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Appendix 6

General

The coefficients of performance (COP) for space heating, cooling, and water heating are generally all different. We've been using the "heat pump" block on the PE sheet in PHPP for the space heating and the "Other" block for heat pump water heating. (The COP for space cooling has its own line item near the bottom of the PE sheet in PHPP.)

Air-to-air heat pumps

Space heating

For the **annual coefficient of performance for space heating** we can use a climate-adjusted HSPF (heating season performance factor) divided by 3.412 (to convert from Btu per watt-hour to a dimensionless COP.)
According to the US Code of Federal Regulations (Title 10, volume 3, part 430, subpart B, Appendix M, paragraph 4.2) HSPF is supposed to be calculated for six climatic regions. However, compliance with energy conservation standards is based on "Region IV", and therefore this is the commonly reported value. (See Appendix for region map.)

For other regions (and perhaps as a general rule) the HSPF should be adjusted to the climate using the "heatcalc.xls" spreadsheet from the DOE, included here and downloadable at http://www.eia.doe.gov/neic/experts/heatcalc.xls.
The HSPF adjustor is at the bottom of the "calculator" tab. The adjustment is based on ASHRAE winter heating 99% dry bulb design temperatures. A few cities are listed in the calculator itself, many more can be found at http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/Outdoor_Design_Conditions_508.pdf?c2d1-2f00
(Follow the link to "HVAC Design Temperatures" on http://www.energystar.gov/index.cfm?c=bldrs_lenders_raters.nh_v2_v3_training_resources
As explained in the Technical Note on the "Efficiency Info" tab of the calculator, this is a rough adjustment. If detailed performance data is available from the manufacturer, covering the range of heating-season monthly average temperatures at the project site, then a heat-demand-weighted-average COP for the heating season may be calculated based on monthly average temperatures and monthly heat demands.
The **total system performance ratio of the heat generator** should be set to the reciprocal of the annual COP if it was derived from the adjusted HSPF According to the PHPP manual 2012, section 30.0, "the performance ratio differs from the reciprocal of the value of the annual coefficient of performance if peak-load coverage is available." However, an annual COP derived from HSPF already covers this (see Appendix.) If using a weighted-average COP calculation, make sure the energy input to any resistive heating elements is included. The included spreadsheet "Annual heat pump performance 2012-11-02.xlsx" assumes that there are either no resistive elements, or that the manufacturer data already includes their effect.

Space cooling

For the annual coefficient of performance for space cooling, we are for the time being, going by the average of EER (energy efficiency ratio) and SEER (seasonal energy efficiency ratio) divided by 3.412 (to convert from Btu per watt-hour to a dimensionless COP.) (The COP for space cooling has its own line item near the bottom of the PE sheet in PHPP.) This matter needs some further investigation - it appears that the SEER is an instance of a rating procedure that may suffice for relative rankings but not for accurate energy modeling.

Geothermal heat pumps

This category includes: DGX (direct geo-exchange) aka "ground loop heat pump", as well as water-to-air (closed loop and open loop) and water-to-water (closed and open loop).

We have not seen a lot of these used in passive house projects. For the time being we are going by the full-load COP (for heating) and EER (for cooling) as defined by Energy Star (AHRI 870 for DGX and AHRI/ISO/ASHRAE 13256-1 for water-to-air and 13256-2 for water-to-water.)

Integrated and complex systems

Nor have we seen much in the way of complex systems (desuperheaters, reverse-cycle chillers, ice storage, solar fraction of space heat). We have the capability to dynamically model such things if necessary.

Water heating

Heat pump water heaters outside the thermal envelope

The Energy Star ratings for Energy Factor (EF) which is basically a COP, are measured at 67.5 F ambient air temperature for all types of water heaters (per US Code of Federal Regulations, Title 10, section 430, subpart B, Appendix E.) However, the performance of heat pump water heaters declines with lower air temperature, and below 40 F most units switch over to electric resistance entirely. Thus, heat pump water heaters outside the thermal envelope need to be derated based on the climate. The included spreadsheet "HPWH outside & DHW pipe 2012-09-08.xlsx" calculates an annual COP assuming the EF varies linearly between its rated value at 67.5 F, and 1.0 at some given lower air temperature. That temperature is defaulted to 40 F but could be ascertained from a performance map test with the water temperature in the operating range of 90-120 F.
The spreadsheet also contains a handy DHW pipe length adder.
An Excel table of Energy Factors for Energy-Star-qualified heat pump water heaters can be downloaded from:
http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=WHH

Heat pump water heaters inside the thermal envelope

In a passive house, the space heating energy on an annual basis can be about the same or even less than the water heating energy. Therefore, a heat pump water heater inside can be a very significant negative internal heat gain. Currently, we take the view that a heat pump water heater inside does not increase the Annual Heat Demand for certification purposes, nor does it decrease the Annual Cooling Demand. Its effect on peak heating load and peak cooling load however, should be taken into account when sizing the heating and cooling systems. This is not done automatically in PHPP; it assumes the heat pump has an outside unit.

Also, *during the heating season, the heat drawn from the air by the water heater needs to be made up by the space heating system*. It is not getting any "free" heat during that time, so the effective COP needs to be derated. The impact is less if the space heating is being done by another heat pump.

Space heat by electric resistance

The simplest situation to figure is when the space heat is by electric resistance. Some limited dynamic modeling has indicated that on an annual basis the heat pump water heater inside effectively acts with a COP of 1.0 during the heating season, and at its rated EF for the rest of the time.

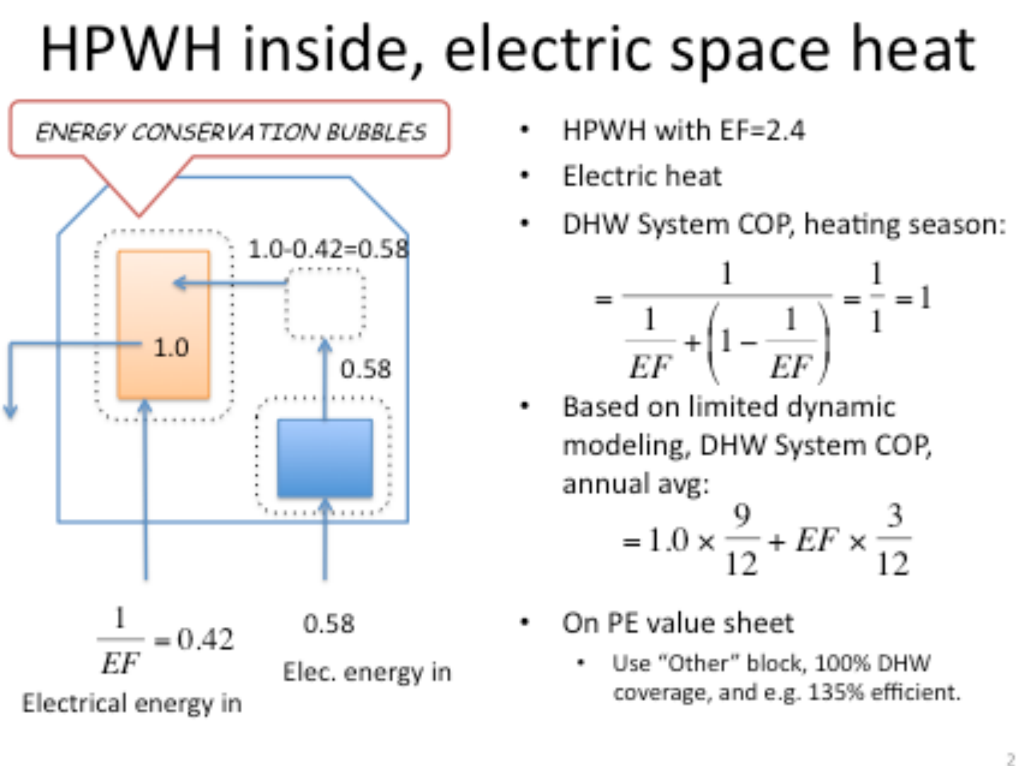

Figure 1. Primary energy representation for a heat-pump water heater inside, with electric space heat.

In a climate of 5300 heating degree days, the length of the heating season for this purpose was 8 months. Using a 9 month heating season will err on the conservative side in most places. In the example of Figure 1, a water heater with an EF of 2.4 would be derated to 1.35. If your climate is very cold or hot we could run a project-specific dynamic model to get a more accurate number.

Space heat by fuel

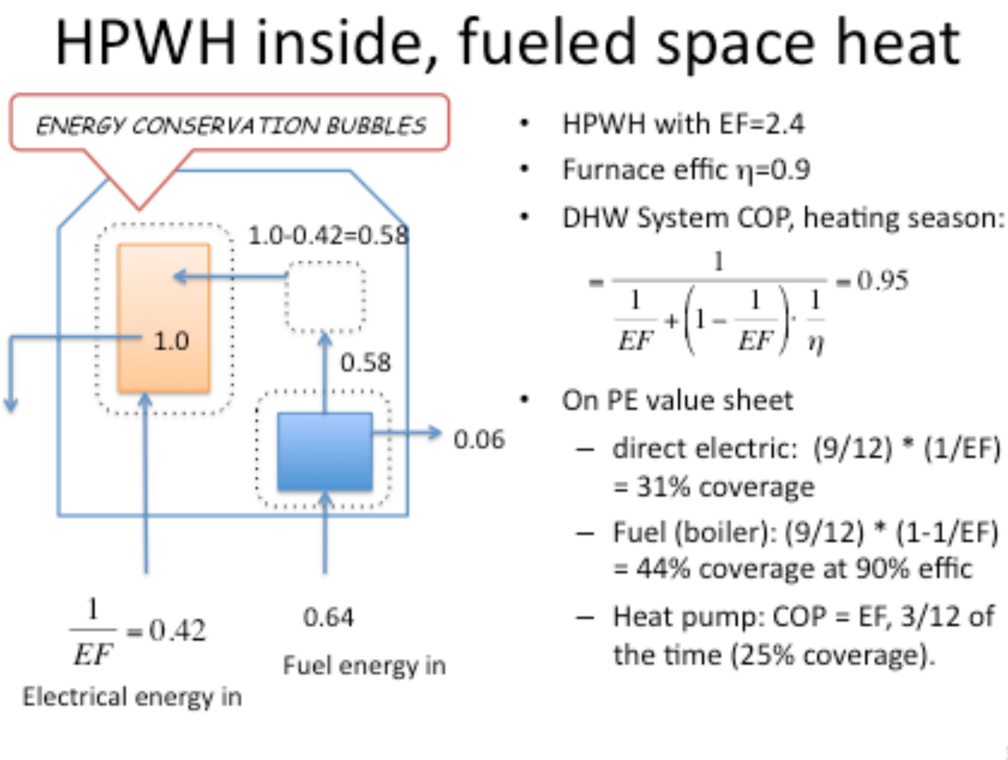

Figure 2. Primary energy representation for a heat-pump water heater inside, with combustion space heat.

When the space heat is supplied by fuel, the water heat energy ends up being supplied partly by fuel and partly by electricity during the heating season, and by electricity at rated COP for the rest of the time. This behavior can be represented by spreading the DHW coverage across the direct-electric, boiler, and heat-pump blocks on the PE sheet, as illustrated in Figure 2.

Space heat by another heat pump

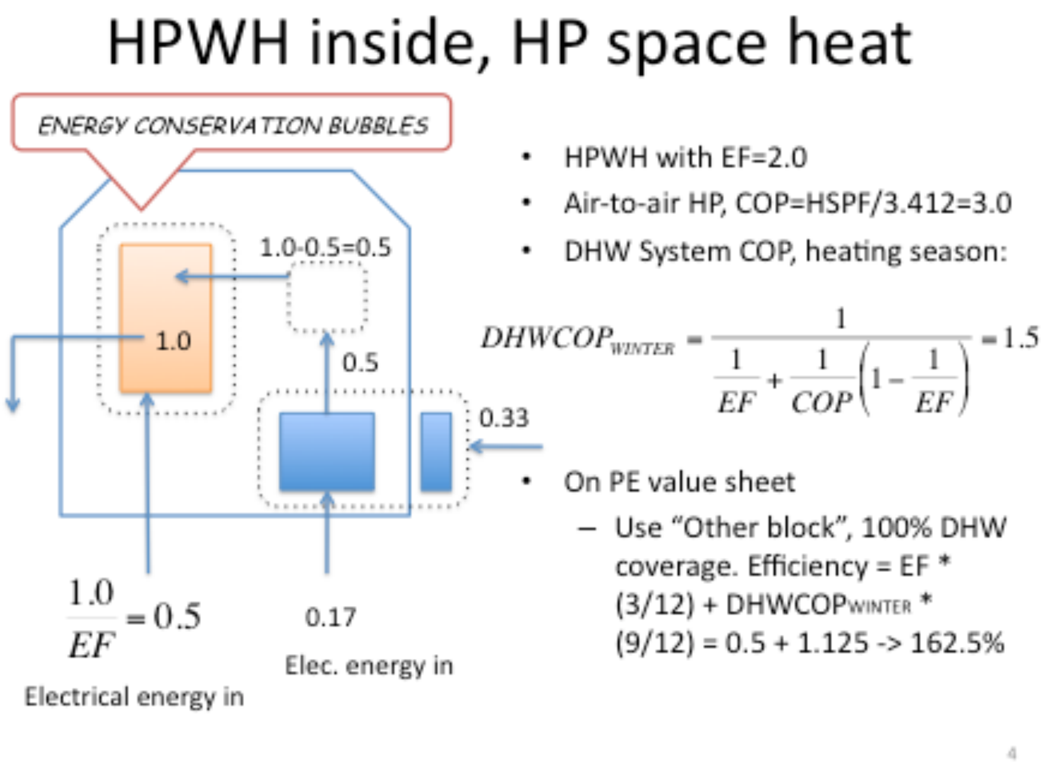

Figure 3. Primary energy representation for a heat pump water heater inside, with heat pump space heat.

For a heat pump water heater inside with space heat also by a heat pump, The water heater gets some leverage even in the heating season. In the example of Figure 3 the heating-season COP works out to 1.5 if the minisplit has a COP of 3 and the water heater has an EF of 2. When we again credit the water heater with its rated EF in the summer, the annual effective DHW COP rises to 1.625 or 162.5%.

This is a conservative calculation in that it does not capture the reduction in primary energy demand due to the desirable space cooling effect of the heat pump water heater during the summer, that is, the SEER for cooling is effectively higher than that of the minisplit alone. This would require some dynamic modeling to pin down.

Appendix

Excerpts from the US Code of Federal Regulations http://www.gpo.gov/fdsys/pkg/CFR-2010-title10-vol3/pdf/CFR-2010-title10-vol3-part430-subpartB-appM.pdf

"1.27 Heating seasonal performance factor (HSPF) means the total space heating required during the space heating season, expressed in Btu's, divided by the total electrical energy consumed by the heat pump system during the same season, expressed in watt-hours. The HSPF used to evaluate compliance with the Energy Conservation Standards (see 10 CFR 430.32(c), Subpart C) is based on Region IV, the minimum standardized design heating requirement, and the sampling plan stated in 10 CFR 430.24(m), Subpart B."

"1.33 Seasonal energy efficiency ratio (SEER) means the total heat removed from the conditioned space during the annual cooling season, expressed in Btu's, divided by the total electrical energy consumed by the air conditioner or heat pump during the same season, expressed in watt-hours. The SEER calculation in section 4.1 of this Appendix and the sampling plan stated in 10 CFR Subpart B, 430.24(m) are used to evaluate compliance with the Energy Conservation Standards. (See 10 CFR 430.32(c), Sub- part C.)"

"1.22 Design heating requirement (DHR) predicts the space heating load of a residence when subjected to outdoor design conditions. Estimates for the minimum and maximum DHR are provided for six generalized U.S. climatic regions in section 4.2."

"4.2 Heating Seasonal Performance Factor (HSPF) Calculations. Unless an approved alternative rating method is used, as set forth in 10 CFR 430.24(m), Subpart B, HSPF must be calculated as follows: Six generalized climatic regions are depicted in Figure 2 and otherwise defined in Table 17. For each of these regions and for each applicable standardized design heating requirement, evaluate the heating seasonal performance factor using..."

"For all heat pumps, HSPF accounts for the heating delivered and the energy consumed by auxiliary resistive elements when operating below the balance point. This condition occurs when the building load exceeds the space heating capacity of the heat pump condenser. For HSPF calculations for all heat pumps, see either section 4.2.1, 4.2.2, 4.2.3, or 4.2.4, whichever applies."

"For heat pumps with heat comfort controllers (see Definition 1.28), HSPF also accounts for resistive heating contributed when operating above the heat-pump-plus-comfort-controller balance point as a result of maintaining a minimum supply temperature. For heat pumps having a heat comfort controller, see section 4.2.5 for the additional steps required for calculating the HSPF."

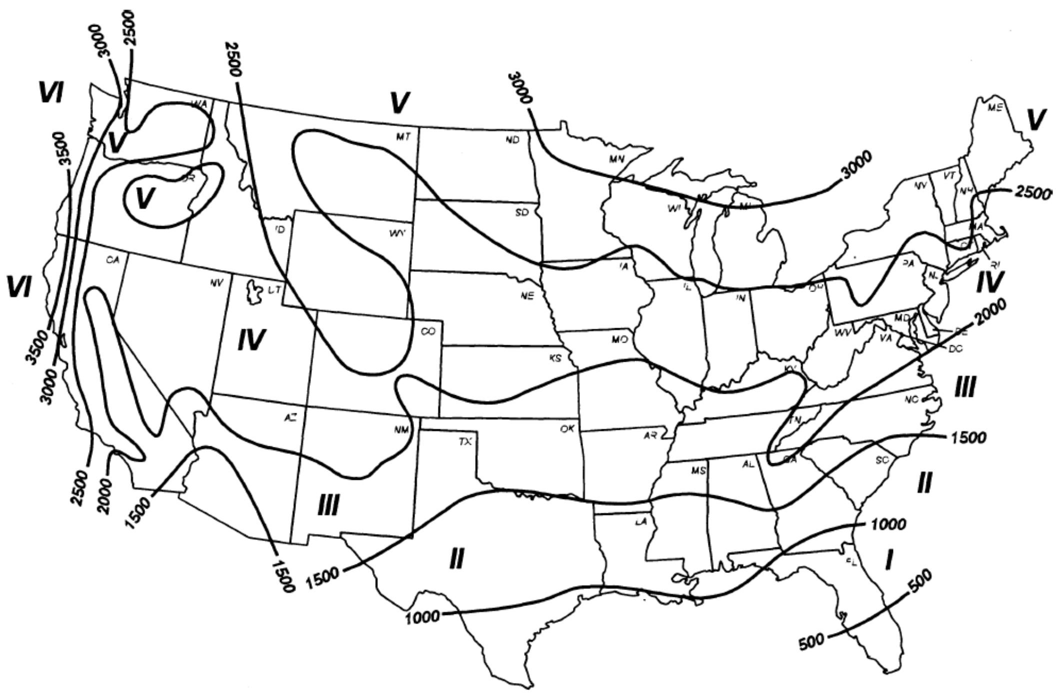

Figure 2 Heating Load Hours (HLH_A) for the United States

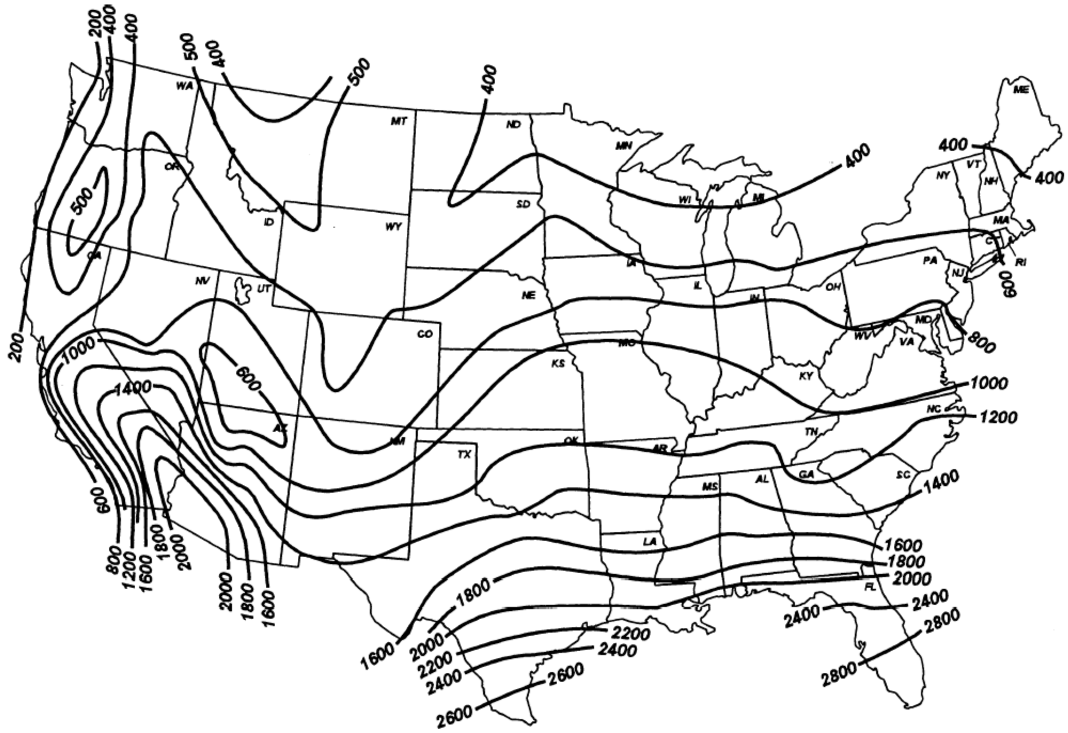

Figure 3 Cooling Load Hours (CLH_A) for the United States