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NRDC Comments on Flexible Demand Appliance Standards RFI

Additional submitted attachment is included below.

NRDC

November 1, 2021

Re: NRDC Comments on 9/1/2021 Request for Information on Flexible Demand Appliance Standards

Dear Commissioner McAllister and Energy Commission Staff:

On behalf of the Natural Resources Defense Council (NRDC) who is advocating for affordable and equitable decarbonization and clean air policies in buildings to help mitigate the climate crisis, we respectfully submit the following comments in response to the California Energy Commission's (CEC) September 1, 2021 request for information (RFI) on the SB 49 Flexible Demand Appliance Standards.

NRDC strongly supports CEC's efforts to develop flexible demand appliance standards under its SB 49 authority. Demand flexibility is a critical pillar of a comprehensive strategy to decarbonize the building and electric sectors affordably. Cost-effective decarbonization requires energy efficient buildings, electrification of heat and hot water using high-efficiency heat pump technology powered by zero-carbon electricity, and demand flexibility to shift load from peak to off-peak time periods, helping integrate renewable energy on the grid and keeping the electric system and utility bills affordable.

Our provide responses to some of the RFI questions below, using the RFI's original question numbers:

2. What additional appliances should be considered for future FDAS development beyond the first three proposed phases and why?

Domestic hot water circulator pumps ("DHW circulator pumps"): DHW circulator pumps circulate hot water in buildings distribution systems, reducing hot water wait times at showers, faucets, and other fixtures, and the amount of water wasted down the drain waiting for hot water to arrive from the water heater. These customer convenience and water-saving benefits are important, but for the vast majority of models sold which are of the 24/7 and timer-controlled type, these benefits come at a very high cost in terms of pumping energy to circulate the water throughout the building several hours per day, and of heating energy use to reheat water that cools down in the distribution pipes in the building. On-demand recirculation models offer the customer convenience and water-saving benefits at a fraction of the energy consumption in unitary applications (single-family and small multi-family), and variable speed pumps with thermal balancing do the same in central applications. But these technologies currently have a low market share.

On-demand and variable speed with thermal balancing circulator pumps are forms of demand flexibility controls applied to 24/7 pumps: the on-demand or other forms of control solutions avoid unnecessary energy use at all times including at times when energy is scarce, dirty, and expensive, and the grid is strained. They are very cost-effective, saving many times more in reduce energy costs than the extra cost of the demand controls, with payback periods between 1.9 and 5.8 years according to the attached analysis by Energy Solutions for NRDC.

NRDC recommends CEC considers requiring all DHW circulator pumps sold in California to be equipped with application-appropriate advanced controls under the Flexible Demand Appliance Standards which are not preempted by federal energy efficiency standards for these products. More information on this opportunity can be found in the attached report by Energy Solutions.

Refrigerators, freezers, and miscellaneous refrigeration appliances like wine coolers: NRDC recommends CEC considers the potential for load shifting by refrigerators, freezers and wine coolers, given that these appliances present two opportunities for demand flexibility: 1) shifting defrost cycles off-peak; 2) reducing compressor operation on-peak by pre-cooling off-peak by a small amount, either within a certain temperature tolerance or even within the existing dead band, and then letting the internal temperature drift within the tolerance or dead band to reduce on-peak compressor operation.

Refrigeration appliances have built-in thermal storage which enables demand flexibility with no customer impact. Refrigerators are ubiquitous, with more than one on average per household. They may present a significant demand flexibility opportunity. This opportunity is already recognized by ENERGY STAR connected criteria, and several models on the market already receive credit for this functionality under the ENERGY STAR program.

4. What other flexible demand approaches are available for staff to consider? Please include references to publicly available sources.

Advanced recirculation controls for hot water circulator pumps: as discussed in question 2, on-demand, and variable-speed thermally balanced controls have the potential to substantially reduce peak-coincident load.

Utility TOU tariff download: Table 3 includes scheduling and connected approaches. Scheduling is defined as “set by the customer”. We recommend clarifying that scheduling does not necessarily need to be performed manually by the customer: in response to Title 24 Joint Appendix 13 for heat pump water heaters (HPWH), most HPHW manufacturers have developed the capability of uploading time-of-use tariffs from the local utility to the HPHW, and for the HPHW to automatically shift load based on time-of-use prices and customer needs. This is an intermediate capability between manual scheduling by the customer and grid connectivity. It can deliver immediate flexibility value to the customer and the grid in areas that don’t yet offer grid flexibility services (most of California today), for HPWH that lose grid connectivity (e.g. due to a change in Wi-Fi router credentials), and for customers who do not want to connect their water heater to the grid but would like to shift their HPWH load according to their time-of-use tariff. We suggest adding this capability as a standalone line item, because it is significantly higher value and more sophisticated than manual scheduling.

5. What inspections or test methods should staff use to verify compliance with each approach?

The ENERGY STAR Water Heaters Connected test method defines how to test load shifting performance for HPWH, particularly how much load can be shifted out of a particular time period.

6. With consideration to high and low projected stocks for Table 1 Phase 1 appliances, what other sources of information are available to estimate current and projected appliance stocks in CA?

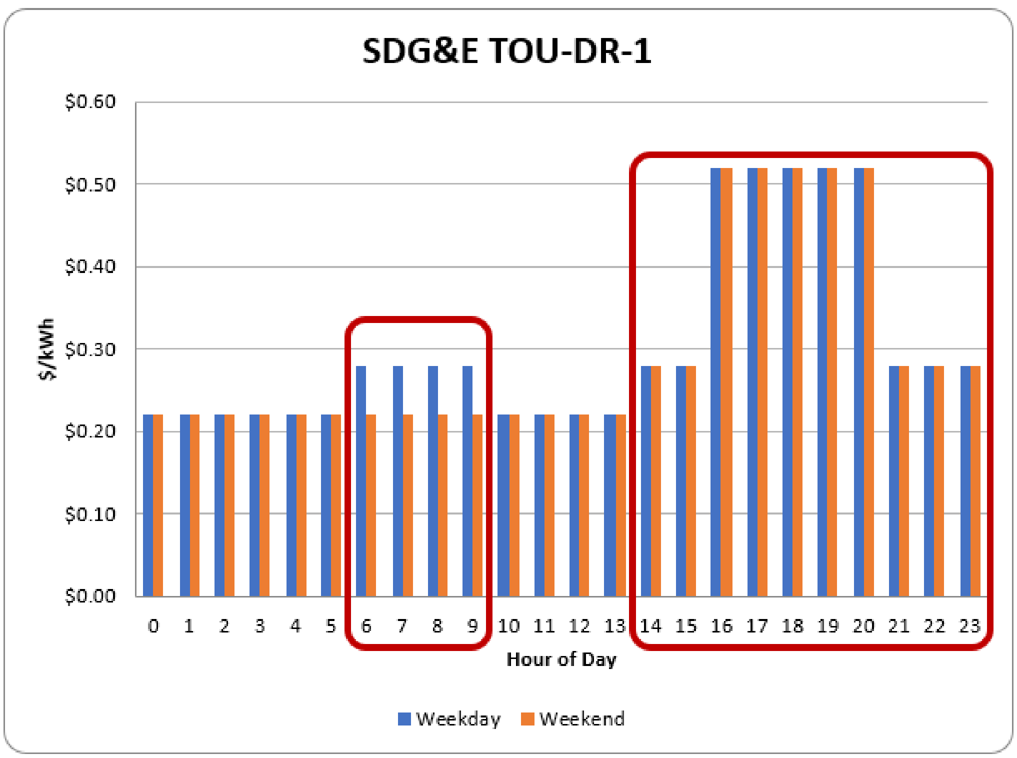
The attached Research and Analysis of the Benefits of Potential Appliance Standard Potential for Domestic Hot Water Circulator Pumps study by Energy Solutions includes stock and sales estimates of hot water recirculation pumps in the U.S. (30 million installed circulator pumps and 3 million annual sales) which give an indication of California stock and sales.

9. What other methods are there to estimate the flexible demand capability of appliances that better account for the range of benefits enabled?

Using only the 5 pm to 8 pm time period significantly underestimates the value of demand flexibility: it doesn't value the ability to absorb renewable energy in the middle of the day, which would otherwise be curtailed, increasing the cost of meeting the state's clean energy and climate goals.

It also doesn't value the ability to reduce winter morning peak load. While winter morning is currently a minor peak relative to the summer evening AC-driven peak, it will increase as space and water heating are electrified. In some California coastal areas with low AC penetration the local grid is already winter peaking today and would see immediate grid upgrade cost avoidance value in winter morning load shifting. The morning peak is already reflected today in SDG&E's TOU-DR-1 tariff shown in Figure 1 that already includes a 4-hour mid-peak time period in the morning and a 10-hour peak and mid-peak evening period, much longer than 5 to 8 pm, and we expect other TOU tariffs to do the same in the coming years as more buildings transition from gas to electric space and water heating under the state's building decarbonization policies and natural market adotion.

Figure 1: San Diego Gas and Electric time-of-use residential tariff



Lastly, focusing exclusively on 5 pm to 8 pm ignores the carbon reduction benefits of shifting from times of higher emissions outside of 5 to 8 pm to times of lower emissions. Smart appliances have the capability to shift load in a much more granular and frequent manner each day than a 3-hour peak period, in response to other current and future time-of-use tariffs, dynamic pricing, or carbon prices such as from WattTime. For example, on SDG&E's TOU-DR-1 tariff, smart water heaters and HVAC could pre-heat before 6am, coast through the 6 to 10 am window, reheat from 10 to 2, and coast from 2 to midnight.

Instead, CEC should assess the potential for devices to reduce cost using marginal grid system costs and marginal emissions metrics. For marginal grid costs and emissions, we recommend using the California Public Utilities Commission's Avoided Cost Calculator (ACC) that provides projections of avoided costs and GHG emissions on an hourly basis for the next 30 years. The ACC is California-specific and is already used to determine the cost-effectiveness of distributed energy resources (DERs) including energy storage and demand flexibility, to evaluate DERs for investments, consistent with California's Integrated Resource Procurement (IRP). It is readily available and updated and improved every year.

10. What forecasts for TOU rates in California are available for staff to consider?

Staff should consider how the high-electrification scenario in the AB 3232 Building Decarbonization Assessment would affect the grid and hourly marginal costs, which would provide an indication of the load shape of future time-of-use rates.

13. What other appliance load shape data sources are currently available?

NRDC and Ecotope performed a simulation study of HPWH load shifting in 2018 and can share the raw data with CEC staff. The study ran thousands of hourly simulation runs over one year for different HPWH models, sizes, draw patterns, CA climate zones, and price signals.

15. What other methods are there to estimate changes in GHG emissions from demand flexibility of appliances?

Long-run marginal emission factors/rates (MERs), such as those from NREL's Cambium dataset, are the best way to estimate GHG emission changes from appliance demand flexibility. Published in November 2020, NREL's Cambium long-run MER dataset forecasts the mix of generation resources that would serve a persistent and large-scale change in end-use demand, taking into account structural changes to the grid in response to the change in demand. [1,2] Long-run MER are most appropriate to model the impacts of widespread electrification of space and water heating, which would have a multi-decade and power plant-scale impact on demand and would lead utilities to adapt their generation portfolio to be able to serve this new load.

In contrast short-run marginal emissions rates represent changes in emissions for a set of electric generators that is not affected by the change in demand. Short-run MERs would be

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[1] P. Gagnon, W. Frazier, E. Hale and W. Cole, "Cambium Documentation: Version 2020," National Renewable Energy Laboratory, Golden, CO, 2020.

[2] National Renewable Energy Laboratory, "Cambium," [Online]. Available at https://www.nrel.gov/analysis/cambium.html

appropriate to represent the impact of minor behavior changes or a small number of participants outside of a broader policy or market trend, as that would not lead utilities to adapt their generation portfolio.

NRDC recommends the use of long-run marginal emissions rates for the analysis of emissions impacts from large-scale and durable changes in electricity demand, such as those driven by flexible demand appliance standards.

16. What forecasts for hourly average GHG emissions intensity are available?

The two most appropriate options for evaluating the potential for load flexibility to help reduce GHG emissions are the following:

1. **CPUC's Avoided Cost Calculator (ACC)**: The ACC provides short-run marginal emissions factors that represent the change of emissions when the change in load does not result in a long-term change in resource procurement. These are the emissions intensity of the marginal generator, and is most times a gas generator, except in situations when renewable resources are curtailed where the marginal resource is renewable. Short-run marginal emissions factors are most appropriate for small-scale or non-persistent changes in load.
2. **NREL's Cambium** dataset provides long-run marginal emissions factors, that represent changes of emissions when the change in load is large and durable and leads to a change of utilities resource portfolio. For example, large-scale demand flexibility may reduce the number of gas peaker plants necessary to meet evening peak load and increase the amount of solar that can be economically deployed. The marginal emissions factor is therefore that of renewable energy in the middle of the day even when the short-run marginal resource may still be a gas plant. Long-run marginal emissions factors are most appropriate for large-scale and persistent changes in load.

If California is serious about deploying demand flexibility at scale as it must do to achieve its climate goals, NREL's Cambium dataset or similar would be the most appropriate emissions profile for assessing the GHG benefits of large-scale demand flexibility. The ACC isn't as appropriate for the purposes of evaluating the impact of appliance standards but could also be used in the short-term for consistency with other state policy tools.

17. For long-term projections on changes in GHG emissions due to load shifting, will estimates of hourly marginal emissions or hourly system average emissions be the best metric?

See answer to question 15.

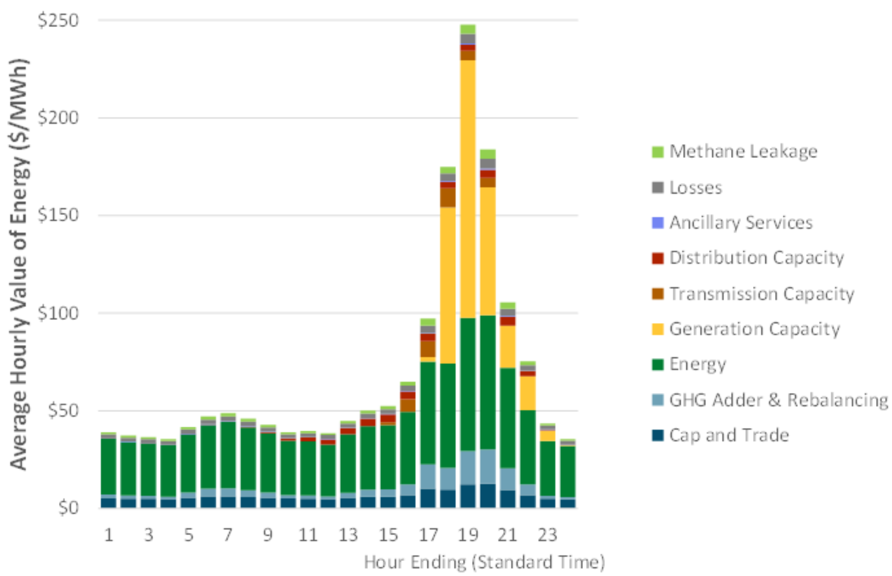
20. What other values in ($) per metric ton of CO2e for GHG emissions data sources are available?

NRDC recommends using the emissions cost factors in the ACC as the most appropriate data source for the cost of avoided greenhouse gas emissions. Specifically, CEC should use the sum of the following three ACC hourly energy cost components:

1. The cap-and-trade allowance price forecast
2. The GHG adder
3. The methane leakage adder

For example, using Figure 2 as an illustration, this would be the sum of the top and bottom two components.

Figure 2: ACC 2021, Average hourly value, PG&E, Climate Zone 3.



The Cap-and-Trade allowance represents the cost of complying with California's Cap-and-Trade regulation

The GHG adder represents the remaining cost, after cap-and-trade allowances, of complying with carbon reduction goals (i.e., how much more are utilities going to have to spend on carbon free resources to meet future carbon reduction targets). The GHG adder is derived from Integrated Resource Planning (IRP) modeling to determine the portfolio of clean energy resources needed to meet all energy needs and carbon goals in a least cost manner.

The methane component represents the GHG impacts from CH4 leakage associated with gas power generation.

28. What considerations should inform staff analyses on the projected equity impacts of proposed standards, to ensure flexible demand appliance sold or leased in California benefit all Californians?

CEC should engage with low-income housing providers and tenant rights stakeholders to discuss the proposed standards and listen to potential concerns and solutions.

29. What consumer protection mechanisms should be considered to prevent hardship or inconveniences to disadvantaged communities?

Low-income housing providers and tenant rights stakeholders should be consulted on cost protection mechanisms. Those may include incentive programs for low-income homeowners and housing providers to cover the upfront cost premium of demand flexibility requirements, with appropriate anti-displacement clauses.

Sincerely,

Pierre Delforge
Senior Scientist
NRDC

Research and Analysis of the Benefits of Appliance Standards for Domestic Hot Water Circulator Pumps

Research Report to NRDC

On Demand Circulator Pump

Continuously Operating Circulator Pump

Energy Solutions

October 2021

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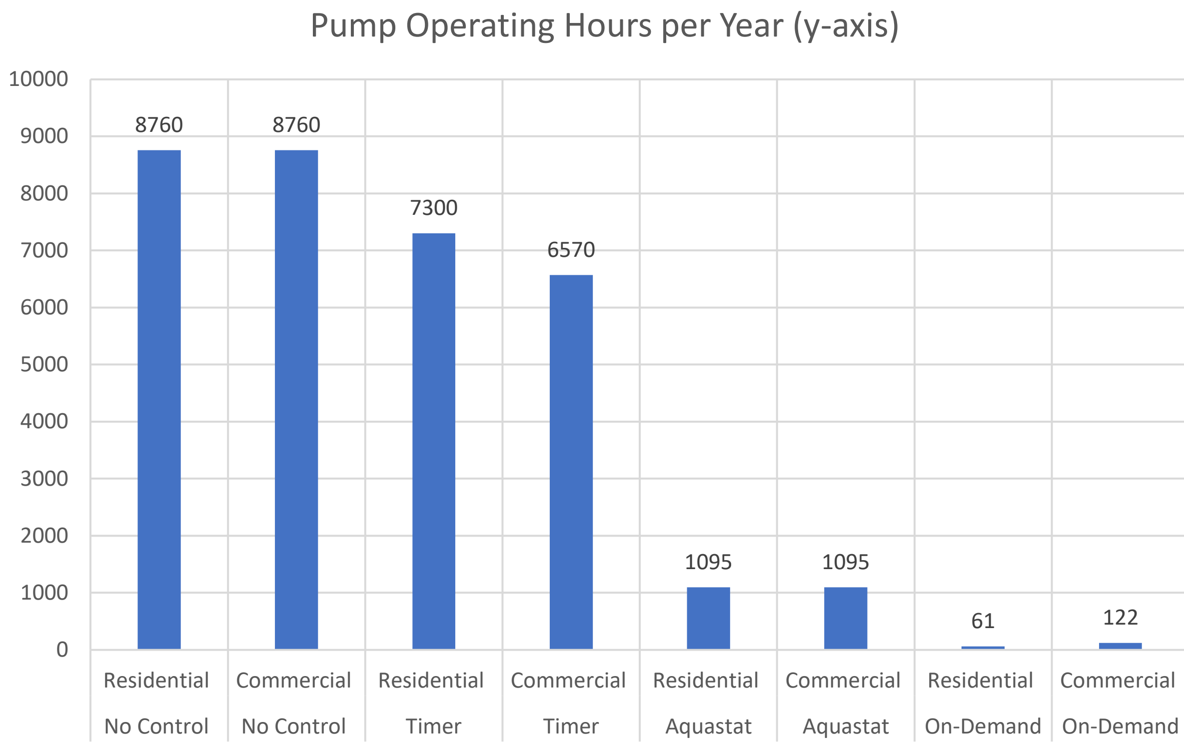
Executive Summary

This report analyzes the opportunities for and applicability of advanced circulator pump controls in residential buildings to provide a range of benefits to California. This report is organized into three sections:

- Baseline state of water heating and circulator pump market and technology
- Water, energy, financial, and carbon savings potential offered through the transition to on-demand circulator pumps in single-family homes
- Regulatory opportunities for requiring on-demand circulator pumps in new installations and replacements.

Hot water circulator pumps have gained popularity across building types to ensure hot water is available from the tap without a long wait or wasting significant potable water. When plumbing systems do not use circulator pumps, a user typically runs the tap until the hot water arrives; during this time, potable (cold) water is wasted (over 1,000 gal a year, per person). A continuously operating circulator pump runs constantly to keep hot water moving through pipes, drawing electricity 24/7 in many cases, as well as pushing water heaters to work frequently to make up for the thermal losses in the hot water pipes in the building; these pumps reduce the amount of potable water wasted, but create another issue of energy waste (the most common pump sold in California draws 87 W and consumes ~ 762 kWh per year, one of the largest uses of electricity in homes). While significant amounts of water are saved through use of a circulator pump, the continued overuse of water heaters, especially those powered by natural gas, is an unnecessary cost, greenhouse gas emissions, and air pollution problem in need of a solution. The increase in energy costs also impacts the end user significantly. For contextual purposes: half the timer-based pumps operate continuously, and the other 50 percent operate for 16 hours a day in residential settings.



There are several alternatives to continuous (a.k.a. 24x7) circulator pumps:

1. **Timer-based** circulator pumps can be used in single family applications where the pump is scheduled to circulate hot water during expected times of high demand. Timer-based pumps are an energy and financial improvement over continuous pumps, but they are often programmed to run 12 or more hours a day, so they still waste considerable energy. And when timers get out of sync due to power outages and backup battery failure, customers often disable them and run their pumps 24x7.

2. **Aquastat-controlled** pumps automatically switch on when the water temperature at one point in the recirculation system falls below a certain threshold and stop when it exceeds another threshold.

3. **Thermally balanced, variable speed** pumps circulate continuously but at a much lower flow rate, just sufficient to maintain an acceptable hot water temperature at the furthest fixture in the loop. This solution is the most effective in central water heater applications.

4. **On-demand** circulator pumps circulate the water when needed. Some are activated manually by pushing a button next to the water fixture. Others are operated by occupancy sensors. On-demand controls are proven to be effective in single family and small central water heating applications.

This report focuses on the potential savings from using button-operated on-demand pumps in unitary residential systems (system serving a single dwelling unit, as opposed to central systems serving more than one unit). Central heat pump water heater (HPWH) systems require more sophisticated recirculation solutions than on-demand circulators. Thermally balanced variable-speed circulators are the best options for central HPWH. A detailed analysis of central HPWH circulation solutions is beyond the scope of this analysis.

An on-demand circulator pump operates using the same basic mechanics of a continuously operating circulator pump but instead of constantly recirculating the water, an on-demand pump operates only when triggered by the user such as through a button push, then waiting for the water to recirculate for just a few seconds until the hot water has arrived. On-demand pumps can also be operated by occupancy sensors. However, a recent study found that occupancy sensors often trigger unnecessarily, circulating the water much more often than needed.[1]

Button-operated on-demand circulator pumps offer a nexus opportunity for savings in California through their ability to save water, electricity from avoided 24x7 pump operation, and energy for water heating. The on-demand pumps have a modest incremental cost but offer enormous energy and financial benefits. When moving from a continuously operating pump to an on-demand pump, electricity savings from reduced pump operation add up to ~ 670 kWh/yr.

On-demand circulator pumps are cost-effective when considering pumping energy alone, not even including the massive water heating energy savings they enable. We used two electrification scenarios (medium and high) to evaluate the savings potential of on-demand pumps, when they are paired with gas, electric, heat pump and propane water heater (and the table below outlines the savings potential)

Potential Savings (between now and 2030)	**CO2 Savings (MMT)**	**Electricity Savings (TWh)**	**Energy Savings from gas and propane (Quadrillion BTUs or Quad)**
Medium Electrification Scenario	6.3	6.10	0.08
High Electrification Scenario	4.9	7.27	0.05

These on-demand models have been found to be technologically feasible, cost effective when considering the significant operational cost savings. They offer potential benefits to disadvantaged communities because of their relatively high potential utilization in multifamily housing, especially in the common scenario where a tenant is not responsible for the cost of installing the pump - but is responsible for the monthly utility bills.

Based on the analysis contained within this report, we draw the following **conclusions**:

1. On-demand circulator pumps show great potential across building typologies as they lead to significant potable water, energy, and monetary savings (especially in cases when no circulator

[1] Association for Energy Affordability, "Getting to All Electric Multifamily Zero Net Energy Construction - EPC15-097," pending publication.

pumps are used currently). With ~ 3 million multifamily buildings in California, we compute a savings potential of 2.9 trillion gal (assuming 20 apartments per multi-family building).

2. RASS 2019 reports unit energy consumption for water heating to be in the range of 1,200-2,700 kWh (electric water heaters) and between 240 - 260 therms (for gas water heaters), across different types of households. Moving from a continuously operating pump to an on-demand pump leads to unit electricity savings of ~ 700 – 1,600 kWh, and 138 therms savings (~ more than half of annual demand).[2]

3. Heat pump water heaters do not work efficiently with continuously operating circulator pumps because those pumps disrupt tank thermal stratification in the tank, causing HPWHs to operate in electric resistance mode much of the time. Approximately 800,000 water heaters are replaced in California every year and CEC's Building Decarbonization Assessment report (Assembly Bill 3232) identifies heat pump water heaters as an important technology option for achieving the 2045 carbon neutrality goal; California is investing significant financial resources to transition to HPWH in all buildings. Hence, on-demand circulator pumps are critical to support this objective.[3]

4. On-demand circulator pumps show great potential for significant reductions in CO_2 emissions: through reduction in continuous operation of the pump, and reduced fuel/electricity needed to constantly re-heat water to offset thermal losses in distribution pipes. The 4.9 – 6.3 MMT CO2 savings potential over ten years from requiring that all new circulator pump installations and replacements be on-demand represents a significant share of AB 3232 reduction goals and is one of the most cost-effective measures available to help achieve building decarbonization goals.[4] It would also remove a barrier to the transition from gas to heat pump water heaters.

[2] 2019 California Residential Appliance Saturation Study Results

[3] Bloomberg Green 2021: How your water heater can be a secret weapon in the climate change fight. Link - https://www.bloomberg.com/news/articles/2021-02-11/how-your-water-heater-can-be-a-secret-weapon-in-the-climate-change-fight Link last accessed on 09/22/2021

[4] Assembly Bill 3232. California Energy Commission. Decarbonization Report, 2021

1. Market Baseline

1.1 Technology background

Hot water circulator pumps have gained popularity across building types to ensure hot water is available from the tap without a long wait or wasting significant potable water. In buildings without circulator pumps, when the hot water tap is turned on, hot water moves from the location where it was heated (most often a hot water tank) through the piping network, to reach the fixture that is demanding it. Depending on the location of the water heater, building configuration, and the fixture location, this piping distance can be over a hundred feet long. This is most often experienced as a delayed response between when a hot water tap is turned to when the hot water arrives at the tap. The water running from a tap before the hot water arrives may not necessarily go to waste; if the water is being collected, such as in a dishwasher or clothes washer, the initial cold water could get mixed with warmer water and still meet the user's needs without wasting water. However, if the hot water is running from the tap to a drain, such as a shower or hand washing, the initial cold water is likely being wasted while the end user waits for the hotter temperature. This system inefficiency is estimated to waste over 1,000 gallons of cold water per person per year (EPA 2021).

A circulator pump works to solve the issue of wasted water while waiting by pumping hot water through a building's piping system in a closed loop going back to the water heater continuously so that hot water is more readily available when the hot water tap is turned on. As the hot water in pipes loses heat over time, it needs to be re-heated by the water heater. Circulator pumps have been installed to provide consumer amenity and save water, however the vast majority of circulator pumps currently installed have created another issue of energy waste. These continuously operating circulator pumps run constantly, drawing electricity 24/7, as well as pushing water heaters to work frequently. While significant amounts of water are saved using circulator pumps, the continued overuse of water heaters, especially those powered by natural gas, is a major barrier to decarbonization efforts in need of a solution.

Hot water circulator pumps can be classified into 4 categories:

1. **Timer-based** circulator pumps can be used in single family applications where the pump is scheduled to circulate hot water during expected times of high demand. Timer-based pumps are an energy and financial improvement over continuous pumps, but they are often programmed to run 12 or more hours a day, so they still waste considerable energy. And when timers get out of sync due to power outages and backup battery failure, customers often disable them and run their pumps 24x7.

2. **Aquastat-controlled** pumps automatically switch on when the water temperature at one point in the recirculation system falls below a certain threshold and stop when it exceeds another threshold.

3. **Thermally balanced, variable speed** pumps circulate continuously but at a much lower flow rate, just sufficient to maintain an acceptable hot water temperature at the furthest fixture in the loop. This solution is the most effective in central water heater applications.

4. **On-demand** circulator pumps circulate the water when needed. Some are activated manually by pushing a button next to the water fixture. Others are operated by occupancy sensors. On-demand controls are proven to be effective in single family and small central water heating applications.

This report focuses on the potential savings from using button-operated on-demand pumps in unitary residential systems (system serving a single dwelling unit, as opposed to central systems serving more than one unit). On-demand circulators are not appropriate with central heat pump water heater (HPWH) systems because they negatively impact their efficiency. Thermally balanced variable-speed circulators are the best options for central HPWH. A detailed analysis of central HPWH circulation solutions is beyond the scope of this analysis.

Button-operated on-demand circulator pumps operate use the same basic mechanics of a continuously operating circulator pump but instead of constantly recirculating the water, an on-demand pump operates only once triggered by the user—such as through a button push—then waiting with no water flowing for several seconds until the hot water has arrived. While the user wait time is not instantaneous, most users can get hot water within a matter of seconds (DOE RFI).

1.2 Baseline Analysis of Building Stock

This section presents information regarding design and architecture for domestic hot water (DHW) systems across residential, commercial, and multifamily buildings. This information will help to determine different opportunities and applications for circulator system installation. Gaps in current information and potential opportunities for future research are also identified.

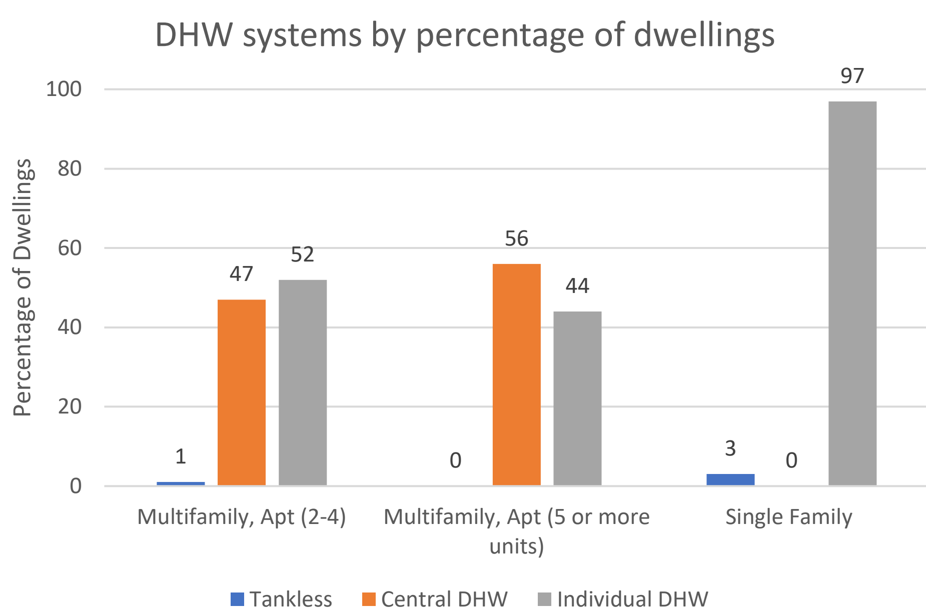
Single-Family and Multifamily Residential Sector

Within residential new construction, a complete hot water loop—known as recirculation—is typically specified (ACEEE 2011, 74). Return lines are generally not feasible to add as a retrofit, so when systems without return lines install a circulator pump, the pump is installed on the farthest fixture from the hot water heater. Across systems, when operating either continuously or with controls, the system empties the cooled water from the hot water line into the cold-water pipe (ACEEE 2011, 74).

Most single-family (SF) residents have a storage tank water heater. Multifamily (MF) buildings are split; in smaller multifamily buildings, about half have an individual or in-home tank with the other half sharing hot water from a central system (national estimates). Overall, central systems are slightly more prevalent than dedicated tanks in multifamily buildings (RECS 2015).

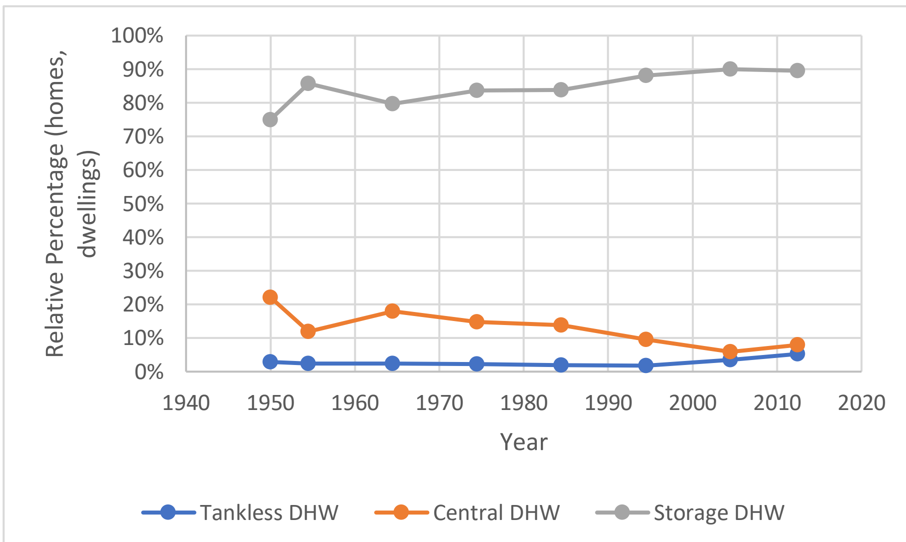
For multifamily buildings, distribution plumbing is often running through unconditioned spaces, increasing loss of heat from water stored in pipes (G. Ayala, 2012, 2-16). The majority of existing multifamily residences do not have any insulation on the recirculation loop or distribution pipes. Existing multifamily buildings generally do not have access to most of their piping system as it is primarily located behind closed walls, which can render insulation projects cost-prohibitive and impractical (G. Ayala, 2012, 2-19).

Figure 1: National Average of Domestic Hot Water (DHW) Systems by Building Type from RECS 2015



When analyzing the national state of water heating by residential building vintage, there are two major trends, as demonstrated in Figure 2. Across buildings constructed since 1950, storage DHW tanks have dominated the market, increasing steadily in comparison to central and tankless DHW. Secondly, instantaneous water heaters have more recently gained market traction and are now being installed in up to 5 percent of new constructions - and trending upwards. While storage units have been the most popular historically, older homes have a greater likelihood of having a central system, and conversely newer homes have a higher likelihood of a tankless system (RECS 2015).

Figure 2: Relative proportions of DHW systems by year of construction from RECS 2015



Commercial Sector

The commercial sector is more diverse than residential with regards to water heating systems. In an analysis with a median commercial building size of 10,000 square feet, ACEEE found that central hot water systems are the most common, installed in approximately 75 percent of commercial buildings; 20 percent of commercial buildings use distributed systems, and the final 5 percent use combination central and distributed systems (ACEEE 2011, 79).

Smaller commercial buildings often use residential water heating equipment and a system architecture with one trunk pipe connected to the water heater with smaller "twig" pipes branching off to service individual fixtures distributed around the building or in a central core (ACEEE 2011, 79). Larger buildings on the other hand typically use recirculation loops which have a return line from the hot water connection (ACEEE 2011, 79-80). These loops can use:

- A pump installed on a continuous hot water loop between the water heater hot water outlet and the cold-water inlet; or

- a return line can be a dedicated line, or the cold-water line, where the cold-water system is used temporarily to eliminate the cold water in the hot water section at the fixture.

When comparing commercial building vintages constructed since 1900 using data from EIA CBECS 2012, central DHW have consistently been the most common system (Figure 3). Combination systems have oscillated in popularity, currently on par with distributed systems. When analyzing this trend by square footage, central systems are most common in smaller buildings (Less than 100,000 square feet) but are much closer in popularity to combination systems as the buildings get bigger. When looking across the size of a building disaggregated by number of floors, central systems still dominate, but combination systems emerge as a close second in taller buildings.

Figure 3: Historical time series of relative percentage of DHW systems from CBECS 2012

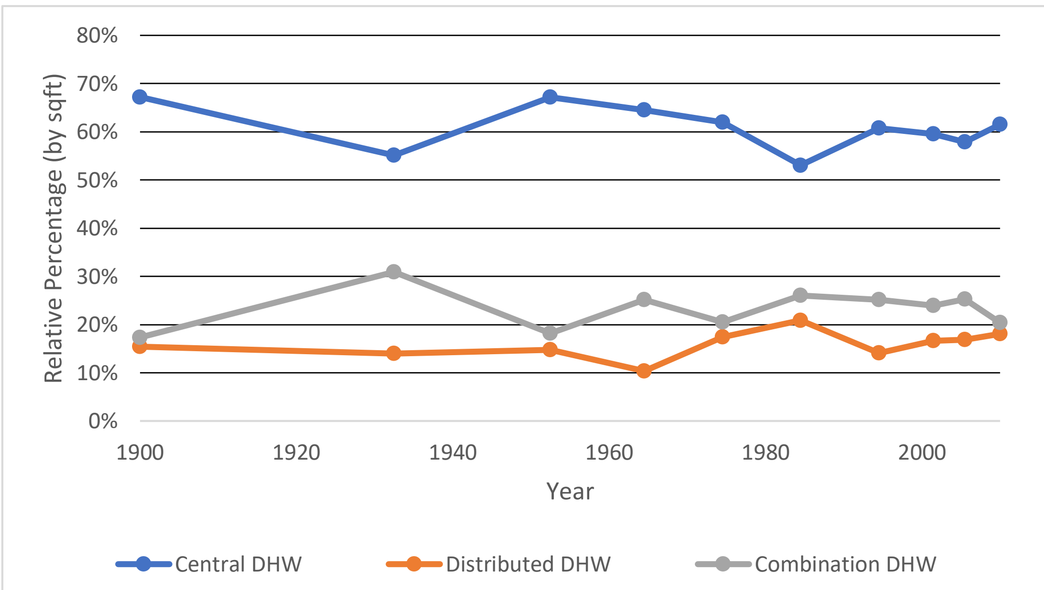


Figure 4: Relative percentage of DHW systems as a function of building area from CBECS 2012

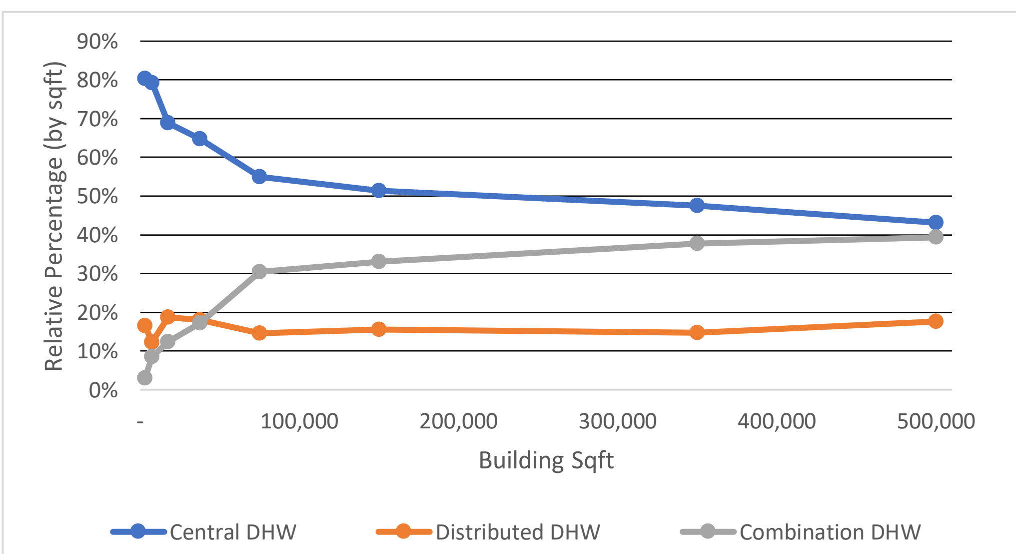
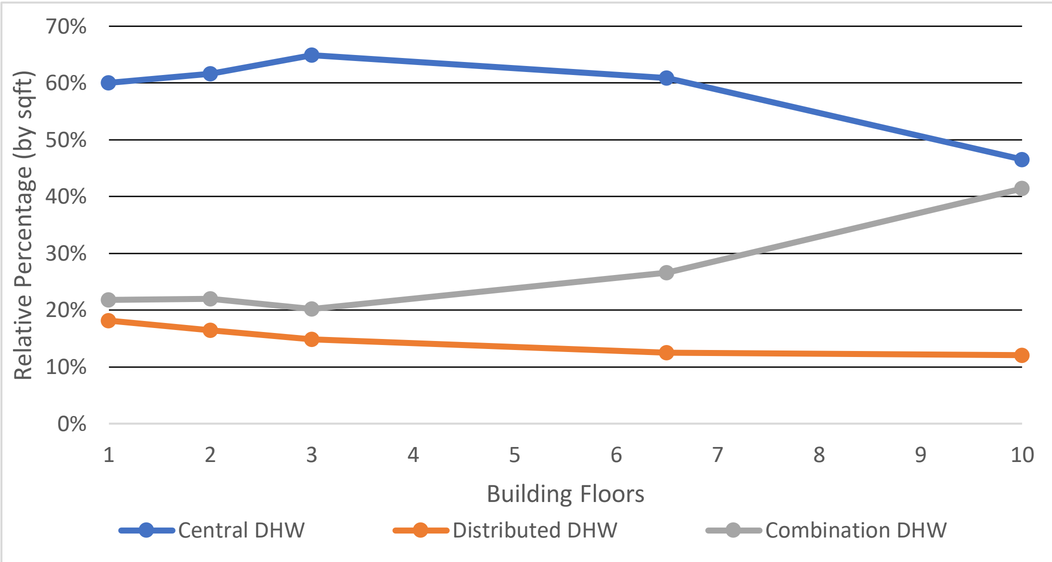
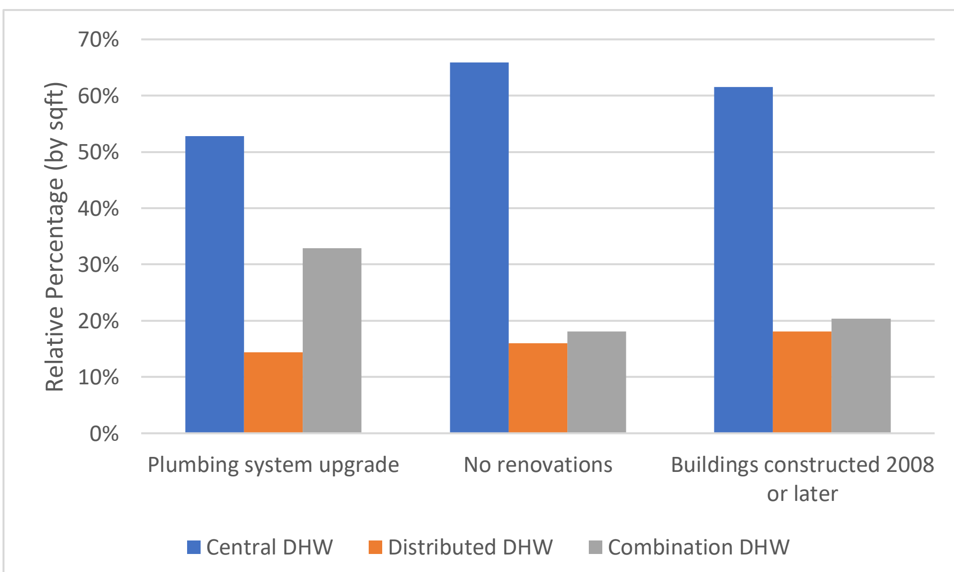


Figure 5: Relative percent of DHW systems as a function of number of building floors from CBECS 2012



As buildings get larger, there are more combination DHW, whereas distributed DHW rates stay generally constant. Buildings that have undergone at least one round of plumbing updates are significantly more likely to have a combination system, as demonstrated in Figure 6 (CBECS 2012).

Figure 6: DHW systems used as a function of renovations & plumbing upgrades from CBECS 2012



1.3 Baseline Analysis of Circulator Pumps

Pump Applications

Across building types in the U.S., there were about 30 million installed circulator pumps, with annual sales of approximately 3 million units in 2011 (EPRI 2011).

Wet-rotor circulators are the most common circulator type (pictured here), and their market share continues to grow. Moving forward, manufacturers have signaled that they may phase-out all other circulator types (i.e., horizontal in-line, and flexibly coupled) as they begin to focus on more efficient ECM-driven models (M. Guernsey, 2015, p 81).

78 percent of all circulators sold are for hydronic heating circulation, while the remaining 22 percent are for potable water applications, which are the object of this study (M. Guernsey, 2015, p 81). One leading manufacturer, Grundfos, provided information in Table 7 with California specific attributes, which is assumed to be representative of other circulator manufacturers (NEEA XMP Validation, 2019). Table A1 in the appendix provides a summary of circulator measure identified across different applications.

The Northwest Regional Technical Forum (RTF) developed an anticipated categorization of circulator pumps (Northwest Regional Technical Forum 2017). Through their analysis, the RTF determined the savings potential presented by on-demand pumps depends on the demand patterns and systems across buildings. The RTF categorized the various use cases across single family/small multifamily, large multifamily, and commercial, and further organized the pump material, motor, expected HP range, and expected system type (Table 1).

Pump Efficiency, Power Draw, Load Profiles and Annual Operating Hours

The typical residential circulator pumps operate at 20-30 W continuously (ACEEE 2011, 74). Since circulator pumps are used in various applications and have different sizes, when the RTF normalized pump efficiency to 1/25 HP, they found wattage estimates ranging from 30-116W. Power draw for varying efficiency levels of motors can be found in Table A2 (Appendix). This nearly four-fold differential in efficiency levels demonstrates that circulator pumps can operate across efficiencies, largely driven by the technological improvement when moving from an induction motor to an ECM. Pumps with controls were found to be much more efficient; in addition to the lower wattage, pumps with controls spend more time at a lower operating point which was less energy intensive, especially variable speed pumps that were observed to spend more than half of their time below a 25 percent flow (Table 2,

Table 3). It is typical for pumps to operate under their rated capacity in this manner. The potential for on-demand efficiency improvements is explored further in Section 2.2.

Table 1: Circulator Pump Characteristics from Northwest RTF 2017

Sector	Pump material	Pump motor	Run-hours Controls	Expected HP Range	Expected System Type
SF or small MF	Cast iron	ECM	No	≤ 1/12	Hydronic heating
SF or small MF	Bronze or stainless	Any	Yes	≤ 1/25	DHW Recirculation
SF or small MF	Bronze or stainless	ECM	No	≤ 1/12	Unknown
Central MF	Cast iron	ECM	No	> 1/12	Hydronic heating
Central MF	Bronze or stainless	Any	Yes	> 1/25	DHW Recirculation
Central MF	Bronze or stainless	ECM	No	> 1/12	Unknown
Commercial	Cast iron	ECM	No	> 1/12	Hydronic heating
Commercial	Bronze or stainless	Any	Yes	> 1/25	DHW Recirculation
Commercial	Bronze or stainless	ECM	No	> 1/12	Unknown

Table 2: Average operating power (W) by nominal HP and Efficiency Level from NEEA 2019

Nominal HP	1/40	1/25	1/12	1/6	1/4	1/2	3/4	1	1.5	2
EL0	43	88	139	158	418	367	1,176			1,373
EL1										
EL2	15	31	102							
EL2.5	25	39	56							
EL3	11	19	24							
EL3.5	10		12	22						
EL4		10	33	19						

Table 3: Load profile by Efficiency Level for Circulators in Hot Water Recirculation from NEEA 2019

	Under 25% of BEP Flow	Between 25% and 50%	Between 50% and 75%	Between 75% and 100%	Between 100% and 110%	Above 110%	n	Average HP	Average Flow Rate (gpm), Normalized to 1/25 HP[67]
Domestic Hot Water	33%	25%	8%	6%	2%	26%	**53**	**1/6**	**4.81**
EL0	8%	21%	8%	12%	4%	47%	**27**	**1/4**	**6.27**
EL1	0%	0%	0%	0%	0%	0%	**0**	-	-
EL2	49%	51%	0%	0%	0%	0%	**4**	**1/30**	**1.70**
EL2.5	40%	40%	20%	0%	0%	0%	**5**	**1/18**	**3.28**
EL3	30%	67%	3%	0%	0%	0%	**3**	**1/20**	**3.90**
EL3.5	62%	22%	0%	0%	0%	17%	**6**	**1/12**	**5.81**
EL4	84%	4%	13%	0%	0%	0%	**8**	**1/12**	**2.00**

Note for table above: The peak of the efficiency curve is called Best Efficiency Point (BEP). Best Efficiency Point is contingent on flow rate for pumps, and in general – pumps run best near their BEP. Hence, if the flow rate at which the pump has its BEP is 50 GPM, 110% represents 55 GPM (i.e. operating window and efficiency)

Finally, we leveraged DOE's (Circulator Pump RFI) analysis to understand annual operating hours based on circulator pump control type (Table 4); while on-demand pumps were the minority of use cases, their operating hours were reduced to mere minutes per day compared to constant operations of traditional circulator pumps.

Table 4: Annual operating hours for different control mechanisms from DOE Circulator Pump RFI 2021

Control Type	Sector	Fraction of Consumers	HPY	Notes
No Control	Residential	50%	8,760	Constant Operation
	Commercial			
Timer	Residential	25%	7,300	50% operate constantly and 50% operate 16 hours/day
	Commercial		6,570	50% operate constantly and 50% operate 12 hours/day
Aquastat	Residential	20%	1,095	3 hours per day
	Commercial			
On Demand *	Residential	5%	61	10 minutes per day*
	Commercial		122	20 minutes per day*

*Assuming that circulator pumps operate for 30 seconds for each demand "push"

Pump Market Availability and Cost

According to US DOE Circulator Pump Request for Information (RFI), there is a wide distribution of circulator pumps across applications and horsepower.

Table 6 shows the range of installed costs across efficiency levels and nominal HPs. The costs range from less than $1000 for the smallest units to over $10,000 for pumps above 4 HPs. DOE explored a broad range of efficiency levels (EL's)– as represented in tables below:

EL0: Baseline induction motor (worst product in the market)

EL1: Efficient induction motor

EL2: Electrically commutated motor (no controls)

EL3: Electrically commutated motor with standard flow or pressure controls

EL4: Demand based controls/advanced run controls motor

Table 5: Circulator pump efficiency distribution 2015 from DOE Circulator Pumps RFI 2021

Application	Efficiency Level	1/40 hp			1/25 hp			1/6 hp			1 hp		
		CP1	CP2	CP3	CP1	CP2	CP3	CP1	CP2	CP3	CP1	CP2	CP3
Heating	EL0	X			X		X	X	X	X	X		X
	EL1	X			X	X		X	X	X	X		X
	EL2									X			X
	EL3				X			X		X	X		
	EL4	X			X			X			X		
Hot Water Recirculation	EL0	X			X		X	X	X	X	X		X
	EL1	X			X	X		X	X	X			X
	EL2	X			X								
	EL3	X			X			X			X		
	EL4*												

*The CPWG agreed that EL4 was not viable for circulator pumps used in hot water recirculation.

Table 6: Total installed cost at different power rating and efficiency levels from California Regional Technical Forum 2020

Name	Nominal HP	EL0	EL1	EL2	EL3	EL4
≤1/30 horsepower (≤50 Max watts)	**1/40**	$537	$537	$658	$813	$871
>1/30 - ≤1/16 horsepower (>50 - ≤100 Max watts)	**1/25**	$530	$530	$707	$747	$790
>1/16 - ≤1/8 horsepower (>100 - ≤200 Max watts)	**1/12**	$732	$732	$922	$1,017	$1,076
>1/8 - ≤1/6 horsepower (>200 - ≤300 Max watts)	**1/6**	$674	$674	$1,107	$1,182	$1,233
>1/6 - ≤1/4 horsepower (>300 - ≤400 Max watts)	**1/4**	$820	$820	$1,245	$1,323	$1,373
>1/4 - ≤1/2 horsepower (>400 - ≤550 Max watts)	**1/2**	$1,258	$1,258	$1,661	$1,747	$1,790
>1/2 - ≤3/4 horsepower (>550 - ≤750 Max watts)	**3/4**	$1,696	$1,696	$2,077	$2,171	$2,208
>3/4 - ≤1.25 horsepower (>750 - ≤1000 Max watts)	**1**	$2,134	$2,134	$2,493	$2,594	$2,625
>1.25 - ≤1.75 horsepower (>1000 - ≤1300 Max watts)	**1 1/2**	$3,201	$3,201	$3,740	$3,892	$3,938
>1.75 - ≤2.5 horsepower (>1300 - ≤1750 Max watts)	**2**	$4,268	$4,268	$4,986	$5,189	$5,250
2.5 HP	**2 1/2**	$5,335	$5,335	$6,233	$6,486	$6,563
>2.5 - ≤3.5 horsepower (>1750 - ≤2350 Max watts)	**3**	$6,402	$6,402	$7,479	$7,783	$7,875
3.5 HP	**3 1/2**	$7,469	$7,469	$8,726	$9,080	$9,188
>3.5 - ≤4.5 horsepower (>2350 - ≤3100 Max watts)	**4**	$8,536	$8,536	$9,972	$10,378	$10,500
4.5 HP	**4 1/2**	$9,603	$9,603	$11,219	$11,675	$11,813
>4.5 - ≤5 horsepower (>3100 - ≤3700 Max watts)	**5**	$10,670	$10,670	$12,465	$12,972	$13,125

The market share of demand-based circulators was estimated at under 1 percent of residential DHW circulators in 2011 (ACEEE 2011, 76). In market data from Grundfos and extrapolated across California (Table 7), it is evident that while efficient circulator pumps make up nearly 30 percent of smaller systems, the larger systems which dominate about 70 percent of the CA market are nearly all inefficient. Across CA, it appears there is a tremendous opportunity for savings, with the full existing CA market estimated at 22,676,330 kWh.

Table 7: California market landscape based on Grundfos sales

CA Wholesale Circulator Market (Up to 120 Watts)							
Plumbing (HWR):	51,400		93.2%	***Focus of Workpaper - Energy Calcs Based On This Market Application***			
Hydronic (HVAC):	3,770		6.8%	***Market Application is EXCLUDED From Energy Calculations***			
TOTAL:	55,170	Qty Pumps Transacted/ Yr					
MARKET SEGMENT - UP TO 25 WATTS - PLUMBING MARKET				**MARKET SEGMENT - 26 - 120 WATTS - PLUMBING MARKET**			
% of CA Market:	22.9%			% of CA Market:	77.1%		
Market Qty:	11,782			Market Qty:	39,618		
Market Standard (Up to 25 Watts)		**Efficient Option (Up to 25 Watts)**		**Market Standard (26 - 120 Watts)**		**Efficient Option (26 - 120 Watts)**	
Market Segment:	70.6%	Market Segment:	29.4%	Market Segment:	99.3%	Market Segment:	0.7%
UP 15-10 B5/TLC (P/N: 59896215)		Comfort PM Auto		UP 15-29 SU/LC (P/N: 59896776)		Alpha 15-55 SF/LC	
Max Watts:	25	UP 10-16 A PM BU/LC (P/N: 98420224)		Max Watts:	87	(P/N: 59896834)	
% Max Watts:	97%	Max Watts:	8.5	% Max Watts:	97%	Steady State Watts:	26.7
Running Watts:	24.25	kW	0.009	Running Watts:	84.2	kW	0.027
kW	0.024	Running Hours/ Day:	4	kW	0.084		
Running Hours/ Yr:	6427	Running Hours/ Yr:	1460	Running Hours/ Yr:	6427	Running Hours/ Day:	6427
kWh/ Yr/ Pump:	156	kWh/ Yr/ Pump:	12.4	kWh/ Yr/ Pump:	541	kWh/ Yr/ Pump:	172
		kWh Savings/ Pump:	143			kWh Savings/ Pump:	370
Existing Market (Qty):	8,318	Existing Market (Qty):	3,464	Existing Market (Qty):	39,341	Existing Market (Qty):	277
Existing Market kWh/ Yr:	1,296,414	Existing Market kWh/ Yr:	42,987	Existing Market kWh/ Yr:	21,289,339	Existing Market kWh/ Yr:	47,589
Existing CA Market kWh:	1,339,401			Existing CA Market kWh:	21,336,929		
Total Existing CA Market kWh:	**22,676,330**						

2. Circulator Pump Savings Opportunities

This section presents an analysis of the opportunities for savings from increasing the penetration of circulator pumps. Our analysis included three cases:

1. **No Circulator Pump:** in this case, the user waits for the hot water to get to their faucet. Water waste is significant. This is referred to as our No Pump case.
2. **24/7 Circulator Pump:** in this case, a standard circulator pump is installed, with no on-demand or timer features. Hot water arrives much faster to the user compared to the No Circulator Pump case; therefore, water waste is low. Energy consumption, however, is high from the continuous operation of the pump and the continuous re-heating of the water. This is referred to as our base case.
3. **On-Demand Circulator Pump:** in this case, a circulator pump is installed but it only operates when water is needed by the user. Hence, this solution reduces water and energy waste. This technology has an on-demand feature, where a user can press a button, trip a motion sensor, or quickly turn the hot water on and off to signal to the system that hot water is required. As such, the pump only operates when needed. This is referred to as our measure case.

We present and discuss results comparing these three cases. We also present information on domestic hot water (DHW) schedules in the field for both commercial and residential sectors. NEEA's Extended Motors Products (XMP) program conducted an extensive in-field analysis on several pump topics, including residential and commercial hydronic and DHW circulator pumps (NEEA XMP Field Study, 2019). The results of this study (Table A3 and A4 in appendix) looked at 13 and 80 different pumps in the residential and commercial settings respectively. While pumps without controls were found to operate continuously, on-demand pumps had very few estimated annual operating hours, in the order of 10-20 minutes per day. Aquastat—a device with high and low temperature bands to stop the boiler or water heater from firing too often—and learning pumps also had lower operating hours than pumps with no controls.

2.1 Savings Potential from Shifting to Circulator Pumps for Single-Family Buildings

Water Saving Benefit: In a No Pump case without a circulator pump installed, a user waits to get hot water each time they turn on the faucet. With reasonable assumptions such as hand washing six times a day using a 1.5 GPM faucet, we estimated that approximately 1,100 gal of cold water is wasted each year for a single person household (EPA 2021). For a three-person household, approximately 3,300 gal of water is wasted every year while waiting for hot water. This problem can be avoided by using a circulator pump, which represents our *base case.*

Circulator pumps operating in buildings with gas hot water heaters impact both the electricity used by the pump, as well as the gas used by the water heater to re-heat the water. For electric resistance water heaters, we realize electricity savings through both reduced pump operation (in the case of an on-demand circulator pump) and through reduced operation of the electric water heater. To quantify these savings, we created an On-Demand Circulator Pump Savings Model. Our model used natural gas storage, electric resistance storage, heat pump and propane water heaters to demonstrate the most common types of water heaters.

Electricity Savings Benefits: Electricity savings are realized by transitioning from a 24/7 circulator pump (base case) to an on-demand pump (measure case) (Figure 7). In this analysis, we use Grundfos technologies to represent both the base and measure cases. Table 8 presents the technical and mathematical parameters embedded in the model.

Figure 7: Base and Measure Case Technologies

Electricity savings are realized when moving from a base case to a measure case due to two main reasons:

1. The measure case technology option has a lower power rating, and thus consumes less electricity throughout its lifetime compared to the base case option.
    a. The power input for the on-demand option is rated between 2 and 45 W. This implies that the pump consumes different amounts of power at different load profiles.
    b. The final weighted average power rating is built using a combination of load profiles at the Best Efficiency Point (BEP, i.e. how long the pump operates in each range) and the power rating applicable for each load profile.
    c. **Weighted Power Rating:** In this case the weighted average power rating is:
    (4 W x 84%) + (10 W x 4%) + (22 W x 13%) = 6.62 W.
    d. The pump spends 84% of time under 25% of BEP flow, 4% between 25% and 50% of BEP flow, and 13% between 50% and 75% of BEP flow, and the corresponding power consumption in those ranges are 4 W, 10 W and 22 W respectively.
    e. In summary, our measure case has a weighted average rating of 6.62 W

2. Reduced annual operating hours for the on-demand option (measure case) when compared to the base case.

The Unit Energy Savings (UES) is contingent on both variables discussed above.

Savings from Reduced Water Heater Operation: While studies reported electricity savings due to the usage of more advanced circulator pumps (EPRI 2013), there is less available information regarding savings accrued from reduced water heater operation. As such, to quantify these benefits, we calculated an estimate to use for our modeling.

Three Cases: No Circulator Pump, 24/7 Circulator Pump, and On-Demand Circulator Pump

When going from the No Pump case to a 24/7 circulator pump base case, the savings a user realizes are water savings. Because the base case user waits with an open tap for less time, a three-person household can realize as much as 3,300 gallons of water per year savings, and possibly even more given - increased handwashing because of COVID-19. Subsequently, we present the base-to-measure case, where we transition from a continuously operating pump to an on-demand pump; in this case, the savings realized by a user are energy savings.

In the base case, as water goes into pipes from the building's water heater, energy is lost as it starts to cool; this is known as a **recirculation loss**. In the base case, the circulator pump is operating continuously; to maintain the temperature of the water, the water heater is running to re-heat water constantly. As such, in the base-case, we estimated that water is heated 24/7 as recirculation losses occur.

The amount of energy lost through recirculation losses are a function of:

- Building characteristics (building area, number of floors)
- Recirculation loop characteristics (height of recirculation loop riser, heat loss from piping)
- Difference between water temperature in the recirculation loop and ambient temperature
- Hours of operation for the recirculation loop

We utilized the analytical framework used by DOE (Commercial Water Heater ECS Rulemaking TSD, Page 190/707) to model recirculation losses (equation below). We capture such losses in the form of annual energy losses. An on-demand circulator pump moves water through the piping system much less frequently when compared to a standard circulator pump. As such, the demands on the water heater are much lower. The on-demand pump also has lower losses because it operates for much less time than a standard circulator pump. For the purposes of this model, we used the building characteristics for California (as reported in the sampling study by California Technical Forum) and recirculation loop characteristics used by DOE in the federal rulemaking.

$$DL_{bldg} = \left(2 \times \sqrt{\frac{SqFt_{bldg}}{N_{floors}}} + Ht_{riser} \times \left(N_{floors} - 1\right)\right) \times P_{ua} \times dT \times T_{recirc}$$

Where

Recirculation Losses			
SqFt	ft2	5,434	Daily heat losses from recirculation loop operation
N		2	Square footage of the building
Ht_{riser}	ft/FLR	10	Number of floors
P_{ua}	Btu/h per (ft F)	0.25	Height of recirculation loop riser
dT	F	50	Heat loss from piping
h1 : base	h/day	24	Difference between recirculation loop hot water temperature & ambient temperature
h2 : measure	h/day	0.25	Hours of recirculation loop operation

Technology options:

We present cost effectiveness metrics for four technology cases

- Gas storage water heater (UEF = 0.58)[5]
- Electric resistance storage water heater (efficiency = 92%)[6]
- Heat pump water heater (UEF = 3.3)[7]
- Propane water heater (UEF = 0.58)[8]

While the electricity consumed by on-demand pump is the same in all cases, the secondary benefit of avoiding frequent re-heating of water (with a continuously operating pump), leads to different benefits based on the fuel used to heat water.

Costs: To fully understand the potential savings from an on-demand circulator pump, we calculated the incremental cost to transition from base to measure cases in the form of first cost and labor cost. First cost is the difference in technology cost between the two Grundfos options, and we used labor cost from published literature (California Technical Forum 2017).

Estimation Method: Unit Energy Savings represent the energy benefits attributed to a transition from base to measure. We use unit energy benefits in conjunction with circulator pump lifetime (15 years) and average retail electricity, gas and propane prices to estimate a stream of financial benefits throughout the equipment lifetime. Prices: we used EIA forecasts for electricity prices, and current gas and propane prices to develop the analysis (average estimates: 17 c/kWh, gas $ 3/MM-Btu, and propane $ 27/MM-Btu). Finally, we discount future stream of benefits at 3 percent, to compute discounted benefits from savings (Table 8).

Cost Effectiveness Metrics: Finally, we assess the cost effectiveness of the transition using Net Present Value (NPV) and Benefit Cost Ratio (BCR) metrics. A positive NPV and a BCR of greater than one both represent economically justifiable solutions.

[5] Federal energy efficiency standards for a 40-gallon gas storage water heater with a medium draw pattern.
[6] Federal energy efficiency standards for a 50-gallon electric storage water heater with a medium draw pattern.
[7] Energy Star for 50-gallon electric water heaters, and representative of the median of the HPWH market.
[8] Federal energy efficiency standards for a 40-gallon gas storage water heater with a medium draw pattern.

Table 8: Pump Savings Model Parameters

Parameters			
Engineering and Labor			
Grundfos 1529	Power	W	84.2
Grundfos Alpha 15-55 HWR-D Comfort	Power	W	6.62
Grundfos Alpha 15-55 HWR-D Comfort	Incremental Cost (to shift to on-demand pump)	$	557
Labor	Incremental Cost (to shift to on-demand pump)	$	300
Market Fraction			
No Control	Mkt Fraction	%	50
Timer	Mkt Fraction	%	25
Aquastat	Mkt Fraction	%	20
On-Demand	Mkt Fraction	%	5
Annual Operating Hours			
No Control	Annual Operating Hours	h	8,760
Timer	Annual Operating Hours	h	6,935
Aquastat	Annual Operating Hours	h	1,095
On-Demand	Annual Operating Hours	h	92

Results

When moving from a No Pump case to a continuously operating circulator pump base case, a three-person household saves approximately 3,300 gal per year, and approximately 50,000 gal of water over a 15-year lifetime. Using a rate of $8.4/100 ft^3 (100 cubic feet = 748.05 gal), we compute a total lifetime water saving benefit of $562.

When transitioning from continuous to on-demand, unit electricity savings from reduced pump operation are calculated at 673 kWh per year. Annual savings from reduced heating was 21 MM-Btu (gas), ~ 4,000 kWh and 1,100 kWh (for electric and heat pump water heaters), and 15 MM-Btu for propane water heater. The benefit cost ratio in all cases was greater than 1, and the payback period ranged between 1.9 and 5.8 (economically viable).

Table(s) 9: Summary of Results (on a unit basis)

Annual Energy Benefits (Unit basis)	**Unit**	**Value**
Unit Energy Savings (UES), Electricity, from reduced pump operation	kWh	673
Unit Energy Savings (UES), Natural Gas (from reduced WH operation)	MM-Btu	21.3
Unit Energy Savings (UES), Electricity (from reduced Electric WH operation)	kWh	3,944
Unit Energy Savings (UES), Electricity (from reduced HPWH operation)	kWh	1,099
Unit Energy Savings (UES), Propane (from reduced WH operation)	MM-Btu	15

Summary Table - Economics & PBP	**NPV ($ 2021)**	**Benefit Cost Ratio (BCR)**	**Payback Period (Years) * Considering only reduced pump operation**	**Payback Period (Years) * Considering reduced pump operation and reduced heating**
Gas Water Heater	1345	2.57	8.9	5.8
Electric Water Heater	9012	11.52	8.9	1.3
Heat Pump Water Heater	2931	4.42	8.9	3.4
Propane Water Heater	5865	7.84	8.9	1.9

2.2 Potential California Statewide Savings Summary – Replacements and New Installations

California replaces ~ 800,000 water heaters per year. We develop our analysis based on a combination of gas, electric resistance, heat pump and propane water heaters meeting the total demand, for the next ten years.[9]

We developed two scenarios:

Scenario 1 – Medium Electrification: Ramping up from current California water heater sales of approximately 86% gas,[10] 6% electric resistance,[11] 7% propane (assumed), and 1% heat pump (assumed), to half HPWH in the next ten years, the assumed average installations would be 26% HPWH, 64% gas storage, 5% electric resistance, and 5% propane. 5% of these installations will have an on-demand pump (in line with DOE's market analysis)

Scenario 2 – High Electrification: In this more ambitious case in line with the AB 3232 high building electrification scenario, a linear ramp-up from 2% HPHW to 100% HPHW sales over the next ten years, would see an average of 51% HPWH, 43% gas storage, 3% propane and 3% electric resistance. 5% of these installations will have an on-demand pump (in line with DOE's market analysis)

What does this analysis tell us?

Based on the profile of water heaters to be installed (replaced) in the next ten years, if 5% of them have an on-demand circulator pump, what are the energy and carbon benefits over a pump lifetime of 15 years?

Table 10: Potential CA Savings (Cumulative between now and 2030)

Potential Savings (between now and 2030)	**CO2 Savings (MMT)**	**Electricity Savings (TWh)**	**Energy Savings (from gas and propane) (Quad)**
Medium Electrification Scenario	6.3	6.10	0.08
High Electrification Scenario	4.9	7.27	0.05

[9] Advanced Water Heating Initiative 2020 – https://newbuildings.org/wp-content/uploads/2021/05/BuildingDemandforUnitaryHPWH2021_final.pdf
[10] Residential Appliance Saturation Survey 2019
[11] Residential Appliance Saturation Survey 2019

3. Opportunities to Increase Deployment of On-Demand Pumps

Given the significant benefits of on-demand pumps, they should be considered for inclusion in appliance standard and building code proposals in California.

3.1 On-demand circulator pumps in California energy code

This section explores the energy code options and opportunities, including Title 24 for California, and IECC, and ASHRAE 90.1 for most other states.

CA Title 24

Title 24 already requires on-demand circulators for new construction and alterations (i.e. renovations).

However, it does not require a circulator pump to be installed. Furthermore, replacing a circulator pump that was already installed is not considered an alteration, but rather a "repair" and does not trigger any of the requirements of Title 24.

Title 24 could require existing continuous recirculation pumps to be replaced by on-demand models at water heater replacement.

ASHRAE 90.1 (2019)

Within the 2019 version of ASHRAE 90.1, section 7.4 includes mandatory provisions that require circulator pumps to have at least automatic time switches or other controls, but do not mandate use of on-demand pumps. This can be found in section 7.4.4.3 Service water-heating system controls Temperature Maintenance controls: "Systems designed to maintain usage temperatures in hot-water pipes, such as recirculating hot-water systems or heat trace, shall be equipped with automatic time switches or other controls that can be set to switch off the usage temperature maintenance system during extended periods when hot water is not required."

2021 IECC

The 2021 version of the national IECC Code includes definitions of "demand recirculation water systems" (outlined below)

Definitions

> "Demand recirculation water system: a water distribution system where one or more pumps prime the service hot water piping with heater water upon a demand for hot water."
>
> C404.6.1 "controls for circulating hot water system pumps shall automatically turn off the pump when the water in the circulation loop is at the desired temperature and when there is not a demand for hot water. The controls shall limit the temperature of the water entering the cold water [/return] piping to not greater than 104 F."
>
> C404.6.1.1 "demand recirculation controls. Demand recirculation controls water systems shall have controls that start the pump upon receiving a signal from the action of a user of a fixture

> or appliance, sensing the presence of a user of a fixture, or sensing the flow of hot or tempered water to a fixture fitting or appliance."
>
> C404.6.3 "controls for hot water storage. The controls on pumps that circulate water between a water heater and a heated-water storage tank shall limit operation of the pump from heating cycle startup to not greater than 5 minutes after the end of the cycle."

On the residential side, there are similar definitions and requirements (R403.5.1). These definitions appropriately categorize on-demand circulator pumps - but stop short of requiring circulator pump installations or on-demand functionality for circulator pumps.

3.2 Potential appliance standards for on-demand circulator pumps

Federal Appliance Standards: In 2016, US DOE adopted the first energy efficiency standards for commercial and industrial pumps; circulator pumps were spun off into a new product class as part of the development of these standards and culminated in a 2016 term sheet by the pump working group for new energy conservation standards and test procedures. DOE did not adopt this term sheet at the time, thus the Hydraulic Institute (HI) developed a voluntary labeling program for circulator pumps under the more recently developed standard HI 41.5-2018 (later updated to HI 41.5-2021).

These voluntary programs alongside utility incentive programs for ECM circulator pumps had a modest impact on the market but did work towards raising the baseline efficiency for circulator pumps, especially in the residential marketplace in hydronic heating market.

In 2021, DOE released a Request for Information (RFI) for circulator pumps. DOE's 2021 analysis of circulator pumps included the review and energy savings estimates of timer and on-demand pumps for hot water circulators - but did not establish specific classes or standards for these products. While DOE has not yet established a standard for circulator pumps, the 2021 RFI is an indication that they intend to set these standards. At this time, DOE expressed interest in adopting the term sheet text for electrically commutated motors without operating point (e.g., pressure controls) or run hour reduction controls (e.g., on demand).

State-Federal Standards Interaction: While there are no current federal efficiency standards in place for circulator pumps, the product is a covered class by U.S. DOE Appliance Standards and DOE has initiated a rulemaking through the 2021 RFI.

California Appliance Standards Opportunities: Given the benefits offered by on-demand circulator pumps, as well as the cost-effectiveness, appliance standards requiring all circulator pumps sold in California be capable of on-demand operation may be an opportunity to reap significant electricity, gas, water, and greenhouse gas savings. Determining whether the California state appliance standards Title 20 program can address this issue, either through energy efficiency or demand flexibility statutory authorities, is the purpose of this section.

SB49 Opportunity: First, we explored the demand flexibility opportunities. Senate Bill 49 defines flexible demand as follows:

> "Flexible demand" means the capability to schedule, shift, or curtail the electrical demand of a load-serving entity's customer through direct action by the customer or through action by a

third party, the load-serving entity, or a grid balancing authority, with the customer's consent (Senate Bill 49).

SB 49 gives CEC the authority to set demand flexibility appliance standards, with demand flexibility defined as "the capability to schedule, shift, or curtail" electric load. Hot water circulator pumps meet all three of the criteria when only one is needed, and therefore clearly fall under CEC's flexible demand standard setting authority:

1. *Can the load from circulator pumps be scheduled?* Yes, timers can be used to schedule circulator pump operation.
2. *Can the load from circulator pumps be shifted?* Circulator pump controls could operate the pump just before the onset of peak price periods, reducing the need for operation during peak periods. This would effectively pre-heat the hot water distribution system, similarly to a smart thermostat pre-heating or pre-cooling spaces off-peak to reduce on-peak HVAC operation.
3. *Can the load from circulator pumps be curtailed?* Yes: replacing a continuous circulator by an on-demand type drastically reduces on-peak operation, effectively curtailing most of peak-coincident energy use, with no customer impact.

Therefore, circulator pumps are excellent candidates for standard setting under SB 49.

Title 20 Appliance Efficiency Standards Opportunity:

Since at this time there is no federal standard in effect for circulator pumps, they are viable candidates to be included in T20 standards.

Summary of options: Building codes and Title 20 appliance standards (both energy efficiency and demand flexibility) are all possible options to shift the market from continuous and timer-based to on-demand pumps.

3.3 Additional considerations in deployment of on-demand circulator pumps

As codes and standards efforts can help transition the building stock to on-demand circulator pumps, we took a specific look into the potential impact or benefit of on-demand circulator pumps for disadvantaged communities (DAC).

Circulator pumps are most prevalent in multifamily buildings in DAC. Much of the DAC population lives in suburban and urban areas where multifamily buildings are more prevalent (94 percent of Californians live in urban areas, California Communities Program, 2021). As reviewed in section 1.1, multifamily buildings use central and storage hot water systems, generally employing a single boiler or water heater, and a pumped circulation loop often running through unconditioned or non-insulated conditions to serve the apartments.

Advanced recirculation controls present a significant opportunity for benefits in multifamily buildings. An appliance standard or code requirement would be particularly effective for DAC renters as the modest incremental first cost of an on-demand circulator pump would most likely be borne by the building owner (landlord), whereas the recurring energy bills—and associated monthly savings—are more likely to be the responsibility of the resident (tenant). This split incentive and often professional installation requirements raise significant challenges in incentive programs, but codes and standards can level the playing field. DAC and other multifamily renters could potentially reap significant benefits without incurring the upfront costs.

3.4 Future directions for circulator pump work

Moving forward - there may be opportunities to use metering data to better understand the full savings opportunities from on-demand circulator pumps. The potential to use circulator pump data from companies such as Recurve and Home Energy Analytics exist, and those databases can potentially be leveraged to illustrate the benefits of on-demand pumps.

Recirculation solutions for central water heating systems warrant further savings and cost-effectiveness analysis.

4. Summary

Current Recirculation Systems and Control Systems

1. **Water Benefits from using Circulator Pumps:** A consumer installing any type of circulator pump can save as much as 1,000 gal of potable water per person per year (for a 3-person household over 15 years, total savings ~ 50,000 gal). With ~ 3 million multifamily buildings in California, we compute a savings potential of 2.9 trillion gal (assuming 20 apartments per multi-family building).
2. **Existing Recirculation Systems:** The vast majority of recirculation systems do not have any insulation, and wet rotor circulators are the most common technology type.
3. **California:** 30 million circulators exist in the country and 3.6 million of them are in California. Grundfos 87 W standard, continuous operation circulator pump is the most common type of circulator sold in California (which when operating 24/7, consumes 762 kWh/year).
4. **Control Types:** We observe four control types (No control, timer, Aquastat, and on-demand). A continuously operating pump operates 71 times as long as an on-demand pump – over a year. Currently, 50 percent of circulators in the market have no control and 5 percent are on-demand.

Recirculation Systems: Annual Operating Hours and Market Distribution

5. **Annual Operating Hours:** Annual operating hours decrease with more advanced control types. The base case with no control is estimated to operate 24/7 for 8,760 hours and year, whereas the on-demand option operates for only 92 hours a year (15 minutes a day).
6. **Incremental Cost:** The representative Grundfos product (15-55 HWR-D) we use for our analysis costs $550. The labor cost is $300.

Recirculation Systems: Savings Model

7. **Energy Savings Model:** We realize savings by using an on-demand circulator pump in two ways – from reduced operation of on-demand circulator pump (well documented), and savings from reduced heating needed by the water heater (estimated).
8. **Base and Measure Cases:** We develop our savings model by shifting from a continuously operating circulator pump to an on-demand circulator pump; we paired those pump types with a gas storage, electric storage, heat pump and propane water heaters.
9. **Unit Energy Savings (UES):** Annual UES when shifting from base to measure case was 673 kWh (from reduced pump operation). Savings from reduced heating are 21 MM-Btu (gas), 4,000 kWh (electric water heater), 1,100 kWh (heat pump water heater) and 15 MM-Btu (propane water heater) – for a year.
10. **Cost Effectiveness (Unit basis):** Shifting to an on-demand pump is economically viable in all cases (benefit cost ratio of > 1) and the payback period ranges between 1.9 and 5.8 years (much lower than pump lifetime).
11. **State Savings Potential:** Based on the profile of water heaters to be installed/replaced in the next ten years, if 5% of them have an on-demand circulator pump, the table below presents the energy and carbon benefits over a pump lifetime of 15 years.

Potential Savings (between now and 2030)	CO2 Savings (MMT)	Electricity Savings (TWh)	Energy Savings (from gas and propane) (Quad)
Medium Electrification Scenario	6.3	6.10	0.08
High Electrification Scenario	4.9	7.27	0.05

On-Demand Circulator Pumps: Policy Options and Equity Implications

- **Options:** Appliance standards and building codes present opportunities to shift away from continuous and timer-controlled to on-demand pumps
- **Heat Pump Water Heaters:** Transitioning to on-demand circulator pumps will remove a barrier to California's efforts to shift the market to HPWH.
- **Equity Implications:** Requiring advanced controls on circulator pumps in low income (multifamily) housing has the potential to alleviate financial stress for households. While the owner of the building often bears the first cost, the families can realize the benefits (electricity and gas savings) of the building utilizing more efficient circulator pumps.

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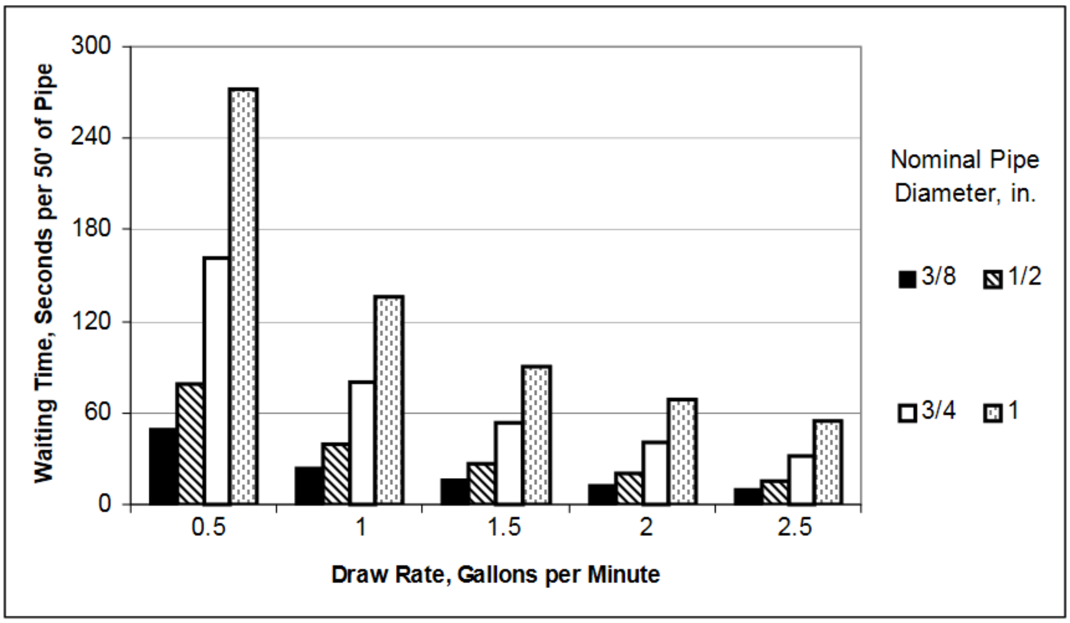
Appendix A. Background of Circulator Products.

DHW Circulators are intended to address the issue of cold (i.e., hot water allowed to cool) water in the lines for hot water service draw applications, such as water taps, faucets, etc..

This extent of this issue is a function of the distance of the pipe from the hot water source, pipe internal diameter, and the draw rate of the water draw.

See below for this challenge in single family homes (Source: J Lutz, et. al., 2002, https://www.aceee.org/files/proceedings/2002/data/papers/SS02_Panel1_Paper11.pdf , figure 3)

Figure 3. Wait Times for Delivery of Hot Water



In one source, it is noted that for most residential, no circulator hot water systems, water draws for short duration items (such as hand washing) never deliver hot water to the user before the draw is concluded (ACEEE 2011, p73).

Table A1: Circulator usage by sector and applications (Table 64, NEEA 2019)

Measure Identifier	Measure Categories	Objective Determinant
Sector	Residential	≤1/16 Nominal Motor HP
	Commercial	>1/16 Nominal Motor HP
Pumping Application	Hydronic Heating	Cast iron pump body
	Domestic Hot Water Recirculation	Bronze/stainless steel pump body with run-hours controls
	Unknown	Bronze/stainless steel pump body without run-hours controls
Nominal Motor HP	13 buckets ranging	Nameplate motors HP or max watts

Table A2: Average power draw by circulators (Table 8, NEEA 2019)

EL	Description	Weighted Average Power, normalized to 1/25 HP		
		Observed Watts	n	RTF Estimate (Watts)
EL0	**Induction Motor**	62	44	116
EL1	**Efficient Induction Motor**	NA	NA	88
EL2	**ECM**	34	8	51
EL2.5	**ECM with Constant Pressure Controls**	34	8	NA
EL3	**ECM with Proportional Pressure Control**	16	5	41
EL3.5	**ECM with Adaptive Pressure Control**	10	10	38
EL4	**ECM with Differential Temperature Controls**	11	10	30

Table A3: Operating hours for DHW circulators (Table 7, NEEA 2019)

Sector	Control Variety	Number of Pumps (n)	Average Operating Hours	RTF Estimate
Residential	No Control	5	8,760	8,760
	Timer-Controlled	2	3,469	7,300
	Aquastat	5	3,913	1,095
	On-Demand	1	60	61
	Learning	0	-	1,095
Commercial	No Control	51	8,218	8,760
	Timer-Controlled	13	3,681	6,570
	Aquastat	1	1,527	1,095
	On-Demand	11	1,704	122
	Timer Control with On-Demand Capabilities	4	274	NA
	Learning	0	-	1,095

Table A4: Operating hours for DHW circulators (observed v RTF estimate) (Table 79, NEEA 2019)

Sector	Run-hour Control Variety	Average Operating Hours	n	Std Deviation	Standard Error	90% Margin of Error	90% Confidence Interval	RTF Estimate
Residential	No Control	8,760	5	-	-	-	8760 to 8760	8,760
	Timer Control	3,469	2	2,501	1,768	2,917	551 to 6386	7,300
	Aquastat	3,913	5	3,809	1,703	2,810	1102 to 6723	1,095
	On-Demand	60	1	-	-	-	60 to 60	61
	Learning	-	0[63]	-	-	-	-	1,095
Commercial	No Control	8,218	51	1,842	258	426	7792 to 8643	8,760
	Timer Control	3,681	13	2,132	591	975	2705 to 4656	6,570
	Aquastat	1,239	8	1,218	431	711	528 to 1950	1,095
	On-demand	-	0	-	-	-	-	122
	Timer Control with On-Demand Capabilities	274	4	43	21	35	239 to 309	NA
	Learning	-	0	-	-	-	-	1,095