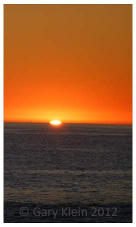
DOCKETED	
Docket Number:	24-BSTD-01
Project Title:	2025 Energy Code Rulemaking
TN #:	256524
Document Title:	Gary Klein and Associates, Inc Comments - Comments on Consumer Product Heat Pump Water Heaters
Description:	N/A
Filer:	System
Organization:	Gary Klein and Associates, Inc.
Submitter Role:	Public
Submission Date:	5/22/2024 10:52:55 PM
Docketed Date:	5/23/2024

Comment Received From: Gary Klein and Associates, Inc.
Submitted On: 5/22/2024
Docket Number: 24-BSTD-01

Comments on Consumer Product Heat Pump Water Heaters

Additional submitted attachment is included below.



Gary Klein and Associates, Inc.

11891 Autumn Sunset Way, Suite A
Rancho Cordova, CA 95742

Telephone: 916-549-7080
Email: Gary@GaryKleinAssociates.com

On behalf of Gary Klein and Associates, Inc. I am pleased to provide these comments on the code change provisions related to consumer product integrated heat pump water heaters. Please reach out to me at the contact information above if you have any questions. Thank you for this opportunity.

Sincerely, Gary Klein

Air Source Heat Pump Water Heaters

1. Consumer Product HPWH. The efficiency of these heat pump water heaters is determined in accordance with the DOE test procedure which results in a UEF. Based on the method of testing, they are intended for installation inside conditioned space.
    a. Hybrid Air-Source Integrated HPWH (I_HPWH-Hybrid). The heat pump is integrated into the unitary water heater, usually above the storage tank. There are electric resistance elements in the storage tank. The controls allow for heat pump only, heat pump and electric resistance, and electric resistance only.
    b. Air-Source Integrated HPWH (I_HPWH). The heat pump is integrated into the unitary water heater, usually above the storage tank. There are no electric resistance elements in the storage tank. The controls only allow for heat pump operation.
2. Air-Source HPWH Split (HPWH_S). The condenser and the evaporator are installed in separate locations. Refrigerant provides the energy transfer to the storage tank.
3. Air-Source HPWH Decoupled (HPWH_D). The condenser and the evaporator are installed in the same location (sometimes called monobloc). Water, with and without antifreeze, provides the energy transfer to the storage tank.

Provisions will need to be written into code for all these types. This discussion will focus on the first two types.

Outline

1. Daily Hot Water Use
2. Room Size for Consumer Product Integrated HPWH
3. Comparisons to Gas and Electric Water Heater Recovery Times
4. Uniform Energy Factor (UEF)
5. Ventilation
6. Backup Heat
7. Rapidly Evolving Product Offerings
8. Consumer Product Integrated HPWH Ready
9. Meeting Decarbonization Goals

1. **Daily Hot Water Use**
    a. How many gallons per day varies widely, both within and among households. It could be as little as 10 gallons per day or more than 200 gallons per day.
    b. Since the amount of hot water needed each day is unknown, HPWH need to be installed so that they can produce hot water 24 hours a day, <u>in heat pump mode</u>. Assuming that the currently available units have 4,000 BTU/hour heat pumps, in 24 hours they can provide 96,000 BTU. This is more than 160 gallons at a 70F temperature rise and almost 130 gallons at a 90F temperature rise. See Table 1.
    c. HPWH with larger compressors can heat more water; the amount is proportional to the capacity. An 8,000 BTU/hour compressor (LG) can heat twice as much water per day. A 12,000 BTU/hour compressor (Rheem 120 VAC) can heat three times as much. A 16,000 BTU/hour compressor (not yet available in a unitary HPWH) would have the same recovery time as a 4,500-watt resistance element in a 240 VAC electric resistance water heater.

Table 1. Energy Needed for Heating Water

	BTU/Day		
	Temperature Rise (F)		
Gallons per Day	**70**	**80**	**90**
10	5,831	6,664	7,497
20	11,662	13,328	14,994
30	17,493	19,992	22,491
40	23,324	26,656	29,988
50	29,155	33,320	37,485
60	34,986	39,984	44,982
70	40,817	46,648	52,479
80	46,648	53,312	59,976
90	52,479	59,976	67,473
100	58,310	66,640	74,970
110	64,141	73,304	82,467
120	69,972	79,968	89,964
130	75,803	86,632	97,461
140	81,634	93,296	104,958
150	87,465	99,960	112,455
160	93,296	106,624	119,952
170	99,127	113,288	127,449
180	104,958	119,952	134,946
190	110,789	126,616	142,443
200	116,620	133,280	149,940

The values in the table are based on the equation:

Q (BTU) = m*cp*delta-T = 8.33* gallons*1*(Thot-Tcold)

They do not include anything for the efficiency of how the water is heated. They represent the minimum energy needed for the task. Everything is proportional to volume and delta-T.

2. **Room Size for Consumer Product Integrated HPWH**
    a. Unless the thermal resistance of the walls, floor and ceiling of the space surrounding a consumer product HPWH is R-2 or less, there is no size of small room that can get enough energy due solely to conduction to provide the energy needed for a 4,000 BTU/hour unit to operate as a heat pump 24 hours a day. The problem gets worse as the heat pump capacity gets larger.
        i. An R-2 enclosure is the equivalent of 1 inch of wood with stationary air films on both sides. Not a typical construction detail.
        ii. An R-4 enclosure is what can be expected from 2x4 framing with sheet rock on both sides.
        iii. An R-10 enclosure is the same construction with insulation between the framing members.
    b. The temperature drop across the enclosed space must always be going into the room. Another way of saying this that the room with the heat pump only gains energy when it is colder that space that surrounds it.
        i. Consumer integrated HPWHs are intended to use conditioned air. In a 1-story dwelling the ceiling of the room will be insulated to at least R-30. If one of the walls is an exterior wall, that will be insulated to at least R-20. The floor may be insulated to R-20 or more.
        ii. A room in the middle of the dwelling with a floor above and a conditioned basement below would be the best case for heat transfer into the room. Otherwise, more energy needs to come through the surfaces that are less well insulated.
        iii. If these water heaters are installed in a garage they are exposed to outdoor conditions. They are not getting conditioned air at relatively stable and warm temperatures. Sometimes the temperature in the garage will be very warm, sometimes it will be very cold. And, the heat flow from outside will not always be into the garage.
    c. Only a portion of the energy comes from the air, the rest comes from the heat pump. How much is the air's contribution?
        i. Assumptions
            1. 400-watt compressor and fan = 1,365 BTU/hour
            2. COP = 3 (roughly true for 68-70F intake air)
            3. 1,365 x 3 = 4,094 BTU/hour
            4. Energy supplied by the air = 4,094 – 1,365 = 2,730 BTU/hour
        ii. As the COP goes down, the air contributes less energy.
        iii. Unless the energy coming into the room via conduction is at least 2,730 BTU/hour, the water heater cannot run in heat pump mode continuously with a high COP.
            1. If continuous operation is not possible, the room will cool down, lowering both the COP and the heat output if the HPWH, which means it will take longer to recover.
            2. Eventually the heat pump mode will stop, and the room will take time to recover the heat that has been extracted.

   a. The ASR studies have shown that it takes at least 1 hour to recover for every 2 hours of heat pump operation. This means that the HPWH is limited to 16 hours a day.
3. Limiting access to new warm air limits the gallons per day that can be heated by the HPWH.
   a. Let's look at an R-4, 450 cubic foot enclosure. Assumptions:
      i. Ambient air temperature outside the enclosure is 70F. Same inside the enclosure at the start of an event.
      ii. Assume there is a 20F delta-T into the room while the HPWH is running. This means that 1,783 BTU will come into the room every hour.
      iii. For 16 hours of operation this will bring 28,528 BTU into the space. This energy will be extracted from the air by the HPWH.
      iv. Over the same time, the compressor will add 16 x 1,365 BTU/hour = 21,840 BTU
      v. Total is 50,368 BTU. About 95 gallons per day. Any additional hot water needs to be heated using resistance heating.
   b. What about an R-10, 450 cubic foot enclosure? Assumptions:
      i. Ambient air temperature outside the enclosure is 70F. Same inside the enclosure at the start of an event.
      ii. Assume there is a 20F delta-T into the room while the HPWH is running. This means that 770 BTU will come into the room every hour.
      iii. For 16 hours of operation this will bring 12,320 BTU into the space. This energy will be extracted from the air by the HPWH.
      iv. Over the same time, the compressor will add 16 x 1,365 BTU/hour = 21,840 BTU
      v. Total is 34,160 BTU. About 59 gallons per day. Any additional hot water needs to be heated using resistance heating.
   c. Which is the more likely enclosure? It doesn't matter, both levels of insulation limit the amount of hot water made by the heat pump.
   d. 59-95 gallons per day may sound like a lot of hot water. But we do not know how much hot water is needed by the occupants.

d. These three tables tell the story. The green highlights show the conditions where there is enough heat coming through the enclosure to support the air flow requirements of a nominal 4,000 BTU/hour HPWH.
   i. With R-2, even a 250 cubic foot enclosure can get enough energy through conduction to run a 4,000 BTU/hour HPWH continuously, but it must maintain a high delta-T to do so. This means that it can produce 96,000 BTU over the course of the day and heat more than 160 gallons with a 70F temperature rise.
   ii. With R-4, the enclosure needs to be at least 500 cubic feet, again only if a high delta-T is maintained.
   iii. With R-10, no enclosure 1,000 cubic feet or smaller can get enough energy through conduction to run a 4,000 BTU/hour HPWH continuously.

Table 2			R-2, U-0.5					
HPWH Location (8 foot tall spaces)			Hourly energy into the space due to conduction (BTU/Hour)					
Area	Volume	Surface Area	Temperature Difference Across the Envelope (F)					
Square Feet	Cubic Feet	Square Feet	5	10	15	20	25	30
16	125	161	403	806	1,209	1,613	2,016	2,419
31	250	243	606	1,213	1,819	2,425	3,031	3,638
56	450	357	891	1,783	2,674	3,565	4,456	5,348
63	500	385	963	1,925	2,888	3,850	4,813	5,775
88	700	487	1,218	2,435	3,653	4,870	6,088	7,305
125	1,000	610	1,525	3,050	4,575	6,100	7,625	9,150

Table 3			R-4, U-0.25					
HPWH Location (8 foot tall spaces)			Hourly energy into the space due to conduction (BTU/Hour)					
Area	Volume	Surface Area	Temperature Difference Across the Envelope (F)					
Square Feet	Cubic Feet	Square Feet	5	10	15	20	25	30
16	125	161	202	403	605	806	1,008	1,209
31	250	243	303	606	909	1,213	1,516	1,819
56	450	357	446	891	1,337	1,783	2,228	2,674
63	500	385	481	963	1,444	1,925	2,406	2,888
88	700	487	609	1,218	1,826	2,435	3,044	3,653
125	1,000	610	763	1,525	2,288	3,050	3,813	4,575

Table 4			R-10, U-0.1					
HPWH Location (8 foot tall spaces)			Hourly energy into the space due to conduction (BTU/Hour)					
Area	Volume	Surface Area	Temperature Difference Across the Envelope (F)					
Square Feet	Cubic Feet	Square Feet	5	10	15	20	25	30
16	125	161	81	161	242	323	403	484
31	250	243	121	243	364	485	606	728
56	450	357	178	357	535	713	891	1,070
63	500	385	193	385	578	770	963	1,155
88	700	487	244	487	731	974	1,218	1,461
125	1,000	610	305	610	915	1,220	1,525	1,830

3. Comparisons to Gas and Electric Water Heater Recovery Times

a. People's perceptions of water heaters are based on the type of water heater they currently have. More than 90 percent of the installed base of residential scale water heaters are either 40,000 BTU/hour atmospheric gas or 4,500-watt 240 VAC electric resistance water heaters.
b. It takes just under 30,000 BTU to heat 50 gallons of water 70 F above the starting cold-water temperature. It takes an atmospheric gas water heater about 1 hour to reheat this amount of water. It takes a 4,500-watt resistance element in a 240 VAC electric resistance water heater about 2 hours to accomplish this. It takes a 4,000 BTU/hour I_HPWH-HYBRID or I_HPWH 7-8 hours to do the same work. See Table 5.
c. A 16,000 BTU/hour compressor (not yet available in a unitary HPWH) would have the same recovery time as a 4,500-watt resistance element in a 240 VAC electric resistance water heater.
d. A 30,000 BTU/hour compressor (not yet available in a unitary HPWH) would have the same recovery time as a 40,000 BTU/hour burner in an atmospheric gas water heater.
e. People want faster recovery times. We should be making sure the spaces we install HPWH can handle the ventilation requirements of these larger capacity units.

Table 5. Energy Output for Water Heaters of Different Capacities

		Energy into the Water (BTU)							
		Hours per Day							
Type of Water Heater	BTU per Hour	1	2	4	8	12	16	20	24
Natural Gas or Propane: 40,000 BTU/hr burner @ 75% thermal efficiency	30,000	30,000	60,000	120,000	240,000	360,000	480,000	600,000	720,000
Electric Resistance: 4,500 watt element @240VAC	15,354	15,354	30,708	61,416	122,832	184,248	245,664	307,080	368,496
AS-HPWH	2,000	2,000	4,000	8,000	16,000	24,000	32,000	40,000	48,000
	4,000	4,000	8,000	16,000	32,000	48,000	64,000	80,000	96,000
	6,000	6,000	12,000	24,000	48,000	72,000	96,000	120,000	144,000
	8,000	8,000	16,000	32,000	64,000	96,000	128,000	160,000	192,000
	10,000	10,000	20,000	40,000	80,000	120,000	160,000	200,000	240,000
	12,000	12,000	24,000	48,000	96,000	144,000	192,000	240,000	288,000
	14,000	14,000	28,000	56,000	112,000	168,000	224,000	280,000	336,000
	16,000	16,000	32,000	64,000	128,000	192,000	256,000	320,000	384,000
	18,000	18,000	36,000	72,000	144,000	216,000	288,000	360,000	432,000
	20,000	20,000	40,000	80,000	160,000	240,000	320,000	400,000	480,000
	22,000	22,000	44,000	88,000	176,000	264,000	352,000	440,000	528,000
	24,000	24,000	48,000	96,000	192,000	288,000	384,000	480,000	576,000
	26,000	26,000	52,000	104,000	208,000	312,000	416,000	520,000	624,000
	28,000	28,000	56,000	112,000	224,000	336,000	448,000	560,000	672,000
	30,000	30,000	60,000	120,000	240,000	360,000	480,000	600,000	720,000

4. **Uniform Energy Factor (UEF)**
    a. The UEF of the consumer product HPWH sold in the US market today are based on a test condition of 68F incoming air. In addition, the cold discharge air is removed from the vicinity of the unit during the testing. Under these conditions, both the UEF and the COP are generally above 3.0.
    b. Based on testing conducted in the Amazing Shrinking Room (ASR) studies, and from field tests in the San Joaquin Valley where the I_HPWH-HYBRID units were installed in garages, when the inlet air temperatures are warmer, the COP can get much higher. Conversely, when the intake air temperatures get colder, the COP can get much lower. As the air temperature approaches the cut-out temperature of the I_HPWH-HYBRID, generally around 40F, the COP of the heat pump is less than 1.5.
    c. It is essential that the I_HPWH-HYBRID and I_HPWH with UEFs tested as described above get intake air from conditioned space or warmer temperatures. At the same time, the cold air they discharge must be moved away from the unit immediately.
    d. The I_HPWH-HYBRID and I_HPWH sold today will perform best if they utilize conditioned air above 68F. This means installation inside conditioned space or using ventilation to access conditioned air. If there is a source of much warmer air, such as a server room, a lighting controls closet or commercial scale refrigeration, they will have even higher COPs. It may make sense to use external fans and ductwork to move the air to and from the location of the unitary HPWH. Much less electricity than resistance elements!

5. **Ventilation**
    a. We don't limit the amount of gas going into gas water heaters, or the electricity going into electric resistance water heaters. Why are we limiting access to the "warm air fuel" needed by I_HPWH-HYBRID and I_HPWH.
    b. Air source heat pump water heaters need access to "warm" air and the ability to discharge "cold" air away from the heat pump.
    c. They need both conditions to be true 24 hours a day so that they can make as much hot water as needed each day. Limiting access to the needed thermal resource limits the amount of hot water that can be made each day in heat pump mode. This increases electric consumption and associated bills.
    d. Consumers listen to the advertisements and are expecting their HPWH to be 3 times more efficient than electric resistance water heaters. And have correspondingly lower costs to operate. These lower costs are needed so that water heating costs aren't significantly different than those for the gas water heaters they are used to.
    e. The majority of the consumer product I_HPWH that have been installed to date in the US have axial fans. These have a very limited ability to overcome friction losses in ductwork. These I_HPWH work best in open spaces provide with enough conditioned air. When installed in enclosed spaces, they need access to conditioned air. This can be accomplished with passive ventilation split equally

between high and low openings, or with ducted ventilation, or a combination of both.

   i. Passive ventilation. Based on the results of the ASR testing, the net free area needs to be at least 75 square inches per kBTU of compressor capacity. For a 4 kBTU HPWH, this means 300 square inches, split equally between high and low penetrations.
   ii. Ducted ventilation is also possible. The fans on most of the existing HPWH are about 150-200 cfm. To keep the friction losses in the duct small, ducts need to be at least 8-inch diameter (or equivalent) per 4kBTU of compressor capacity. Because most units have axial fans, duct installations need to be very short, with large radius elbows, otherwise a duct booster fan is needed to maintain proper air flow.
   iii. Ventilation needs to account for all HPWH installed in a given space.

f. It is possible to install through-the-wall fans or inline fans in ducts to assist the removal of cold air from the space where the I_HPWH has been installed. The cold air needs to be discharged so that it isn't perceived of as "too cold". Some installations have connected the exhaust to the return for the space conditioning system, allowing that fan to spread the cold air around the entire building, diluting its impact with the rest of the return air.

g. What is a square foot of space worth to a builder?
   i. Assume it is worth least $300 per square foot.
   ii. Assume that a HPWH needs at least 16 square feet. A 450 cubic foot room is 56 square feet. The difference, 40 square feet, is worth at least $12,000.
   iii. Why not spend, say 10 percent of this on properly installed passive or ducted ventilation, and put the rest of the space to some better use?

6. Backup Heat

a. Unless there is a guaranteed access to conditioned air, or warmer, most of the I_HPWH-HYBRID and I_HPWH need to have some form of backup heating. The reason is that the heat pumps get much less efficient as the intake air temperature drops toward the cut-out temperature of the compressor.
   i. The I_HPWH-HYBRID have resistance elements inside the storage tanks. I-HPWH need external backup heating.

b. Backup heat is required when I_HPWH-HYBRID and I_HPWH utilize unconditioned air or access to conditioned air is limited (such as in a sealed room, or in a room with limited ventilation).

c. However, backup heating is not needed when I_HPWH-HYBRID and I_HPWH are able to operate under "cold climate" conditions. Here are two ways of describing this capability:
   i. Backup heating is not required where the compressor cutout temperature is below 34.6F, (as found in the table of 'n-Year Return Period Values of Extreme Temperature' where n=5 years from 2021 ASHRAE Fundamentals Handbook) (Outside California)

ii. Backup heating is not required when the compressor cutout temperature is below the Winter Median of Extremes for the closest location listed in Table 2-3 from Reference Joint Appendix JA2. (Inside California)

f. As of this writing, AO Smith, Bradford White, Rheem, and Steibel-Eltron HPWH have cutout temperatures about 40F. This is not low enough for them to utilize unconditioned air in the winter or even to be installed in garages throughout most of California.
   i. Steibel-Eltron publishes a chart that shows a COP above 2.4 at the 42F cutout temperature.
   ii. The ASR tests show the AO Smith and Rheem units have COPs less than 2.0 at their cutout temperatures.

d. I_HPWH-HYBRID and I_HPWH have both lower and upper limits for their operation. High temperature cutouts limit their installation in garages and attics with high summer temperatures. None of the current units can be installed outdoors unless they are protected from the elements.

7. Rapidly Evolving Product Offerings

a. The vast majority of currently available HPWH have small compressors and axial fans. They also have side ports for water and air and clearances to the walls to allow for airflow.

b. However, some models now have water ports on the top (just like typical gas and electric water heaters) and others have centrifugal fans and intake and exhaust ports on the top of the tank, reducing side clearances to walls.

c. AO Smith has started using centrifugal fans in its I_HPWH. Rheem has a centrifugal fan on their 12,000 BTU/hour 120VAC I_HPWH. These fans are more capable of overcoming friction losses in ductwork. The duct diameter for this unit needs to be 10-inches. Since the centrifugal fans discharge the cold air, ducting the exhaust makes the most sense.

d. LG, Rheem, and Steibel-Eltron have unitary HPWH with 6,000-12,000 BTU/hour capacities.

e. Several companies are bringing residential scale cold-climate heat pumps for space conditioning to market with the ability to also make hot water. These units are split or decoupled technology: only the storage tank will be inside the building. Heating capacities for making hot water range from 24,000-60,000 BTU/hour, making them at least as fast as typical gas storage water heaters. And, since they are designed for cold climates, electric resistance backup will rarely be needed.

8. Consumer Product Integrated HPWH Ready

a. Given the rapidly evolving product offerings, it is difficult to predict what to reserve for a future consumer product I_HPWH. To better match consumers' expectations, future HPWH will likely have larger compressors that will need correspondingly larger ventilation. Some will be cold-climate rated and able to use unconditioned air.

b. I_HPWH-ready installations should be designed to accommodate a unit with a 16,000 BTU/hour compressor and provide the ventilation requirements for this future unit at the time of the first install, or make sure that the ability to increase the ventilation to this amount can easily be accomplished later. And, based on the current method of determining the UEFs, the thermal resource for the HPWH will come from conditioned air.
    i. This translates into 1,200 square inches of net free area for passive ventilation and 12-inch round duct (or equivalent) for ducted ventilation.
    ii. Where I_HPWH are installed at the time of construction, they should provide the same level of access to ventilation.

c. Please note that the volume of the space the HPWH is installed in makes much less difference than ensuring access to the warm thermal resource for the currently available units that are not “cold-climate” capable. The source of energy for the HPWH is coming from the space conditioning system.

d. When “cold-climate” unitary HPWH become available, then using unconditioned air as the thermal resource will make sense.

9. Meeting Decarbonization Goals

a. Public policy is pushing decarbonization of everything, including water heating.

b. UEFs for I_HPWH-HYBRID and I_HPWH are generally between 3 and 4. Public policy wants all HPWH to operate in heat pump mode: less electricity, less carbon.

c. While a COP of 2 is better than the existing COP of 1 for an electric resistance water heater or a COP of 0.75-0.95 for a gas water heater, it isn’t very good for a device that, under the conditions its UEF was determined has a COP of 3 or more.

d. People are expecting that their HPWH will operate with a high efficiency. The electric resistance backup will only be needed under exceptional circumstances. Not because of a sub-optimal installation that results in the use of the backup daily.

e. We need to ensure that installations allow for the HPWH to operate in heat pump mode 24 hours a day.