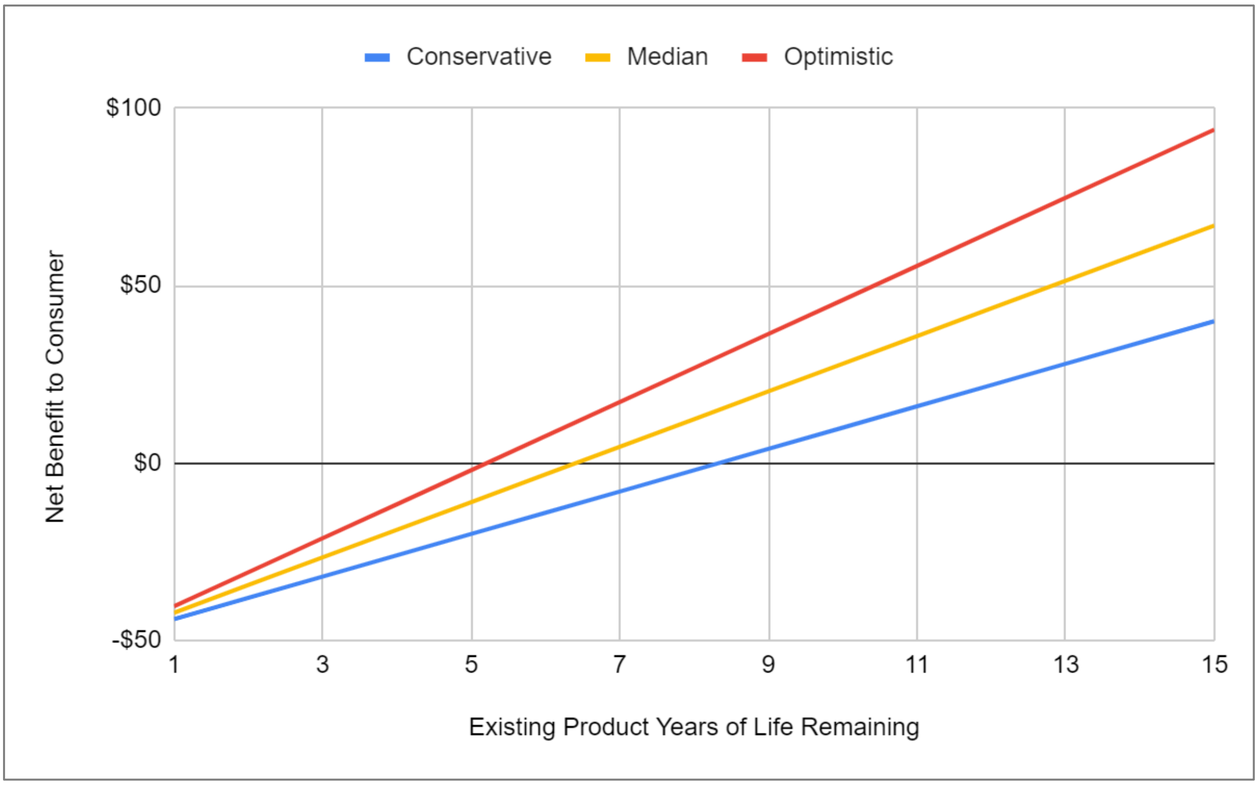

Figure 6. Energy benefit breakeven of the SmartDry laundry sensor connected retrofit.

The breakeven analysis suggests that if the sensor can indeed reduce dryer run time by 25% and the user can consistently exhibit behavioral control to interrupt the dryer cycle, the SmartDry device might be able to pay for itself in terms of net benefits to the consumer within 5 to 9 years. Although the energy savings potential could theoretically be improved by adding an electrical control strategy, the complications and risks of accomplish this are difficult to justify.

6 BARRIERS TO ADOPTION

Amidst the landscape of available connected retrofit solutions, there are several retrofit devices that present considerable opportunities to achieve energy benefits. However, there are also a number of challenges that inhibit the uptake of connected retrofit devices.

One barrier to adoption is the lifespan of the existing product being considered for a connected retrofit. If the product is approaching the end of its useful life, the consumer may be reluctant to spend money on a retrofit when those funds could instead go toward the purchase of a replacement product later on. There is a perception, perhaps justified, that a retrofit is a short-term solution that may require forfeiture of other features and functions that may be provided from a newer connected version of the residential product in question. Only a few products – HVAC systems, water heaters, and some large appliances – possess an anticipated lifespan long enough that the consumer may feel like a retrofit can be an investment in energy savings.

The incompatibility of some retrofits with end use products is another barrier to adoption. It can be difficult to design a retrofit device that functions properly with every iteration of the end use product, and in the end a manufacturer must ultimately device how all-inclusive their retrofit device can reasonably be.

Interoperability is another prominent barrier to retrofit adoption. A lack of standard smart home platforms has led to a diverse range of connected products built with proprietary interfaces and communication protocols. The drawback is that a consumer seeking benefits of smart home connectivity might have to endure the use of five different mobile apps to control five different products around the home. While manufacturers of some retrofit products make an effort to provide an application programming interface (API) so the device can interact with other devices, most do not.

Of related concern is the long-term viability of manufacturers bringing connected retrofit solutions to market. Even just in our investigation we encountered several examples of retrofit devices whose websites were abandoned and creators appeared to have ceased production and support for their products.

Finally, there is a perceived notion that product connectivity within the home exposes the consumer to security risks. Retrofits may not have been built with user security in mind, therefore a consumer may be unwilling to retroactively connect a water heater due to the perceived threat that it might be in some way hacked.

7 Conclusions and Recommendations

Our exploration of connected retrofit solutions and the energy benefits they might provide suggests that only a few noteworthy opportunities currently exist, and those are primarily retrofits of existing HVAC equipment, tank-based water heaters, and some appliances. These opportunities can represent significant energy benefits in some cases, due the high energy usage, flexibility of operation, and long lifetime of the products the retrofit acts on.

We anticipate that connected retrofits are and will be adopted by tech-savvy consumers interested in creating a smart home ecosystem, but increasing the adoption of retrofits for energy benefits will likely need encouragement from governments, energy efficiency advocates, and utilities. One avenue for promoting adoption of high-value retrofits is ENERGY STAR's recently developed Smart Home Energy Management Systems (SHEMS) specification (ENERGY STAR 2019). The specification aims to encourage smart home products that can yield energy savings and demand response or other load shifting, offered as a package of products. These products include retrofit products such as connected thermostats and smart outlets or plug strips. Other high-value retrofits may be encouraged as part of this or other smart home programs. These programs should also require manufacturers of connected retrofits to meet certain energy-based and interoperability criteria that could then increase the long-term potential energy benefit of a connected retrofit, as the SHEMS specification does (ENERGY STAR 2019).

Utilities can play a major role in increasing adoption of retrofits, especially those that can increase the number of loads that can participate in DR or other demand flexibility programs. Many utilities already encourage connected thermostat adoption to expand HVAC DR programs; water heater retrofit solutions may similarly expand demand flexibility opportunities or those energy-intensive products.

Retrofit adoption may require consumer education that helps them better understand their own energy usage and the energy benefits of connectivity so they feel compelled to purchase and install beneficial retrofit products. The source of such education can range from governments and efficiency advocates, to manufacturers and utilities, and to products themselves that report usage and help consumers understand how to save energy and cost. However, even educated consumers may not be highly motivated by energy savings, and therefore the installation and maintenance burden of retrofits must be low in order to be widely adopted. This includes simple, plug-and-play installation, and essentially no required maintenance.

Finally, while connected retrofits present an intriguing and unique opportunity to realize energy benefit, there should continue to be a strong emphasis on energy efficiency of end use products, including retrofits products. Retrofit market adoption programs and policies should ensure that the retrofits solutions they promote are efficient products in their own right, and achieve energy benefits that far outweigh the additional energy use required by the retrofit product itself.

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