WorkPaper
High Performance Circulator (HPC) Pumps
Revision # 2.1

Stephen Putnam/ Grundfos Pumps Corporation

High Performance Circulator Pump Workpaper: California Technical Forum, 2017

HPC Pumps

Variable speed domestic hot water circulator pumps with brushless permanent magnet motor (BLPM) or electrically commutated motor (ECM) and controls

02/23/2017

At-a-Glance Summary

	HPC Pumps
Measure description[1]	Properly sized, high-efficiency ECM pump for domestic hot water recirculation with variable speed capabilities and controls to match demand.
Program delivery method	Upstream (Direct to wholesale distributor)
Measure application type	ROB (replace on burnout)
Base case description	Source: Market standard/ knowledge Market standard circulators consist of a pump driven by non-regulated, low-efficiency induction type motors, do not utilize variable frequency drives (VFD), and do not have the control capability to match demand.
Energy and demand impact common units	Per unit based on typical running power (watts taken from nameplate, calculated, or field data as noted)
Peak Demand Reduction (kW/unit)	**Peak Demand Reduction (kW/unit):** 1. Base Case: Grundfos UP 15-29 SU/LC – 84.2 Watts (Running Watts, most popular pump sold into CA market) 2. Measure Case: Grundfos Alpha 15-55 – 26.7 Watts (Derived from Alpha Field Survey average)* 3. **Savings: 84.2 Watts – 26.7 Watts = 57.5 Watts (0.058 kW/unit)** *Field survey results were conducted over an average of 7 days – the calculated running wattage is 12.1 after full optimization. See reference section for optimized running wattage calculations associated with this value
Energy savings (Base case – Measure) (kWh/unit)	**Energy Savings (kWh/unit):** 1. Assumed: 6,427[2] Running Hours/ Year 2. Base Case: 0.084 kW 3. Measure Case: 0.027 kW 4. **Savings: 0.058 kW/unit x 6,427 Running Hours/ Yr = 370 kWh Savings/ Year/ unit**

[1] Although this technology can be used in hydronic heating applications the scope of this workpaper is focused only on the hot water recirculation application. Only brass or stainless pumps will be eligible, effectively limiting this to domestic hot water recirculation.

[2] The Department of Energy (DOE) is currently undergoing a negotiated rulemaking for circulator pumps and the topic of annual operating hours was a topic of discussion. The result of that discussion is a weighted average of pumps that are running with no controller, with timers employed, aquastats employed and on-demand. See reference section #5 for chart breakdown.

Gas savings (Base case – Measure) (therms/unit)	None. The high efficiency replacement pump will run the same number of hours as the base case, with heat loss from the plumbing system is assumed to be the same. There is a possibility that with temperature control, and/or a lower flow rate that gas usage may be reduced, but this has not been calculated and is not being claimed.
Full measure cost[3] ($/unit)	Grundfos Alpha 15-55: $336 Material Cost Labor Cost: $300 Installation Cost Full Measure Cost: **$636/Pump**
Incremental measure cost[3] ($/unit)	Measure Equipment Cost: $336 Baseline Equipment Cost: $231 Incremental Measure Cost: **$105/Pump*** *VFD and controls are built into pump and flange to flange dimension is often the same the result is no additional installation cost as compared to the baseline technology
Effective useful life[4] (years)	15 Years per DEER EUL for circulator pumps for the commercial sector.
Net-to-gross ratio(s)	IOU → All-Default<=2yrsSource: 0.70[5] POU → 0.875 • Based on CA market knowledge, as outlined in section 1.1, and Efficiency Vermont's (EV) HPCP program[6]. For a breakout of the net-to-gross calculations see subsection 6F in the references section.
Important comments	1/28/2016 High-Efficiency Pumping Systems Abstract was presented at the California Technical Forum meeting in San Francisco. We received unanimous support for moving forward with the workpaper. In addition, there are measures and existing programs (E.g., EV, Energize Connecticut[7], Focus on Energy[8]) that offer rebates for HPCPs. While focusing on the same technology, these programs all focus on hydronic heating as that is their primary use in colder climates of the United States. In California, domestic hot water (DHW) is the primary use.

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[3] *Source* – Grundos Contactor Cost - Costs are estimated based on market knowledge and it is assumed that the labor costs for the measure and base case are equal thus the IMC labor cost is $0.

[4] *Source* – DEER Resource 2014 EUL Tables - EUL_ID Motors-pump for Water Loop Pumps. Accessed 2/12/2017 - <http://www.deeresources.com/files/DEER2013codeUpdate/download/DEER2014-EUL-table-update_2014-02-05.xlsx>

[5] *Source* – DEER Resource 2016 NTG Tables – NTG All-Dafult<=2yrs. Accessed 2/13/2017 - http://www.deeresources.com/files/DEER2016/download/DEER2015-2016-NTG-Update-2015-10-20.xls

[6] https://www.efficiencyvermont.com/rebates/list/high-performance-circulator-pumps

[7] http://www.energizect.com/your-home/solutions-list/High-Efficiency-Furnace-Natural-Gas-Boiler-Rebates

[8] https://focusonenergy.com/sites/default/files/2016_HVAC_Plumbing_Incentive_Catalog.pdf, page 38. "Variable Speed Pump with Electronically Commutated Motor (ECM)."

Document Revision History

Revision #	Revision Date	Section-by-Section Description of Revisions	Author (Name, PA)
1	9/22/2016	Presentation to Cal TF	Stephen Putnam, Grundfos
2	2/16/2017	Refer to References Section 6 for questions and answers from Cal TF and CPUC from September Cal TF Meeting and follow up discussions. Additionally, adjust measure case to very conservative operating wattage based on Alpha field result survey	Stephen Putnam, Grundfos
2.1	2/20/2017	Update values and tables to reflect final alpha field survey test data. Updated measure case kW, control findings, SS vs instant & sustained demand, and associated values.	Stephen Putnam, Grundfos

Commission Staff Review and Comment History

Revision #	Date Submitted to Commission Staff	Date Comments Received	Commission Staff Comments
1	9/22/2016	12/1/2016	See reference section 6 for reviewer questions & subsequent answers
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Section 1. General Measure & Baseline Data

1.1   Product Measures

General Description

High Performance Circulator (HPC) Pumps for residential (single and multi-family) domestic hot water applications.

QUALIFYING PUMPS Brass or stainless circulator pumps using electrically commutated motors (ECM) with integrated variable frequency drives (VFDs) with onboard pump controlling logic with self-optimizing programing allowing for the pump to learn and operate at the best efficiency point on the pump curve. These features are utilized without any end user interaction and save energy throughout the 15 year useful life of the pumping system.

General Information

A circulator pump is a specific type of pump used to circulate liquids in open or closed loop systems. The focus of this workpaper is on residential (single and multi-family) domestic hot water (DHW) applications which are considered open loop systems.

Open loop: Hot water recirculation where fresh water is introduced into the system. Stainless steel or bronze bodied pumps are used in this application in order to negate the opportunity for rust due to fresh water (oxygen) being introduced into the system. Stainless steel or bronze bodied pumps have a higher initial cost as compared to cast iron bodied pumps. In these open loop systems friction head, and static head need to be overcome in order to deliver hot water.

Closed loop (for reference only, as this measure is applicable only to domestic hot water recirculation): Hydronic heating or cooling where no fresh water is introduced into the system. Cast iron bodied pumps are used in these applications as they are the most cost-effective option due to no risk of rust because no fresh water (oxygen) is entering the system (compared to open loop systems). Friction head losses are the only losses that need to be overcome so inherently these pumps are smaller in horsepower (HP).

Targeted Application in California: Hot Water Recirculation

Circulating pumps are often used to circulate domestic hot water (DHW) so that faucets will provide hot water instantly or in a short time after a user's "on demand" request. The latter "on-demand" system conserves more energy & water, but is less popular in replacement applications as it is less convenient for the user. Is also much more expensive than direct replacement as a replacement on burnout measure. With rising concerns over water conservation DHW systems employing circulator pumps are becoming more popular.

In typical one-way plumbing without a circulation pump, water is simply piped from the water heater through the pipes to the tap. Once the tap is shut off, the water remaining in the pipes cools, producing the familiar wait for hot water effect the next time the tap is opened. A circulator pump, which, with the exception of the "on-demand" system, constantly circulates a small amount of hot water through the pipes from the heater to the farthest fixture and back to the heater. This results in the water at the faucets and in the hot water distribution pipes always being hot. With on-demand domestic hot water, no water is wasted waiting for the water temperature to increase but, as previously mentioned, this option is less popular as hot water is not automatically dispensed from the faucet when called for by the user.

The "wet rotor" sealed units used in home applications often have the motor rotor, pump impeller, and support bearings combined and sealed within the water circuit. This offers longer life and avoids one of

the principal challenges faced by the larger, two-part pumps: maintaining a water-tight seal at the point where the pump drive shaft enters the pump body.

Pumps that have a steady stream of oxygenated, potable water flowing through them, i.e. open loop systems, must be made of materials such as bronze & stainless steel that resist corrosion.

2015 Estimated Residential (including multi-family) ROB Market Landscape in California:
Plumbing (HWR): 51,400 (93.2% of CA market – Targeted application for workpaper)
Hydronic (HVAC): 3,770 (6.8% of CA market)
TOTAL estimated CA 2015 plumbing consumption: 22,677,400 kWh

"Small" Market Segment: Up to 25 Watts (12, 744 pumps transacted – 22.9% of CA plumbing market)
- 1,339,401 kWh Consumed in 2015
- Market Standard Pumps: 8,318 (70.6% of market segment)
  - 1,410,244 kWh consumed
- Efficient Option: 3,464 (29.4% of market segment)
  - 42,987 kWh consumed

"Large" Market Segment: 26 – 120 Watts (39,618 pumps transacted – 77.1% of CA market)
- 21,336,929 kWh Consumed in 2015
- Market Standard Pumps: 39,341 (99.3% of market segment)
  - 21,289,339 kWh consumed
- Efficient Option: 277 (0.7% of market segment)
  - 47,589 kWh consumed

kWh Savings Potential by Market Conversion Rate for 26-120 W market
- 25%: 3,634,549 (16% kWh savings as compared to current market)
- 50%: 7,269,098 (32% kWh savings as compared to current market)
- 75%: 10,904,016 (48% kWh savings as compared to current market)
- 100%: 14,538,565 (64% kWh savings as compared to current market)

See subsection 3 in References section for calculation methodology

Technical Description
The Alpha 15-55[9] is the energy efficiency measure that we are proposing as the measure case because it is the most common applicable residential HPC Pump option. A variety of manufacturers also make pumps that fit within the measure case description. In addition, we have identified roughly 519 wholesale distribution locations throughout the state of CA where these pumps are sold. Pumps in the measure case are all driven by an electrically commutated motor (ECM), have integrated variable frequency drives (VFD), and controlling logic which allows the pump to match the demand of the system.

- ECM: Saves ~50% energy as compared to a non-regulated, inefficient induction type of motor.
- VFD: Many utilities such as Pacific Gas & Electric and Southern California Edison recognize the energy savings potential that VFDs offer in pumping systems by offering an incentive via prescriptive (express solutions) programs. However, many times end-users will only apply for these incentives for larger horsepower (HP) systems, typically greater than 25 HP, because of the small incentive amount or cost. HPC Pump technology extends the energy saving opportunity of VFDs to the fractional HP realm, which has previously been overlooked.
- Controlling Logic: The inclusion of controlling logic offers additional energy savings by allowing the pump to only consume as much energy as is need to perform the duty the system requires. HPC Pumps have the ability to (through the VFD) actively speed up and slow down

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[9] Alpha 15-55 Product Specification

according to needs of the system, resulting in higher energy savings. The Grundfos Alpha 15-55 controlling logic utilizes an operational mode called "AutoAdapt" where the pump will measure shaft tension to detect changes in the system pressure (i.e. hot water demand) and adjust flow rates accordingly. The logic allows the pump to operate along a system specific proportional pressure curve closely mirroring the specific system curve into which the pump is installed. When a new maximum flow is recognized a new, lower proportional pressure curve is created that the pump will now operate within, resulting in a lower steady-state power draw as the interaction between the pump curve and system curve move to the left of the flow charts. All without end user interaction.

1.2   Product Parameter Data

1.2.1   DEER Data

The table below is meant to give a quick summary of any applicable DEER measures and the reason this work paper uses a method which deviates from DEER.

Table 1.2.1.1. DEER difference summary

DEER	Used in Workpaper Approach?
Modified DEER methodology	No
Scaled DEER measure	No
DEER base case used	No
DEER measure case used	No
DEER building types Used	No
DEER operating hours used	No
Reason for Deviation from DEER	There are no measures that directly contain this technology because it encompasses multiple technologies into one unit. There are past 2005 DEERs that tangentially relate to the technology such as DEER ID's: • **D03-046** – Variable Flow Chilled Water Loop • **D03-047** – VSD Chilled Water Loop Pump • **D03-048** – Variable Flow Hot Water Loop • **D03-049** – VSD Hot Water Loop Pump • **D03-089** – Effic. Motors – Chilled Water Loop Pumps • **D03-090** – Effic. Motors – Hot Water Loop Pumps • **D03-095** – Circulator Pump Timeclock Retrofit • system with electric storage water heater
DEER Version	N/A
DEER ID and Measure Name (Sample)	N/A

Table 1.2.1.2. DEER Net-to-Gross ratios for IOU

From DEER Tables					
NTGR_ID	Description	Sector	Building Type	NTG	Program Delivery
DEER EUL ID:_All-Default<=2yrs_)	New Entry	Res	Home	0.7	ROB

Table 1.2.1.3. DEER Net-to-Gross ratios from existing programs for reference

From Existing Program Tables[10,11]					
Program Name	Description	Sector	Building Type	NTG	Program Delivery
Efficiency Vermont	HPCP Upstream	Res/Comm	Home/Office	0.95	ROB
Energize Connecticut	HPCP Upstream	Res/Comm	Home	0.95	ROB

Table 1.2.1.4. Calculated Net-to-Gross ratio for POU

Description	Sector	Building Type	NTG	Program Delivery
Derived from Grundfos wholesale market sale knowledge and Efficiency Vermont HPCP Program. See reference section 6F for breakdown of calculations	Res	Home	0.875	ROB

Effective Useful Life / Remaining Useful Life

Table 1.2.1.5. DEER EUL values/methodology

READi EUL ID	Market	End Use	Measure	EUL (Years)	RUL (Years)
Motors-pump	Residential	Circulation	High Performance Circulator Pump	15	5

It is worth noting that the Efficiency Vermont HPCP program carried an EUL of 20 years for the measure case brushless permanent magnet circulator pump, and 15 years for the base case AC induction motor circulator pump[11].

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[10] While these programs are principally directed towards hydronic heating applications, the current market share of HPC's is similarly low as what is found for domestic hot water circulators.
[11] *Source* – Efficiency Vermont: Technical Reference User Manual (TRM) 3/16/2015: TRM User Manual No. 3/16/2015, Brushless Permanent Magnet (BLPM) Circulator Pump, pg: 28. http://psb.vermont.gov/sites/psbnew/files/doc_library/ev-technical-reference-manual.pdf

In-Service Rate / First Year Installation Rate:

It is assumed that the installation rate for all ROB products could eventually reach close to 100%. However, we can reference the Efficiency Vermont 1st year sales which saw a first year increase in sales of over 1,000%. Meaning moving from a few hundred annual pre incentive program to a few thousand in the first year with an incentive program. These sales values are referenced on multiple occasions in this workpaper.

Homeowners do not stockpile circulator pumps nor does the homeowner select the pump that will be used in their application. Plumbing contractors may keep a stock of one or two pumps on their service truck. The pump selection is made by the plumbing contractor who would visit the wholesaler at least two to three times per week to have pumps readily available to service the market. The Alpha serves the market well in this capacity as with its "right-sizing" ability, it is the single pump solution to the vast majority of installation opportunities. This eliminates the "over-sizing" problem that exists in the marketplace.

Table 1.2.1.6. Installation rate

From DEER Tables					
GSIA_ID	Description	Sector	Building Type	GSIA Value	Program Delivery
Motors-pump	HPC Pump	Res	Home	1	ROB

Table 1.2.1.7. READi Tech IDs

READi Field Name	Values included in this workpaper
Measue Case UseCategory	SHW
Measure Case UseSubCats	Distribute
Measure Case TechGroups	LiquidCirc
Measure Case TechTypes	FlowTempCtrl
Base Case TechGroups	LiquidCirc
Base Case TechTypes	FlowTempCtrl

1.2.2   Codes & Standards Requirements Base Case and Measure Information

Title 20: No Title 20 requirements exist for this product.

Title 24: No Title 24 requirements for ROB. But some NC requirements are in place:

- Section 150.1(c)8 – For recirculation distribution systems serving individual dwelling units, only demand recirculation systems with manual control pumps (as specified in T24 reference appendix RA4.4.9) shall be used.

- Section 150.1(c)8b – requiring central-heating systems in multiple dwelling units to have a water heating recirculation loop that meets the requirements of sections 110.3(c)2 and 110.3(c)5 and is equipped with an automatic control system that controls the recirculation pump operation based on measurement of hot water demand and hot water return temperature.

- Section 150.2(b)1Gii – in reference to prescriptive approach for additions and alterations to existing low-rise residential buildings. "For recirculation systems, only demand recirculation systems with manual control pumps" shall be used unless a water

heating system is installed that is shown to no more energy that the prescribed methods.

- o If a larger replacement of the domestic hot water system is occurring that triggers T24 a manually controlled demand based recirculation pump would be required. The replacement of a circulator pump is considered a "repair" and would not trigger Title 24.

Federal Standards: No Federal Standards at this time exist for in-line pumps smaller than 5 hp that are defined as circulator pumps. However, the Department of Energy (DOE) has begun formal negotiations on this product category with the intention of establishing energy efficiency standards, which will likely become effective in 4 years from the date of adoption.

One Quick Market Stance Note: The "right-sizing" ability of an HPCP is a tremendous energy savings advantage over the market standard. This workpaper targets the retrofit (ROB) applications where a contractor replaces a pump that has reached the end of its useful life. The mindset of that contractor is to replace the old pump with the current version of the new pump (taking into account the HP or wattage rating as the only sizing parameter). And if that pump is oversized to start it is "re-oversized" at replacement. This begs the question, "shouldn't a contractor know how to accurately size the proper circulation pump?" The short answer is yes they should but knowing that these installations take place in a retrofit application the contractor does not have access to the information needed to properly size the "right-sized" circulator pump. The contractor will need to know the length and diameter of the pipe used in the piping system as well as the number of valves and fittings in the system and this is not possible as the walls in which these pumps are installed are covered with sheetrock. In order to accurately properly "right-size" the pump, the contractor will need to remove sheetrock and/or enter the crawl space or attic which is not practical for contractors to do. The "right-sizing" HPCP presents the best opportunity for wide-spread market adoption.

1.2.3   Relevant EM&V Studies

1. Efficiency Vermont HPCP Rebate Program
https://www.efficiencyvermont.com/rebates/list/high-performance-circulator-pumps (last accessed 6/10/2016). As this program takes place in the northeast where HVAC applications are more prevalent than in California, this specific program focuses on circulator pumps for hydronic heating compared to DHW as is being proposed in this workpaper. However, the success from offering a rebate to incentivize the purchases of HPC Pumps is very apparent with this program, as outlined in Figure 1.2.3.1.
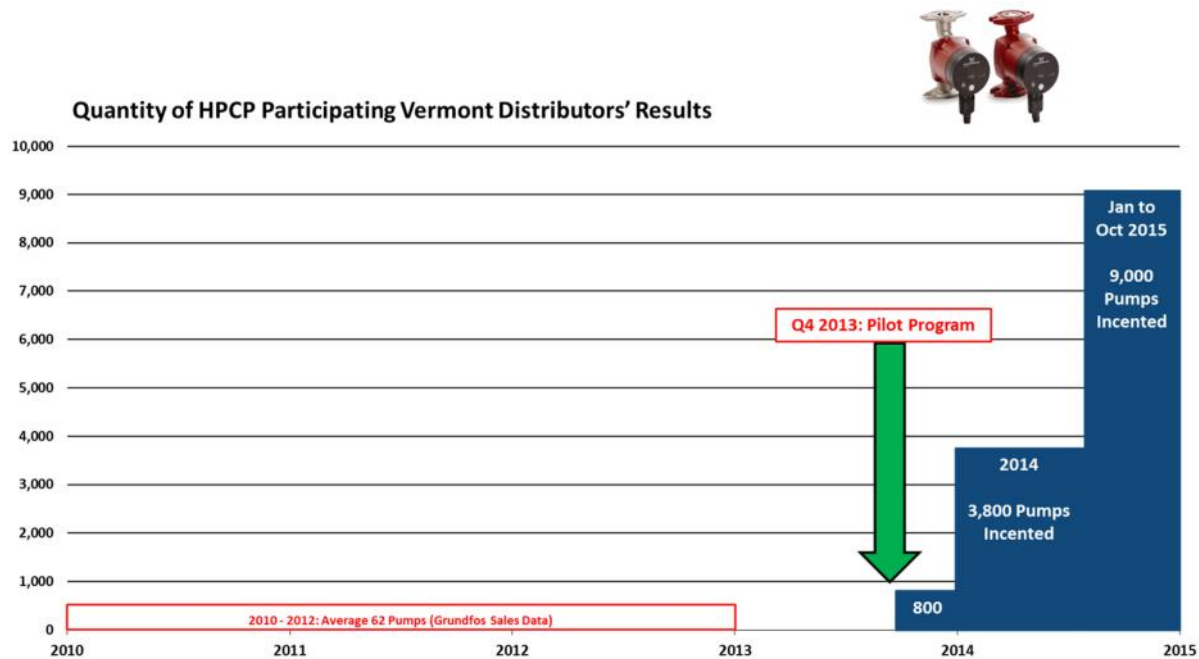
Figure 1.2.3.1. Outlining sales data from the Efficiency Vermont HPC Pump rebate program.

1.2.4 Relevant Workpaper Dispositions

No relevant workpaper dispositions that relate to HPC Pumps that we are aware of.

1.2.5 Other Sources for non-DEER Methods

- EPRI Report ("Assessment of New Energy Efficient Circulator Pump Technology", Product ID: 1020132, Published: Nov 15, 2010)
- Department of Energy Final Rule on Pump Efficiency, "Pumps ECS Final Rule"
- EPRI Report ("Assessment of New Motor Technologies and their Applications", Product ID: 3002001762, Published: Dec, 2013)
- Alpha Product Guide

Section 2. Calculation Methods

2.1 Program Implementation Analysis

Table 2.1.1. Baseline by measure application type

Measure Application Type	Baseline	Baseline Technology	Duration
ROB	First	pump driven by non-regulated, low-efficiency induction type motors, do not utilize variable frequency drives (VFD), and do not have the control capability to match demand	EUL 15

2.2 Electric Energy Savings Estimation Methodologies

Table 2.2.1. First baseline

Energy and demand impact common units	Per unit based on running wattage (taken from calculations based on submittal data)
Energy savings (Base case – Measure) (kWh/unit)	**Energy Savings (kWh/unit):** 1. Assumed: 6,427 Running Hours/ Year 2. Base Case: 0.084 kW 3. Measure Case: 0.027 kW 4. Savings: 0.058 kW/unit x 6,427 Running Hours/ Yr = 370 kWh Savings/ Year

2.3 Demand Reduction Estimation Methodologies

Table 2.3.1. First baseline

Peak Demand Reduction (kW/unit)	**Peak Demand Reduction (kW/unit):** 1. Base Case: Grundfos UP 15-29 SU/LC – 87 Watts (Nameplate), **84.2 Watts (Running Watts** –see submittal data in REFERENCES section), most popular Grundfos pump sold into CA market 2. Measure Case: Grundfos Alpha 15-55 – 5 Watts minimum -45 Watts maximum (Nameplate), **26.7 Watts (observed from Alpha field test outlined in Appendix 6 – minimal operation time).** Calculated optimized running wattage value of 12.1 W is outlined in Reference section 4. 3. **Savings: 84.2 Watts – 26.7 Watts = 57.5 Watts (0.058 kW/unit)**

PLEASE NOTE: 6,427 running hours/ year is assumed in this workpaper and is the weighted average of pumps running with a combination of "on-demand", timer controlled, aquastatically controlled and no controls. With a strong knowledge of the CA market, Grundfos feels that the vast majority of pumps that would be targeted for replacement in this workpaper have an annual runtime of 8,760/ year. This is why we are carrying the Peak Demand Reduction based on the typical running and optimized running wattage.
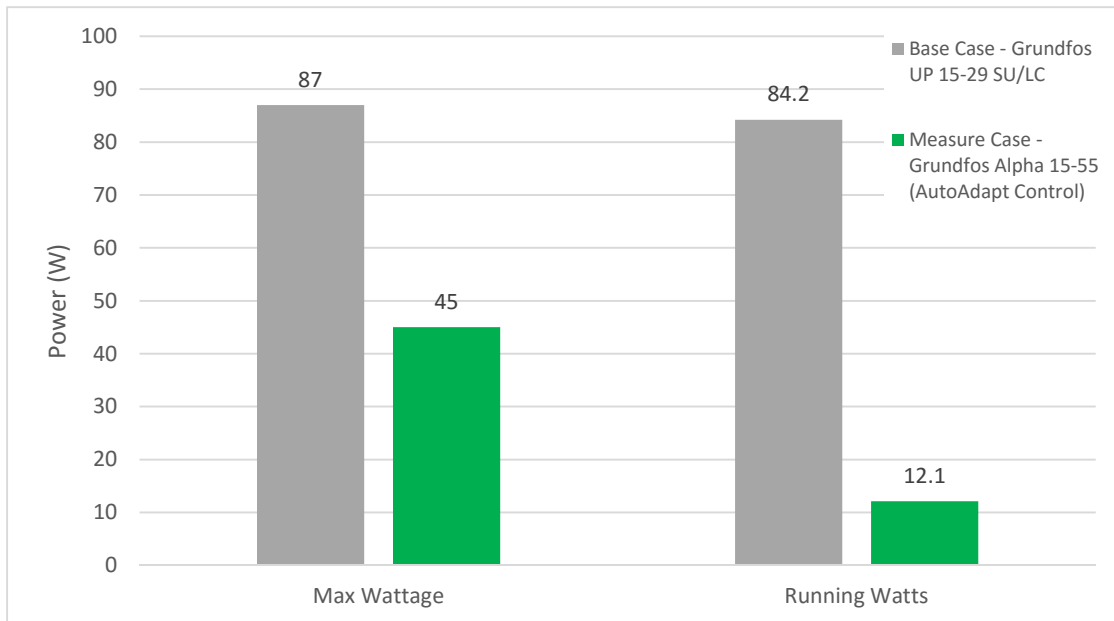

Figure 2.3.1. Illustrating the savings potential from the base case to measure case when in and out of AUTOADAPT controlling mode. The base case does not utilize any type of VFD or controlling logic, this is typical in the market place. The figure above shows the electrical savings potential due to the combination of the ECM, integrated VFD and controlling logic as the pump self-optimizes during its operation. See reference section for details on calculations from max watts to running watts.

This workpaper is currently carrying a non-optimized AutoAdapt measure case running wattage of 26.7 watts as this was the value found in a limited field study with an average installation length of seven days. The authors of this workpaper will work to acquire more field data from Alpha pumps with longer installation lifetimes to verify optimized running wattage to claim/verify additional savings.

2.4   Gas Energy Savings Estimation Methodologies

Not calculated, as measure case is assumed to be the same as the base case with respect to gas usage.

2.5   Load Shapes

Target sector was used because the building type is residential homes, and the measure technology will be replacing a fixed speed pump that operates on the weighted average of controls installed in the market.

Table 2.5.1. Building types and load shapes

Building Type	E3 Alternate Building Type	Load Shape
Residential Home	NON_RES	Flat @ 6,427 hours

Table 2.5.2. Weighted operating hours distribution based on market knowledge from DOE ASRAC federal negotiation members. Including all major manufacturers and efficiency advocates

Control Type	Sector	Fraction of Consumers	HPY	Notes
No Control	Residential	50%	8760	Constant Operation
	Commercial			
Timer	Residential	25%	7300	50% @ 24/7 & 50% @ 16hrs/day
	Commercial		6570	50% @ 24/7 & 50% @ 12hrs/day
Aquastat	Residential	20%	1095	3 hrs/day
	Commercial			
On Demand	Residential	5%	61	10 min/day[1]
	Commercial		122	20 min/day[1]

1 - Assuming that circulators operate for 30 seconds for each demand "push"
2 - Assuming operating hours do not vary by region

Section 3. Base Case, Measure, and Installation Costs

Table 3.1. Measure cost summary by application type

Measure Application Type	Base Case Equipment Cost ($/unit)	Measure Equipment Cost ($/unit)	Installation Cost ($/Unit)	Incremental Measure Cost ($/unit)	Full Measure Cost (1st Baseline period)[12] ($/unit)	Full Base Cost (2nd baseline period)[13] ($/unit)
ROB	$231	$336	$300*	$105	$636	NA

* The installation cost is the same for the base case and the measured case.

3.1   Base Case Costs

Costs have been taken directly from Grundfos sales channels and data, costs shown reflect pumps that will be installed in hot water recirculation (HWR) applications in CA. Pumps installed in HWR should be either bronze or stainless steel bodied. Pumps that are installed into HVAC applications should be cast iron bodied. Cast iron bodied pumps cost less, but are outside the scope of this workpaper. Because we are a manufacturer of the product identified in this workpaper we have intimate knowledge of the sales process and pricing levels. Costs can deviate based on sales area - and comparable pumps from a variety of manufacturers are going to be priced within 5 – 10% of our

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12 Full measure cost = measure equipment cost + installation cost, for first baseline period
13 Full base cost = 2nd baseline equipment cost + installation cost, for the second baseline period

estimated figures. See qualifying product list[14] from the Efficiency Vermont program where the incentive (similar to our IMC) will pay out the same for a variety of HPC Pumps from different manufacturers in the same class.

3.2   Measure Case Costs

Costs have been taken directly from Grundfos sales channels and data. Because we are a manufacturer of the product identified in this workpaper we have intimate knowledge of the sales process and pricing levels. Costs can deviate based on sales area - and comparable pumps from a variety of manufacturers are going to be priced within 5 – 10% of our estimated figures.   See qualifying product list[14] from the Efficiency Vermont program where the incentive (similar to our IMC) will pay out the same for a variety of HPCPs from different manufacturers in the same class.

3.3   Installation/Labor Costs

The scope of this workpaper is constrained to hot water recirculation applications. There may be a difference in labor costs for HVAC applications, but here we assume the installed and labor costs are the same for the base and the measure case. The estimate for installation and labor is approximately $300/unit, however, this number will vary by contractor.

3.4   Incremental & Full Measure Costs

Table 3.4.1. Incremental measure cost calculations

Measure Application Type	Equation ($/unit)	Results ($/unit)
ROB	**Incremental Measure Cost** = (Measure Equipment Cost + Measure Labor Cost) – (Base Case Equipment Cost + Base Case Labor Cost)	($336+$300) - ($231+$300) = $105

Appendices

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2. Commission Staff Comments/Review
3. Measure Application Type Definitions
4. CPUC Quality Metrics
5. DEER Resources Flow Chart
6. Alpha Measure Field Test Documents & Details

Appendix 1 – Cal TF Workpaper Template

Cal TF Workpaper
Template.xlsx

Appendix 2 - Measure Application Type Definitions

The DEER Measure Cost Data Users Guide found on www.deeresources.com under *DEER2011 Database Format* hyperlink, DEER2011 for 13-14, spreadsheet *SPTdata_format-V0.97.xls*, defines the measure application type terms as follows:

Table A2.1. Measure application type

Code	Description	Comment
ER	Early retirement	Measure applied while existing equipment still viable, or retrofit of existing equipment
EAR	Retrofit Add-on	Retrofit to existing equipment without replacement
ROB	Replace on Burnout	Measure applied when existing equipment fails or maintenance requires replacement
NC	New Construction	Measure applied during construction design phase as an alternative to a code-compliant standard design

Table A2.2. Baseline technologies for UES and cost calculations[15]

Measure Application Type	Baseline	Baseline Technology	Measure Cost Calculation	Duration
ER	First	Existing technology	Measure equipment cost + labor cost	RUL = $1/3*EUL$[16]
	Second	Code or standard	(-1)*(Code/standard equipment cost + labor cost)	EUL - RUL
REA	First	Existing technology	Measure equipment cost + labor cost	EUL
	Second	N/A	N/A	N/A
ROB	First	Code or standard	(Measure equipment cost + labor cost) – (Code/standard cost + labor cost)	Full EUL
	Second	N/A	N/A	N/A
NC	First	Code or standard	(Measure equipment cost + labor cost) – (Code/standard cost + labor cost)	Full EUL
	Second	N/A	N/A	N/A

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[15] According to the Energy Efficiency Policy Manual v.5 at page 32, the measure cost for an early-retirement case is "the full cost incurred to install the new high-efficiency measure or project, reduced by the net present value of the full cost that would have been incurred to install the standard efficiency second baseline equipment at the end of the [RUL] period". Page 33 elaborates that "the period between the RUL and EUL defines the second baseline calculation period…the measure cost for this period is the full cost of equipment, including installation, for the second baseline equipment measure".
[16] The Energy Efficiency Policy Manual v.5 at page 33 states "the remaining useful life (RUL)…[is established by DEER] as one-third of the expected useful life (EUL) for the equipment type".

Appendix 3 – Measure Cost Overview

Measure Cost
rev9.docx

Appendix 4 – CPUC Quality Metrics

CPUC workpaper development actions to ensure quality are listed below, adapted from ex ante implementation scoring metrics described in Attachment 7 of Decision (D).13-09-023. The corresponding scoring metrics are shown below.

Table A4.1. Scoring metrics to ensure workpaper development quality.

Metric	Workpaper Development Action to Ensure Quality
2	Address all aspects of the Uniform Workpaper Template[17]
3a[18]	Include appropriate program implementation background
3b	Include analysis of how implementation approach influences development of ex ante values
3c	Include all applicable supporting materials
3d	Include an adequate[19] description of assumptions or calculation methods
4	Pursue up-front collaboration on high impact measures with Commission staff prior to formal submission for review
7	Include analysis of recent and relevant existing data and projects that are applicable to workpaper technologies for parameter development that reflects professional care, expertise, and experience
9	Appropriately incorporate DEER assumptions, methods, and values for new or modified existing measures using professional care and expertise
10	Incorporate cumulative experience into workpaper through inclusion of an analysis of previous activities, reviews, and direction. (ED expects IOUs to immediately incorporate disposition guidance into workpapers to be submitted for formal review)

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[17] The Uniform Workpaper Template is not posted on the DEER website as of 4/21/14, and is currently in Microsoft Access Database format.

[18] Metric 3 is not split among a – d in Attachment 7, however metric 3 was separated into four subcategories in this document for the purposes of identifying individual workpaper development actions to address quality.

[19] "Adequate" is defined in Attachment 7 such that derivations of underlying assumptions of workpaper are easy to understand by the CPUC reviewer.

Appendix 5 – DEER Resources Flow Chart

Draft DEER
Resources Flow Cha

Appendix 6 – Alpha Measure Field Test Documents & Details

This field test was created in response to the California Technical Forum and CPUC comments from the HPCP presentation on September 22nd and subsequent discussions. The comments/questions to be addressed by this field test are noted below and are addressed at length in reference section 6, along with additional TF and CPUC questions. The primary questions to answer with the field survey are:

- What are the typical in-field baseline pumps? The baseline details outlined in this workpaper are based on Grundfos sales data and members of the Cal TF were interested in field data to support these claims.
- What are typical hours of operation for single family residence (SFR) DHW recirculation in California? The value carried in this workpaper is a nationwide average and not necessarily representative of California.
- What is the instantaneous and sustained demand values? In other words, compared to the steady-state operation, does the power draw increase or decrease when the system is opened (e.g., a faucet is turned on) and when water demand is sustained.

Grundfos gifted 15 measure case Alpha 15-55 circulator pumps to the market to be installed in SFRs to address the questions of the TF and CPUC. They gifted these pumps to their California Bay Area Manufacturer representative Osborn Company. Bill Schwartz, the Vice President of Osborne Co, managed the survey and distributed the measure case pumps to various contractors for installation. At this point the process followed the steps outlined in Figure A6.1 below and the results were used to answer their respective questions in reference section 6.
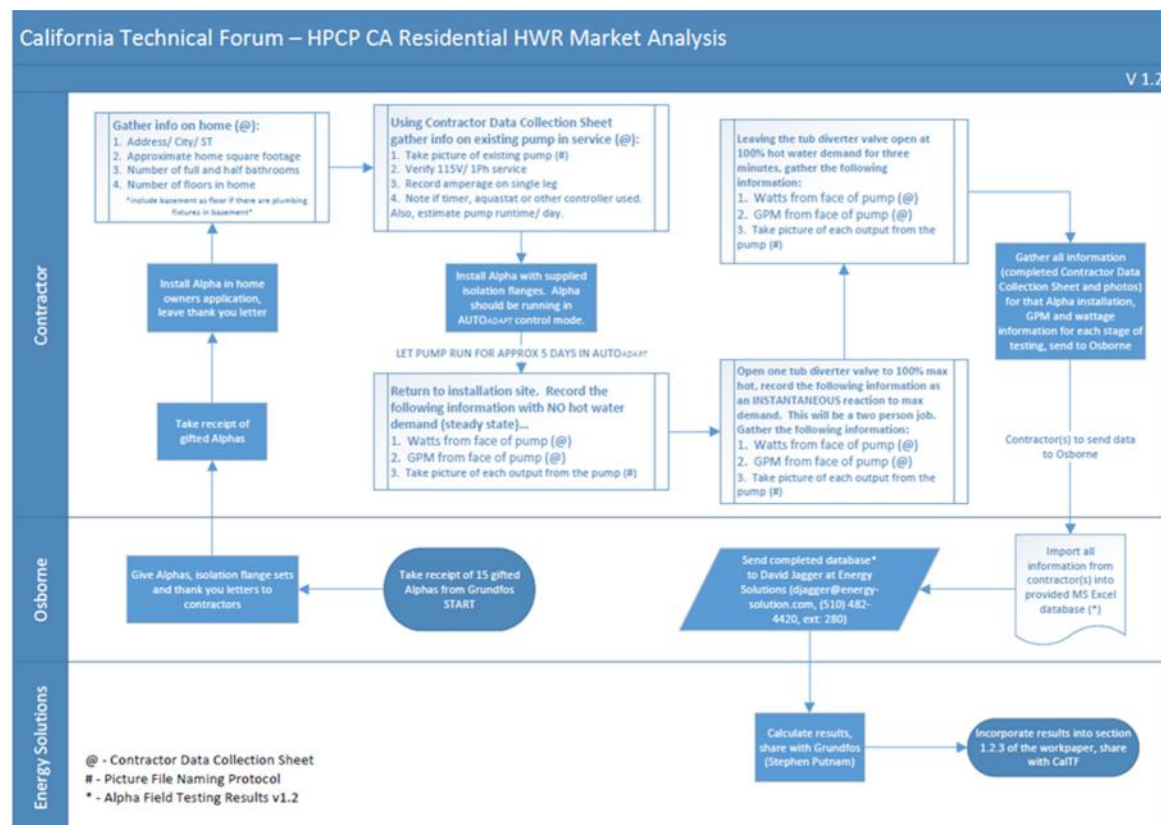

Figure A6.1. Flow chart highlighting Alpha field survey process

Of the 15 Alpha circulator pumps gifted to the market, 13 have data that was used to answer the questions outlined in this appendix and reference section 6. The other two pumps were not included for the following reasons:
- One was installed at a commercial building
- One Alpha pump had electrical issues out of the box. This needed to be repaired and was found out too late to send another pump into the market.

For these reasons the results are based on 13 pumps.

The results first need to be qualified that these pumps were gifted into the market and installed free-of-cost to the customer. Contractors approached customers if they would be ok with replacing their current DHW circulator pump with the Alpha pump. Customers were selected in this format instead of a more desirable service call because of the compressed timeline to complete the field survey and a desire to address the operating (SS vs instant and sustained demand) questions. Typically a customer would wait until they needed to replace their current circulator pump to upgrade to the Alpha model, but, out of necessity, this was not the case for the field test.

This customer selection process would result in existing pumps that are more similar to what would be found in an ER program. Meaning that the efficiency, and control equipment of the found pumps are likely be to more adept than those that would be found in an ROB program. As historically, especially with 15 years EUL, controls were not as advanced, pumps were not as efficient, contractors were not as well versed on installing advanced equipment or sizing a system. Additionally, the Alpha may not go into a system where it would be a substantial benefit compared the replacement pump as the contractors were instructed to focus on finding systems as soon as possible for installation to verify the SS, instantaneous, & sustained demand attributes.

Contractor Data Collection Sheet   *California Technical Forum - HPCP Field Test*

Contractor: _____   **Phone:** _____

Installer: _____   **Email:** _____

Installation Date: _____

Home Information:

Address Line 1 _____	Approx SF of Home _____
Address Line 2 _____	Number of Full Baths _____
City _____	Number of Half Baths _____
ST _____	Number of Floors _____
Zip _____	*Include basement as a floor ONLY if there are plumbing fixtures in the basement*

Existing Pump Info: *(Take picture of pump in place PRIOR to removal, see file naming protocol)*

Manufacturer _____   Control Type (Circle One)

Model _____   NONE   Timer   Aquastat   T + A

Voltage _____   If Timer - Running Hours/ Day _____

Amp Reading _____

Install provided Grundfos Alpha, operate in AUTOADAPT mode (default mode at start up)

Return to site approximately 5 days after Alpha install

Step 1: Steady State Performance

Date _____

Record the following from face of Alpha...

GPM _____

Watts _____

With all hot and cold water fixtures closed, please record the following outputs from the face of the provided Grundfos Alpha pump. *Please take pictures of both readings from the pump, naming in accordance with protocol.*

Step 2: Instantaneous Demand Performance

Record the following from face of Alpha...

GPM _____

Watts _____

This will require two people. Open all tub diverter valves to 100% hot water demand and record the INSTANT reaction of GPM and Watts from the face of the Grundfos Alpha. *Please take pictures of both readings from the pump, naming in accordance with protocol.*

Step 3: Sustained Demand Performance

Record the following from face of Alpha...

GPM _____

Watts _____

After the tub diverter valve(s) have been left open for 3 minutes from step 2, record the SUSTAINED reaction of GPM and Watts from the face of the Grundfos Alpha. *Please take pictures of both readings from the pump, naming in accordance with protocol.*

Figure A6.2. Contractor survey form.

The results as they pertain to the questions from Cal TF members and CPUC staff are addressed in Reference section 6. Some characteristics of the 12 field tested SFRs are listed in the table below.

Table A6.1. Housing characteristics for the 13 field tested SFRs

	ft^2	Num of Floors	Num of Bathrooms	Length of Installation (Days)
Average	5,434	2.1	3.2	6.9
Min	2,400	1	2	4
Max	13,820	3	6	15

11 of the 13 SFRs are located in California climate zone 3, one SFR is located in climate zone 2, and the final SFR is located in climate zone 12. However, as noted throughout the workpaper, from manufacturer knowledge and the DOE ASRAC federal negotiations, it is held that climate zones do not differentiate DHW operation.

Five different installers participated in this field test.

References

Table of Contents

1. BASE CASE PUMP SUBMITTAL DATA

UP 15-29 SU/LC

Circulator pumps

Product photo could vary from the actual product

Conditions of Service		Pump Data		Motor Data	
Flow:	9.99 US gpm	Maximum operating pressure:	145 psi	Max. power input:	87 W
Head:	5.496 ft	Liquid temperature range:	35.6 .. 230 °F	Rated power - P2:	0.121 HP
Efficiency:		Maximum ambient temperature:	104 °F	Rated voltage:	115 V
Liquid:	Water	Approvals:	UL, CSA	Main frequency:	60 Hz
Temperature:	140 °F	Type of connection:	S.S. Union	Insulation class:	F
NPSH required:	ft	Flange standard:	USA Threaded	Motor protection:	CONTACT
Viscosity:		Pipe connection:	1 1/4" NPSM	Thermal protection:	internal
Specific Gravity:	0.985	Product number:	59896776		

UP 15-29 SU/LC, 60Hz

Q = 9.99 US gpm
H = 5.496 ft
Pumped liquid = Water
Liquid temperature = 140 °F
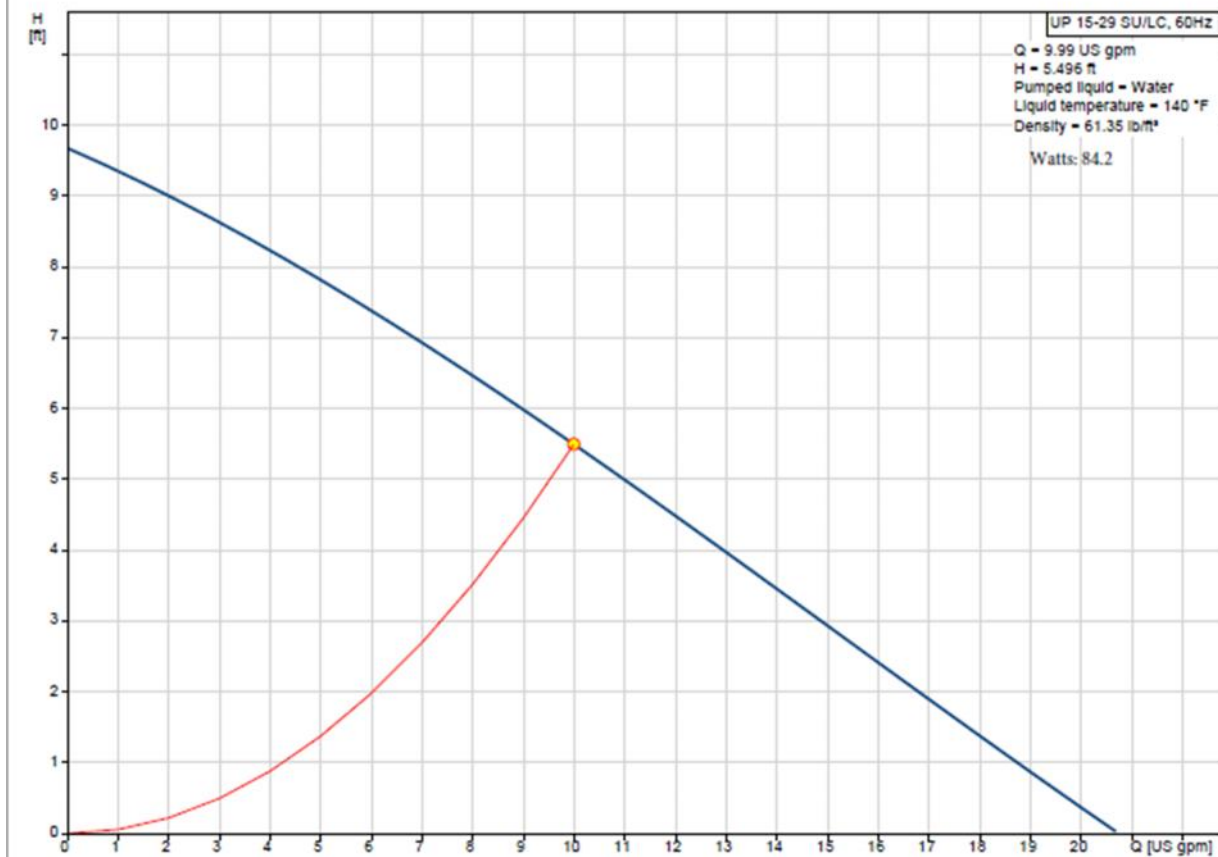Density = 61.35 lb/ft³

Watts: 84.2

Figure R1.1. Base case pump submittal data

2. MEASURE CASE PUMP SUBMITTAL DATA

GRUNDFOS

Company name: Grundfos Pumps
Created by:
Phone:

Date: 7/7/2016

Description	Value
General information:	
Product name:	ALPHA 15-55SF/LC
Product No.:	59896834
EAN:	5700312930129
Price:	On request
Technical:	
Actual calculated flow:	2.45 US gpm
Resulting head of the pump:	5.5 ft
Head max:	18.05 ft
TF class:	110
Approvals on nameplate:	ETL, FCC
Materials:	
Pump housing:	Stainless steel
	DIN W.-Nr. 14308
	ASTM CF8
Impeller:	Composite, PES
Installation:	
Range of ambient temperature:	32 .. 104 °F
Maximum operating pressure:	145 psi
Pipe connection:	G 1 1/2
Pressure stage:	PN 10
Port-to-port length:	6 1/2 in
Liquid:	
Pumped liquid:	Water
Liquid temperature range:	35.6 .. 230 °F
Liquid temp:	140 °F
Density:	61.35 lb/ft³
Electrical data:	
Power input - P1:	5 .. 45 W
Main frequency:	60 Hz
Rated voltage:	1 x 115 V
Maximum current consumption:	0.1 .. 0.65 A
Enclosure class (IEC 34-5):	IP42
Insulation class (IEC 85):	F
Motor protection:	NONE
Thermal protec:	ELEC
Controls:	
Pos term box:	6H
Others:	
Net weight:	5.95 lb
Gross weight:	6.17 lb
Shipping volume:	87.6 ft³
Sales region:	USA

ALPHA 15-55SF/LC, 60Hz

Q = 2.45 US gpm
H = 5.5 ft
Pumped liquid = Water
Liquid temperature = 140 °F
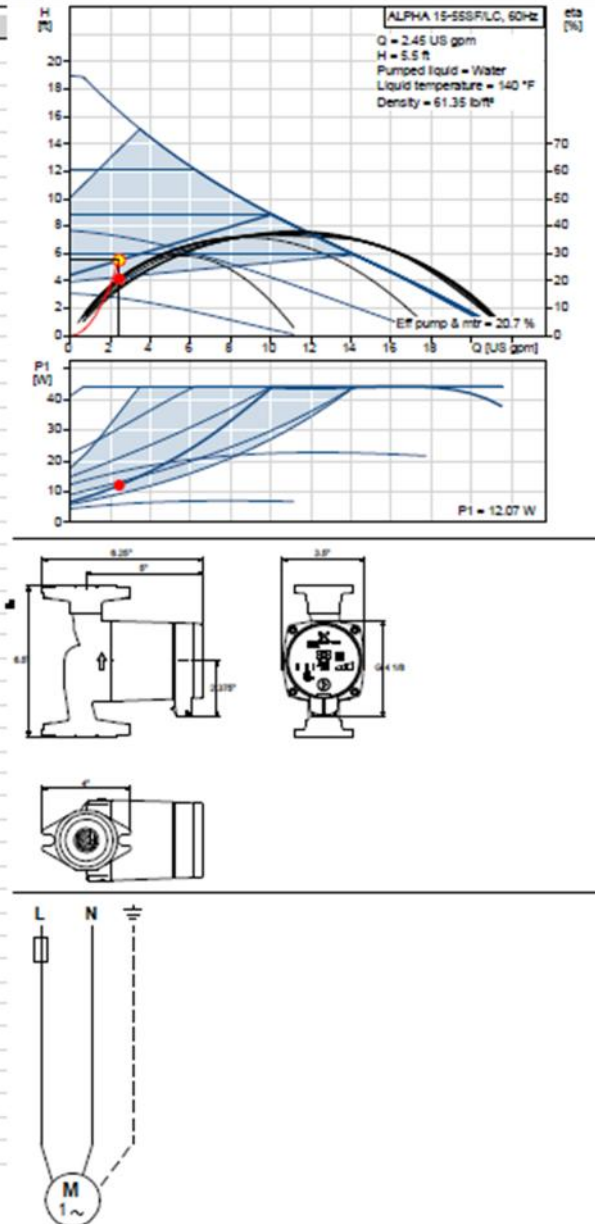Density = 61.35 lb/ft³

Eff pump & mtr = 20.7 %

P1 = 12.07 W

L N

M
1 ~

Figure R2.1. Measure case pump submittal data

2.A.   Efficient Option Component Breakdown

Grundfos Alpha 15-55 SF/LC

Pump Wet End: Stainless Steel for OPEN (plumbing) applications, Cast Iron for CLOSED (HVAC) applications, 6-1/2" flange-to-flange (standard)

Integrated VFD: VFD built directly into the pump, allows for self-optimization ability

Self-Optimizing: Algorithm dictates pumps performance and right-sizes for the specific application into which it is installed

Control Modes: Single button allows changing to seven different control modes. AUTOAdapt is default setting. Active mode is lit.
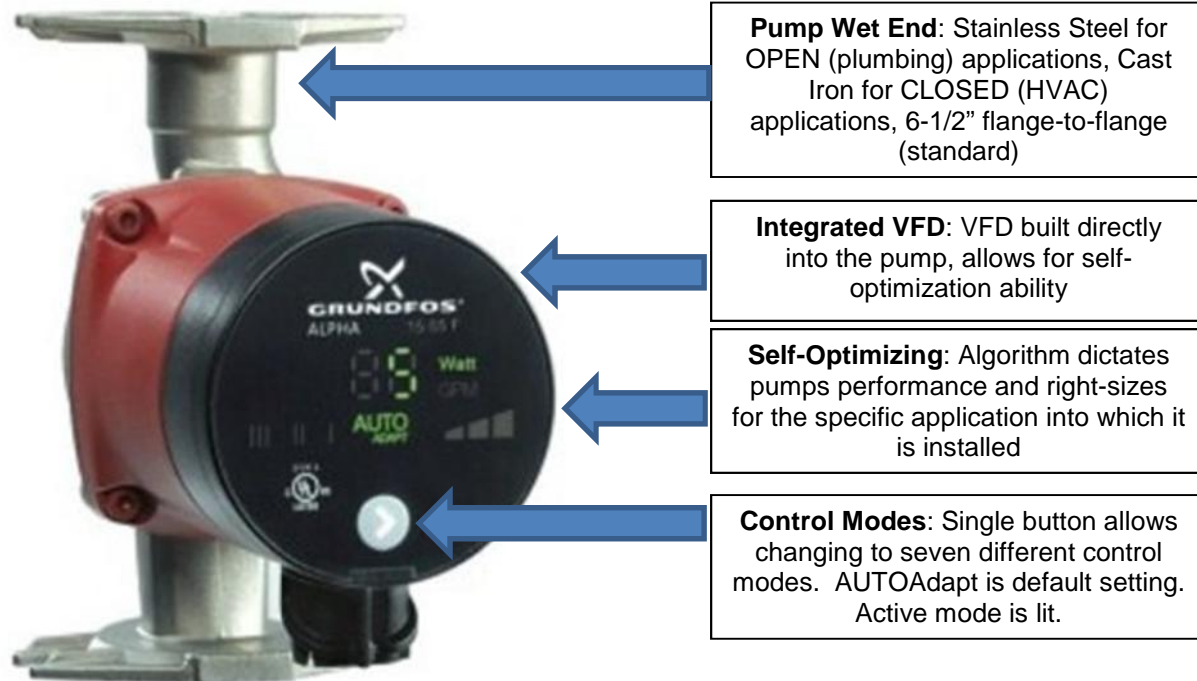
Figure R2.2. Component detail for measure case pump

Control Modes: The Grundfos Alpha offers seven different control modes: AUTOAdapt (self-optimizing, default setting), three fixed speeds (HI, MED, LOW) and three constant pressure (HI, MED, LOW). The Alpha is defaulted to operate in AUTOAdapt at start up and is the optimal control mode to optimize energy consumption. In the event of a power outage, the Alpha will restart in the control mode that was last utilized. The display on the Alpha alternates between a flow indication (in GPM) and current wattage consumption. The display will alternate between these two figures every four seconds.

UNITARY SOLUTION: The Grundfos Alpha is a unitary solution. This means that it is a "plug and pump solution". Out of the box, the Alpha has the wet end pump, integrated VFD and self –optimizing ability. There is no need for external equipment in order to gain energy savings.   Installation takes no additional time, expense or complication as compared to the current market standard.

3. California Circulator Wholesale Market Landscape Analysis

Table R3.1. California market landscape analysis based on Grundfos sales data and extrapolation to full CA market

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

Transformed Market Potential			Market Conversion Rate:	100%

Market Standard (Up to 25 Watts)		Efficient Option (Up to 25 Watts)		Market Standard (26 - 120 Watts)		Efficient Option (26 - 120 Watts)	
Qty Pumps Transacted:	0	Qty Pumps Transacted:	11,782	Qty Pumps Transacted:	0	Qty Pumps Transacted:	39,618
kWh:	0	kWh:	146,215	kWh:	0	kWh:	6,798,484

Transformed CA Market kWh: 146,215		Transformed CA Market kWh: 6,798,484	

Total Transformed CA Market kWh: 6,944,699

kWh Savings by Market Conversion Rate for 26-120 Watt Market			
25%: 3,634,549	16%	75%: 10,904,016	48%
50%: 7,269,098	32%	100%: 14,538,565	64%

High Performance Circulating Pumps (HPCP)   2/23/2017
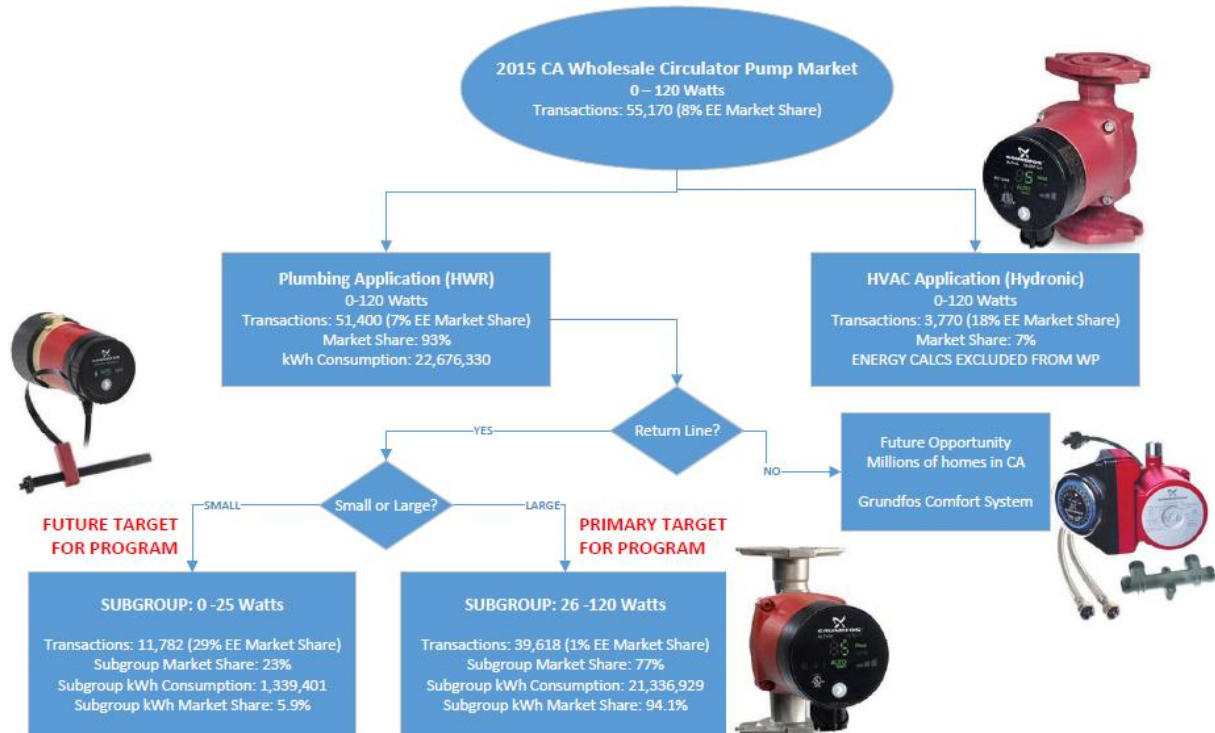
Figure R3.1. Circulator pump equipment breakdown across the market

4.   How is running wattage calculated?

Calculating running wattage for this class of fractional HP circulating pumps can be difficult as power and efficiency curves are often NOT published. This is especially the case for the market standard (inefficient) option. However, for the efficient option (measure case) Grundfos DOES publish the power and efficiency curves.

Market Standard:
For the purposes of the work paper, we included unpublished information on the wattage at the best efficiency point (BEP). Max wattage from nameplate is 87 Watts when running with 115 Volts and 97 Watts when operating at 230 Volts. The most common operation is considered to be 115 Volts and was utilized in the following calculation.

Table R4.1. Base case operating characteristics

Operation	GPM	TDH	Watts
Dead Head (Max Head)	0.0	9.7	80.4
BEP	10.0	5.0	84.2
Run Out (Max Flow)	19.4	0.7	85.8

In the hot water recirculation application, the selected pumps flow is sized based on maximum water consumption ("worst case scenario" – all taps open) and total dynamic head is calculated based on length and diameter of pipe, valves and fittings. In reality the pumps operation would be at very low flows the vast majority of its operating hours, this would result in an over production of head as the market standard pumps operating performance is set on its fixed speed pump curve. The result is that the actual power consumption may be a bit less than the estimate provided in this work paper, but Grundfos is assuming that the market standard is operating at its best efficiency point. The difference between actual wattage consumption and calculated running watts would be minimal (within 5%) but could be verified potentially through future M&V.

Efficient Option – Optimized Running Wattage:
The default and most efficient mode across all systems will be the AUTOAdapt control mode, which is a proportional pressure control scheme. This means that as flow decreases, head will also decrease. Knowing this we can estimate the (1) flow rate in GPM, (2) the head produced based on the proportional pressure operation and lastly (3) the running wattage.

1.   Assumed ½" return line on hot water return line to heat source, water traveling at 4 ft./ second velocity, **GPM would be 2.45**.
2.   Based on the operation of AutoAdapt, we can firmly estimate the proportional pressure curve on which the Alpha will operate. The total dynamic head **(TDH) will be 5.5'**.
3.   Because power and efficiency curves ARE published, we know that the Alpha consumes **12.1 Watts of power at 2.45 GPM @ 5.5' TDH**.

In reality, the pump may run at a lower flow as the pump continues to operate in and learn the system into which it is installed. So the "steady state" duty point and consumption may be less than what is estimated in this work paper. The minimal wattage consumption for the Alpha is 5 Watts so the "steady state" power consumption could be between 5 Watts and 12.1 Watts.

This optimized running wattage was initially carried through for the measure case wattage but was adjusted to carry the results from the Alpha field test results. The power draw was measured on a short timeline, an average of installation of only 7 days, and Grundfos believes this SS number will decrease over time as the AutoAdapt control scheme optimizes operation for the system it is installed in. Grundfos would like to revisit these values at a later date to confirm this assumption and update the carried measure case wattage.

5. Dept. of Energy Circulator Work Group Circulator Pump Running Hours

Table R5.1. Operating hour's breakdown across control types. Estimated market penetration.

Control Type	Sector	Fraction of Consumers	HPY	Notes
No Control	Residential	50%	8760	Constant Operation
	Commercial			
Timer	Residential	25%	7300	50% @ 24/7 & 50% @ 16hrs/day
	Commercial		6570	50% @ 24/7 & 50% @ 12hrs/day
Aquastat	Residential	20%	1095	3 hrs/day
	Commercial			
On Demand	Residential	5%	61	10 min/day[1]
	Commercial		122	20 min/day[1]

1 - Assuming that circulators operate for 30 seconds for each demand "push"
2 - Assuming operating hours do not vary by region

Running hours/ year of 6,427 is assumed in this work paper. Note that this is a weighted average of pumps that have no control, timer, aquastat, and On-Demand operation type. This is equally applicable to the measure and base case pump. While some pumps are shipped with onboard controllers many are installed as external pieces of equipment which can be installed with equal opportunity on the base and measure case.

6. CPUC Questions Submitted December 1, 2016

A. **Baseline determination**: What is the typical pump being replaced? The proposed savings are based on what may be a larger pump than is standard to use for single family residence (SFR) applications although it may be the larger selling item due to use in other applications. There should be some data on typical pumps in SFR installations currently as well as the current replacement market or NC market for recirculation DHW pumps in SFRs. This data should be used to develop a typical baseline kWh/hr of operation.

The scope of this workpaper includes SFRs as well as multi-family residences. While the two are thought of as different applications, in the scope of pump sizing and energy consumption there is no difference. All data called out in the workpaper is based on transactional history. From this transactional history we have established the market size as well as the pump defined as the market standard, UP 15-29 SU/LC which is the most commonly sold pump through the wholesale channel. While the nameplate wattage size is the majority of sales through the wholesale channel.

To corroborate these transactions, a field test was conducted as outlined in appendix 6. The results as they relate to the topic of existing pumps and baseline determination is outlined in the data below. However, the results should first be qualified that these customers volunteered to have the measure case pump installed at their residence. These retrofits were not initiated by the customer and thus not all existing pumps would have been replaced had it not been for this free installation/incentive.

The nameplate power of the base case pump for this workpaper is 87 Watts. The survey results of the existing pumps found in the field test show a range of installed nameplate power with the vast majority of the existing pumps being in the same size range as the base case pump. Meaning that the carried base case pump model and power consumption is representative of the market. Even when considering that all of the replaced pumps may not have undergone replacement had they not been provided free installation of a free Alpha 15-55 pump.

Table R6A.1. Alpha field test existing pump nameplate wattage

Power (W)	Units
~25	1
~90	9
~180	2
~245	1

Table R6A.2. Alpha field test existing pump models

Model	Size (W)	Units
UP10-16	25	1
UP15-29	87	3
UP15-18	90	3
UP15-42	95	2
UP15-35	114	1
UP25-64	180	2
UPS26-99	245	1

B. **Hours of operation**: What are the typical hours of operation for SFR DHW recirculation pumps in CA SFRs? It does not look like data for CA homes was collected. Rather, the proposal is to

use typical hours that may not represent typical CA use. For instance, current popular pumps on the market have timers that people can set to operate hours they normally use DHW. The proposed measure technology does not seem to have that as a standard feature. Perhaps these are installed in homes where the pumps are turned off due to cost and they are using this to re-activate; perhaps they are used in homes with short operation hours scheduled and these now run 8760; or perhaps they are replacing pumps schedule to run 8760 or with timers set for 8760). The reality is some combination of these cases and perhaps other cases, and the typical savings cannot be established without good data on HOU in a representative sample of CA SFRs.

Grundfos and PG&E, with knowledge of the transactional activity know that a small number of pumps are sold into the California wholesale market with timers, and a similarly small number are sold with any type of temperature controls that would minimize the running hours per year. This means that the market standard pump would have a typical run time of 8,760 hrs/yr, or slightly lower. However, we realize that carrying this value would be challenging to justify. As a solution, PG&E has found a weighted average of runtime hours for circulating pumps in residential and hot water recirculation applications (see section 5 of the references of this workpaper). This weighted average takes into account those pumps with no operational logic, those controlled with timers and aquastats, and those pumps controlled "on-demand". The weighted average that was utilized in the DOE ASRAC federal negotiations, and the value we are carrying in this workpaper is 6,427 hours per year.

The Alpha field test conducted in response to these questions and outlined in appendix 6 collected controls data from existing pumps to verify this claim. However, the results should first be qualified that these customers volunteered to have the measure case pump installed at their residence. These retrofits were not initiated by the customer and thus not all existing pumps would have been replaced had it not been for this free installation/incentive. Meaning that some of the replaced pumps had not reached the end of their useful life and may offer more advanced controls than those that have reached the end of their EUL.

The field test data as it pertains to this question is shown in the tables below.

Table R6B.1. *Control types and operating hours found in existing pumps from the alpha field tests.*

Control Type	Units	% of Pumps Found	Operating Hours[1]
No Controls:	4	31%	8760
Timer w/ Hours:	3	23%	5645
Timer w/o Hours:	2	15%	8760
Aquastat:	4	31%	1095
On Demand:	0	0%	0

1 - As Aquastat operating hours are unknown. The ASRAC working group agreed upon number of 3 hrs/day or 1095 hrs/yr was carried

Table R6B.2. *Weighted average operating hours from field survey compared with carried value.*

Source	Weighted Operating Hours (hrs/yr)
Field Survey:	5,683
DOE ASRAC Number Carried:	6,427
Variation:	**11.6%**

Considering these surveyed figures, the qualification of existing equipment not perfectly representing the ROB market, and the ASRAC working group values, we recommend moving forward with the DOE ASRAC carried number. This value is based on manufacturer, installer, and efficiency advocate input while reasonably representing the models found in the Alpha field test. Which can be considered to have, in general, been installed more recently than ROB products with more advanced technology and controls.

Both the measure and base case pump are carrying the same HOU at 6427 hrs/yr as they are equally as likely to have external controls (a timer or aquastat) installed.

C.   **What is the instantaneous and sustained kW demand?** Primarily compared to the steady-state operation. Does the kW increase or decrease when there is an instant or sustained demand for hot water?

To address this question the measure case pump field test was deployed as outlined in Appendix 6. The results of this field test as it applies to this questions are noted in the table below.

To preface, based on the operation of the AutoAdapt control system and typical installation practices we would expect the instantaneous & sustained flow and power demand to be lower than the SS flow and power demand. The base and measure case circulator pumps are intended to be installed near the water heater on the dedicated hot water return line. Because of this location, the water draw from an open tap is seen upstream of the pump. Meaning that at the instantaneous moment of water demand, the flow to the circulator pump decreases as water is being drawn from the system and more water is being pulled from the water heater. For this reason we believe in a properly installed system, the instantaneous and sustained power draw should decrease compared to the steady state operation.

Table R6B.2. *Alpha field results for steady-state (SS), instantaneous water demand, and sustained water demand.*

		Power Demand			Flow		
	# of units	Avg SS (W)[1]	Avg Instant %	Avg Sustained %	Avg SS (GPM)	Avg Instant %	Avg Sustained %
Number of residences where flow and demand **decreased** with instant and sustained water demand	8	25.1	-24%	-29%	2.9	-33%	-67%
Number of residences where flow and demand **increased** with instant and sustained water demand	4	32.3	10%	26%	7.3	38%	72%
Mix of increase and decrease	1	17.0	-12%	6%	4.0	-25%	0%
Weighted Average		26.7	-10.7%	-6.9%	4.0	1.8%	7.1%

1 - SS power demand will continue to decrease as the pump continues to find the most efficiency proportional pressure curve for the system
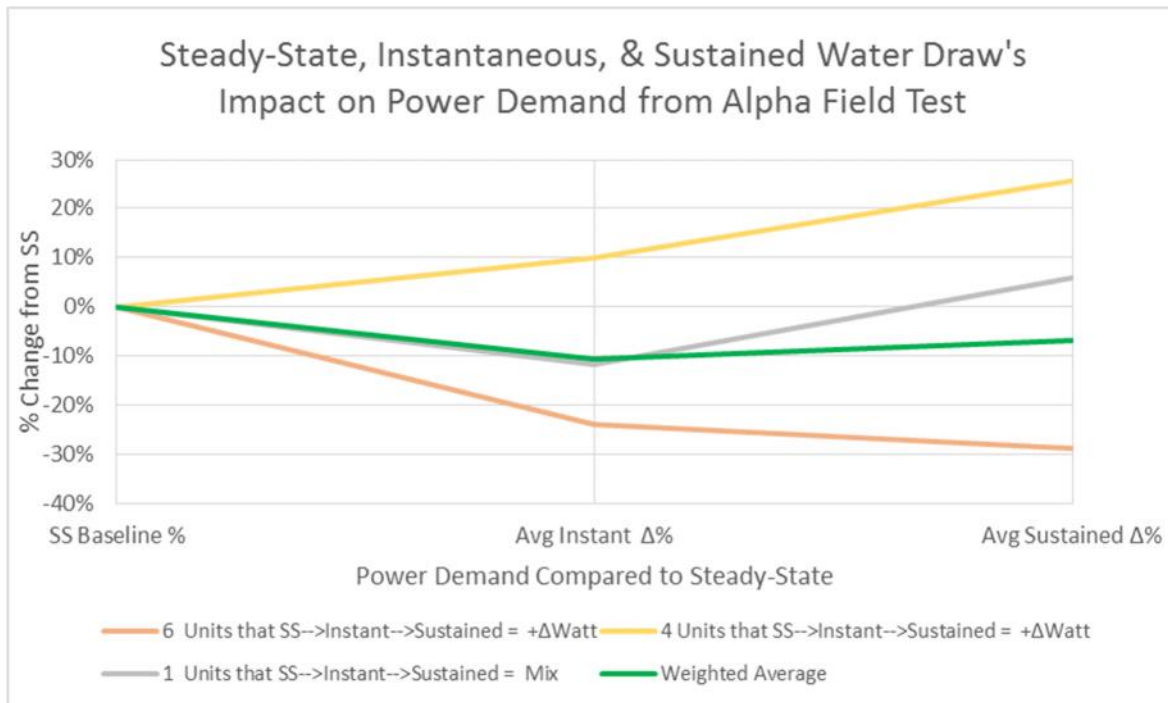Note: Negative   % represent a decrease in flow or power demand

Figure R6B.1. *Alpha field results for steady-state (SS), instantaneous water demand, and sustained water demand.*

First, to address the average SS wattage noted. The results are based on limited operation time from installation to SS, instantaneous, and sustained water demand measurements. On average just over 7 days. The result of this limited operation is that the pump has not necessarily had time to adequately adapt to the system in which they are installed. The AutoAdapt control system reacts to the maximum flow requirement to set the appropriate proportional pressure control curve. In SS operation the operating point on this curve falls to a minimum power demand by lowering the system to the minimum flow and head operating points.

In short, the AutoAdapt system finds lower (with lower slopes) proportional pressure curves by recognizing the maximum required flow and adjusting accordingly. Over the length of installation the Alpha pump is more likely to see the maximum flow for the system and thus find the lowest SS operating point. For this reason, we believe that given more installation time we would see the SS wattage decrease. This comment will be followed up on by the author of this workpaper.

However, in the practice of holding field trial results to a higher standard than calculated values we are moving forward with the higher average found wattage of 26.7 until field data shows the expected lower wattage from longer installation.

Second, the SS power versus the instantaneous and sustained power demand: It can be seen from table R6B.2. and figure R6B.1. that while the majority of pumps operated as expected, four operated in an opposite manner (while one pump landed in the middle, possibly due to rounding errors as the power went up by 1 Watt on a measurement system that rounds to whole numbers). The reason for this abnormal behavior in these four pumps is being investigated further. All four were installed by the same installing company and contractor. It is possible that the pumps were installed in an inconsistent manner than with traditional installations as previously noted. The lead installer with this company is planning on returning to these sites to verify correct installation and to understand the difference between these installations and installations where the change in power decreased when moving from SS to sustained water draw. However, due to tight timelines in this field test, we were not able to include these follow up results in the workpaper.

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The follow up results will be amended after these four SFRs have been investigated.

However, if it is found that everything was installed properly, it is still suggested that the sustained and instant water demand would not have a negative impact on savings estimates.

*This is justified by taking the average change in power during SS, instantaneous, & sustained water draw and comparing these values. I.e. assuming that if in some installations the power consumption will increase and some it will decrease during sustained water draw, what is the average across all installation? Table R6B.2. and Figure R6B.1. show that accounting for all of the field tested pumps, the sustained power demand **decreased** from SS to instantaneous and sustained water draw. With this reference point, the proposal of carrying a constant value for all hours of operation is conservative as during hours of sustained water draw the power is lower.*

D.   **Useful life:** what is the EUL of the new unit and the replaced equipment, so we have an RUL of the replaced unit if needed.

Grundfos is carrying a 15 year EUL in this workpaper. This value is derived from the 2014 DEER database for commercial applications with EUL_ID "Motors-pump" for water loop pumps. The citation and link of which are listed on the At-a-Glance Summary at the introduction of this workpaper.

From Grundfos market and contractor knowledge, there is no reason that a residential and commercial installed circulator pump would have a difference in operation practice and effective useful life. If anything, a circulator pump would have a higher usage rate in commercial applications where, in theory, there are more users and activation points (e.g., faucets, showers, bathrooms). Meaning that the 15 year EUL is a conservative value to carry.

It is also mentioned in this workpaper that Efficiency Vermont carried an EUL of 20 years for the measure case pump (a similar ECM based pump) and 15 years for the base case pump in their HPCP program. Citations of which are listed in section 1.2.1. However, we agree to defer to the DEER represented value of 15 years for the base and measure case.

E.   **Measure type/Delivery/Rebate:** Is this planned as early retirement (ER) or normal replacement (NR/ROB) and what are the baseline values of the above parameters (HOU, delta watts) that correctly represent ER or NR/ROB (it may not make any difference if it is ER or ROB for baseline if the current typical replacement and install pumps are similar in performance, however this should be understood). If the measure is planned as ER is there a 2nd period savings and if so where does the difference in typical installed and typical replacement unit performance come from? Is the delivery to be upstream/midstream or downstream and what is the rebate/incentive amount; the delivery method may impact baseline assignment (if there are baseline differences).

The workpaper proposes a ROB (replace on burnout) incentive structure at an upstream (distributor) level. To this end, the incentive levels should bring the contractor incurred cost on par with the current market standard contractor incurred cost. Meaning a rebate of $105 to address the listed IMC.

We acknowledge that if incentives were more than the incremental cost by a significant percentage, the program would shift to an ER (early retirement) incentive structure. This is because the contractor is the decision maker on which pump is installed (the market standard or an efficient option), if the program were to have higher incentive levels the program could potentially become a source of revenue for contractors so they would actively find opportunities to install HPCPs versus a ROB incentive structure where the contractors only replaces when opportunities arise. At this point in time, we do not see the need for an ER incentive structure but it may be a future opportunity.

F.   **Net-to-gross:** Clarify the proposed NTG. Past and post-rebate sales data need to be collected/provided to support the proposed NTG. Provide data along with the period over which the data was collected. We are interested in sales data to support baseline sales determination and post rebate sales data to determine program lift and support NTG.

Unfortunately, Grundfos is unable to provide raw sales data in this workpaper as they operate in a competitive business. However, we can use some extrapolated data to justify the proposed NTG value of 0.875.

There are two main factors in establishing the net-to-gross value: the free ridership and program potential to influence sales. We used two different sources of sales data to determine these impacts.

First, Grundfos market knowledge and market sales information for 2014 & 2015 allowed us to break down sales for open loop circulators in the 26-120W nameplate range and identify the annual growth rate for the HPCP market. Effectively showing the natural growth sales of these products as growing at a rate of 46.6% over these two years. We can carry this annual growth rate value to determine expected natural HPCP sales in future years. The sales figures represent the amount of customers who would purchase a HPCP without a program in place, i.e., the free ridership potential.

Second, we can review the sales impact of a similar HPCP upstream model from Efficiency Vermont. As shown in table R6F.2., the annual growth rate from the year prior to program implementation grew by 1,167% to the annual sales of the 1st year post-program implementation. This success continued to the 2nd year of the program with a 28% increase of annual sales of HPCPs. We can carry this percentage increase to the California market to determine the total sales from implementing a HPCP program for the two years after program implementation. By including the natural market annual growth rate we can break apart overall sales after program implementation into those from free riders and those who relied upon the program to influence their decision.

Table R6F.1. Base case operating characteristics

	Pre-Program	1st Year Post-Program Implementation			2nd Year Post-Program Implementation			
	HPCP Sales[2]	HPCP Sales[2]	Annual Growth Rate[3]	Natural Market Sales	Program Influenced Sales	HPCP Sales[4]	Annual Growth Rate[3]	Natural Market Sales	Program Influenced Sales
Efficiency Vermont HPCP 2013 2015:	300	3,800	1167%			4,874	28%		
California HPCP 2015 2017:	277	3,509	1167%	406	3,103	4,501	28%	595	3,906

2 - Efficiency Vermont 2014 Annual Report - https://www.efficiencyvermont.com/Media/Default/docs/plans-reports-highlights/2014/efficiency-vermont-annual-report-2014.pdf
3 - Assuming identical annual growth rate from Efficiency Vermont and the CA market
4 - *Swimming to Midstream: New Residential HVAC Program Model.* Bickel Et al. 2016 ACEEE Summer Study on Energy Efficiency in Buildings

Working with the ~359 kWh/year annual savings per HPCP we arrive at a net-to-gross value of 0.875.

Table R6F.3. Base case operating characteristics

	Projected 2016	Projected 2017	Totals
Net Potential Savings (kWh Saving/Year):	1,146,691	1,443,472	2,590,163
Gross Potential Savings (kWh Saving/Year):	1,296,760	1,663,356	2,960,116
NTG[5]:	0.884	0.868	**0.875**

5 - Calculations assume natural HPCP market growth continues at 2014-2015 rates & HPCP sales increase by same % as Efficiency Vermont HPCP

Some assumptions that are carried through this methodology:
- *The 2014-2015 Grundfosales data represent an accurate portrayal of the market moving forward. I.e. 46.6% growth rate for HPCP is representative moving forward.*
- *That the Efficiency Vermont HPCP program sales figures and growth, which focuses on the hydronic heating application, is applicable to the California market.*