Ecotope, Inc.
1917 1st Avenue, Suite 300
Seattle, WA 98101
P: 206-322-3753
F: 206-325-7270

MEMORANDUM

To: Robert Weber, Engineering Technical Lead, Bonneville Power Administration

Keshmira McVey, Program Manager Emerging Technologies, Bonneville Power Administration

From: Adria Banks, Quantitative Analyst, Ecotope

Jon Heller, President, Ecotope

Subject: CHPWH System Coefficient of Performance – definition and calculation (Ecotope Task 29 – M&V Program and Database)

Date: March 1, 2022

Ecotope has collected Measurement & Verification (M&V) data on many of our commercial heat pump water heater (CHPWH) designs/installations as part of the Technology Innovation Model work with Bonneville Power Administration. Monitoring has proven these systems can perform substantially better than incumbent water-heating technologies while also providing invaluable insights into these emerging technologies and feedback for product improvements. Integral to these efforts, Ecotope has developed a method for assessing CHPWH system coefficient of performance (SysCOP) which provides a metric for the performance of the overall water heating system. This memo serves to summarize a standardized approach for describing CHPWH system efficiency from M&V monitoring and to suggest uniform methods and terminology for expressing SysCOP as the most relevant metric to reflect actual energy use for CHPWH systems, as well as its value for ongoing energy efficiency and electrification market transformation efforts aimed at moving the water heating market toward CHPWHs.

CHPWH System

CHPWH systems described in this memo conform with the Northwest Energy Efficiency Alliance's Advanced Water Heating Specification draft version 8.0. These systems:

- Serve more than four dwelling units or commercial loads needing more than a total of 120 gallons of storage volume and/or more than 6 kW of input power.
- Are comprised of the water heating equipment (for primary and temperature maintenance loads), storage tanks (for primary and temperature maintenance storage), recirculation or thermal distribution strategies, controls and sensors, and all the appurtenances necessary to have a fully functional system.
- Are often comprised of components from different manufacturers and can be configured several ways.

Having a standard methodology for describing their operational performance is key to ensuring that CHPWH systems can be successfully integrated into prescriptive energy codes and utility programs, and that anticipated savings are achieved.

Performance Metrics

Figure 1 shows several levels of performance that can be described and how SysCOP captures the system as a whole.

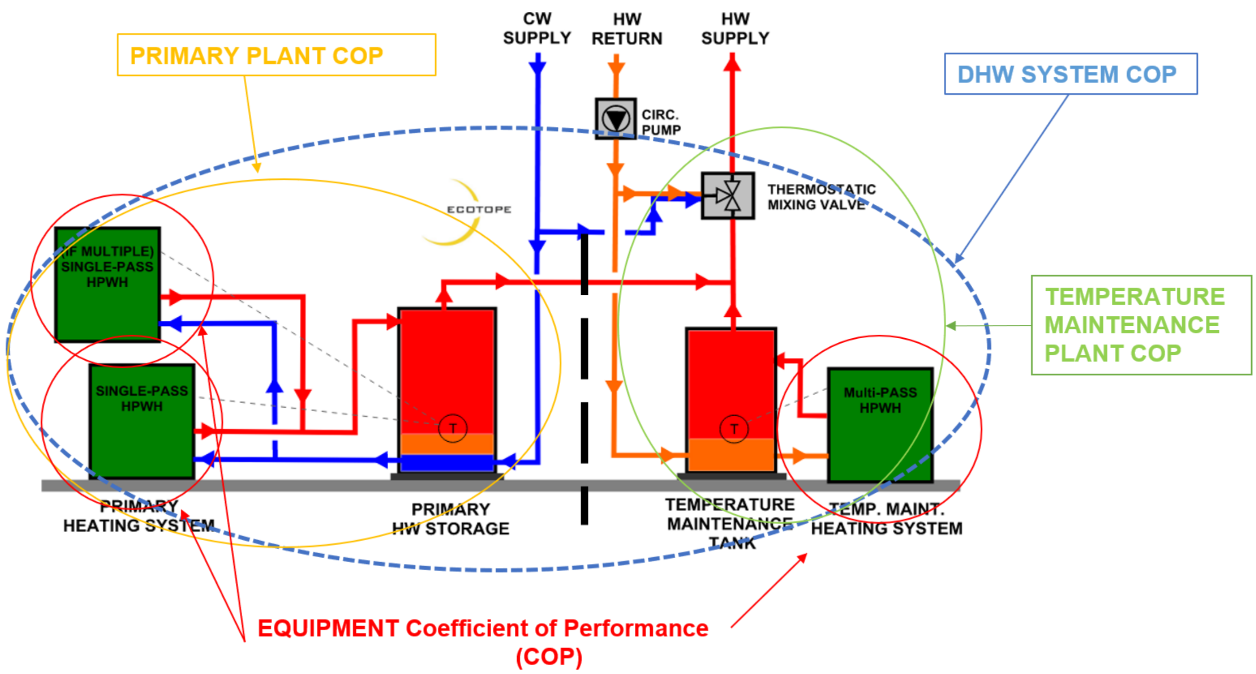

Figure 1. Schematic showing scope of different levels of performance metrics.

Equipment Performance

HPWH equipment performance is commonly reported through performance map testing, in which equipment is operated under set temperatures for entering air, as well as entering and leaving water. The measured output capacity under these specific conditions is divided by the power input to report equipment performance. This performance metric is helpful for understanding how a HPWH will perform under different ambient conditions, but the performance for an isolated piece of equipment is inadequate to describe the efficiency of a CHPWH system because it does not account for how all the components perform together, nor does it account for the expected actual conditions while operating.

Plant Performance

A CHPWH system will always have a primary heating plant and will often have a temperature maintenance plant. Temperature maintenance loads can typically be 30% of the domestic hot water (DHW) load in multifamily buildings, have a large impact on overall water heat energy, and should not be ignored. It's common for these plants to incorporate back-up heating systems (such as redundant HPWH capacity or electric resistance elements in storage tanks) in case the main water heating equipment needs to be serviced. As a result, the performance of these plants depends on tank stratification and the operation of the main heaters and back-up equipment (if any). These isolated segments of the system cannot capture all the water heat energy.

System Performance

SysCOP describes the average annual heat provided by the water heating system divided by the total amount of energy input. It captures all the outputs and inputs to the system and, thus, the total efficiency of the CHPWH system, which is the metric owners, utilities, and code jurisdictions are interested in. This is analogous to what is measured in an integrated residential HPWH, including the compressor, tanks, controls, and back-up electric resistance. Although in a CHPWH system these components may come from different manufacturers, they are functioning as a single water heating system. Calculating SysCOP allows systems of different configurations to be compared with a standard metric. Figure 2 shows the minimum data points needed to calculate SysCOP for a CHPWH system including a swing tank (and no back-up heaters for primary heating).

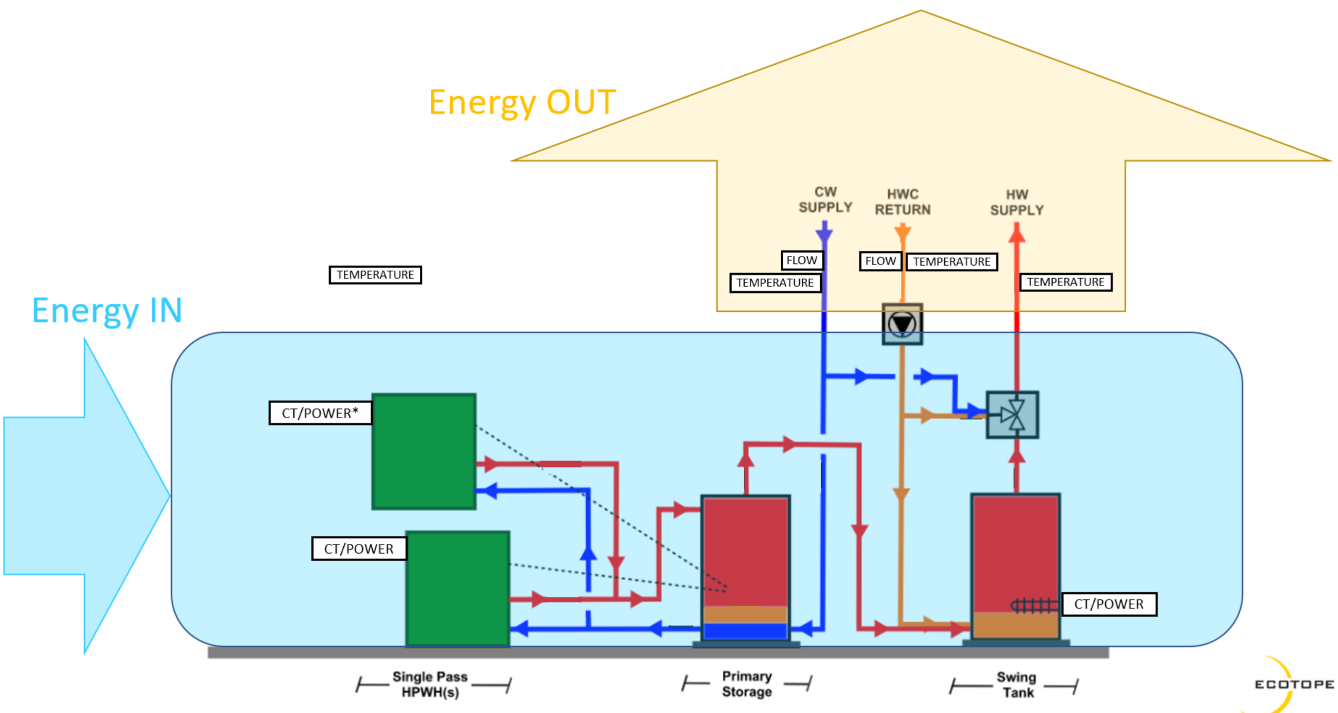

Figure 2. Schematic showing minimum data points needed to calculate SysCOP for an example CHPWH system. Current transducer and power meter(s) may be installed at the electrical panel assuming dedicated circuits exist to capture the needed inputs.

System Performance Calculation

As depicted in the schematic above, SysCOP captures all the thermal energy outputs and energy inputs and is calculated as:

$$\text{SysCOP} = \frac{Delivered_{Energy\,Out} + Recirculation\ Loss_{Energy\,Out}}{PHPWH_{EnergyIn} + TMH_{Energy\,In} + BUH_{Energy\,In} + Ancillary_{Energy\,In}}$$

Where:

- $Delivered_{Energy\,Out}$ = Energy content of the water delivered for use in the building
- $Recirculation\ Loss_{Energy\,Out}$ = Change in energy content of the water from the supply to the return side of the circulation loop
- PHPWH = Primary HPWH
- TMH = Temperature maintenance heater
- BUH = Backup heater(s) (if present)
- $Ancillary_{Energy\,In}$ = May differ depending on the system configuration. For example, it should include pumps needed to move storage water to water heating equipment. It is meant to capture all meaningful energy needed to produce hot water for delivery to the building.

These terms may also be expressed as the output capacity and input capacity as described in the following sections, which review the outputs in more detail.

Delivered Energy/Capacity

This calculation uses a flow meter on the cold-water make-up line, which is upstream of the pipe that brings cold water to the tempering valve. This measures all the domestic hot water flowing to the building. The temperature sensors on the cold-water line and on the hot water supplied to the building (i.e., recirculation loop supply) capture the change in temperature provided by the CHPWH system. Delivered energy is then:

$$Delivered_{Energy\,Out} = Flow_{cold} * Cp * (Temp_{Recirc\,Supply} - Temp_{cold})$$

Where Cp is the heat capacity of water (1Btu/lb F)

Recirculation Losses/Capacity

This calculation uses a flow meter on the return side of the recirculation loop and temperature sensors on the supply and return side of the loop. This captures the energy lost to the recirculation loop in the building. Although it is not useful energy at the tap, this is energy that needs to be made up by the CHPWH system. Recirculation losses is then:

$$Recirculation\ Loss_{Energy\ Out} = Flow_{Recirc\,Return} * Cp * (Temp_{Recirc\,Supply} - Temp_{Recirc\,Return})$$

Power Metering/Inputs

These measurements capture power and energy used by the water-heating system. This requires current transducers and (one or more) power meters, for all the main system components that consume electricity and without which hot water could not be delivered to the tempering valve. Converted to the same units as the outputs described above, their sum is the denominator in the SysCOP calculation.

Annual Performance

To calculate performance, all the outputs are summed and divided by the sum of the inputs. Instantaneous COPs can vary widely as there is commonly an offset between when the CHPWH system is charging the storage with hot water and when that hot water energy is used by building occupants. Typically, the COP calculation is performed daily (on daily sums) and there will be some variability day to day. To capture annual COP, monitoring is typically longer-term, and annual SysCOP calculated as an average of the daily metrics. Because ambient air conditions, entering water conditions, and hot water demand load profile change seasonally, M&V projects should either be of sufficient duration to capture winter, summer, and shoulder conditions or use appropriate estimation methods to account for this annual diversity in order to properly characterize annual system performance under field conditions.

Value of a Standardized SysCOP

CHPWHs can be two to three times more efficient than traditional electric and gas water heating equipment[1,2,3,4]. As these products permeate the mainstream market, they have the potential to be a powerful tool in energy efficiency programs nationwide. The aim is to have consistent methods and terminology so that standard performance metrics are comparable across equipment types and manufacturers. Real-world measured SysCOP will be critical to verify or to adjust modeled performance predictions, and/or to provide feedback to manufacturers or contractor training programs regarding where issues are being uncovered in the field. Standardization will ensure that findings are comparable across climate zones, system designs, and control strategies and will ensure that anticipated, reliable savings are achieved and that CHPWHs can be successfully integrated into prescriptive energy codes and utility programs.

---

[1] Heller, J. and Oram, S. 2015. *RCC Pilot Project: Multifamily Heat Pump Water Heaters in Below Grade Parking Garages in the Pacific Northwest.* Bonneville Power Administration Emerging Energy Efficient Technologies Program Final Report.

[2] Heller, J., Piepmeier, L., Larson, B., and Carew, N. 2018. *Multifamily Central Heat Pump Water Heating: Optimization and Energy Savings Persistence.* Bonneville Power Administration Emerging Energy Efficient Technologies Program Final Report.

[3] Banks, A., Grist, C. and Heller, J. 2020. CO2 *Heat Pump Water Heater Multifamily Retrofit: Seattle WA*. Bonneville Power Administration Emerging Energy Efficient Technologies Program Final Report.

[4] Spielman, S., Banks, A., Heller, J, and Townsend, H. 2021. *CO2 Heat Pump Water Heater Study: Hopeworks Station Place, Everett WA.* Bonneville Power Administration Emerging Energy Efficient Technologies Program Final Report.