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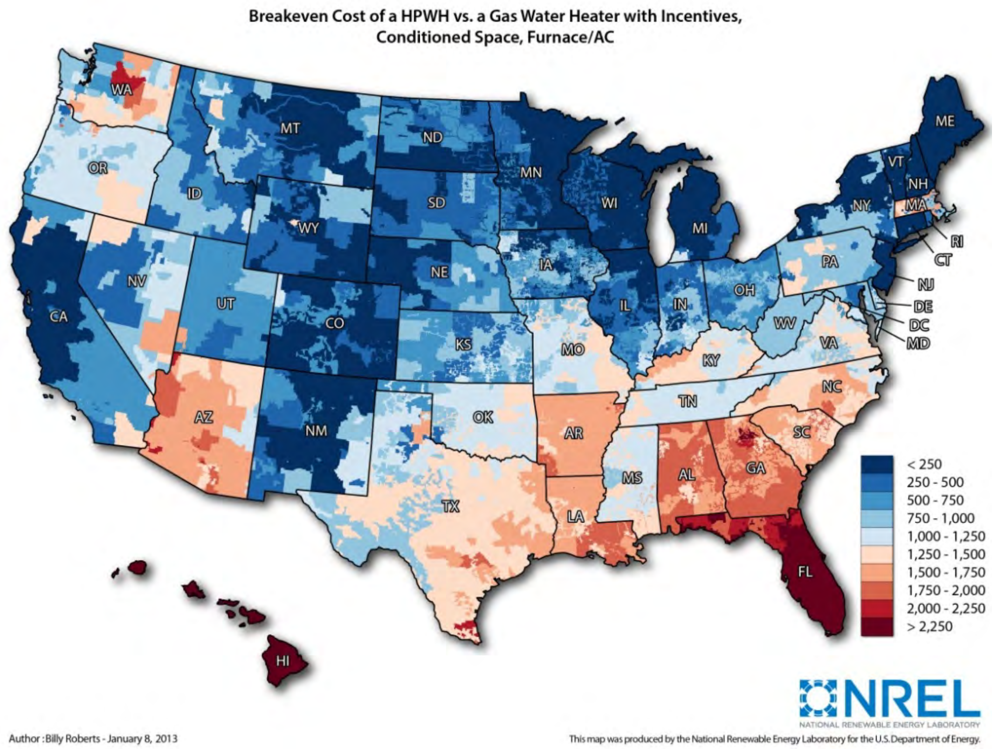
Holland & Knight References (5 of 11)

The attached document is the fifth of 11 separate uploads that contain the references cited in Holland & Knight's DEIR Comment Letter.

Additional submitted attachment is included below.



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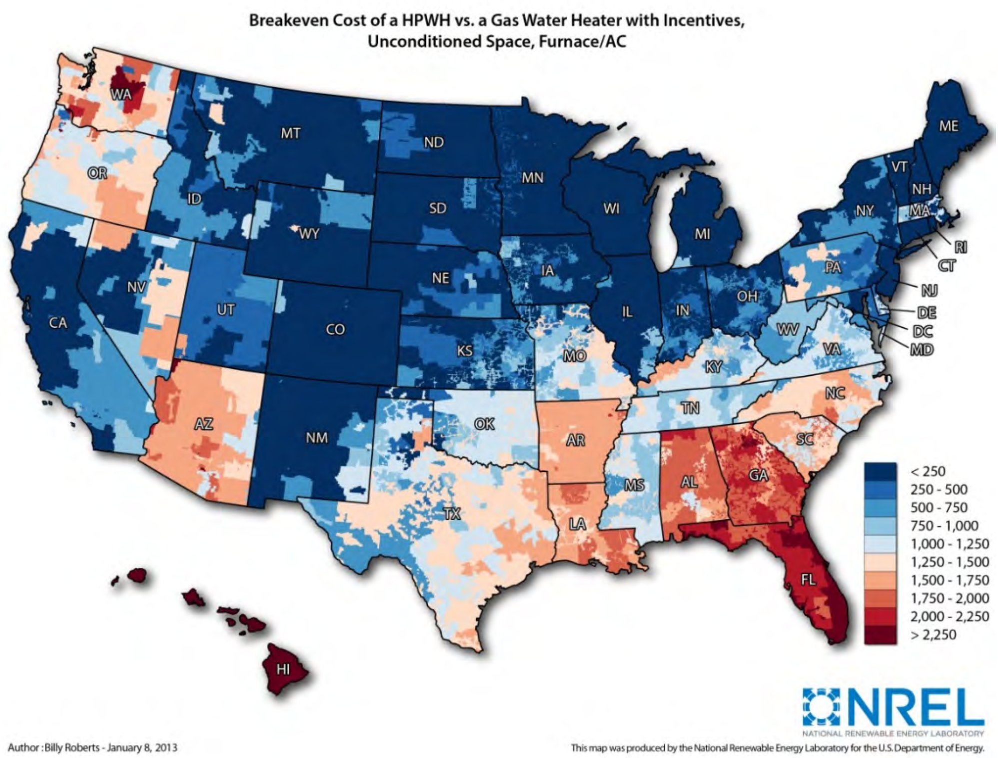

(b)

Figure 17. Breakeven cost with incentives of a 50-gal HPWH relative to a gas WH for a home with a furnace/AC when the WH is in (a) conditioned and (b) unconditioned space

6 Conclusions

The energy and cost savings potential of HPWHs as replacements for gas and electric WHs is examined in this paper. HPWHs have a significant potential to save energy as replacements for standard electric WHs; annual source energy savings of 18 MMBtu are possible in the most favorable situations. Savings are highest in hot and humid locations and gradually decrease with colder locations, although positive source energy savings relative to an electric WH are possible in every situation considered here. If a home has high efficiency electric space heating equipment, installations in conditioned space can save more than those in unconditioned space because the HPWH performance increases from conditioned space in colder locations outweighing the HVAC penalty. In the case of lower efficiency electric space heating equipment, the HVAC penalty imposed by the HPWH is large enough that installing equipment in unconditioned space can save more energy.

To determine the economic viability of HPWHs, breakeven costs are also calculated. Local variations in utility rates cause the breakeven costs to vary significantly, even in regions with similar climates. In general, the highest (and most favorable) breakeven costs are seen for installations in conditioned space replacing an electric WH in homes with high efficiency electric space heating equipment. For cases with lower efficiency electric space heating equipment and installation in unconditioned space, the breakeven costs drop because of a larger space heating penalty from the lower equipment efficiency. An HPWH can likely be a cost-effective and energy-efficient replacement to an electric WH in many situations. However, local utility rates and the actual net installed cost of an HPWH vary significantly and the economic viability of an HPWH as a replacement for an electric WH will vary significantly on a case by case basis.

When comparing HPWHs to gas WHs, positive source energy savings are possible only in some locations in the South, and the HPWH is likely to break even in only a few southern states. Given that most WHs in these locations are electric, the potential national source energy and economic savings associated with replacing a gas WH with an HPWH are low.

This study demonstrates the regional variations in the efficiency and economic viability of an HPWH across the continental United States for several installation locations. However, this study considered only one HPWH (although an additional 80-gal unit is considered in Appendix B), subjected to a "typical" hot water draw profile, in one particular home. The efficiency, energy savings potential, and economic viability of an HPWH as a replacement for a typical gas or electric WH may vary significantly depending on the installation location, HPWH, and draw profile.

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Appendix A: Regional Variations in Water Heating Fuel by Census Region

Figure 18 shows the number of households using gas, electricity, or other fuels for water heating. The “other” category includes propane, fuel oil, solar, wood, and any other fuels that may be used for water heating. For each census region, any available state-specific data are also provided to show the breakdown of water heating fuels in a region. This can be especially useful for census regions such as the Pacific, which are dominated by one populous state.

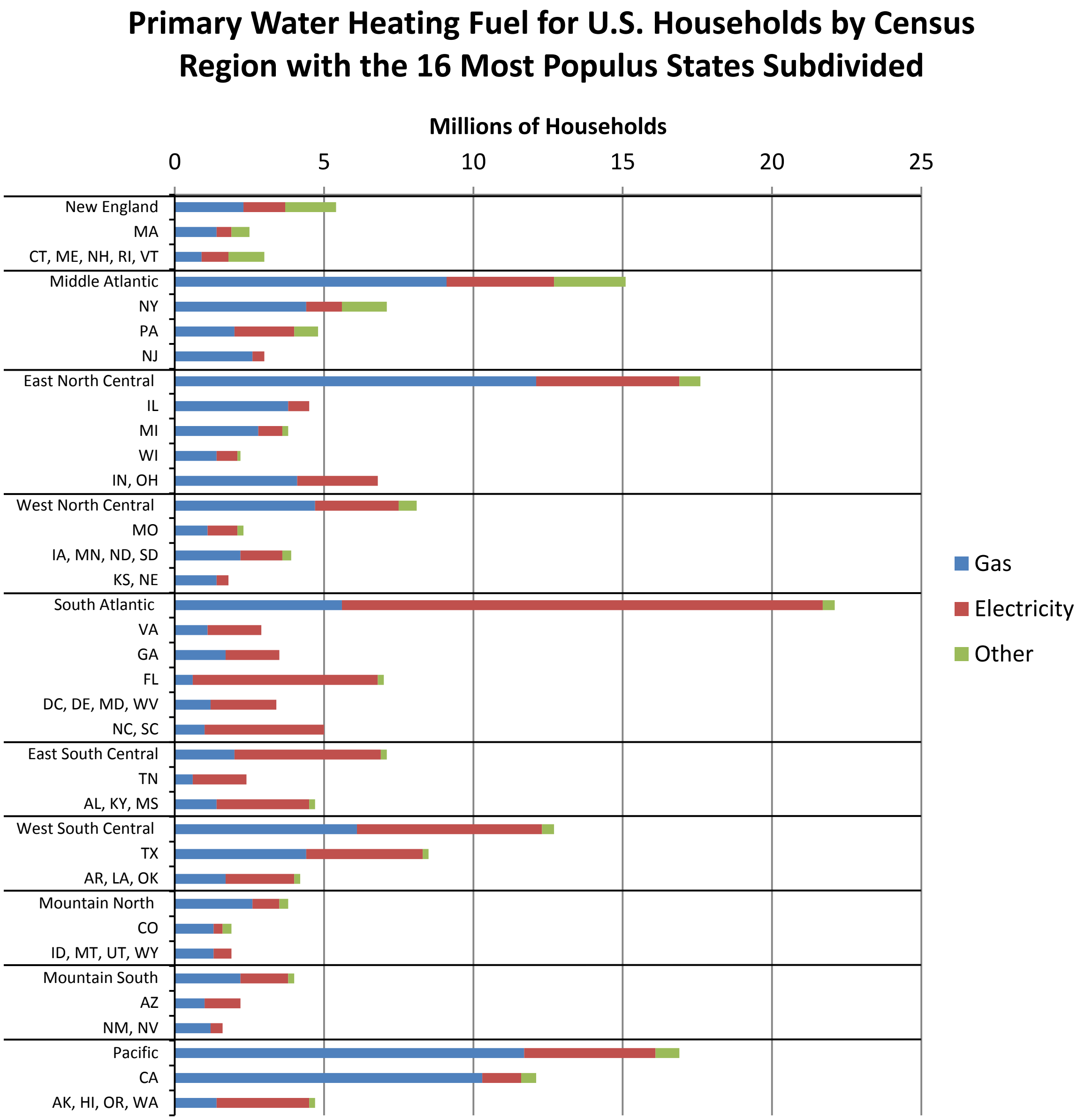


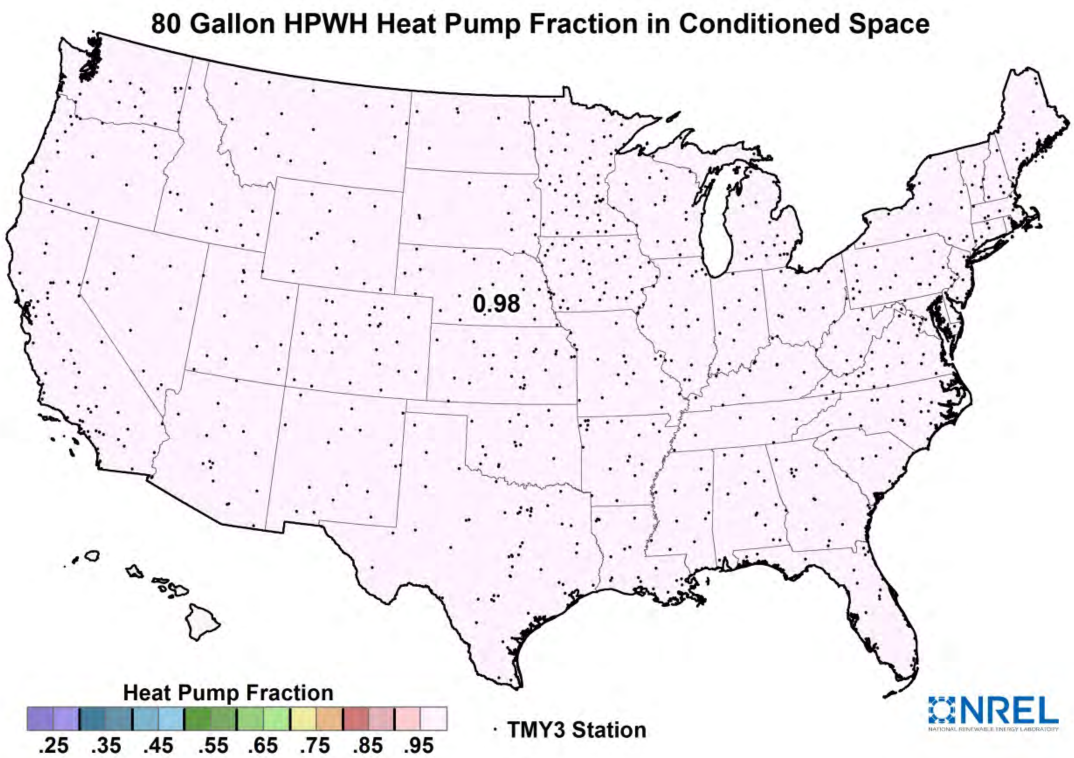
Figure 18. Water heating fuel use by census region, further subdivided for the 16 most populous states (EIA, 2009)

Appendix B: 80-Gallon Heat Pump Water Heater Modeling Results

An 80-gal HPWH was also simulated; the model used here was also based on laboratory testing (Sparn, Hudon, & Christensen, 2011) and captures the actual performance of one tested unit. There are differences in the control logic, heat pump specifications, tank insulation, and element sizes and location between the two units. In particular, the control logic for this unit does not use the electric elements to fully recover any time an element turns on. Instead, if demand is large enough to trigger an electric element, the element will stay on until the tank has recovered to the set point that triggered it, then the heat pump will complete the remainder of the recovery. This control logic is much more efficient than the elements for full recovery, which further boosts the efficiency of this unit compared to the 50-gal HPWH.

Figure 19 shows the HPF of an 80-gal HPWH installed in conditioned and unconditioned space. For the conditioned space case, there is only slight variation in the HPF and it is above 0.95 for every location. In this case, the electric elements are rarely needed because the increased storage volume can provide enough hot water to meet the load. During high demand scenarios when the elements are triggered, the control logic of the 80-gal unit uses the elements for partial recovery only, which further increases the HPF.

In unconditioned space, regional variations in the HPF are considerable. Climate and installation location are particularly important. The heat pump could be used to meet almost the entire load in conditioned space; however, in unconditioned space the ambient air temperature can go outside its operating range (45°–120°F). The frequency of this occurrence has a strong impact on HPF, as the heat pump could otherwise meet most of the load. As ambient air temperature decreases, the heat pump capacity decreases, so the electric elements are required more often. For garage installation, the ambient air temperature is much more likely to go outside the heat pump's operating range for some part of the year. Basements have much less variation in space temperature, which is mostly dependent on ground and conditioned space temperatures. This results in a higher HPF for homes where the HPWHs are installed in basements instead of garages, even if the homes are in similar climates.



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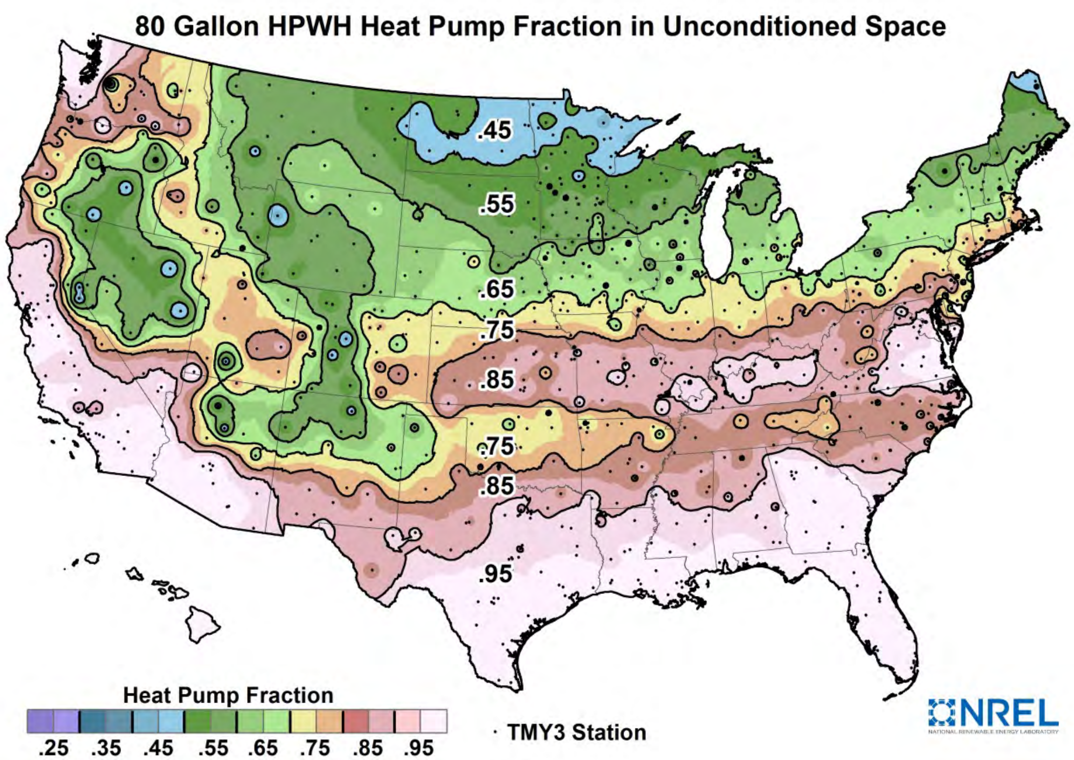

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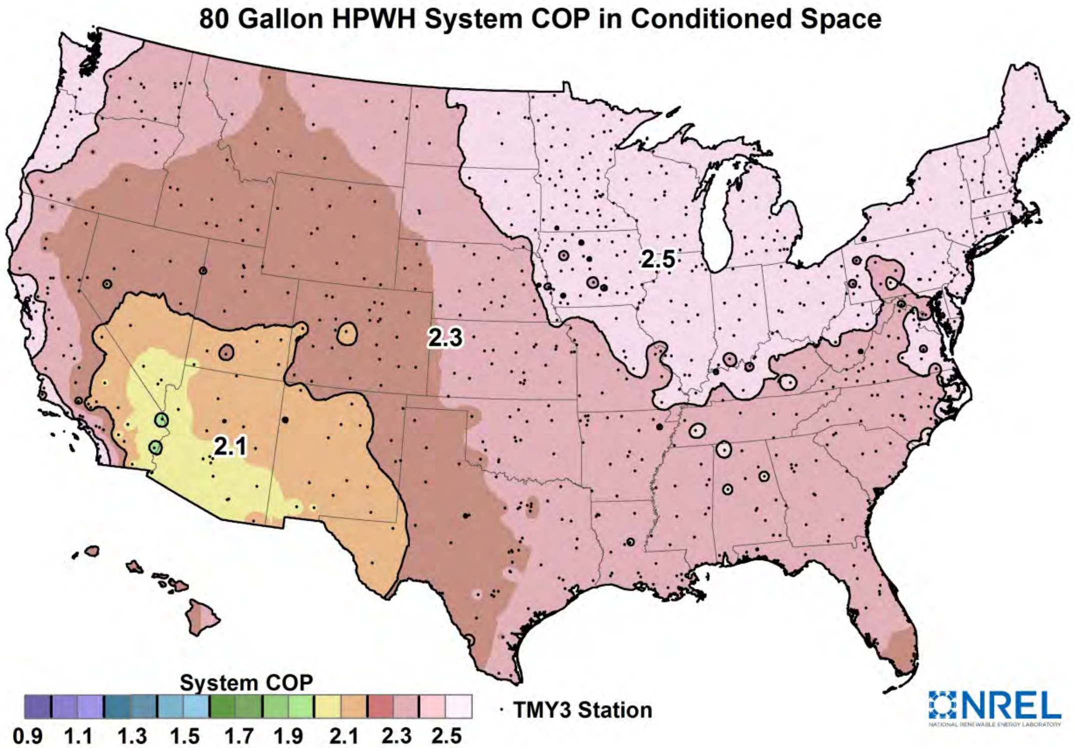
Figure 19. HPF of the 80-gal HPWH in (a) conditioned and (b) unconditioned space

Figure 20 shows the COP_{sys} for an 80-gal HPWH in conditioned and unconditioned space. In conditioned space, the COP_{sys} tends to increase as the mains temperature decreases because the lower mains water temperature leads to higher energy demand. In a lower energy demand situation, a larger portion of the heat from the heat pump goes to making up standby losses instead of meeting the load, which decreases overall efficiency. This same trend of higher efficiency at higher load is seen in gas and electric storage WHs. However, it is not seen in the case of a 50-gal HPWH because the HPF is lower in regions with high load: the heat pump cannot fully meet the load with only 50 gal of storage and the control logic between the two units varies significantly. The ambient humidity also has an impact on the COP_{sys}. The heat pump performance is affected by the storage tank temperature and the ambient wet bulb temperature. Although the conditioned space temperature is controlled, the humidity is not, which lowers wet bulb temperatures and reduces heat pump COP in drier locations such as the western United States. The lower wet bulb temperature and slight HPF variations with location lead to COP_{sys} in the locations with the highest loads being lower than locations such as the Pacific Northwest and New England, which have slightly lower loads but higher humidities. In unconditioned space, the COP_{sys} follows similar trends to the highly variable HPF, which is the primary driver of COP_{sys}.

The EF of this 80-gal HPWH is 2.3. The COP_{sys} is not always this high, but the unit can achieve a $COP_{sys} \geq 2.3$ for most of the country when it is installed in conditioned space. However, the COP_{sys} does not account for normalization or any changes in HVAC energy consumption, which may significantly impact the overall energy savings associated with installing an HPWH.



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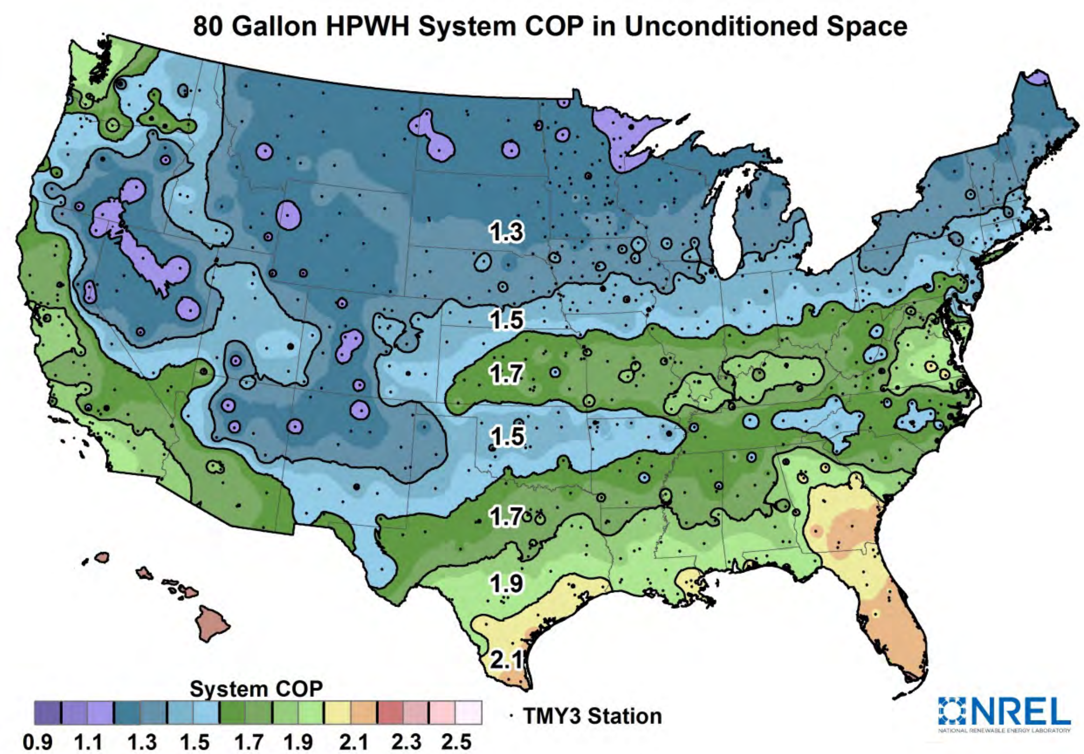

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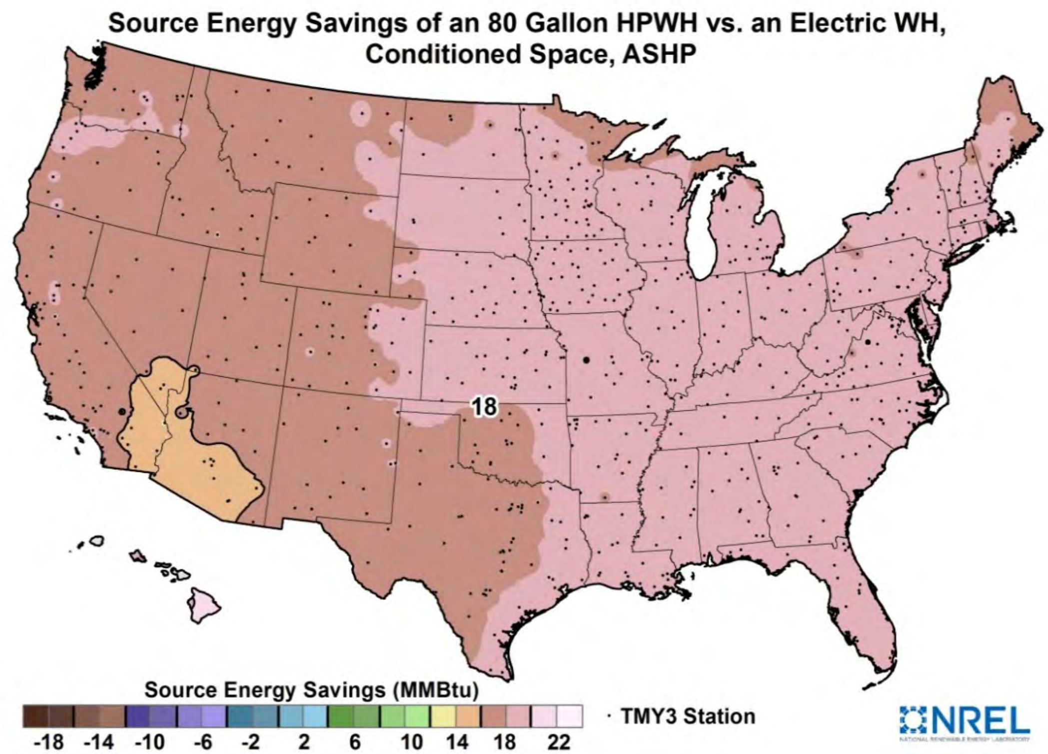
Figure 20. COP_{sys} of the 80-gal HPWH in (a) conditioned and (b) unconditioned space

Figure 21 shows the source energy savings for a home with an electric WH and an ASHP in conditioned and unconditioned space. In the conditioned space case, the potential source energy savings are relatively constant across the United States; savings are slightly higher in the East. Northern climates show high savings for the energy required to heat water because of the high heat pump COP and the larger load, but there is a correspondingly higher space conditioning penalty. Warmer locations receive a net space conditioning benefit from running the HPWH, but the smaller load leads to lower savings in the energy required to heat water. The net result of the space conditioning impact and variations in the load leads to the roughly constant savings across the country.

In unconditioned space, the source energy savings follow many of the same trends seen in the COP_{sys} plot. Although the space conditioning impact in this case is relatively small (especially in garage installations), the water heating load has a significant impact. The locations with the highest COP_{sys} (Hawaii and southern Florida) do not have the highest savings because the load is relatively low. Interestingly, the highest savings are seen in coastal Washington. This location has both a high COP_{sys} (because the unit is installed in a basement in a relatively mild climate with high ambient humidity) and a high load. Even though this is a heating-dominated climate, the relatively mild winters allow the ASHP to use the heat pump for most of the year, which lessens the HPWH's impact on the space conditioning load.



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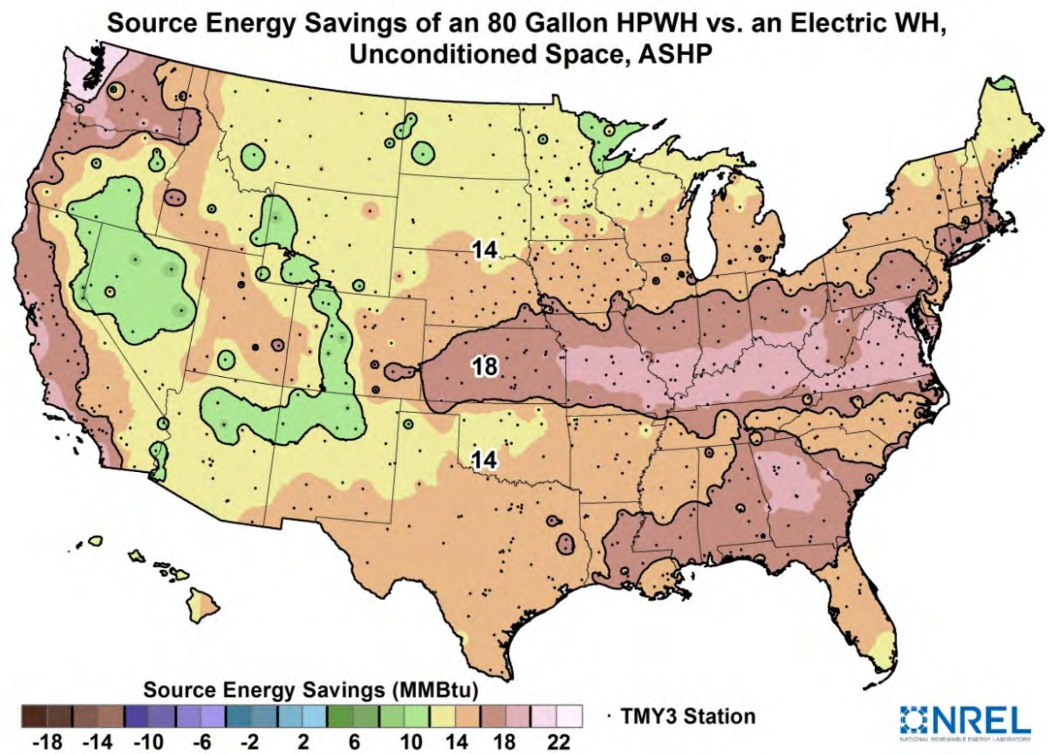

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Figure 21. Source energy savings of an 80-gal HPWH relative to an electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space

Figure 22 shows the source energy savings for a home with an electric WH and ER heat/AC in conditioned and unconditioned space. For these homes the efficiency in conditioned space is significantly lower than the ASHP case in all locations that have some heating load. ER heat is significantly less efficient than an ASHP, so this drop is expected. The largest drops in savings are seen along the west coast, which has a mild climate but a small heating load for much of the year, especially in northern locations. The heat pump provides a small amount of cooling year round, so the space conditioning penalty is largest in these locations. However, positive source energy savings are possible in all locations. In unconditioned space, the efficiency is slightly lower for cases with ER heat than with an ASHP. The effect is more pronounced in locations with basement installations, which also tend to have a higher heating requirement.

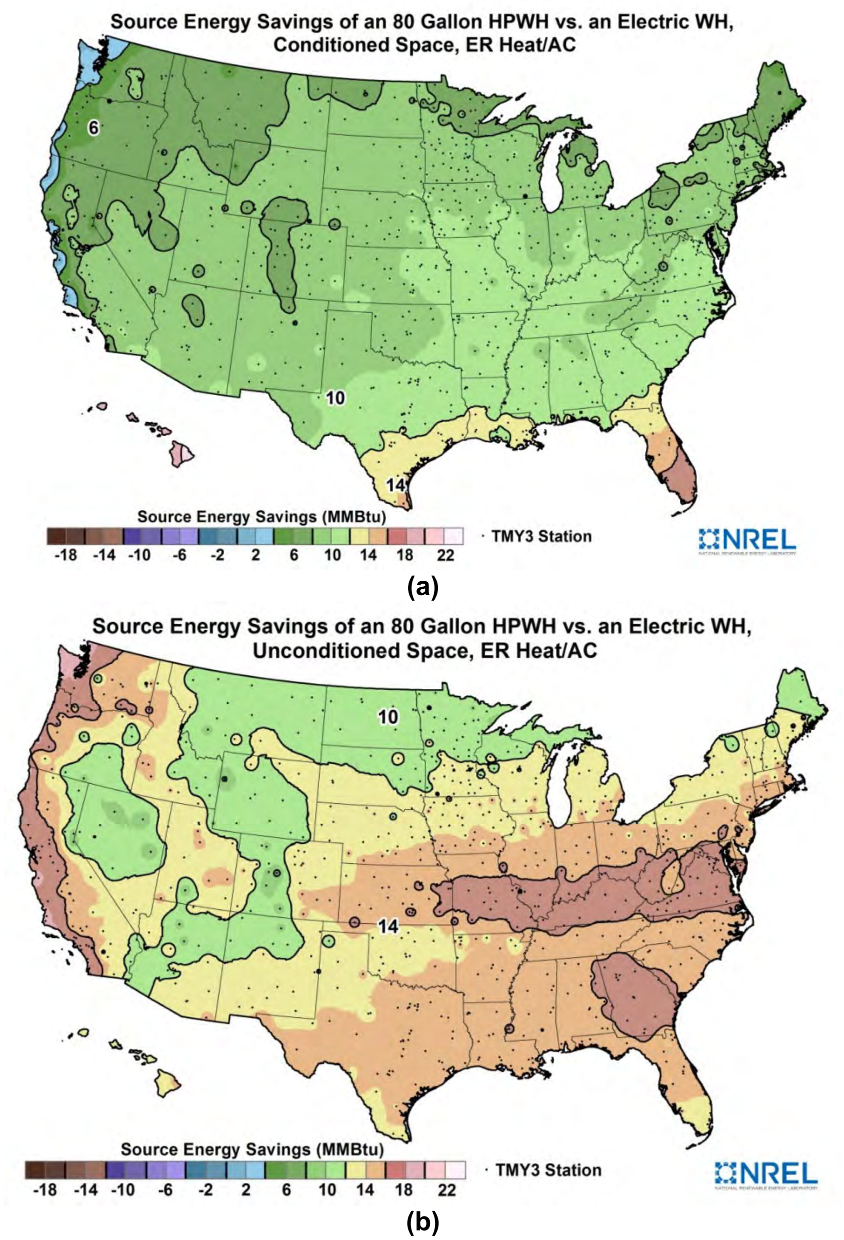


Figure 22. Source energy savings of an 80-gal HPWH relative to an electric WH for a home with ER heat/AC when the WH is in (a) conditioned and (b) unconditioned space

Figure 23 shows the source energy savings for a home with a gas WH and a furnace/AC in conditioned and unconditioned space. Even in the case of an 80-gal HPWH, positive source energy savings are limited to the South in conditioned and unconditioned space. The region where positive source energy savings are possible is larger in the 80-gal HPWH case than in the 50-gal case. However, this region still predominantly uses electric WHs.

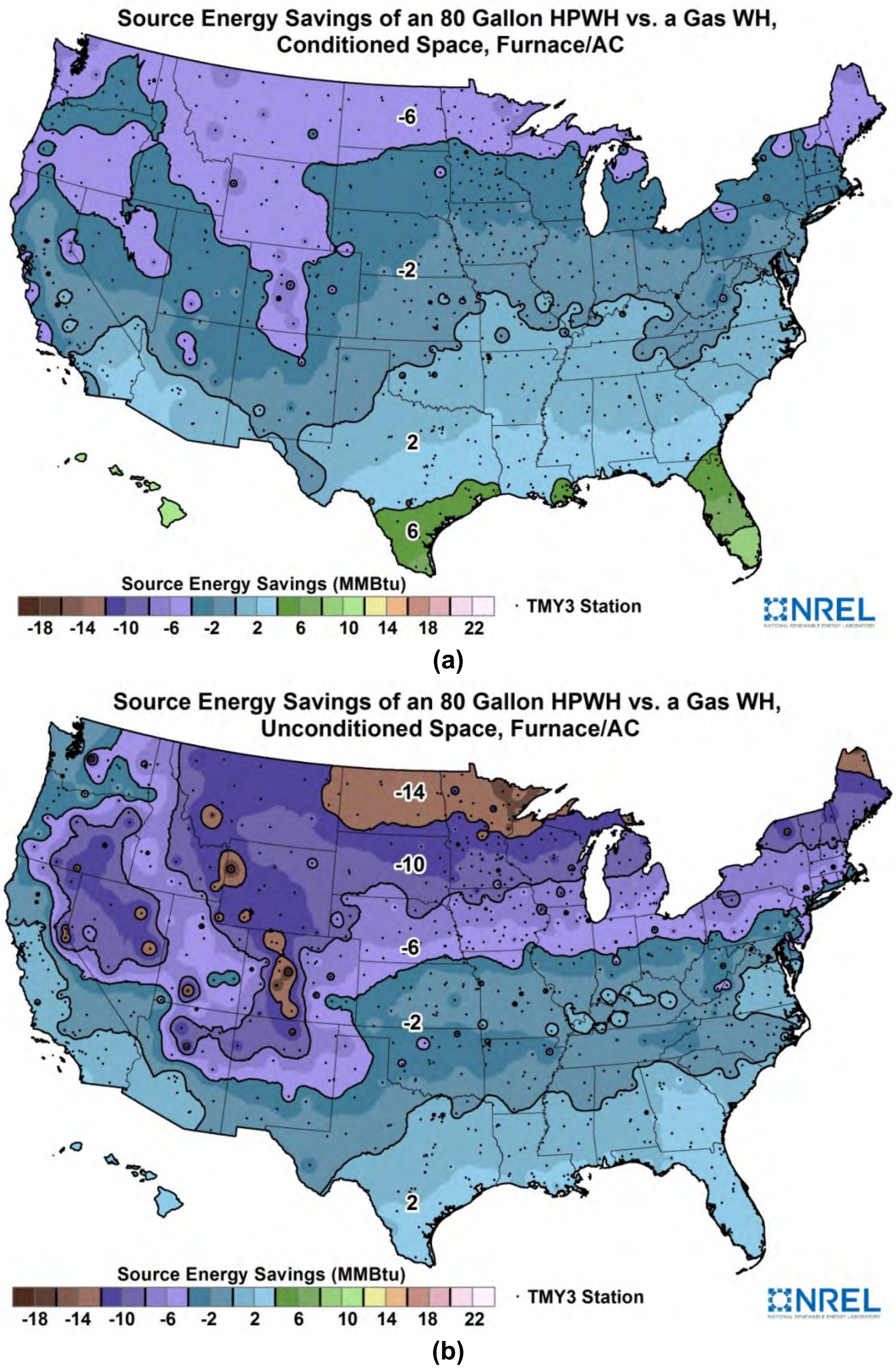
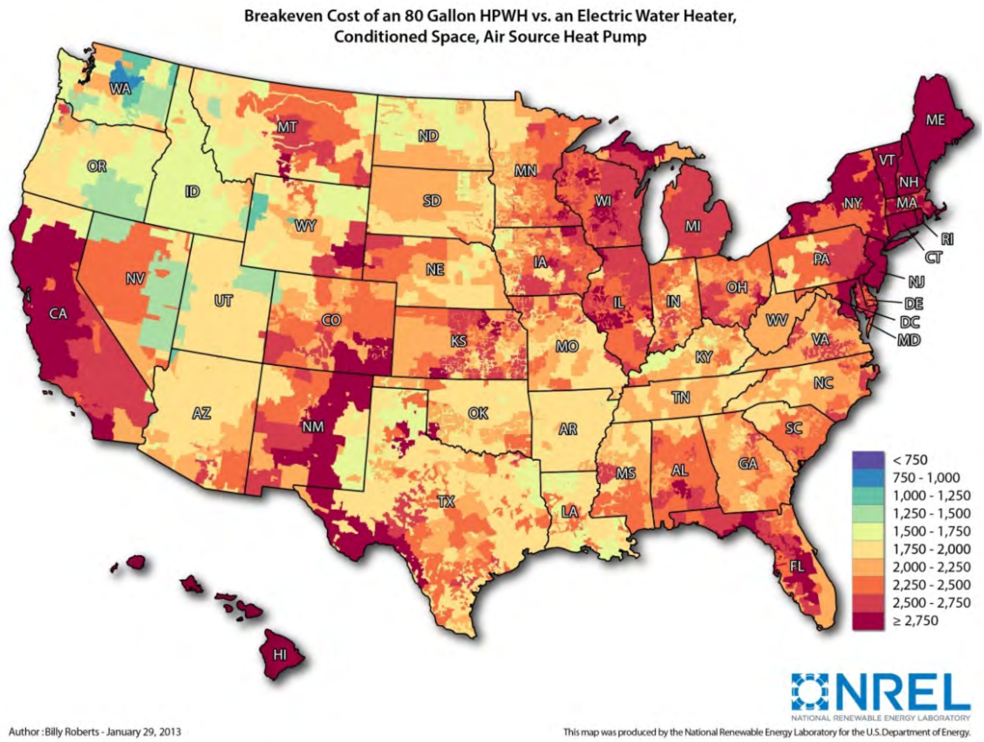


Figure 23. Source energy savings of an 80-gal HPWH relative to a gas WH for a home with a furnace/AC when the WH is in (a) conditioned and (b) unconditioned space

The breakeven costs for the case of an 80-gal HPWH were also calculated. The net installed cost of an 80-gal HPWH will be higher than that of a 50-gal HPWH. The 80-gal HPWHs are significantly more expensive than the 50-gal units (more than $1800 retail) (Lowes.com, 2013). This is higher than some estimates of the average net installed cost of the 50-gal unit and a significant premium, although it would be reasonable to expect that this cost will decrease as more manufacturers start offering multiple sizes of HPWHs. There may also be additional installation costs for the 80-gal HPWH, especially in retrofit scenarios where size is a factor. The current net installed cost of an 80-gal HPWH is thus higher than the 50-gal case and likely exceeds $2000 in many cases with current prices.

To emphasize the differences in net installed cost between the 50- and 80-gal cases and to better capture the range of likely net installed costs for an 80-gal HPWH, a new scale was used for these breakeven maps. However, all the details of how the breakeven cost was calculated are identical to the case of the 50-gal HPWH. Figure 24 shows the breakeven costs for an 80-gal HPWH in conditioned and unconditioned space when replacing an electric WH in a home with an ASHP. Many of the same trends that were seen in the 50-gal case are apparent here since the utility rates in both cases are the same. However, the breakeven cost is generally higher because the 80-gal case shows greater savings. In particular, there are greater savings in the northern Mountain region, which leads to significantly higher breakeven costs than the 50-gal case.



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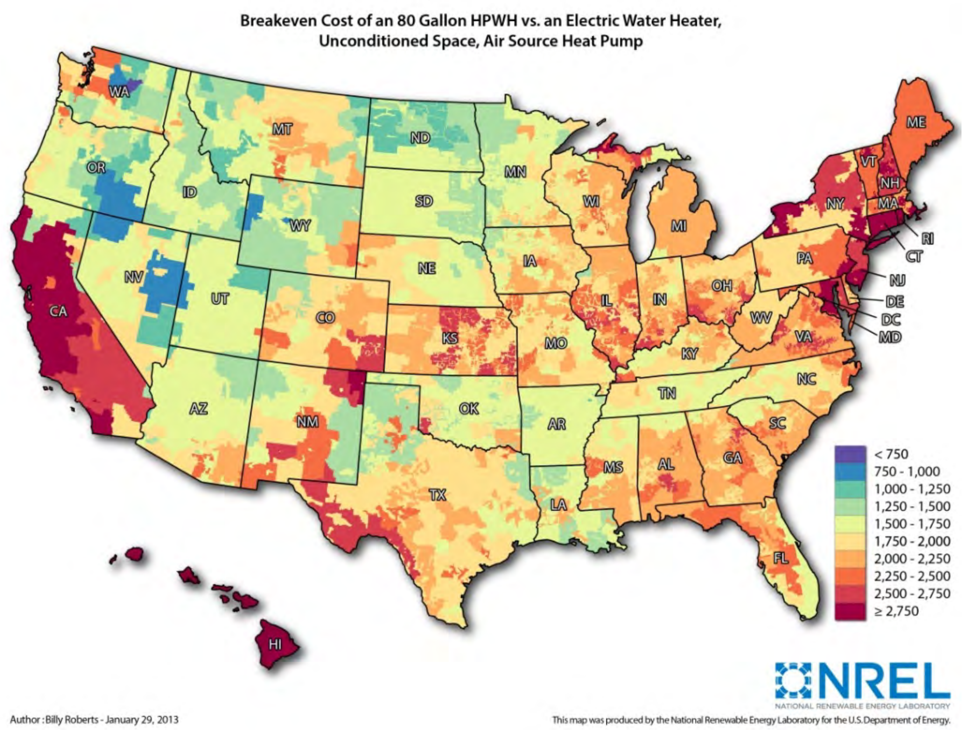

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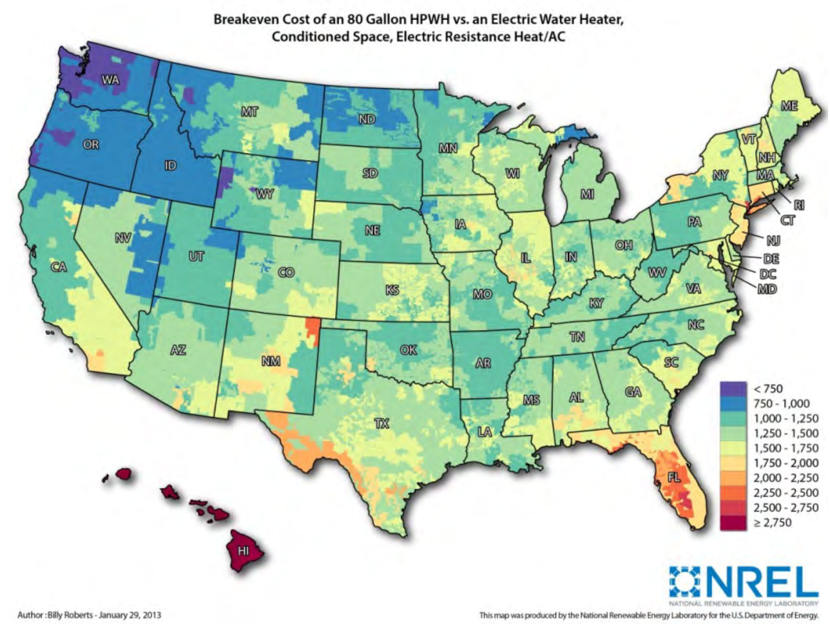
Figure 24. Breakeven cost of an 80-gal HPWH relative to an electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space

Figure 25 shows the breakeven costs for replacing an electric WH in a home with ER heat and an AC. The difference between this case and that of an ASHP is much more drastic for conditioned space. Nevertheless, in unconditioned space many regions had their breakeven costs drop by at least one scale level, particularly in locations with basements. In the conditioned space case, there is a significant drop in breakeven costs and only a few locations have breakeven costs that exceed $2000.



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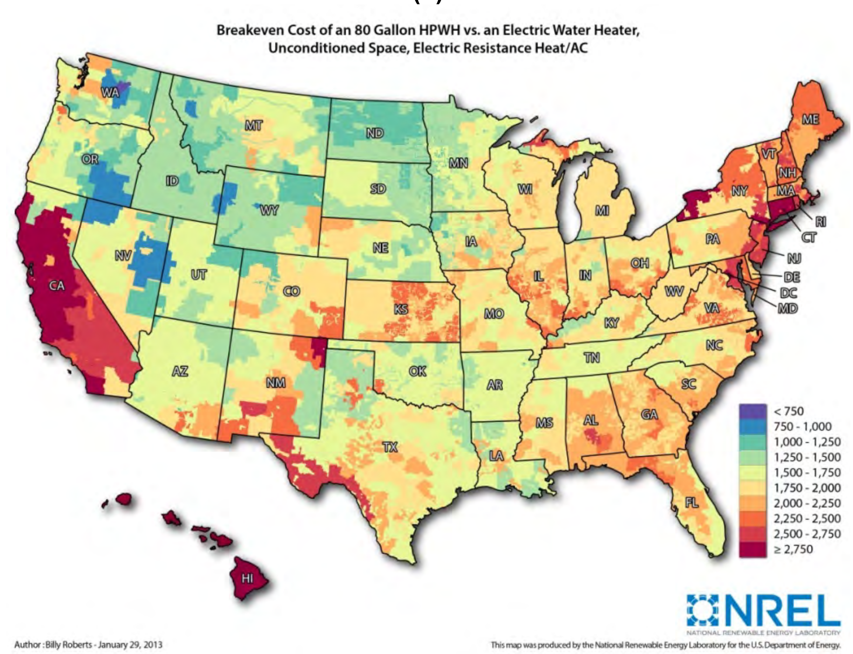

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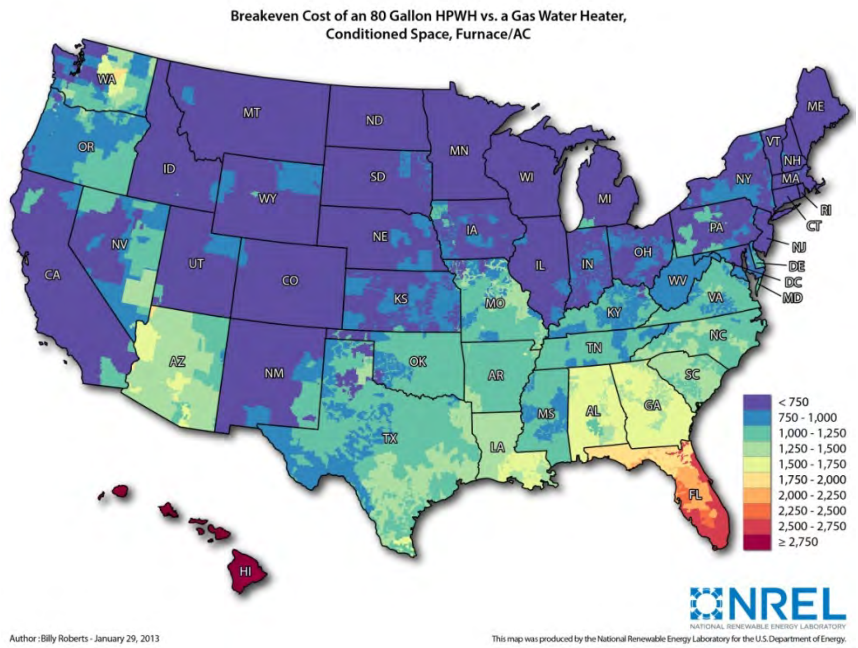
Figure 25. Breakeven cost of an 80-gal HPWH relative to an electric WH for a home with ER heat and an AC when the WH is in (a) conditioned and (b) unconditioned space

Figure 26 shows the breakeven costs for the case where the HPWH is replacing a gas WH in a home using a furnace/AC. In this case the breakeven costs are generally very low, although there are high breakeven costs in a few locations such as southern Florida. However, because gas WHs are uncommon in locations with high breakeven costs, the number of installations where it may be economically viable to replace a gas WH with an HPWH is low, even with the larger and generally more efficient 80-gal HPWH.



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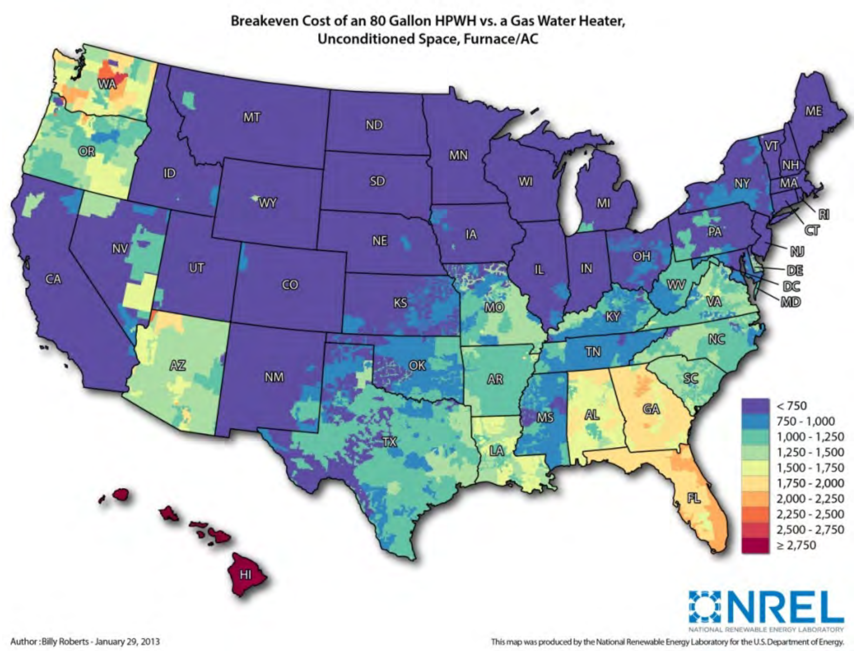

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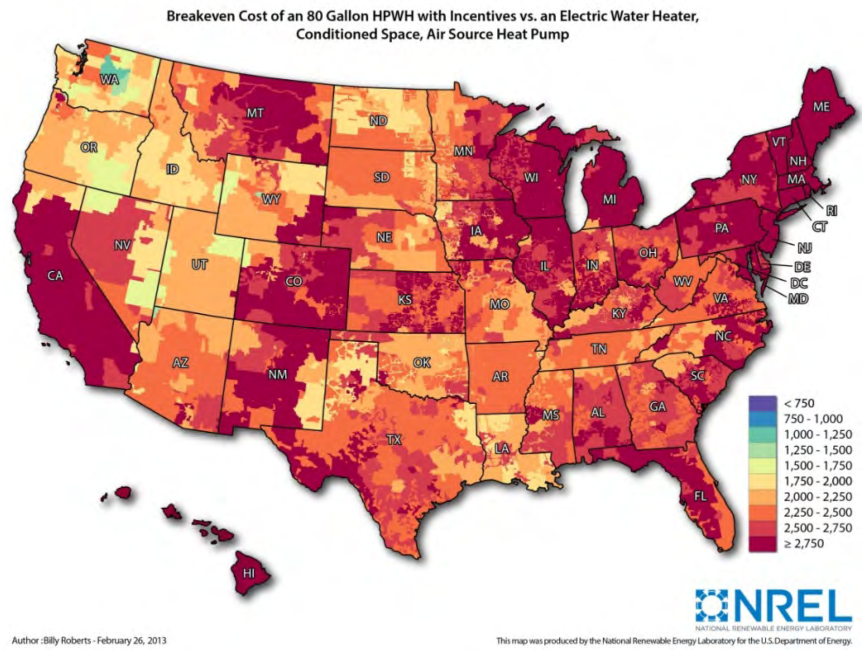
Figure 26. Breakeven cost of an 80-gal HPWH relative to a gas WH for a home with a furnace and an AC when the WH is in (a) conditioned and (b) unconditioned space

Figure 27 through Figure 29 show cases where incentives are considered. The same incentives that were used in the 50-gal case (including the $300 federal incentive) are applied here. Current incentives can frequently make the 80-gal HPWH significantly more attractive, although even with incentives installing an 80-gal HPWH is often still unattractive. For example, when replacing a gas WH, favorably high breakeven costs are still seen only in the South and a few parts of Washington.



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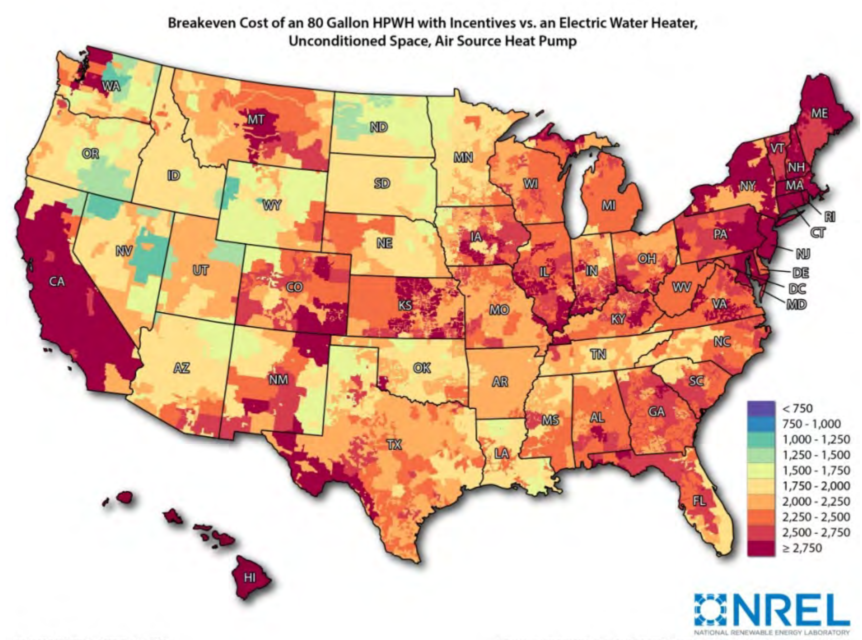

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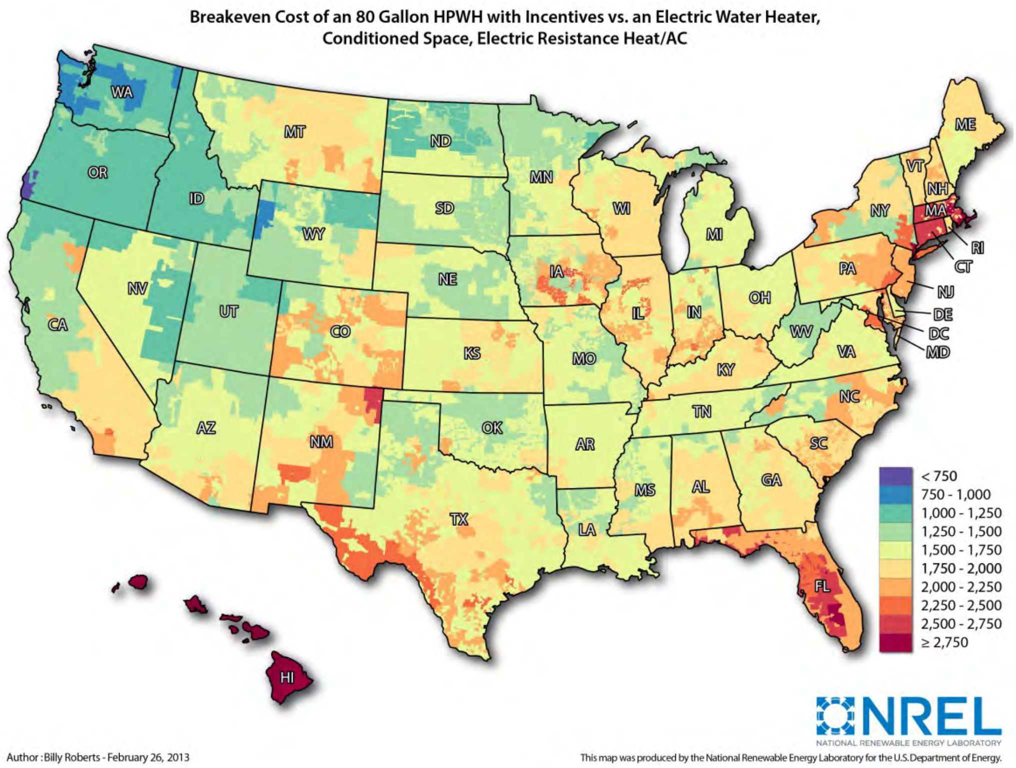
Figure 27. Breakeven cost with incentives of an 80-gal HPWH relative to an electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space



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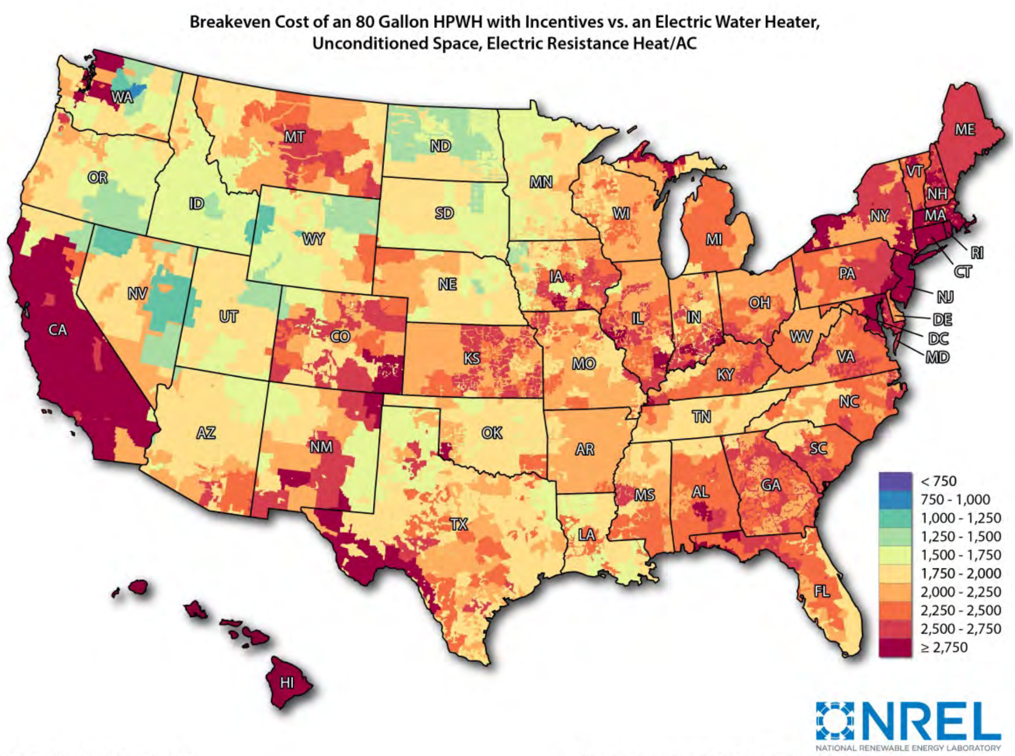

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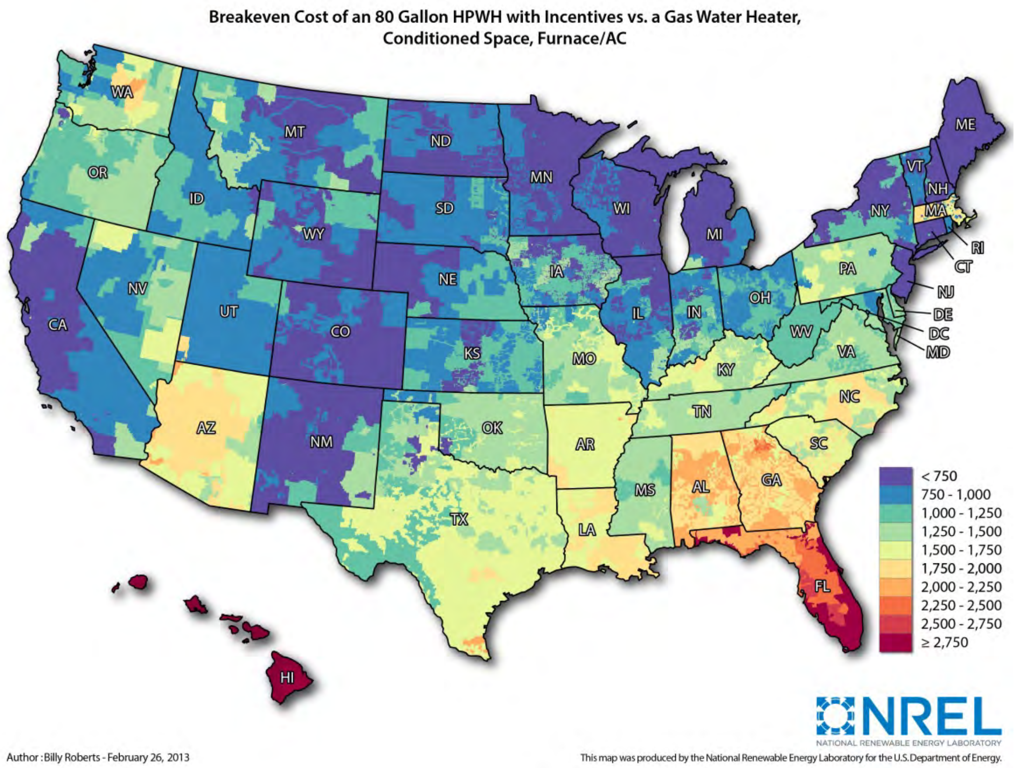
Figure 28. Breakeven cost with incentives of an 80-gal HPWH relative to an electric WH for a home with ER heat and an AC when the WH is in (a) conditioned and (b) unconditioned space



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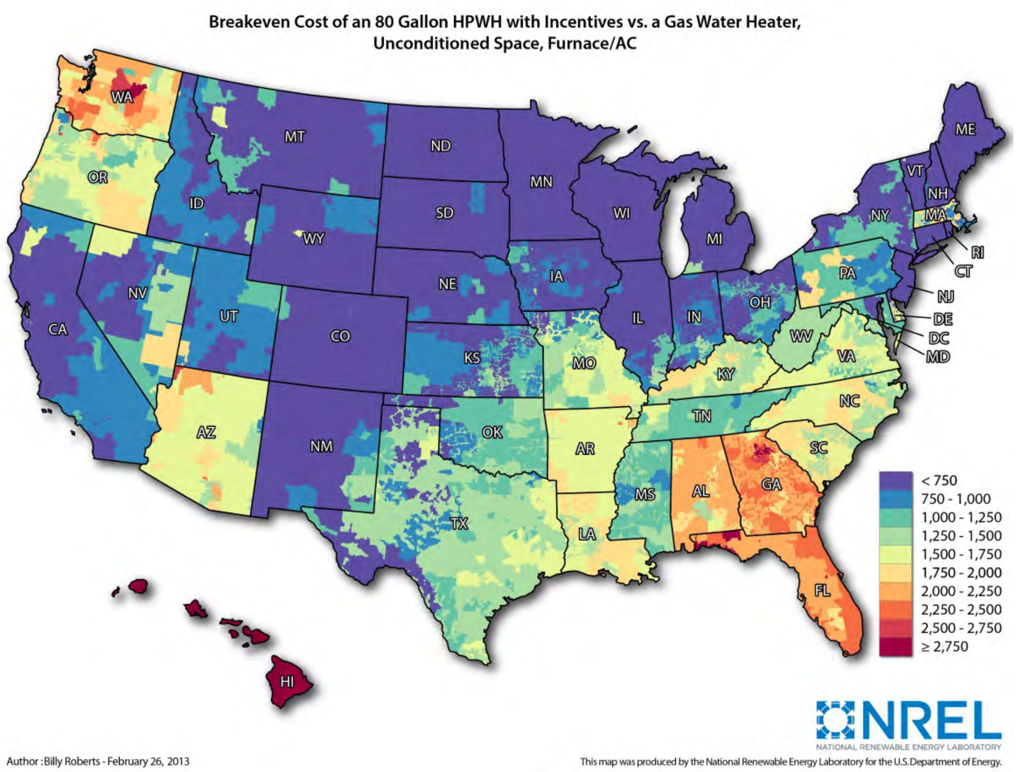

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Figure 29. Breakeven cost of an 80-gal HPWH relative to a gas WH for a home with a furnace and an AC when the WH is in (a) conditioned and (b) unconditioned space

Appendix C: Components of Net Source Energy Savings

Table 2 through Table 13 show the source energy savings that comes from normalization energy, space heating and cooling interactions, and actual WH savings. To show the impact of climate on each factor, the results are split up by BA climate zone (Pacific Northwest National Laboratory and Oak Ridge National Laboratory, 2010) (see Figure 30). Tables were created for the 50-gal HPWH presented in the main body of this paper and the 80-gal HPWH presented in Appendix B to demonstrate the differences. All the tables provide the net annual source energy savings (in MMBtu); negative savings indicate an increase in source energy consumption when switching to an HPWH. Although the data are divided by climate region, there may be significant variations from site to site in a particular climate region.

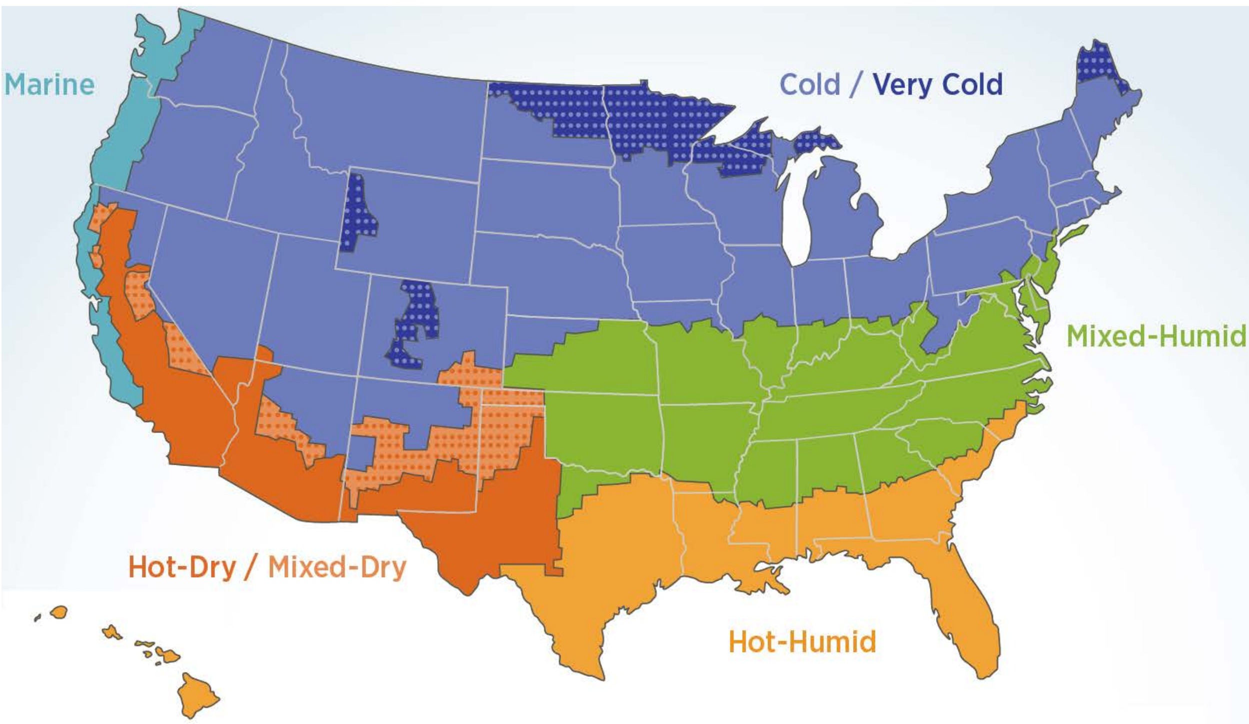


Figure 30. BA climate zones (Pacific Northwest National Laboratory and Oak Ridge National Laboratory, 2010)

Table 2. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/ASHP/Replacing an Electric WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	16.98	–1.90	3.65	–1.19	17.54
Mixed-Humid	19.78	–4.17	2.54	–1.77	16.38
Hot-Dry	17.50	–2.79	2.15	–1.49	15.37
Mixed-Dry	19.19	–4.28	1.79	–2.05	14.64
Marine	21.13	–5.28	0.59	–1.90	14.53
Cold	21.41	–6.16	1.68	–2.24	14.69
Very Cold	22.84	–8.09	1.03	–2.59	13.20

Table 3. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/ASHP/Replacing an Electric WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	15.64	–0.05	0.18	–1.33	14.44
Mixed-Humid	14.63	–0.28	0.36	–1.75	12.95
Hot-Dry	15.22	–0.05	0.08	–1.76	13.49
Mixed-Dry	12.24	–0.08	0.11	–2.08	10.18
Marine	16.46	–0.31	0.06	–2.14	14.06
Cold	11.67	–0.32	0.35	–2.06	9.63
Very Cold	9.76	–0.29	0.23	–2.28	7.41

Table 4. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/ER Heat and AC/Replacing an Electric WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	16.59	–5.44	3.14	–1.18	13.10
Mixed-Humid	19.38	–10.08	2.22	–1.73	9.79
Hot-Dry	17.08	–8.32	1.90	–1.47	9.19
Mixed-Dry	18.79	–9.97	1.62	–2.00	8.44
Marine	20.72	–15.44	0.52	–1.86	3.94
Cold	21.01	–12.66	1.49	–2.17	7.67
Very Cold	22.47	–14.95	0.91	–2.51	5.92

Table 5. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/ER Heat and AC/Replacing an Electric WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	15.26	–0.16	0.10	–1.31	13.89
Mixed-Humid	14.25	–0.82	0.29	–1.72	12.00
Hot-Dry	14.84	–0.19	0.06	–1.73	12.98
Mixed-Dry	11.85	–0.24	0.08	–2.02	9.66
Marine	16.07	–0.97	0.04	–2.08	13.06
Cold	11.28	–0.99	0.30	–2.00	8.58
Very Cold	9.36	–1.01	0.20	–2.22	6.33

Table 6. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/Furnace and AC/Replacing a Gas WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	3.64	–2.81	4.07	–1.23	3.67
Mixed-Humid	2.09	–5.21	2.80	–1.90	–2.22
Hot-Dry	2.53	–4.31	2.48	–1.55	–0.85
Mixed-Dry	0.41	–5.28	2.08	–2.21	–5.01
Marine	1.97	–7.88	0.67	–2.04	–7.28
Cold	–0.02	–6.59	1.87	–2.48	–7.23
Very Cold	–1.64	–7.75	1.13	–2.96	–11.22

Table 7. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/Furnace and AC/Replacing a Gas WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	2.31	–0.10	0.14	–1.35	1.00
Mixed-Humid	–2.91	–0.55	0.39	–1.89	–4.96
Hot-Dry	0.33	–0.12	0.08	–1.81	–1.52
Mixed-Dry	–6.38	–0.18	0.12	–2.24	–8.68
Marine	–2.53	–0.57	0.06	–2.25	–5.30
Cold	–9.56	–0.82	0.41	–2.31	–12.28
Very Cold	–14.47	–0.98	0.26	–2.65	–17.83

Table 8. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/ASHP/Replacing an Electric WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	17.63	–2.45	3.95	–0.52	17.63
Mixed-Humid	22.07	–5.66	2.77	–0.38	18.80
Hot-Dry	18.71	–3.62	2.23	–0.52	16.81
Mixed-Dry	22.06	–5.86	1.97	–0.44	17.73
Marine	23.97	–6.97	0.60	–0.34	17.27
Cold	25.64	–8.85	1.91	–0.30	18.40
Very Cold	28.90	–12.13	1.19	–0.23	17.74

Table 9. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/ASHP/Replacing An Electric WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	16.01	–0.04	0.12	–0.70	15.38
Mixed-Humid	17.88	–0.53	0.35	–0.81	16.88
Hot-Dry	16.13	–0.03	0.01	–0.85	15.27
Mixed-Dry	14.39	–0.12	0.07	–1.12	13.22
Marine	19.95	–0.45	0.04	–0.84	18.69
Cold	15.99	–0.65	0.37	–1.04	14.67
Very Cold	13.51	–0.59	0.25	–1.10	12.07

Table 10. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/ER Heat and AC/Replacing an Electric WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	17.24	–7.06	3.40	–0.51	13.08
Mixed-Humid	21.69	–13.59	2.43	–0.35	10.18
Hot-Dry	18.31	–10.77	1.97	–0.50	9.01
Mixed-Dry	21.68	–13.73	1.79	–0.41	9.34
Marine	23.59	–20.27	0.53	–0.31	3.54
Cold	25.27	–18.01	1.70	–0.26	8.70
Very Cold	28.54	–22.18	1.05	–0.18	7.23

Table 11. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/ER Heat and AC/Replacing an Electric WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	15.63	–0.14	0.03	–0.69	14.84
Mixed-Humid	17.49	–1.32	0.28	–0.79	15.67
Hot-Dry	15.75	–0.10	0.00	–0.83	14.82
Mixed-Dry	14.00	–0.29	0.04	–1.09	12.67
Marine	19.56	–1.25	0.03	–0.82	17.53
Cold	15.60	–1.66	0.32	–1.00	13.26
Very Cold	13.12	–1.64	0.23	–1.05	10.66

Table 12. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/Furnace and AC/Replacing a Gas WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	3.75	–3.48	4.33	–0.55	4.05
Mixed-Humid	3.88	–6.68	3.01	–0.52	–0.31
Hot-Dry	3.18	–5.33	2.55	–0.58	–0.18
Mixed-Dry	2.68	–6.84	2.25	–0.62	–2.54
Marine	4.35	–9.89	0.68	–0.48	–5.34
Cold	3.66	–8.82	2.08	–0.58	–3.65
Very Cold	3.81	–10.76	1.26	–0.62	–6.30

Table 13. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/Furnace and AC/Replacing a Gas WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	1.96	–0.09	0.07	–0.73	1.22
Mixed-Humid	–0.63	–0.76	0.39	–0.96	–1.96
Hot-Dry	0.33	–0.08	0.02	–0.91	–0.65
Mixed-Dry	–5.52	–0.20	0.08	–1.30	–6.94
Marine	–0.02	–0.69	0.05	–0.99	–1.65
Cold	–6.54	–1.10	0.43	–1.31	–8.51
Very Cold	–12.20	–1.24	0.30	–1.48	–14.62

Appendix D: Breakeven Cost Calculation Methodology

The breakeven cost of an HPWH is defined as the point where the NPC of the system equals the NPB to its owner:

$$NPC = NPB \tag{6}$$

The NPC is the cumulative discounted cost of the system, including initial cost, financing, tax impacts, incentives, and O&M, equal to the sum of the cost in each year multiplied by the discount factor in that year. The NPC is:

$$NPC = IC_{HPWH} - IC_{base} + \sum_{i=0}^{n} (MC_i - I_i) DF_i \tag{7}$$

where:

IC_{HPWH}	=	the net installed cost of the HPWH,
IC_{base}	=	the net installed cost of the base case water heater,
n	=	the study length (15 years),
MC_i	=	the maintenance costs in year i ($100 every 5 years),
I_i	=	the incentives in year i, and
DF_i	=	the discount factor in year i.

The discount factor can for any given year is:

$$DF_i = \frac{1}{(1+d)^i} \tag{8}$$

where d is the discount rate (5%).

The NPB is the discounted cumulative benefits of reduced electricity bills over the evaluated period or the sum of the benefits in each year multiplied by the discount factor. The NPB is:

$$NPB = \sum_{i=0}^{n} \$_{saved,i} \cdot DF_i \cdot FEF_i \tag{9}$$

where:

n	=	the study length (15 years),
$\$_{saved,i}$	=	the annual bill savings in year i, and
FEF_i	=	the fuel escalation factor in year i.

The fuel escalation factor for any given year is:

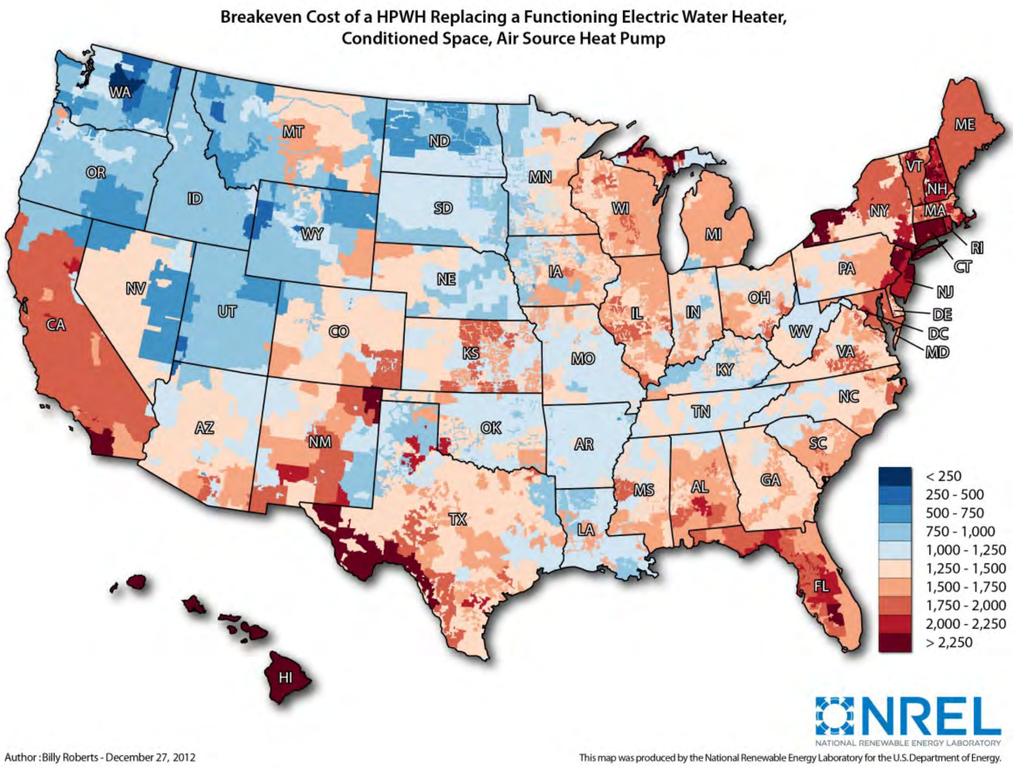
$$FEF_i = (1 + e)^i \tag{10}$$

Where e is the fuel escalation rate (0.5%).

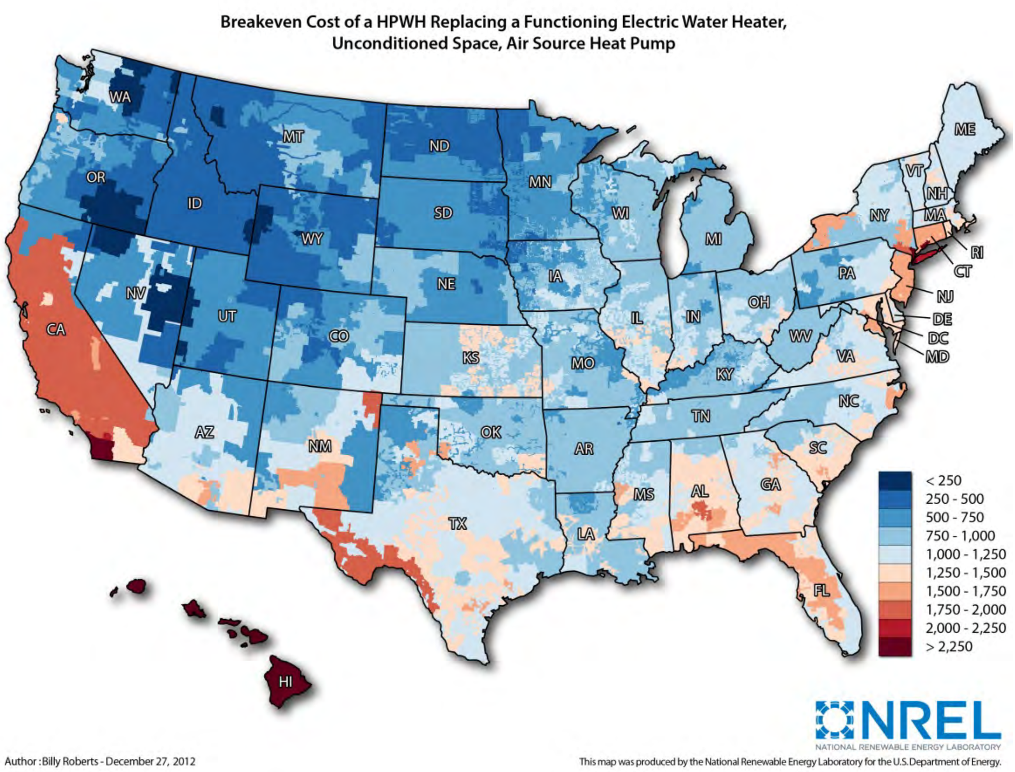
To calculate the breakeven cost of the HPWH, Equations 6–9 are combined and solved for IC_{HPWH}, the breakeven cost.

Appendix E: Breakeven Costs for Cases Replacing a Functioning Water Heater

The maps presented here show cases where a functioning WH is replaced by a 50-gal HPWH when no incentives are considered. In this case, the existing WH is assumed to have no value, even though it may have several years of useful life remaining; it is unlikely (although not impossible) that the used water heater will be sold. Thus, the breakeven costs in this case are all lower than when a failed WH is replaced or an HPWH is installed in new construction. Despite this, in a few locations (notably Hawaii, in New England, Florida, and California), it may make sense to replace a functioning electric WH with an HPWH when a home has an ASHP and the WH is installed in conditioned space. This also applies to California for all-electric homes when the WHs are in unconditioned space. Figure 31 through Figure 33 show the breakeven costs for all cases where functioning WHs are replaced with HPWHs.

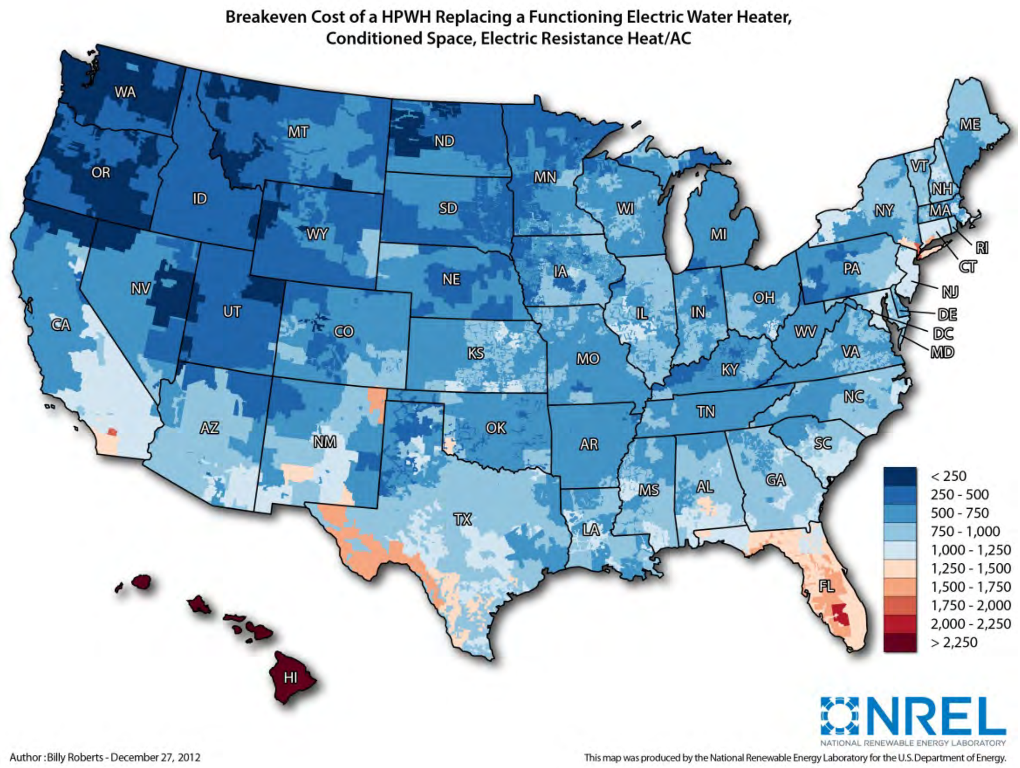


(a)

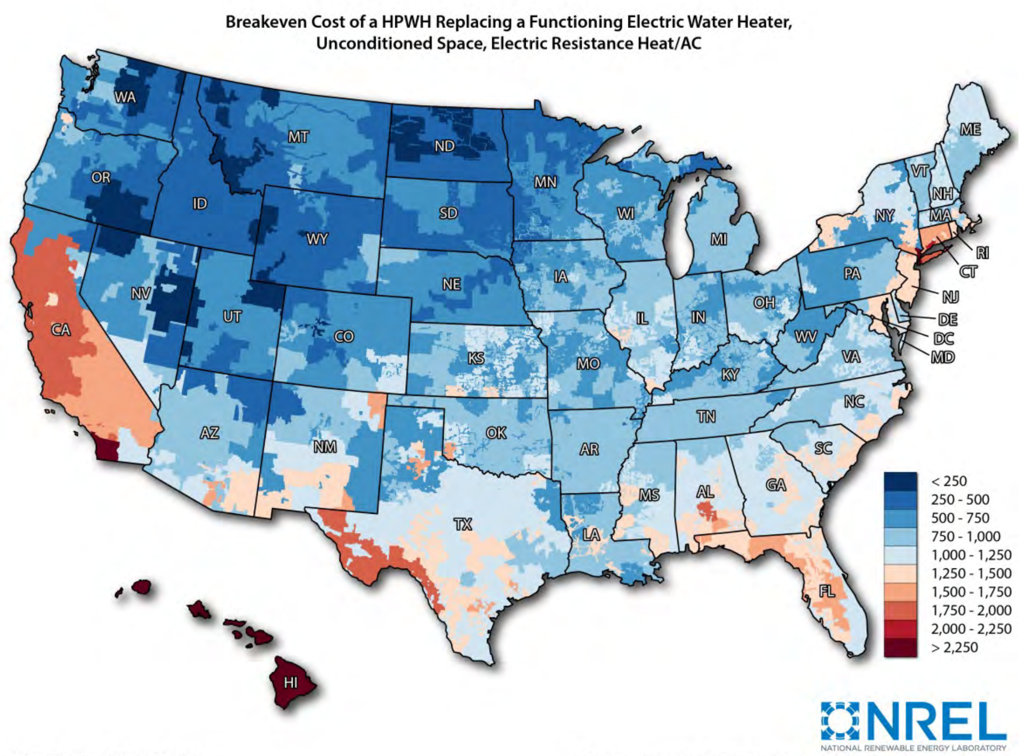


(b)

Figure 31. Breakeven cost of an HPWH replacing a functioning electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space

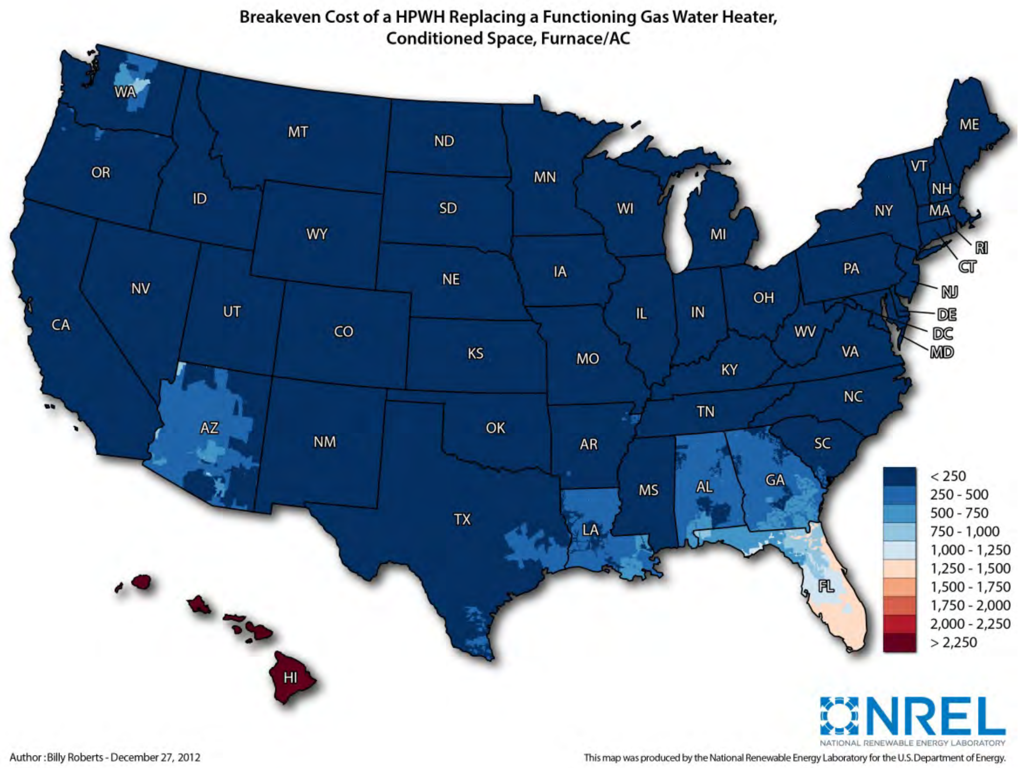


(a)

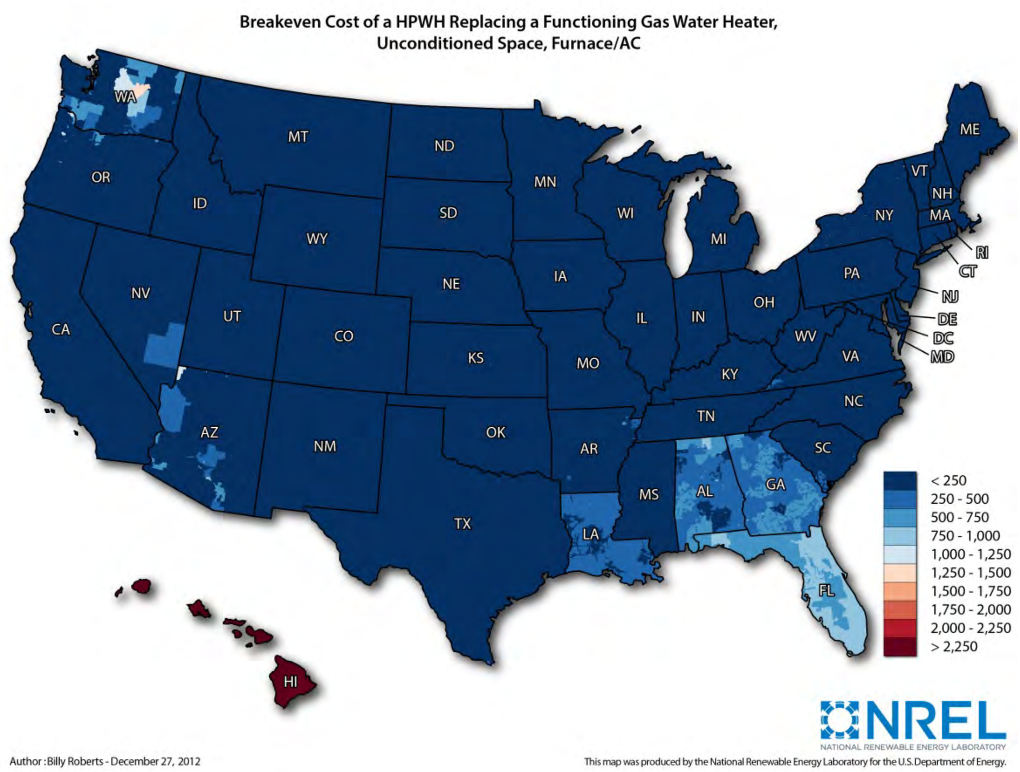


(b)

Figure 32. Breakeven cost of an HPWH replacing a functioning electric WH for a home with ER heat and an AC when the WH is in (a) conditioned and (b) unconditioned space



(a)



(b)

Figure 33. Breakeven cost of an HPWH replacing a functioning gas WH for a home with a furnace and an AC when the WH is in (a) conditioned and (b) unconditioned space

Appendix F: Incentives Used in This Study

Table 14 provides the full list of incentives used in this study. This list was created on March 2, 2012 and includes all incentives that were available at that time (Interstate Renewable Energy Council, 2012). The incentive type category indicates whether the incentive is a utility rebate program (URP), a state rebate program (SRP), or a personal tax credit (PTC). SRP and PTC incentives are statewide programs; URPs apply to the specific utility service territory. The notes indicate if the incentive applies to specific cases (for example, if it is available only for homes replacing a gas WH with an HPWH). The current $300 federal incentive was also applied to all locations for any case that includes incentives.

Table 14. Complete List of Local Incentives Used in This Study

State	Incentive Provider	Incentive Type	Value ($)	Notes
AL	Alabama Power	URP	200	Replacing gas WH
AL	Gulf Power	URP	700	
AZ	Sulphur Springs Valley Electric Co–Op	URP	100	
AR	Southwestern Electric Power Company	URP	40	
AR	State	SRP	200	
CA	City of Palo Alto	URP	200	
CA	Lassen MUD	URP	200	
CA	Modesto Irrigation District	URP	25	
CA	California Pacific Power	URP	40	
CA	Pacific Gas & Electric	URP	30	
CA	Southern California Edison	URP	30	
CA	San Diego Gas & Electric	URP	30	
CA	Silicon Valley Power	URP	1000	
CA	Truckee Donner Public Utility District	URP	100	
CO	Empire Energy Association	URP	250	
CO	Gunnison County Electric Association	URP	70	
CO	Highline Electric Association	URP	375	
CO	KC Electric Association	URP	75	
CO	KC Electric Association	URP	150	
CO	Morgan County Rural Electric Association	URP	370	
CO	Mountain Parks Electric Association	URP	20	
CO	Mountain View Electric Association	URP	70	
CO	Poudre Valley Rural Electric Association	URP	270	
CO	Sangre De Cristo Electric Association	URP	100	
CO	San Miguel Power Association	URP	100	
CO	San Isabel Electric Association	URP	100	

State	Incentive Provider	Incentive Type	Value ($)	Notes
CO	Southeast Colorado Power Association	URP	100	Replacing electric WH
CO	Southeast Colorado Power Association	URP	200	Replacing gas WH
CO	Xcel Energy	URP	450	
CO	Y–W Electric Association	URP	350	Replacing electric WH
CO	Y–W Electric Association	URP	400	Replacing gas WH
CT	Connecticut Light & Power	URP	400	Replacing electric WH
CT	Groton Utilities, Borzah L&P	URP	500	
FL	Clay Electric Co–Op	URP	175	
FL	Gainsville Regional Utility	URP	200	Replacing electric WH
FL	Gulf Power	URP	700	
FL	City of Tallahassee Electric	URP	600	Replacing gas WH
FL	Orlando Utility Commission	URP	650	
GA	Diverse Power	URP	150	Replacing electric WH
GA	Diverse Power	URP	500	Replacing gas WH
GA	Electric Power Board	URP	50	Replacing electric WH
GA	Georgia Power	URP	250	
GA	Jackson EMC	URP	525	
GA	Marietta Power & Water	URP	250	Replacing gas WH
GA	Walton EMC	URP	200	Replacing gas WH
GA	Sawnee Electric	URP	100	Replacing electric WH
HI	Hawaiian Energy	URP	200	
HI	Kauai Island Utility Cooperative	URP	300	
ID	Avista	URP	50	
ID	Idaho Northern Lights Corp.	URP	25	
ID	Rocky Mountain Power	URP	50	
IL	Adams Electric Cooperative	URP	75	Replacing gas WH
IL	City Water, Light, and Power	URP	200	Replacing gas WH
IL	Corn Belt Energy	URP	400	
IL	Rural Electric Convenience Cooperative	URP	200	
IL	Southeaster Illinois Electric Cooperative	URP	250	
IL	Wayne–White Electric Cooperative	URP	400	
IL	Western Illinois Electric Cooperative	URP	75	
IN	Bartholomew County REMC	URP	400	
IN	Clark County REMC	URP	400	
IN	Daviess–Martin County REMC	URP	400	
IN	Harrison REMC	URP	400	
IN	Henry County REMC	URP	400	
IN	Jackson REMC	URP	375	
IN	Johnson County REMC	URP	50	

State	Incentive Provider	Incentive Type	Value ($)	Notes
IN	Lagrange County REMC	URP	400	Replacing electric WH
IN	Marshall County REMC	URP	200	
IN	Orange County REMC	URP	400	
IN	Parke County REMC	URP	50	
IN	RushShelby Energy	URP	400	
IN	Southeastern Indiana REMC	URP	375	
IN	Southern Indiana Power	URP	400	
IN	Tipmont REMC	URP	400	
IN	United REMC	URP	100	Replacing gas WH
IN	Wabash Valley Power Association	URP	400	Replacing electric WH
IN	Whitewater Valley REMC	URP	50	
IN	Win Energy REMC	URP	400	
IA	Alliant Energy Interstate Light & Power	URP	100	
IA	Butler County REC	URP	300	
IA	Calhoun County REC	URP	300	
IA	Consumer Energy REC	URP	500	
IA	Clarke Electric Cooperative	URP	500	
IA	Coon Rapids Municipal Utilities	URP	100	
IA	East Central Iowa REC	URP	500	
IA	Easter Iowa REC	URP	500	
IA	Farmers Electric Cooperative	URP	400	
IA	Franklin REC	URP	300	
IA	Guthrie County REC	URP	500	
IA	Linn County REC	URP	500	
IA	Marquoketa Valley REC	URP	500	
IA	MidAmerican Energy	URP	50	
IA	Midland Power Cooperative	URP	500	
IA	Pella Electric Cooperative	URP	500	
IA	Raccoon Valley Electric Cooperative	URP	300	
IA	Southwest Iowa REC	URP	500	
IA	Spencer Municipal Utilities	URP	500	
IA	TIP REC	URP	600	
KY	State	PTC	250	
MD	Delmarva Power	URP	350	
MD	PEPCO	URP	350	
MD	Southern Maryland Electric Cooperative	URP	350	
MA	Cape Light Compact	URP	1000	
MA	Nstar	URP	1000	
MA	National Grid	URP	1000	

State	Incentive Provider	Incentive Type	Value ($)	Notes
MA	Unitil	URP	1000	
MA	Western Massachusetts Electric	URP	1000	
MI	Alger Delta Electric Cooperative	URP	100	Replacing electric WH
MI	Coverland Electric Cooperative	URP	100	Replacing electric WH
MI	City of Escanaba	URP	100	Replacing electric WH
MI	Great Lakes Energy	URP	100	Replacing electric WH
MI	Homeworks Tri–County Electric	URP	100	Replacing electric WH
MI	Marquette Board of Light & Power	URP	100	Replacing electric WH
MI	Midwest Energy	URP	100	Replacing electric WH
MI	Presque Isle Electric & Gas	URP	100	Replacing electric WH
MI	Thumb Electric	URP	100	Replacing electric WH
MN	Dakota Electric Association	URP	100	
MN	Marshall Municipal Utilities	URP	500	
MS	Mississippi Power	URP	300	Replacing gas WH
MS	Pearl River Valley Electric Power Association	URP	150	Replacing gas WH
MO	Co–Mo Electric Cooperative	URP	50	Replacing electric WH
MO	Missouri Cuivre River Electric	URP	50	Replacing electric WH
MO	Independence Power & Light	URP	300	
MO	Intercounty Electricity Cooperative	URP	50	Replacing electric WH
MO	Kirkwood Electric	URP	100	Replacing gas WH
MO	Missouri Rural Electric Cooperative	URP	50	Replacing electric WH
MO	Ozark Border Electric Cooperative	URP	75	Replacing gas WH
MO	Ozark Border Electric Cooperative	URP	50	Replacing electric WH
MO	White River Valley Electric Cooperative	URP	50	Replacing electric WH
MT	Montana	PTC	350	
MT	Flathead Electric Cooperative	URP	60	
MT	Yellowstone Valley Electric Cooperative	URP	150	
NM	Central New Mexico Electric Cooperative	URP	70	
NY	Central Hudson Gas & Electric	URP	400	
NY	Consolidated Edison	URP	400	
NC	Carteret–Craven Electric Cooperative	URP	200	
NC	City of High Point Electric	URP	150	
NC	City of Statesville	URP	150	
NC	Lumbee River EMC	URP	450	
NC	Progress Energy Carolinas	URP	350	
NC	South River Electric Membership Corporation	URP	200	
OR	Ashland Electric Utility	URP	65	

State	Incentive Provider	Incentive Type	Value ($)	Notes
OR	Central Electric Cooperative	URP	25	
OR	Central Lincoln People's Utility District	URP	25	
OR	EPUD	URP	30	
OR	EWEB	URP	25	
OR	Forest Grove Light & Power	URP	25	
OR	Mcminnville Water & Light	URP	25	
OR	Monmouth Power & Light	URP	25	
OR	Oregon Trail Electric Co–op	URP	100	
OR	Salem Electric	URP	60	
OR	Tillamook County PUD	URP	50	
PA	PenElec	URP	300	
PA	Penn Power	URP	300	
PA	Met–Ed	URP	300	
PA	West Penn Power	URP	300	
PA	PECO	URP	300	
PA	PPL Electric Utilities	URP	300	
SC	Progress Energy Carolinas	URP	350	
SC	Santee Cooper	URP	35	
SC	South Carolina Gas & Electric	URP	250	
SD	MidAmerican Energy	URP	50	
TN	Cookeville Electric Department	URP	100	
TN	Fort Loudoun Electric Cooperative	URP	50	
TN	Middle Tennessee Electric Membership Corporation	URP	200	Replacing gas WH
TN	Middle Tennessee Electric Membership Corporation	URP	50	Replacing electric WH
TN	Mursfreesbro	URP	100	Replacing gas WH
TN	Mursfreesbro	URP	25	Replacing electric WH
TN	Southwest Tennessee EMC	URP	200	Replacing gas WH
TN	Southwest Tennessee EMC	URP	50	Replacing electric WH
TN	Tennessee Valley Authority	URP	50	
TN	Upper Cumberland EMC	URP	100	
TN	Winchester Utilities	URP	100	
TX	Austin Energy	URP	500	Replacing electric WH
TX	CoServ Electric Co–op	URP	25	
TX	Farmers Electric Cooperative	URP	100	
TX	GVEC, Gonzales	URP	300	
TX	Magic Valley Electric Cooperative	URP	250	
TX	Tri–County Electric Cooperative	URP	75	
UT	Dixie Escalante Power Company	URP	500	Replacing gas WH

State	Incentive Provider	Incentive Type	Value ($)	Notes
UT	Dixie Escalante Power Company	URP	150	Replacing electric WH
UT	Rocky Mountain Power	URP	50	
VA	City of Danville Utilities	URP	100	
WA	Avista	URP	50	
WA	Benton PUD	URP	25	
WA	Clallam County PUD	URP	25	
WA	Columbia REA	URP	25	
WA	Cowlitz PUD	URP	25	
WA	Grays Harbor PUD	URP	25	
WA	Inland Power & Light Company	URP	25	Replacing electric WH
WA	Mason PUD	URP	250	
WA	Modern Electric Water Company	URP	25	
WA	Orcas Light & Power	URP	25	
WA	Pacific Power	URP	50	
WA	Peninsula Light Co	URP	50	
WA	Port Angeles Public Works & Utilities	URP	25	
WA	Puget Sound Electric	URP	500	Unconditioned space
WA	Richland Energy Services	URP	25	
WA	Seattle Light & Power	URP	250	Unconditioned space
WI	Focus on Energy	SRP	25	
WI	Riverland Energy Cooperative	URP	300	
WI	Vernon Electric Cooperative	URP	300	
WY	Cheyenne Light, Fuel & Power	URP	75	
WY	Rocky Mountain Power	URP	75	

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Measure Guideline: Heat Pump Water Heaters in New and Existing Homes

C. Shapiro, S. Puttagunta, and D. Owens
Consortium for Advanced Residential Buildings (CARB)

February 2012

Building America
U.S. Department of Energy

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Definitions

CARB	Consortium for Advanced Residential Buildings
COP	Coefficient of Performance
DHW	Domestic Hot Water
EF	Energy Factor
ERWH	Electric Resistance Water Heater
GE	General Electric
IECC	International Energy Conservation Code
NREL	National Renewable Energy Laboratory
ROI	Return On Investment
SPB	Simple Payback Period

Foreword

Heat pump water heaters (HPWHs) promise to significantly reduce energy consumption for domestic hot water (DHW) over standard electric resistance water heaters (ERWHs). While ERWHs perform with energy factors (EFs) around 0.9, new HPWHs boast EFs upwards of 2.0. High energy factors in HPWHs are achieved by combining a vapor compression system, which extracts heat from the surrounding air at high efficiencies, with electric resistance element(s), which are better suited to meet large hot water demands. Swapping ERWHs with HPWHs could result in roughly 50% reduction in water heating energy consumption for 35.6% of all U.S. households.

This Building America Measure Guideline is intended for builders, contractors, homeowners, and policy-makers. While HPWHs promise to significantly reduce energy use for DHW, proper installation, selection, and maintenance of HPWHs is required to ensure high operating efficiency and reliability. This document is intended to explore the issues surrounding HPWHs to ensure that homeowners and contractors have the tools needed to appropriately and efficiently install HPWHs.

Section 1 of this guideline provides a brief description of HPWHs and their operation. Section 2 highlights the cost and energy savings of HPWHs as well as the variables that affect HPWH performance, reliability, and efficiency. Section 3 gives guidelines for proper installation and maintenance of HPWHs, selection criteria for locating HPWHs, and highlights of important differences between ERWH and HPWH installations.

Throughout this document, CARB has included results from the evaluation of 14 heat pump water heaters (including three recently released HPWH products) installed in existing homes in the northeast region of the United States.

Acknowledgements

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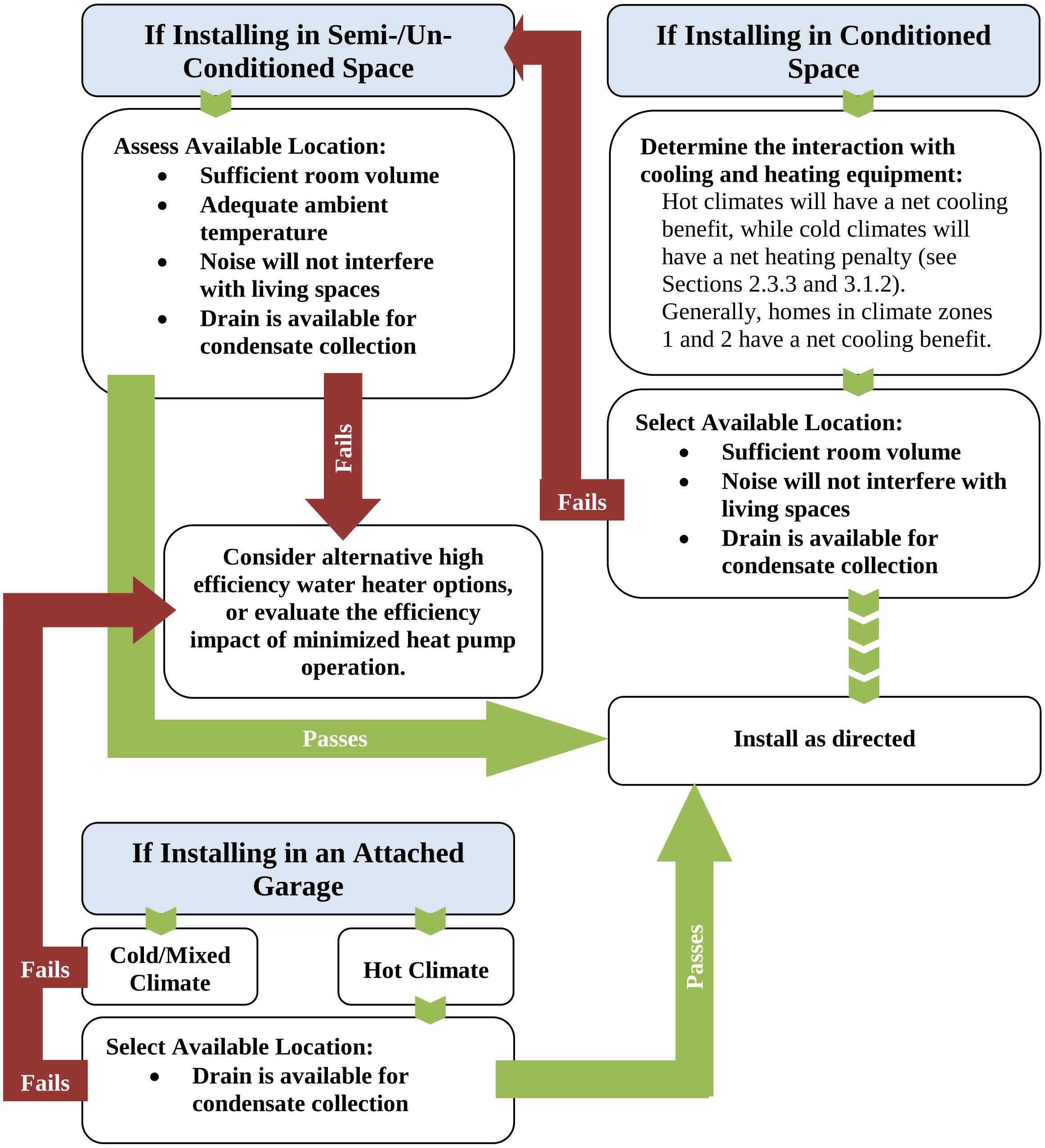
Progression Summary



1 Introduction

1.1 Background

Heat pump water heaters (HPWHs) promise to significantly reduce energy consumption for domestic hot water (DHW) over standard electric resistance water heaters (ERWHs). While ERWHs perform with energy factors (EFs) around 0.9, new HPWHs boast EFs upwards of 2.0. High energy factors in HPWHs are achieved by combining a vapor compression system, which extracts heat from the surrounding air at high efficiencies, with electric resistance element(s), which are able to help meet large hot water demands. Water heating is the third largest contributor to residential energy consumption, after space heating and space cooling (EERE 2011). Swapping ERWHs with HPWHs could result in roughly 50% reduction in water heating energy consumption for 35.6% of all households nationally, as shown in Table 1.

Table 1. 2005 RECS Data Sample of Households with ERWHs (Franco et al. 2010)

Census Region	Fraction of Households with ERWH by Region
Northeast	17.1%
Midwest	26.7%
South	58.8%
West	21.5%
National	35.6%

While HPWHs are not new, products designed for the residential market have achieved minimal market penetration in the past, primarily because past products were produced by smaller, niche-market manufacturers, encountered reliability issues, and operated with limited market infrastructure. Although HPWHs were first commercialized in the 1980s, they were typically add-ons to existing ERWHs, which required specialized knowledge for installation and often required both an HVAC contractor and a plumber to install the system. The development of drop-in HPWHs allowed for easy installation by a single trade (Tomlinson 2002).

Recently, major manufacturers, such as General Electric (GE), Rheem, AO Smith, and Stiebel-Eltron, have introduced “drop-in” HPWHs (Table 2). The development of these models has been fueled by the large electric water heater replacement market and ENERGY STAR® certification of many HPWHs, which often allows for state, federal, local, and utility rebates, tax credits, and other incentives. Furthermore, the new federal water heater standard, which takes effect in 2015, mandates EFs around 2.0 for all new electric storage water heaters with capacities greater than 55 gallons (Federal Register 2010). This regulation effectively mandates that water heaters be HPWHs in applications with large hot water demands and the need for electric storage water heaters.

Table 2. Key Specifications of Some HPWHs Currently Available in the U.S. Market

Model	Capacity (gal)	Energy Factor	First Hour Rating (GPH)
GE GeoSpring	50	2.35	63.0
AO Smith Voltex	60 / 80	2.33	68.0 / 84.0
Stiebel Eltron Accelera300	80	2.51	78.6
Rheem EcoSense	40 / 50	2.00	56.0 / 67.0
AirGenerate ATI	50 / 66	2.39 / 2.40	60.0 / 75.0

1.2 What Are Heat Pump Water Heaters?

In residential applications, the most common water heater appliances are electric resistance with storage tank (ERWH), natural gas with storage tank, and tankless natural gas. HPWHs are designed as replacements for standard ERWHs and are able to achieve higher energy factors by adding an additional heating mechanism to existing ERWH designs. The primary heating mechanism is a heat pump refrigeration cycle (like those in a refrigerator or air conditioner, but operating in reverse) that transfers heat from the surrounding air to the water stored in the tank (Figure 1). Auxiliary electric resistance elements are also included for reliability and quicker recovery. Unlike most previous models, most current HPWHs are truly hybrids: They integrate a heat pump and electric resistance element(s) into a single storage tank.

Figure 1. HPWH operation

The heat pumps can heat water in the storage tanks at high efficiencies, but the heat pumps have heating capacities lower than those of traditional electric resistance elements. Typical 4.5-kW electric resistance elements can reliably heat over 20 gallons of water per hour (GE 2011), whereas the heat pump has a longer heating rate (GE claims 8 gallons per hour at 68°F air temperature). The efficiency of a HPWH will vary considerably based on several operating parameters, such as inlet water temperature, tank temperature, inlet air temperature, and temperature set point.

These units often have several modes of operation, such as hybrid mode, heat pump mode, and electric resistance mode. The names of these modes differ by manufacturer, but most models include some combination of the above. The hybrid mode uses both the electric resistance element(s) and the heat pump to meet demand, but uses the heat pump whenever possible to maximize the efficiency of the unit. Heat pump mode includes only heat pump operation, which improves the efficiency of the unit, but reduces the recovery capacity of the water heater. Electric resistance mode works like a traditional ERWH and can be used when the ambient temperature of the space is inadequate or there is a problem with the heat pump.

2 Cost and Performance

Using HPWHs is a potentially cost-effective method of substantially reducing energy use for DHW when compared to use of electric resistance water heaters. Section 2.2 explores the energy and cost savings of HPWHs, while Section 2.3 explores the variables that affect the overall performance of HPWHs. Sections 2.4 and 2.5 discuss the dehumidification potential, reliability, and safety of HPWHs.

2.1 Performance Metrics

The efficiency of residential electric water heaters in the United States is measured and reported using the energy factor (EF) value. The energy factor represents the efficiency of the electric element and tank losses under a consistent, 24-hour test procedure. In this procedure, 64.3 gallons of water are drawn from the tank in six equal draws spaced one hour apart. The temperature of the drawn water must be 135±5˚F and the ambient temperature is 67.5˚F. The energy factor is simply the ratio of energy output to energy input during the test procedure (Burch and Erickson 2004; Federal Register 1998).

Since the energy factor is defined under the specific test conditions outlined above, for a unit that operates under real-world conditions or conditions different than the standard test, the coefficient of performance (COP) is the term used here to describe the efficiency of the unit under the measured conditions. Like EF, COP is the unit-less ratio of energy output to energy input during its operation.

When comparing energy use of water heaters using different fuels, EF or COP can be misleading because energy use is only measured at the home and does not include energy lost to extraction, conversion, or transmission of the energy. Therefore, water heaters using different fuels should be compared using a different metric. While energy usage is usually measured in site energy, which is the energy used at the home and is typically measured at a utility meter in units of kWh (electricity), therms (natural gas), or gallons (fuel oil or propane), a better metric for measured energy usage is source energy, which is the sum of energy used at the home and the energy lost to extraction, conversion, or transmission. Site energy easily can be converted to source energy using a site-to-source ratio (Deru and Torcellini 2007) for the given fuel.

When comparing water heaters that use different fuels, this guideline will use two metrics: cost to deliver each unit of water heating energy ($/delivered mmBTU) and "source COP," which is the efficiency of converting source energy into water heating energy. These metrics include the efficiency of extraction, conversion, and transmission.

2.2 Energy and Cost Savings

Traditional ERWHs are an inefficient and expensive form of water heating. As shown in Table 3 , electric resistance water heating has the lowest source COP and the highest cost per mmBTU of delivered water thermal energy. On the other hand, HPWHs have efficiencies and operating costs similar to natural gas storage water heaters, making HPWHs an excellent choice for homeowners who currently use an electric resistance, fuel oil, or propane water heater and do not have access to natural gas. Replacement of natural gas water heaters with HPWHs is not recommended in heating dominated climates because HPWHs will increase the load on the space heating system without a similar benefit to the space cooling system.

Table 3. Comparison of Water Heaters by Fuel Type

Water Heater Type	Storage Tank	Site-to-Source Ratio	Fuel Cost	EF	Source COP	$/Delivered mmBTU
Electric Resistance	Tank	3.365	$0.1126/kWh	0.90	0.27	$36.67
Heat Pump	Tank	3.365	$0.1126/kWh	2.00	0.59	$16.50
Fuel Oil	Tank	1.158	$2.8/gal	0.59	0.51	$34.22
Natural Gas	Tank	1.092	$1.1633/therm	0.59	0.54	$19.72
Natural Gas	Tankless	1.092	$1.1633/therm	0.82	0.75	$14.19
Condensing Natural Gas	Tankless	1.092	$2.03/gal	0.94	0.86	$12.38
Propane	Tank	1.151	$2.03/gal	0.59	0.51	$37.40

Marketed as replacements for electric resistance units, HPWHs promise to save considerable electric energy and money over traditional ERWHs. According to the U.S. government EnergyGuides for a 50 gallon ERWH with an EF of 0.90 and a HPWH with an EF of 2.35, a HPWH could save 2,684 kWh per year for an average family (Table 4). These water heaters are considerably more expensive to install than traditional ERWHs, but electric savings will likely save more money over the course of the water heater's life. Table 4 shows the installation and annual operating costs, according to the National Renewable Energy Laboratory's (NREL) National Residential Efficiency Measures Database and the U.S. government Energy Guide labels.

Table 4. HPWH vs. ERWH (U.S. Government EnergyGuide Labels)

Water Heater	Annual Electric Usage (kWh)†	Installation Cost*	Annual Operating Costs†
HPWH (50 gal, EF = 2.35)	1,856	$2,100	$198
ERWH (50 gal, EF = 0.90)	4,879	$590	$520

* NREL National Residential Efficiency Measures Database
† US Government Energy Guide Labels

Two methods of evaluating the cost effectiveness of energy efficiency measures are simple payback (SPB) and return on investment (ROI). The SPB period is the ratio of incremental initial cost (dollars) to annual energy savings (dollars/year).

$$SPB = \frac{\text{Initial Cost}}{\text{Annual Utility Savings}} \text{ years}$$

The ROI is the ratio of net proceeds to the investment costs.

$$\text{Simple ROI} = \frac{\text{Total Utility Savings} - \text{Measure Cost}}{\text{Measure Cost}} \times 100\%$$

Using the costs and savings in Table 4, the SPB period for HPWHs is 4.7, and the ROI is 113%.

Supporting Research

Field evaluations suggest that a 50-gallon HPWH has the potential to save a typical home 1,500 to 2,200 kWh per year, which represents a 45%-65% reduction in electricity usage for domestic hot water. These results are not comparable to U.S. government estimates because they reflect varying household usage patterns and, in some cases, the operation of the electric resistance element that reduces overall efficiency. Utilizing a TRNSYS model, actual household usage data for a new 50-gallon HPWH were compared to a typical 50-gallon ERWH with an EF of 0.92. The expected lifetimes of these units are 10 years, and 13 years, respectively. Using the Building America Standard Benchmark DHW Schedules for 1, 2, 3, 4 and 5 bedrooms (Hendron et al. 2010), expected annual energy savings for 1, 2, and 3+ bedroom houses are between 1,750 and 2,200 kWh per year (Table 5).

Table 5. Expected Annual Energy Savings by House Size

Number of Bedrooms	Average Daily Hot Water Usage (Gallons)	Expected Annual Energy Savings (kWh)	Annual Utility Bill Savings	Return on Investment	Payback Period (years)
1	35	1,750	$221	46%	6.6
2	45	2,000	$260	72%	5.8
3+	55	2,200	$286	89%	5.3

2.3 What Affects Performance?

Although the cost and energy savings discussed in the sections above are quite compelling, real world savings of each individual HPWH may be vastly different than those described above. Unlike conventional ERWHs, the efficiency of HPWHs is hard to predict and strongly dependent on hot water usage patterns (see Section 2.3.1) and ambient temperature (see Section 2.3.2). Furthermore, HPWH operation may impact the space conditioning equipment, increasing heating loads and decreasing cooling loads (see Section 2.3.3). Inadequate space and ambient temperature will also markedly reduce HPWH efficiency (see Sections 2.3.4 and 2.3.4).

2.3.1 Hot Water Usage

The primary driver of the efficiency and energy usage of a HPWH is hot water demand (e.g. gallons used per day). As with traditional ERWHs, standby losses reduce overall efficiency, particularly at lower hot water demands. Unlike ERWHs, however, HPWHs experience a reduction in efficiency as electric resistance heating is required to meet larger hot water demands.

There are two ways in which hot water consumption affects efficiency. Electricity consumption certainly increases with overall water consumption (i.e. average gallons used per day). However, electric consumption is even more dependent upon the intensity of hot water use. As the data below show, during intense, high-volume hot water draws, a hybrid HPWH will often operate in electric resistance mode. Electric resistance can provide more hot water faster, but it also consumes at least twice the electricity when compared to heat pump mode.

Figure 3 shows one day's worth of data where a HPWH uses the heat pump to satisfy all hot water needs. Figure 4 shows the same HPWH relying exclusively on the electric resistance elements to meet demand for a day with the same total hot water demand (70 gallons). Each data point in these charts is the totalized consumption over a 15 minute period. The first figure has a distribution of demand across the day, while the second day has large, concentrated draws during the afternoon and evening.

Supporting Research

Overall efficiency peaks around 20-30 gallons per day and decreases with increased demand due to an increase in hot water electric resistance element use. Overall electric usage strictly increases with domestic hot water demand. Figure 2 shows the average COP and electricity used for one HPWH model monitored during CARB's HPWH evaluation. These curves are smoothed fits to daily data and are meant to show the effect of hot water usage on efficiency and electricity usage.

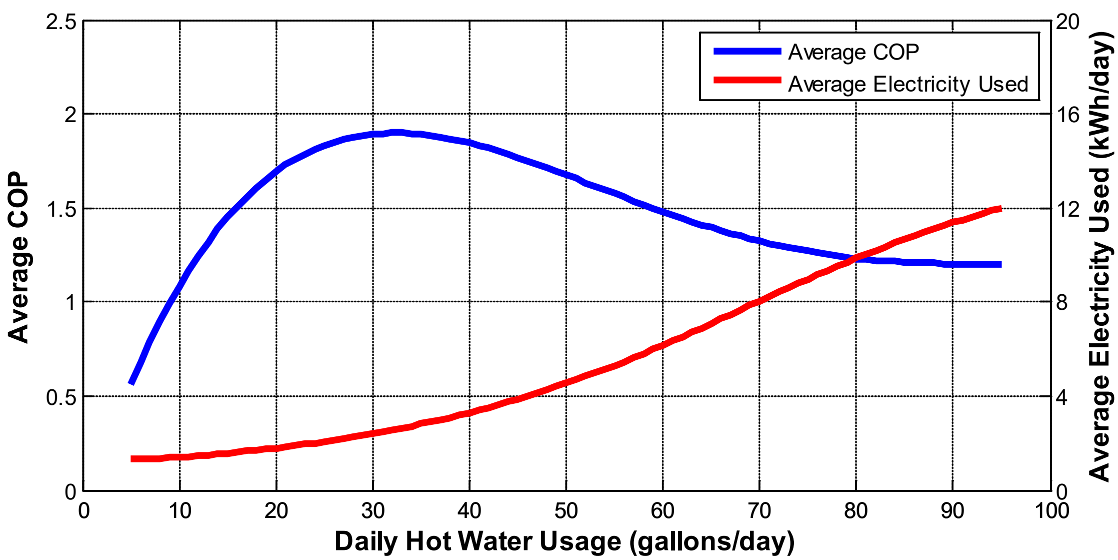


Figure 2. Efficiency and electricity usage as a function of hot water demand

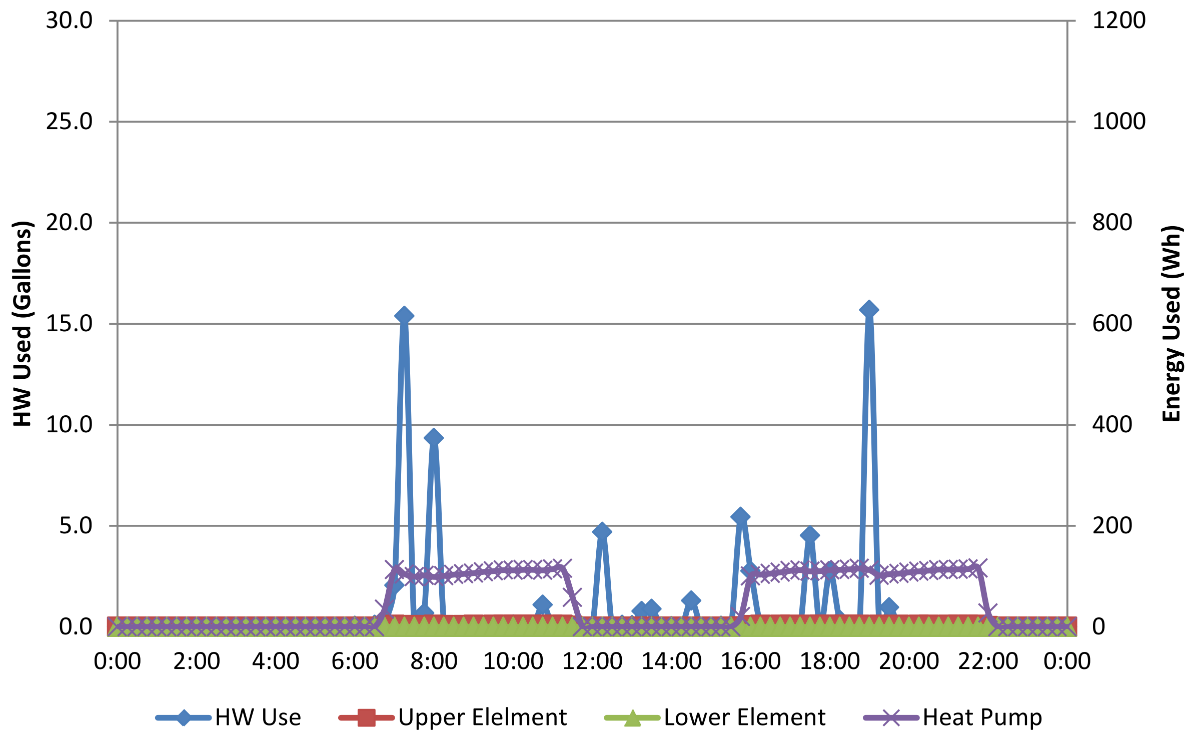


Figure 3. Majority heat pump usage to meet demand

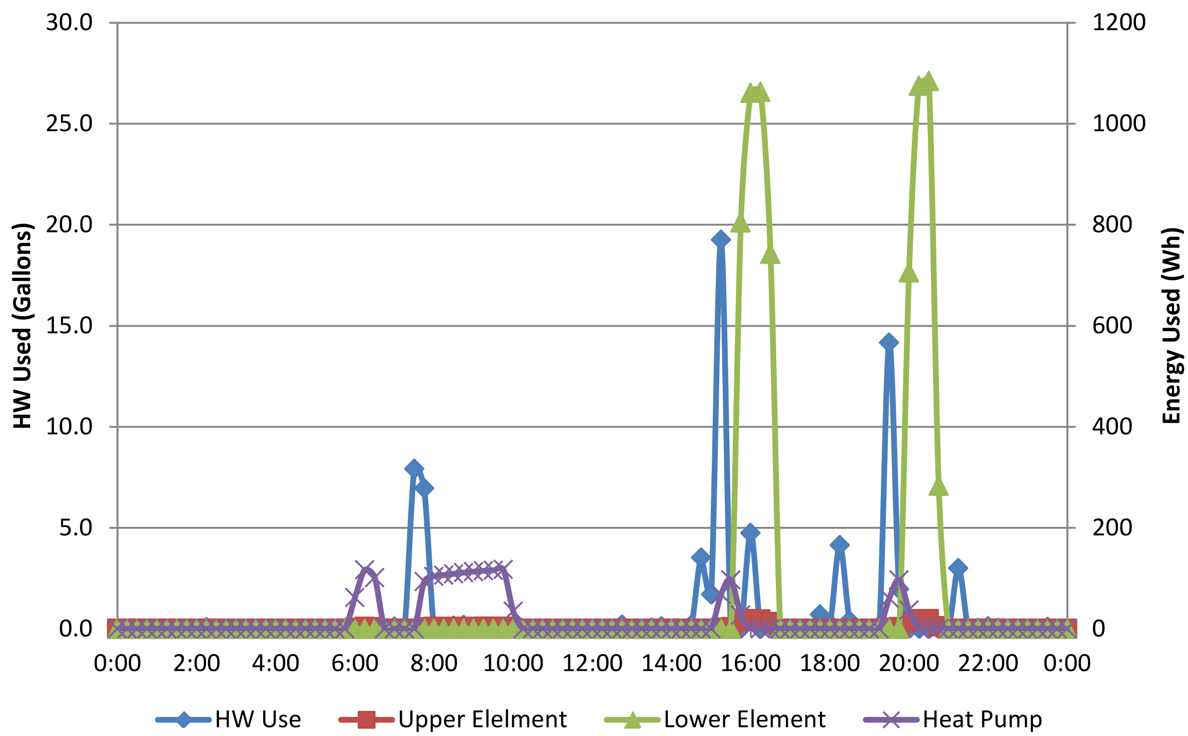


Figure 4. Majority electric resistance usage to meet demand

2.3.2 Ambient Temperature

The efficiency of a HPWH increases substantially with increased ambient temperature (i.e. the air temperature of the space where the HPWH is located). Heat pumps become much more efficient when the heat source (in this case the ambient air) becomes warmer. Warmer air also reduces standby losses.

Supporting Research

Figure 5 shows the effect of ambient temperature on the expected performance of a HPWH operating in heat pump mode. Higher ambient temperatures result in considerably higher COPs. At increased water use levels, an increase in ambient temperature from 50°F to 80°F results in an increase in COP of approximately 0.5.

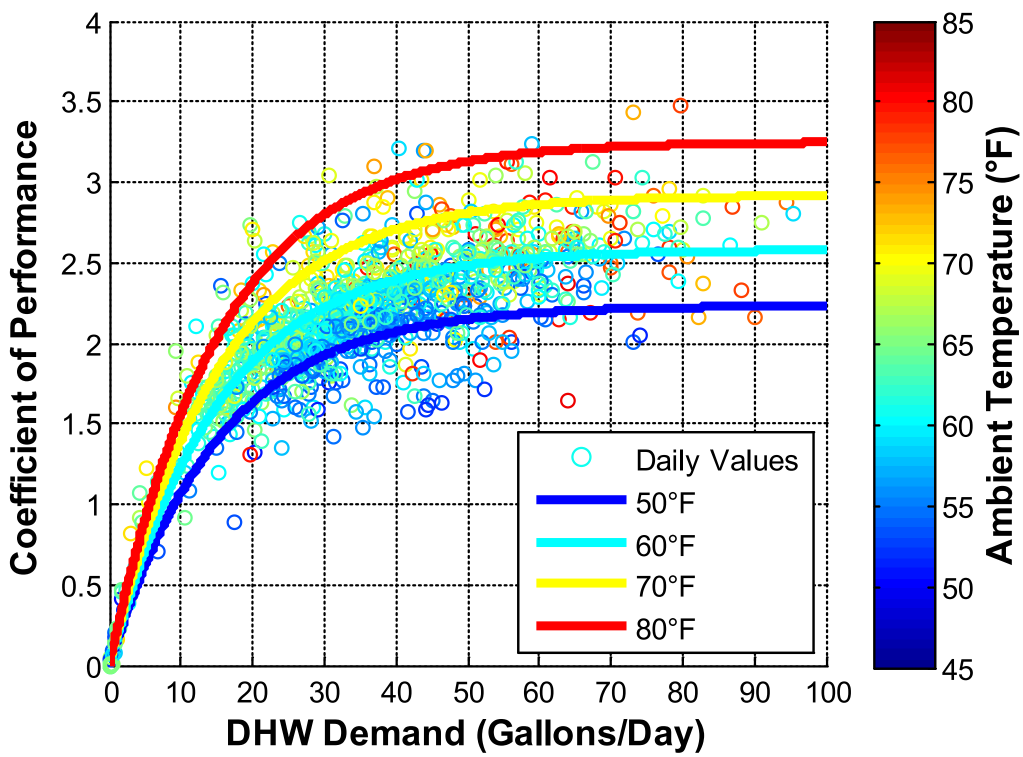


Figure 5. Efficiency of a 50-gal HPWH operating in heat pump mode

The HPWHs will only operate in heat pump or hybrid mode if the ambient temperature of the air entering the water heater is between ~45°F and ~110°F. When the temperature of the incoming air drops below the minimum temperature, the HPWH will switch into electric resistance mode, reducing the efficiency of the unit. In practice, the temperature of the space must be several degrees above the minimum temperature due to the cooling effect of the heat pump operation, which drops the temperature of the space. On the lower end of this temperature range, system efficiency can be compromised due to:

- Increased electric resistance back-up heating
- Decreased hot water output
- Decreased hot water temperature rise.

Supporting Research

As shown in Figure 6, heat pump operation dropped the ambient temperature by over 4°F, from 49°F to near 45°F, which is the minimum allowable ambient temperature for this unit. Colder air temperatures forced the electric resistance elements to turn on to meet hot water demand.

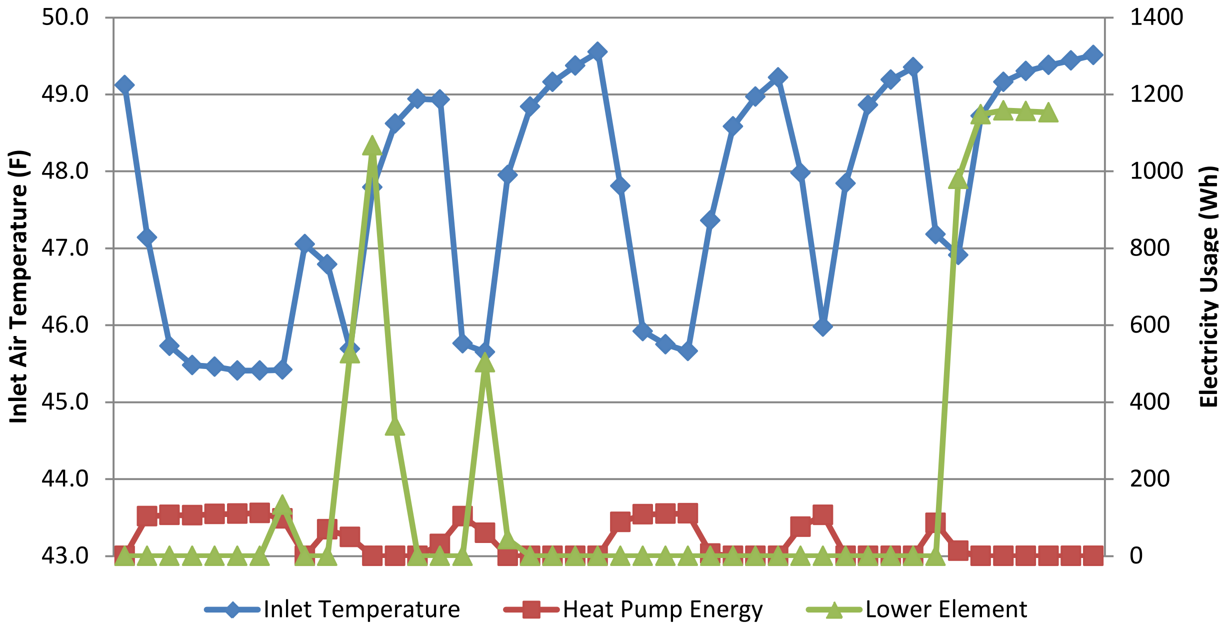


Figure 6. Electricity usage for heat pump and lower element vs. inlet air temperature

2.3.3 Interaction with Space Conditioning Systems

As mentioned above, HPWHs transfer heat from the ambient air to water; this means HPWHs can have a significant impact on the heating and cooling load of a building if the HPWH is installed in conditioned space. HPWHs may reduce the ambient temperature 2F°-6°F when in operation (Stiebel- Eltron 2010), though this is heavily dependent on HPWH run time and the space in which the HPWH is located. Often, HPWHs are touted as providing free energy due to COPs greater than 1.0, but when located within the building envelope, heat moved into the storage tank by a heat pump typically needs to be replaced by the home's heating system. HPWHs can extract between 4 and 11 MMBTU/year of energy from the surrounding space. In hot climates, locating the HPWH in attached garages is an excellent way to optimize water heating performance without concern for the cooling effect of the unit.

2.3.4 Inadequate Space

The HPWH must be able to extract sufficient energy from the surrounding air, and the energy available in the air is primarily a function of the size of the space. Therefore, HPWHs must be installed in rooms with adequate volume to ensure efficient operation (see manufacturer literature for space requirements). Adequate clearances must be provided to allow for proper airflow and maintenance (see Section 3.1.1). If a unit is installed in an area with insufficient space, the space can experience a dramatic reduction in temperature during HPWH operation.

Supporting Research

At one test site, the HPWH was installed in a location with inadequate space and showed a significant reduction in efficiency. The HPWH was installed in a small, unconditioned basement mechanical room with a door that was kept closed. The mechanical room's area was approximately 440 ft^3, significantly less than the required 750 ft^3 for the unit, contained a washer and dryer, and was used for storage. The overall COP of the unit was 30% lower than the expected COP of a HPWH installed with adequate space.

2.4 Dehumidification Potential

Because HPWHs remove heat from the ambient air using a heat pump refrigeration cycle, they also remove moisture from the air. The water vapor in the air will condense as it passes across the HPWH's evaporator coils and, as a result, will provide dehumidification. This has the potential to reduce the need for dehumidifiers in damp spaces, such as unconditioned basements. Although the dehumidification is not predictable, because it relies on operation of the HPWH, the HPWH can reduce the energy consumed by dehumidifiers in these spaces.

2.5 Reliability and Safety

Integrated (or "drop-in") HPWHs are a relatively new technology that was first commercialized in the early 2000s. Earlier models were "add-on" configurations that heated the water outside of the storage tank. Unfortunately, the first commercialized, integrated HPWHs experienced problems with reliability and safety.

Supporting Research

In 2004, evaluation of an early integrated HPWH, the WatterSaver HPWH, demonstrated effective COPs, but some consistent drawbacks with the systems and their daily operation were identified, such as excessively hot water temperature. Monitoring showed that water temperature near the top of the tank often reached more than 150°F, partly because of excessive tank stratification – water temperatures near the top could be 50°F higher than temperatures near the bottom. In fact, high-temperature switches in many of the systems shut down the water heaters completely (high-temp safety switches are designed to turn off water heaters when temperatures reach 170°F). Control boards were also replaced because of problems with exposure to hot and humid conditions. Ultimately, because of the problems with installed performance and a nonexistent service infrastructure, this product is no longer on the market.

Monitoring of the current 14 HPWHs, however, has shown no issues with safety to date. Only one unit experienced a heat pump failure shortly after installation, but was quickly repaired by an authorized service provider. Upon failing, the unit switched from hybrid mode to electric mode and, as a result, the home did not experience a loss of hot water. Furthermore, all of the HPWHs under evaluation have yet to display problems with excessive or inadequate hot water temperatures.

Although the higher complexity of HPWHs over standard ERWHs may lead to greater reliability issues, so far modern HPWHs do not seem to be experiencing the same reliability issues that plagued earlier models. An accelerated durability test of older HPWH models performed at Oak Ridge National Laboratory found no long term reliability issues with these models (Baxter and Linkous 2004). These early results suggest that modern HPWHs may last as long as traditional ERWHs under extended operation.

3 HPWH Implementation Details

As noted in the introduction, hybrid heat pump water heaters are new to the mainstream market. Installing contractors should be aware that installation of these units is not as straightforward as a standard electric resistance water heater. Heat pumps require special attention to the air space (to ensure adequate air flow) around the unit and require condensate collection and removal. Installers may not be familiar with these units or heat pump models in general, and it can be difficult to install these units in existing homes.

3.1 Selecting the Best Location for a HPWH

Selecting an appropriate location for a standard ERWH is relatively straightforward. Any space large enough for the water heater, piping, and servicing can be appropriate for an ERWH. However, HPWHs require special consideration as they require more space (see Section 2.3.4) and weigh more than traditional ERWHs. The added weight of these units, due to the heat pump components, may mean that two or more people are required to move and install the unit. Furthermore, the best location must be chosen with respect to the interaction with the space conditioning equipment, the ambient temperature of the space, and noise (see Section 3.1.2). For reference, Table 6 lists the weight, volume, clearance, and operating temperature requirements for several current HPWH models (this is presented as an example; for accurate information, refer to up-to-date literature for specific HPWHs).

Table 6. Weight, Volume, Clearances, and Operating Temperatures for Various HPWH models

Model	Dry Weight (lbs)	Wet Weight (lbs)	Minimum Room Volume (ft^3)	Minimum Clearances					HP Inlet Air Operating Temperature (°F)
				Air Inlet	Air Outlet	Front	Rear	Top	
GE	190	602	700	7"	7"	5.5"	5.5"	14"	45-120
Rheem	197	576/680	1,000	N/A	N/A	N/A	2"	8"	40-120
AO Smith	332*/ 410*	827/ 1,069	750	3'	5'	2'	6"	None	45-109
Stiebel-Eltron	287	952	500	16"	15.75"	8"	8"	16"	42-108

* shipping weight

3.1.1 Space Requirements

The HPWHs require more space than traditional ERWHs because of their additional height, weight, required air volume, and clearance requirements; HPWHs are generally taller and heavier than traditional ERWHs. Measures to manage condensate, such as placing the unit on blocks (see Section 3.2.1), may further increase the height requirements of HPWHs. The additional weight of the unit, particularly larger capacity models, may require reinforcement of the floor to ensure structural soundness.

Because HPWHs extract energy from their surrounding environment (see Section 1.2), enough air volume and adequate clearances must be provided to allow for proper operation of the unit. Improperly placed HPWHs are significantly

HPWH Space Requirements Checklist

- ✓ Does the room meet the volume requirements of the unit (> 750 ft^3)?
- ✓ Are the ceilings high enough to accommodate the extra height of the HPWH?
- ✓ Is there adequate space to allow maintenance of the heat pump components?
- ✓ Can the HPWH be placed in the room such that there is sufficient clearance for airflow around the unit?
- ✓ Is there enough clearance for removal and cleaning of the air filter?
- ✓ Is the floor able to support the additional weight of the HPWH?

less efficient than properly installed units (see Section 2.3.4). Generally, HPWHs must be installed in a room with a volume of at least 750 ft^3, which corresponds to a 10 ft by 10 ft room with 7'6" ceilings. Furthermore, HPWHs require larger clearances for proper operation. Air entry and discharge must be free of obstructions to provide proper air circulation and ensure a continuous supply of fresh air. Figure 7 shows a properly installed HPWH with adequate clearances at the air entry and discharge, while Figure 8 shows a poorly installed unit with the air discharge directed towards a wall. Added clearances are also required for removal and cleaning of the air filter and for servicing of the unit. Piping installation must be carefully considered to prevent the pipes from blocking the air filter or maintenance panels.

Figure 7. HPWH installed with adequate clearances

Figure 8. Improper HPWH with air discharge facing wall

3.1.2 Conditioned or Unconditioned Space?

When selecting an appropriate location for a HPWH, the interaction with the heating and cooling system must be closely considered. As mentioned in Section 2.3.3, HPWHs extract heat from the surrounding air and therefore increase heating loads and decrease cooling loads when installed in conditioned spaces. An analysis of the total impact on heating and cooling source energy usage (Table 7) reveals that for the vast majority of the United States, there is a net potential heating penalty on source energy usage for space conditioning. Cities in climate zone 2 may have a net potential cooling benefit. If the decision is made to relocate an interior water heater to a semi-conditioned space (i.e. garage or basement), consideration needs to be given regarding the impact on distribution system performance and hot water waiting times.

Table 7. Impact of Placing HPWH in Conditioned Space on Space Conditioning Usage

City	Climate Zone	HDD65	CDD65	Potential Impact
Atlanta, GA	3A	2,694	1,841	Heating Penalty
Baltimore, MD	4A	4,567	1,228	Heating Penalty
Boston, MA	5A	5,621	750	Heating Penalty
Chicago, IL	5A	6,311	842	Heating Penalty
Denver, CO	5B	5,942	777	Heating Penalty
Houston, TX	2A	1,414	3,001	Cooling Benefit
Orlando, FL	2A	544	3,379	Cooling Benefit
Phoenix, AZ	2B	941	4,557	Cooling Benefit
San Francisco, CA	3C	2,708	142	Heating Penalty
Seattle, WA	4C	4,729	177	Heating Penalty

Conditioned Space

In climates with a net heating penalty, it is not advisable to place HPWHs in conditioned space without further exploring the potential impact. In locations with potential cooling benefit, HPWHs may be placed in conditioned space, although special consideration must be used when deciding the best location for the HPWH. Although these units have a potential to reduce overall space conditioning loads, the cooling from these units may lead to over-cooling of the space because the operation of the unit is not controlled by a thermostat. Follow these guidelines when choosing a proper location for the HPWH:

- Never place the unit close to a thermostat, as this may result in improper heating or cooling of the home.
- Never place the unit near the kitchen. Oils from cooking can ruin the unit.
- Place the unit in a location that is not sensitive to colder temperatures.
- Make sure to meet the manufacturer's space requirements (e.g. Section 3.1.1). Do not place the unit in a closet unless the closet door has a louvered door. Even with a louvered door, locating the HPWH in a closet will likely reduce overall performance of the unit.
- Noise may be an issue because the HPWH uses a compressor and fan to move air through the unit. Do not place the unit near bedrooms or other noise-sensitive locations.

When installing a HPWH in a room with a furnace, ensure that the unit does not interfere with operation of the furnace. Air flows inside the room will change as a result of HPWH installation.

Unconditioned Space

In most U.S. climates, HPWHs can be placed in unconditioned or semi-conditioned spaces. Semi-conditioned spaces are spaces that are inside the thermal boundary, but not directly heated or cooled. The most common semi-/unconditioned locations are garages and basements. Crawlspaces are generally too short for HPWHs, and HPWHs are typically not recommended to be placed in attics (because of potential for water leaks, weight of unit, ambient temperature that fluctuates outside the heat pump's operating range, etc.).

The primary consideration for unconditioned spaces is the size of the room (see Section 3.1.1) and the ambient temperature of the space. The minimum temperature of the space should not be below 50°F. Operation of the HPWH will result in a significant drop in ambient temperature, and such a drop may result in an air temperature below the minimum recommended operating temperature in heat pump mode (see Section 2.3.2). HPWHs with electric resistance modes may be placed in colder basements, but the HPWH will not operate at its rated efficiency during colder months. In more temperate climates, the attached garage can be a suitable location, as long as plumbing lines are not too long and can be properly insulated. In colder climates, however, the basement will likely have the highest temperature of all unconditioned spaces.

Figure 9. HPWH installed in boiler room

Interesting Fact

At one site in CARB's evaluation of 14 HPWHs, the unit was placed in an unfinished basement in the mechanical room next to the boiler. The waste heat from the boiler increased the ambient temperature of the room in the winter, meaning that the room was 70°F or warmer throughout winter. The waste heat improves the efficiency of the HPWH and minimizes the impact of the HPWH on the space heating loads of the house.

3.2 Proper Installation and Maintenance

Good installers of HPWHs pay close attention to condensate management (Section 3.2.1), heat traps (Section 3.2.2), and mixing valves (if applicable, Section 1.1.1). Proper maintenance includes inspection of the condensate lines and regular cleaning of the air filter. Installations should always comply with local and state codes.

HPWH Installation Checklist

- ✓ Place the unit on blocks
- ✓ Install a drain pan
- ✓ Install a condensate pump, if applicable
- ✓ Install heat traps to prevent thermosiphoning
- ✓ Install a mixing valve, if applicable

3.2.1 Managing Condensate

As warm, moist air travels over the evaporator coils of a HPWH, some moisture in the air will condense, and the resulting condensate is removed from the unit through a condensate drain line. This condensate must be effectively removed to prevent damage to the unit. While manufacturer's condensate requirements vary slightly, in the simplest configuration a hose is connected to the condensate line and properly pitched toward a drain in the floor. If a suitable drain is not available, a condensate pump must be installed to ensure that condensate is properly removed. Based on contractor feedback, a 240V condensate pump is recommended for this application to avoid potential call backs related to tripped ground-fault circuit interrupter (GFI) outlets used to power 120V condensate pumps.

To protect the unit from a condensate line failure or other condensate issue, HPWHs should be installed on blocks with a drain pan. These precautions prevent the unit from sitting in water and ensure that the condensing water is properly transferred to a drain.

Drain pans are used to capture overflow due to condensate pump failure, piping failure, and condensate line obstructions. Because HPWHs are relatively new to the mainstream market, the installers may not be aware of the need for drain pans. Given the low cost, all HPWHs should have a drain pan installed. Concrete blocks are often used to raise the bottom of the unit above the lip of the drain pan which prevents the bottom of the unit from resting in water (and possibly corroding should a leak occur). Figure 10 shows a HPWH that does not properly remove condensate away from the unit into the drain. The unit ended up sitting in water due to a kinked condensate line. Figure 11 shows a proper HPWH installation, where the unit is set on blocks in a drain pan and a condensate pump is used.

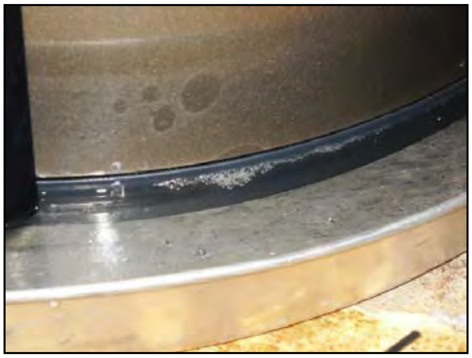


Figure 10. Condensate problems from improper installation

Figure 11. Proper HPWH installation

If the condensate line becomes clogged or kinked, the drain hose must be removed and cleared of any debris. The owner should periodically inspect and clear any debris from the condensate line to prevent condensate overflow.

3.2.2 Heat traps

Heat traps should be installed on all hot water systems to prevent thermosiphoning, which is the transfer of heat from the storage tank down the cold or hot water lines. Thermosiphoning reduces the efficiency of the unit by increasing the standby losses to the environment. Figure 12 shows a HPWH installed without heat traps, while Figure 13 shows a properly installed HPWH with heat traps.

Figure 12. HPWH without heat traps

Figure 13. HPWH with heat traps

3.2.3 Mixing Valves and Setpoint Temperature

With any water heater that generates relatively high water temperatures a mixing valve should be installed to minimize the risk of burns or scalding (see Table 8). If a HPWH generates temperatures above 125F°-130°F (or if the temperature is likely to be set above this), a mixing valve should be installed (Figure 14).

Table 8. Time/Temperature Relationships in Scalds (Shriners Burn Institute)

Temperature	Time to Produce a Serious Burn
120	More than 5 minutes
125	1.5 – 2 minutes
130	About 30 seconds
135	About 10 seconds
140	Less than 5 seconds
145	Less than 3 seconds
150	About 1.5 seconds
155	About 1 second

Figure 14. Heat pump water heater with mixing valve

Mixing Valves

The hot water outlet temperature may change over the course of the year, increasing during the summer as the mains temperature increases.

HPWH Piping Issues

The inlet and outlet pipes of most ERWHs enter the top of the unit. Due to the inclusion of the heat pump at the top of the unit, some HPWHs have different locations and orientations of the water lines. In Figure 14, the water lines enter the unit at the side and are placed horizontally. This orientation will likely require additional plumbing.

Furthermore, the air filter in some units is placed near the water piping. As a result, the installer must pay close attention to the piping installation to avoid obstructing the air filter.

Just as a high water temperature could result in scalding, a low temperature could result in the growth of the bacterium Legionella, which causes lung infections. This bacterium thrives in warm water, but temperatures over 119°F will minimize Legionella growth. Temperatures above 122°F will kill 90% of the bacteria in 80-124 minutes, and temperatures above 140°F will kill 90% of the bacteria in 2 minutes (WHO 2007). Temperatures around 120°F (but not less than 119°F) are the recommended temperature set point to minimize scald potential and reduce standby losses while maintaining water quality. If the vacation mode of a water heater is used (or temperature setpoint lowered), ensure that the unit is given adequate time to recover to a temperature higher than 122°F for several hours upon return from vacation before using the hot water.

3.2.4 Filter Maintenance

If a HPWH has an air filter, the filter must be regularly cleaned to ensure that the unit runs at peak efficiency. In Figure 15, a HPWH with a dirty air filter is shown. On some units, the air filter is removed from the top of the unit, and therefore extra clearance must be provided to ensure that the unit's filter can be properly cleaned.

Figure 15. Dirty filter: finger rubbed against filter to show accumulation of dirt

3.2.5 Typical Maintenance (for HPWH or ERWH)

In addition to cleaning the air filter, both HPWHs and ERWHs require regular maintenance to ensure proper operation and extend the life of the unit. Table 9 lists the required maintenance items for water heaters and the recommended timing.

Table 9. Water Heater Maintenance Schedule

Maintenance Item	When?	Why?
Check temperature pressure relief valve	Yearly	Ensure proper operation
Discharge water from tank	Monthly	Prevent hard water deposits from accumulating
Inspection by qualified service provider	Yearly	Ensure proper operation

Check Temperature Pressure Relief Valve

Lift and release the lever handle on the temperature pressure relief valve (check manual for location).

Ensure lever moves freely.

Allow several gallons to flow through the discharge line to an open drain.

Discharge Water from Tank

Suspended solids in tap water may settle at the bottom of a water heater's tank. To ensure that these solids do not collect at the bottom of the tank, a few quarts of water should be drained from the drain valve of the tank every month. See the section below for instructions for draining the tank.

Draining the Tank

Note: Drainage hose should be rated for at least 180°F. Otherwise, turn off power to water heater and open hot water faucet until the water runs cold.

Shut off power to the water heater.

Turn off cold water supply.

Open a hot water faucet to allow air to enter the tank.

Attach a hose to the drain valve on the water heater and direct the stream of water to a drain.

Open the relief valve.

Drain water heater.

Close relief valve.

Disconnect hose from valve.

Turn on cold water supply.

Keep hot water faucet open until water runs through the faucet.

Close hot water faucet.

Turn on power to the water heater.

Helpful Tip

Even new electrical appliances may make hissing or singing sounds during operation. However, if these noises increase excessively, the electric resistance elements may need cleaning. Contact a qualified installer or plumbing contractor to inspect the unit.

Inspection by Qualified Service Provider

Periodically contact a qualified electric appliance repair service provider to inspect the operating controls, heating elements, anode rod, and wiring.

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Appendix A: Measure Implementation Checklist

1. **Select the best type of location for the HPWH. Determine the interaction with cooling and heating equipment.** Should the unit be placed in conditioned space, semi-/unconditioned space, or in an attached garage? Hot climates will have a net cooling benefit, while cold climates will have a net heating penalty (see Sections 2.3.3 and 3.1.2). Generally, homes in climate zones 1 and 2 have a net cooling benefit. For climate zones 1 and 2, installation in an attached garage of unconditioned space may be appropriate.
2. **Select available location.** Can the HPWH be installed in the selected location? If the location does not meet the requirements then consider a new location or an alternative high efficiency water heater option, or evaluate the efficiency impact of minimized heat pump operation.

Sufficient room volume (750 to 1,000ft^3)	YES	NO
Adequate ambient temperature (> 50°F)	YES	NO
There is sufficient space to meet clearance requirements	YES	NO
Noise will not interfere with living spaces	YES	NO
Drain is available for condensate removal	YES	NO

3. **Can the floor support the unit?** If not, reinforce as necessary.
4. **Removal of older equipment (if applicable).** In the case of existing home retrofits, follow accepted industry procedures and practices as listed in the Standard Work Specification (SWS):
   a. Remove old water heater and associated components.
   b. Seal any unused chimney openings.
   c. Remove unused oil tank, lines, and associated equipment.
5. **HPWH installation.** Follow the guidelines for installation as listed in the Standard Work Specification (SWS). These requirements are as follows:
   a. Repair any existing water leaks before installation.
   b. Seal any penetrations to the exterior of the home created by the installation of the equipment.
   c. Install an emergency drain pan a minimum of 4” above floor. Connect a ¾” drain line or larger to tapping on pan and run to drain or pumped to daylight.
   d. If needed, install a stainless steel bladder expansion tank will on the cold water side using a direct connection with no valves between the storage tank and expansion tank.

e. Correct temperature and pressure relief valve will be installed according to manufacturer specifications. Temperature and pressure relief valve discharge tube will terminate within 6” of the floor, or as prescribed by local code.
f. Install di-electric unions according to manufacturer specifications.
g. Discharge temperature will be set to not exceed 120° or as prescribed by local code.
h. Commissioning will be in compliance with manufacturer specifications and relevant industry standards. The following will be checked once the system has been filled and purged:
    - Safety controls
    - Combustion safety and efficiency
    - Operational controls
    - Water leaks
    - Local code requirements.
i. Occupants will be educated on the safe and efficient operation and maintenance of the system, including:
    - Adjustment of water temperature and target temperature per local code
    - Periodic drain and flush
    - Expansion tank and backflow preventer (no occupant maintenance required).

In addition to the requirements outlined by the SWS, remember to install the following items for HPWHs:

a. Place the unit on blocks.
b. Install a drain pan.
c. Install a condensate pump, if applicable.
d. Install heat traps to prevent thermosiphoning.
e. Install mixing valves, if needed.

Appendix B: HPWH Installation Checklist (*leave behind with unit*)

Home Address:______________________ City:____________ State:_____			
Is the site suitable for a HPWH?	Adequate Ambient Temperature (> 50°F)		☐
	Condensate Drain Available		☐
	Noise will not Interfere with the Living Space		☐
What HPWH is being installed?	Manufacturer	____________________	
	Model #	____________________	
	Tank Size	______ Gallons	
Are minimum requirements met?	Sufficient Room Volume (> ______ ft^3)		☐
	Minimum Clearances: Air Inlet (> ______ in) Air Outlet (> ______ in) Front (> ______ in) Rear (> ______ in) Top (> ______ in)		 ☐ ☐ ☐ ☐ ☐
	Is the floor able to support the weight of the HPWH?		☐
How is the system configured?	Location of HPWH	Semi-/Un-Conditioned ☐ Conditioned ☐ Garage ☐ Attic ☐	
	HPWH Operation Mode	Hybrid Mode ☐ Heat Pump ☐ Electric Resistance ☐	
	Temperature Set Point (120°F recommended)	______ °F	
	Condensate Pump		☐
	Heat Trap		☐
	Mixing Valve		☐
Maintenance	How often should filter be cleaned?	Every ______ Months	

* Blanks to be filled out per manufacturer's minimum specifications for model to be installed.

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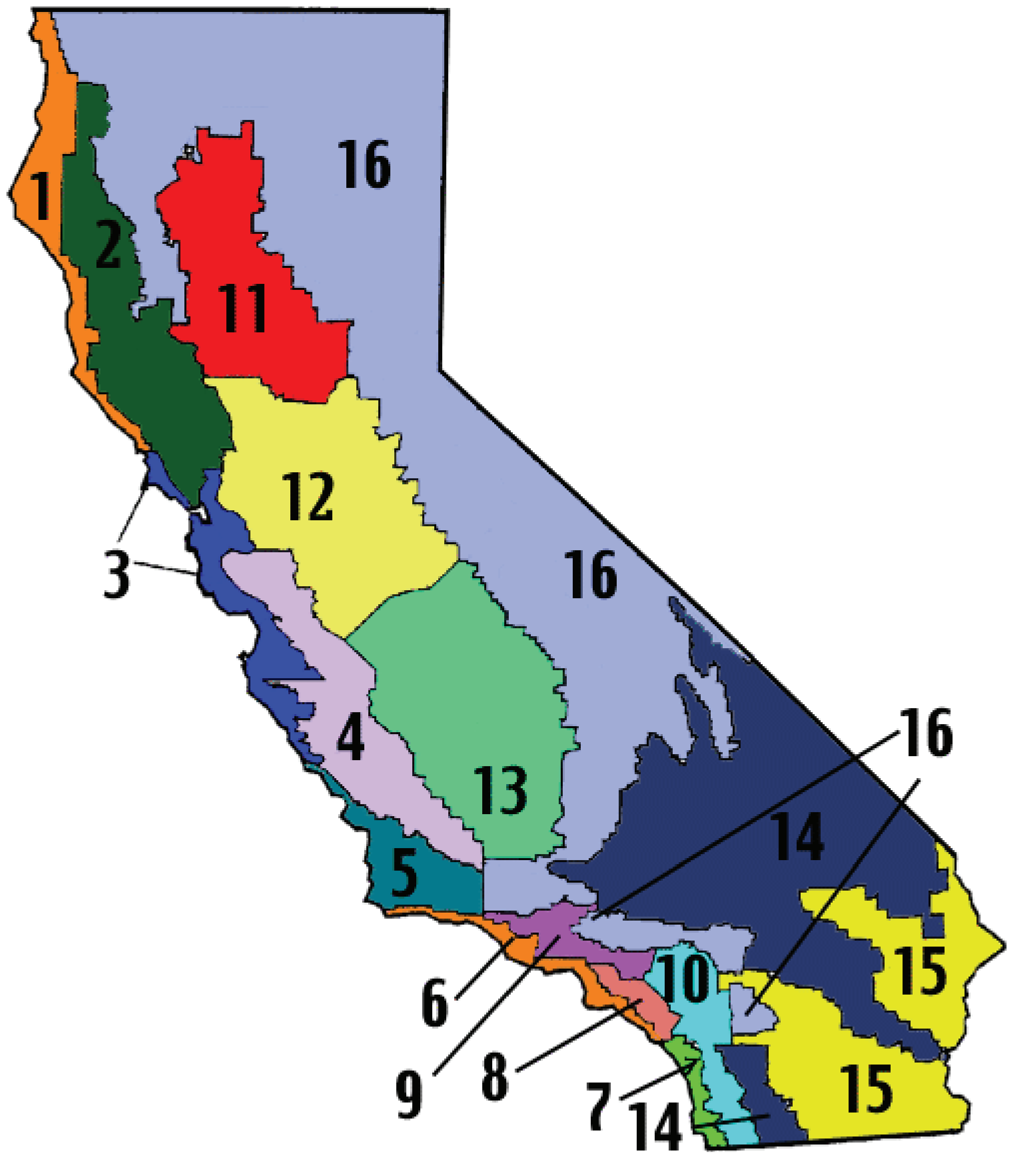
The Pacific Energy Center's Guide to:

California Climate Zones



http://www.energy.ca.gov/maps/climate_zones.html

and Bioclimatic Design

October 2006

PEC's Guide to California Climate Zones

This document of climate data was made for designers to inform energy-conscious design decisions. The information for 16 California Climate Zones is summarized and suggestions are given for passive design strategies appropriate to each climate.

Weather data is given for a reference city typical of each zone. Each zone contains a summary of the following types of data:

Basic Climate Conditions: Summer Temperature Range, Record High and Low Temperature
Design Day Data: Percentage of time dry bulb temperature in given season is *above* the stated value. Mean Coincident Wet-bulb Temperatures, and Relative Humidity also given for the summer.
Climate Design Priorities: Suggestions of design strategies to use in this zone for winter and summer seasons for a more energy passive design.
Title 24 Requirements: California's residential building energy code requires minimum ceiling and wall insulation values specific to different zones. Window U-values and maximum total area is also given. The complete document of requirements can be found on the California Energy Commission's website www.energy.ca.gov.
Climate Description: An overview of the general characteristics of the climate zone, such as geographical influence, typical patterns of weather and seasons, and precipitation.
HDD (Heating Degree Days) and CDD (Cooling Degree Days): Given for four cities in each zone. HDD value is the summation of degrees of the average temperature per day below 65F for the year. CDD is the summation of degrees of the average temperature per day above 80F for the year.

Charts and Graphs

Bioclimatic Chart: Defines dry bulb temperature and humidity levels for occupant thermal comfort and passive design strategies. The average minimum relative humidity and maximum temperature is plotted with the maximum relative humidity and minimum temperature for each month on the Bioclimatic chart. The chart is broken up into zones corresponding to design strategies for thermal comfort appropriate for that particular combination of temperature and humidity ranges. The best passive design strategies for each location are identifiable from the plotted data.

Zones and Strategies for the Bioclimatic Chart:

Comfort Zone: Humans are comfortable within a relatively small range of temperature and humidity conditions, roughly between 68-80 F (20-26.7 C) and 20-80% relative humidity (RH).
Passive Solar Heating: If 1700 BTU-day/sf from the sun comes into a given space, then occupants will feel comfortable inside if it is between 45-68 outside. This range can be lowered with better the insulation and more effective solar heat collected in thermal mass.
Natural Ventilation: Passive cooling strategies for natural ventilation are effective for temperatures in the range 68F to 90F. Cooling effectiveness decreases with higher humidity. In conditions below 20% RH natural ventilation may seem too dry.
Evaporative Cooling: Below 80% RH, evaporative cooling can be an effective passive cooling strategy. Adding moisture to the air can effectively cool temperatures up to 105F.
High Thermal Mass: Thermal Mass dampens and delays temperature swings to make it cool during the warm day, and warm during cool nights. It is most effective for places with large diurnal temperature changes. Thermal Mass is effective for temperatures up to 95F, with decreasing effectiveness in higher humidity.
High Thermal Mass with Night Ventilation: Thermal mass absorbs heat during the day and releases heat at night. By opening the building at night, cool air flushes out the hot air and cools down the thermal mass. This strategy is effective for average high temperatures up to 110F. This strategy requires occupant intervention.

Shading: Though not part of the Bioclimatic Chart, shading is an important part of passive cooling. All of the temperature ranges for cooling can be increased with proper shading and mitigation of solar heat into the space.
Heating: Temperatures below 45F is often too cold for passive methods of heating. In these conditions heating using any variety of fuels and methods of delivery are necessary to keep the space warm. Some methods of heating include mechanical heating through forced air vents, radiant heating systems, electrical heating systems, and wood fire stoves. The energy and pollution impacts are important to consider in selecting an efficient active heating system.
Air Conditioning: When temperatures exceed the temperature range of passive cooling strategies air conditioning is required for comfort. The amount of energy needed to cool something is more than to heat it.
Humidification and Dehumidification: Humidity can be added or removed using mechanical systems and energy.

Temperature: Monthly average, maximum, and minimum temperatures are shown on this graph.
Degree-Days: The monthly averages of degrees above or below a base temperature are graphed for an average year. The base temperature of 65°F is used for heating degree-days; 80F is used for cooling degree-days.
Relative Humidity: Monthly average, maximum, and minimum relative humidity levels are shown on this graph.
Terrestrial Radiation: Terrestrial radiation is solar radiation filtered through the atmosphere as well as reflected from terrestrial (earth-bound) objects. Also known as global radiation, the value provided is the sum of direct and diffuse radiation striking a horizontal surface at ground level.
Wind Speed and Direction: Average monthly wind speed in mph, and prevailing wind direction are plotted on this graph. Arrows indicate the direction that the wind generally comes from during that month – north is up. Natural ventilation is most effective when wind speed is 5 mph or greater. Alignment with the wind direction is necessary to achieve the wind speed indicated.

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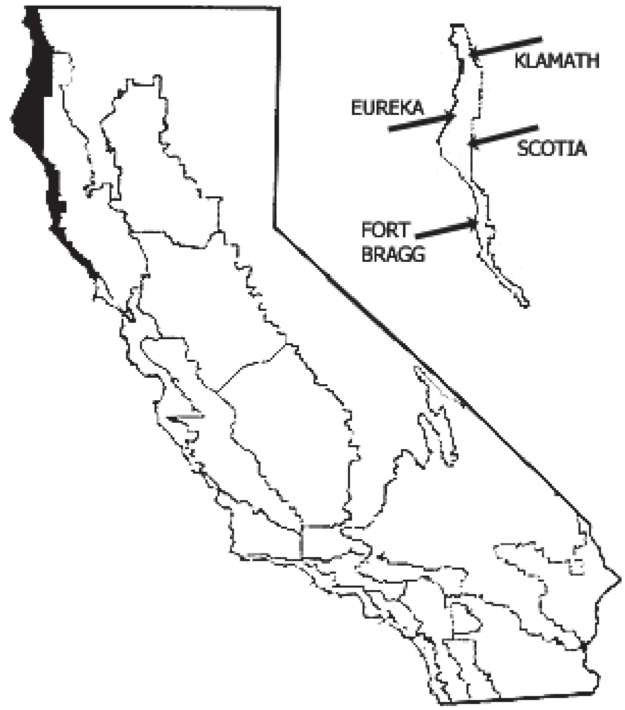
California Climate Zone 1

Reference City: Eureka
Latitude: 41.3 N
Longitude: 124.28 W
Elevation: 43 ft



Design Day Data

	Eureka (F)	RH	Arcata (F)	RH
Winter 99%	35		31	
Winter 97.5%	38		33	
Summer 1%			68	63
Summer 2.5%			65	71

Degree Days

	Eureka	*Scotia*	*Klamath*	*Fort Bragg*
HDD	4496	3828	4554	4301
CDD	0	47	5	6

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days (base 80F)

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar
Summer: Shade
Allow natural ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R38
Wood Frame Walls	R29	R21
Glazing U-Value	0.42	0.57
Maximum Total Area	14%	20%

Basic Climate Conditions

Summer Temperature Range (F)	15
Record High Temperature (1979)	85
Record Low Temperature (1972)	21

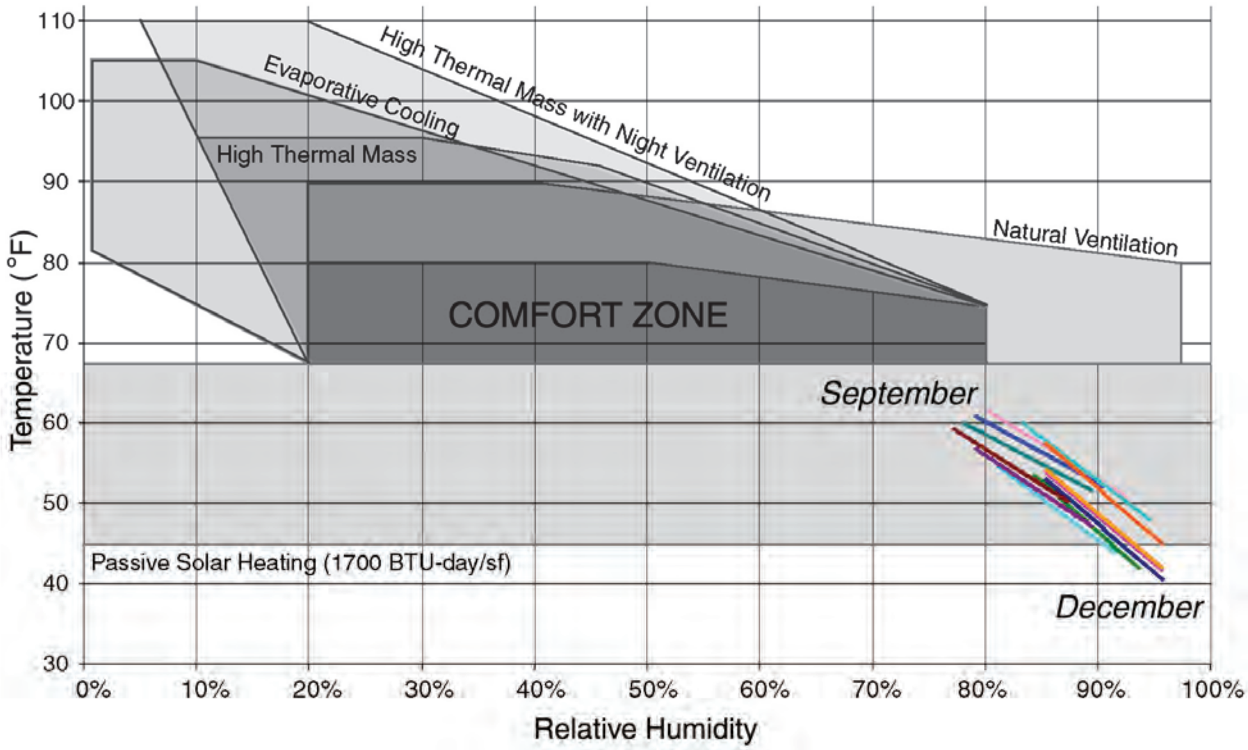
Climate

The northern coastal region is situated west of the Northern Coastal Range and has a moist, cool climate influenced greatly by the conditions of the Pacific Ocean.

The cool, wet winters, and cool summers with frequent fog and strong winds make it a climate that requires a lot of heat for comfort. Fog comes in high and fast, interposing a cooling and humidifying blanket between the sun and the earth, reducing the intensity of the light and sunshine. In winter the temperatures are cool and rain is common.

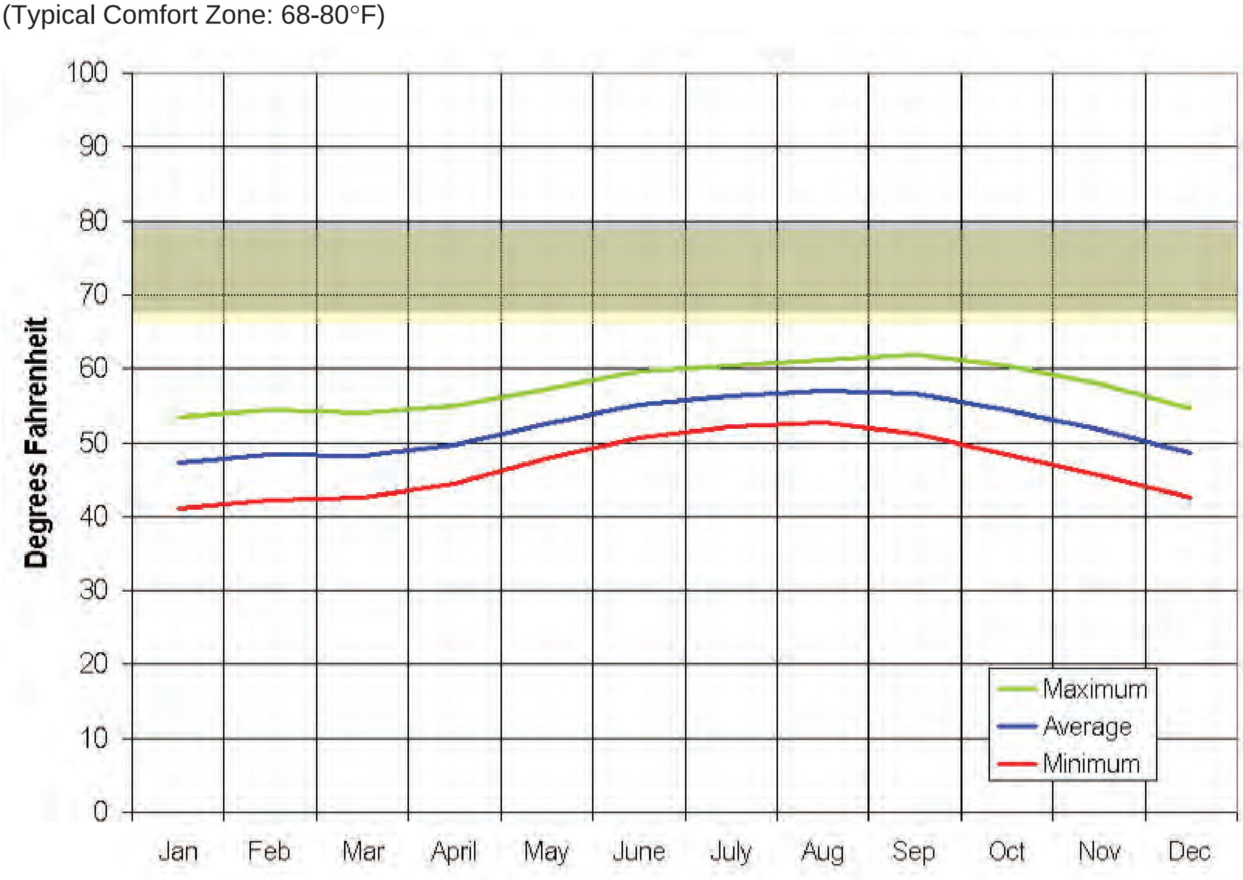
The annual precipitation for Climate Zone 1 is about 25 inches annually, most of it occurring in the winter months. The summers are drier and sunnier, but only warm enough to call for a few CDD. Though Climate Zone 1 is the coolest climate in California with the most HDD, it rarely freezes and seldom frosts.

Bioclimatic Chart

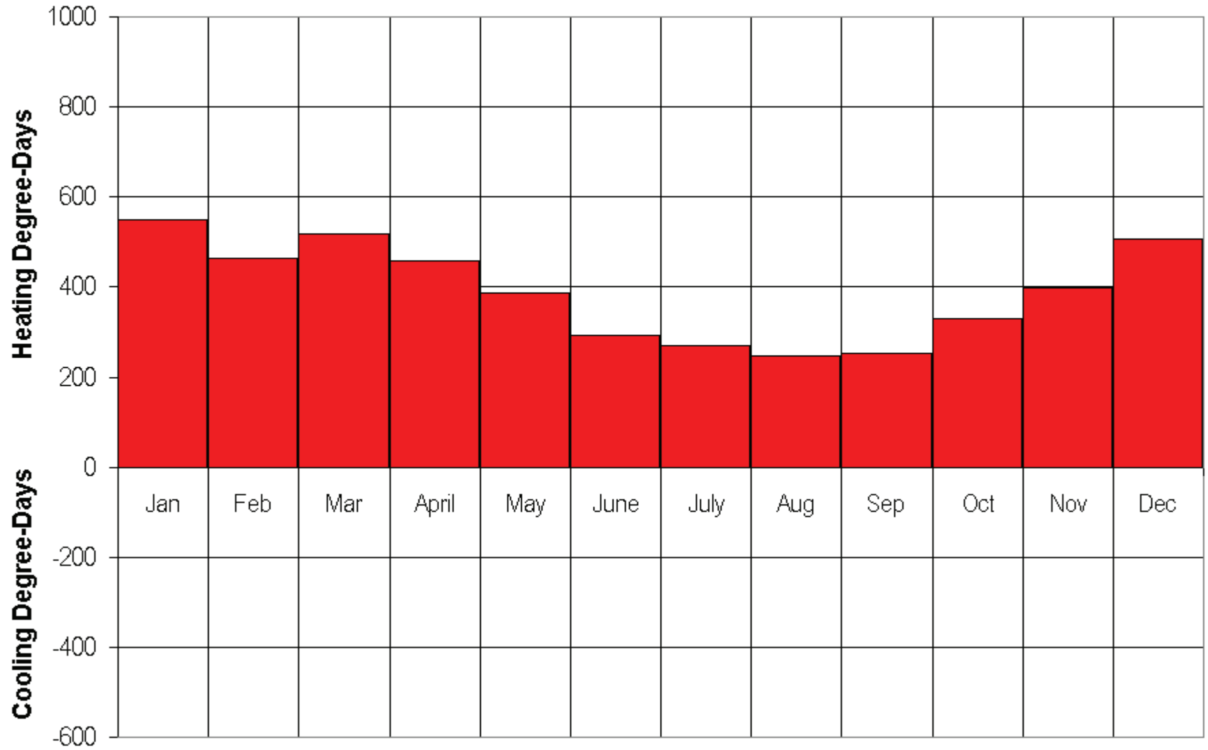


Temperature

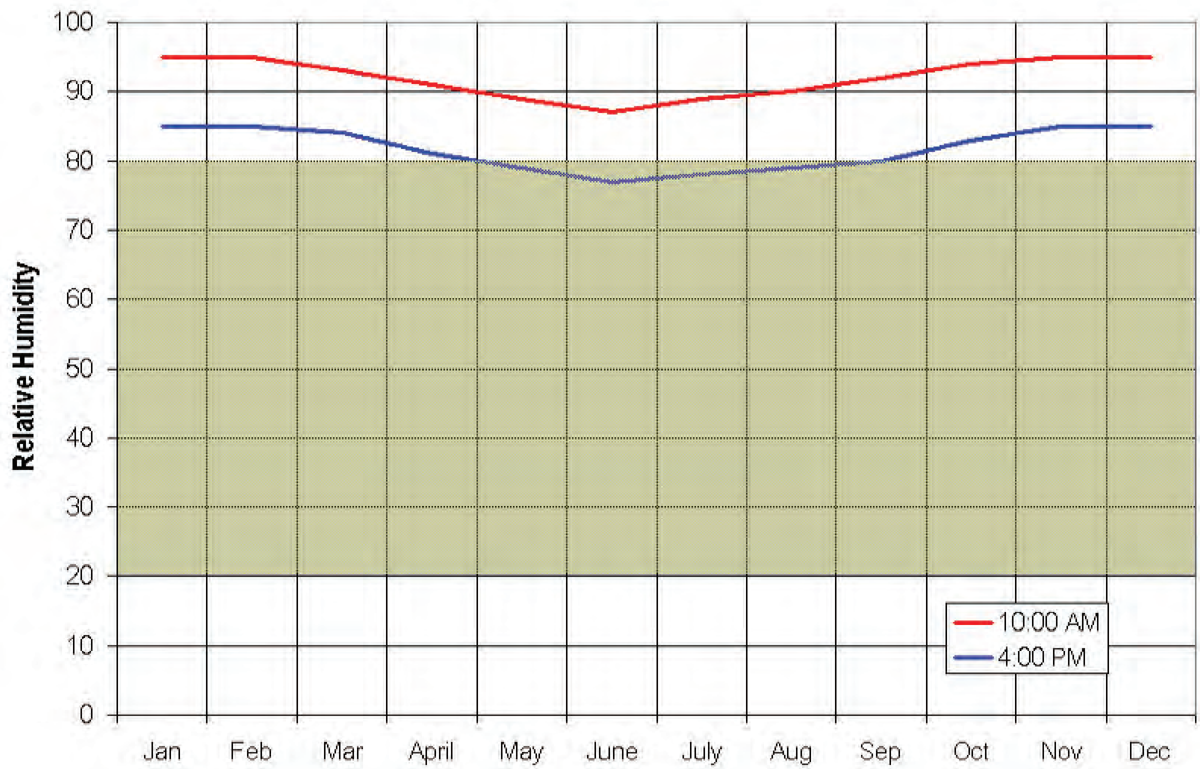
(Typical Comfort Zone: 68-80°F)



Degree Day
(Base 65°)

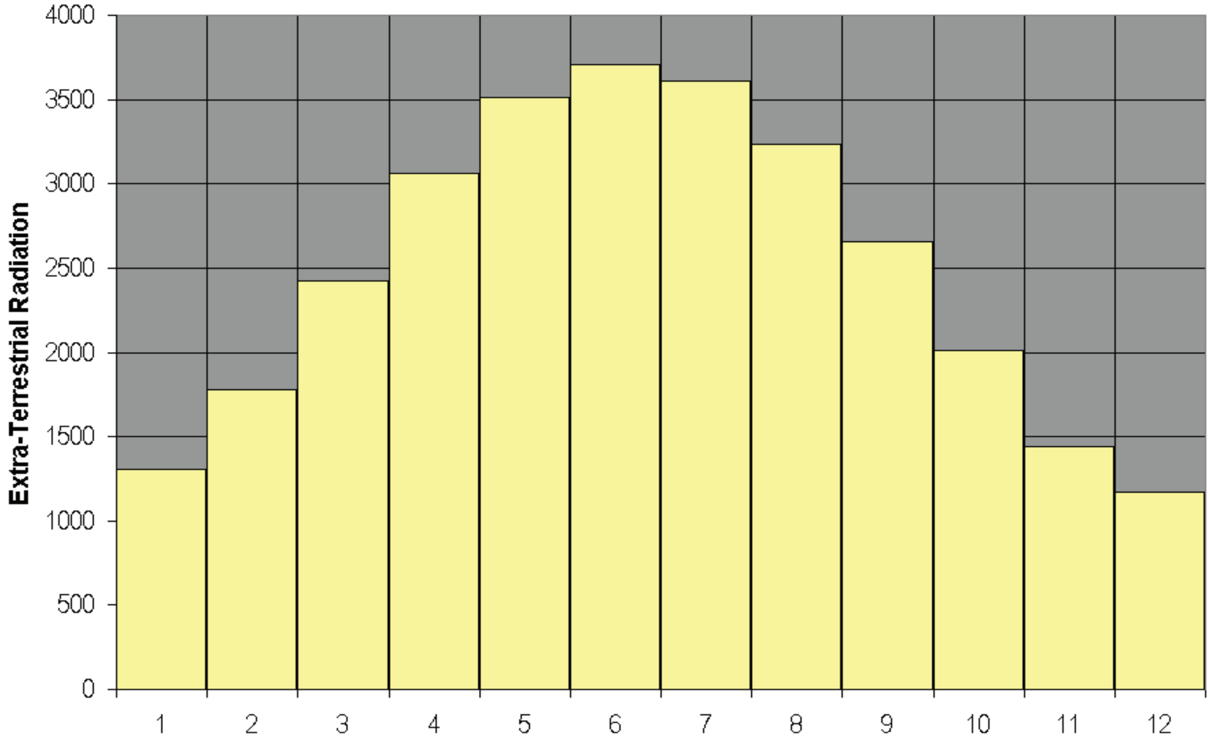


Relative Humidity
(Typical Comfort Zone: 20-80%)

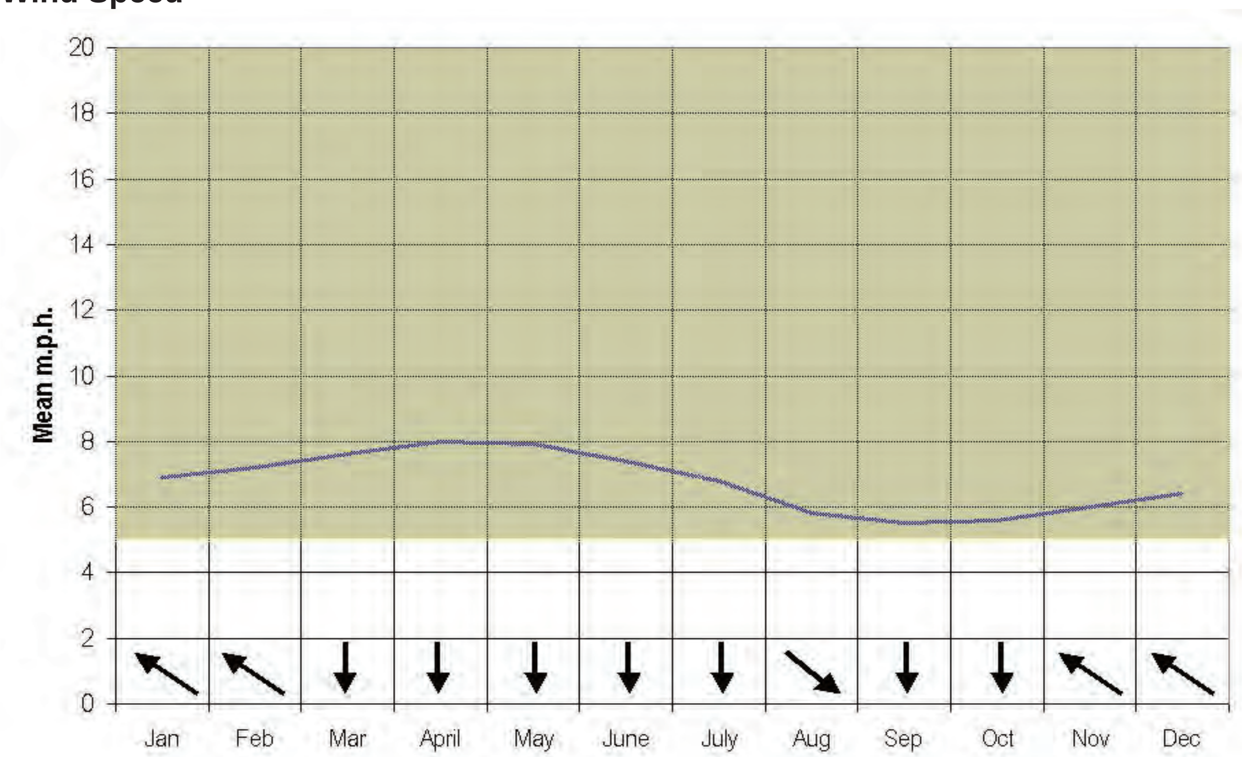


Extra-Terrestrial Radiation

Daily Mean ETR: 2493



Wind Speed



Prevailing Wind Direction
Summer: N
Winter: SE

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate Zone 2

Reference City: Napa
Latitude: 38.28 N
Longitude: 122.27 W
Elevation: 60 ft

Design Day Data

	Napa (F)	RH	Mare Island (F)	RH
Winter 99%	31		30	
Winter 97.5%	34		32	
Summer 1%			89	MCWB 68
Summer 2.5%			84	MCWB 66

Degree Days

	Napa	*Ukiah*	*Willits*	*San Rafael*
HDD	2844	2954	4195	2581
CDD	456	894	202	449

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days (base 80F)

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar
Summer: Shade
Allow natural ventilation
Distribute Thermal Mass

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R30
Wood Frame Walls	R29	R13
Glazing U-Value	0.38	0.57
Maximum Total Area	16%	20%

Basic Climate Conditions

Summer Temperature Range (F)	29
Record High Temperature (1961)	113
Record Low Temperature (1990)	14

Climate

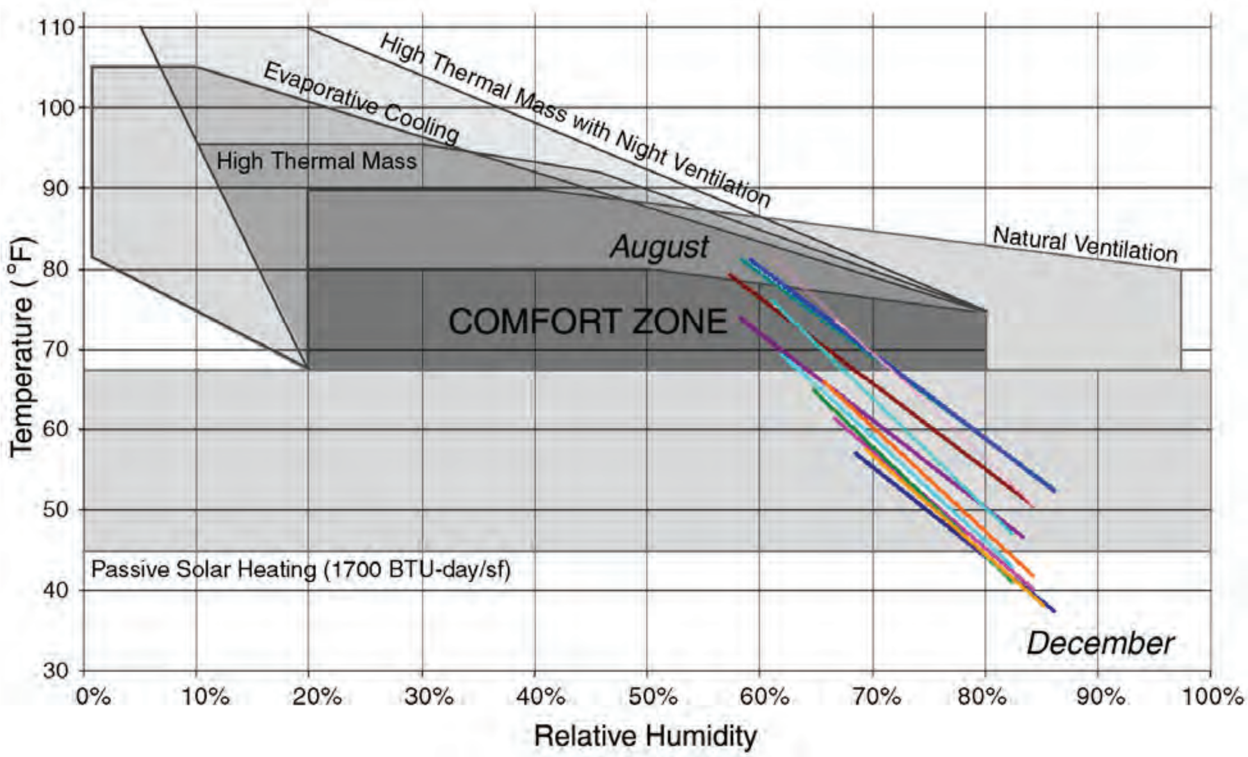
Climate Zone 2 includes the hilly Coastal range to the edge of the Northern Central Valley.

The zone has a coastal climate, influenced by the ocean approximately 85% of the time and by inland air 15% of the time. HDD dominates the climate design, although some cooling is necessary in the summer.

There are many microclimates in this varied geography that are affected by proximity to the ocean and elevation. Marine air influence lessens with distance from the san Francisco Bay Area.

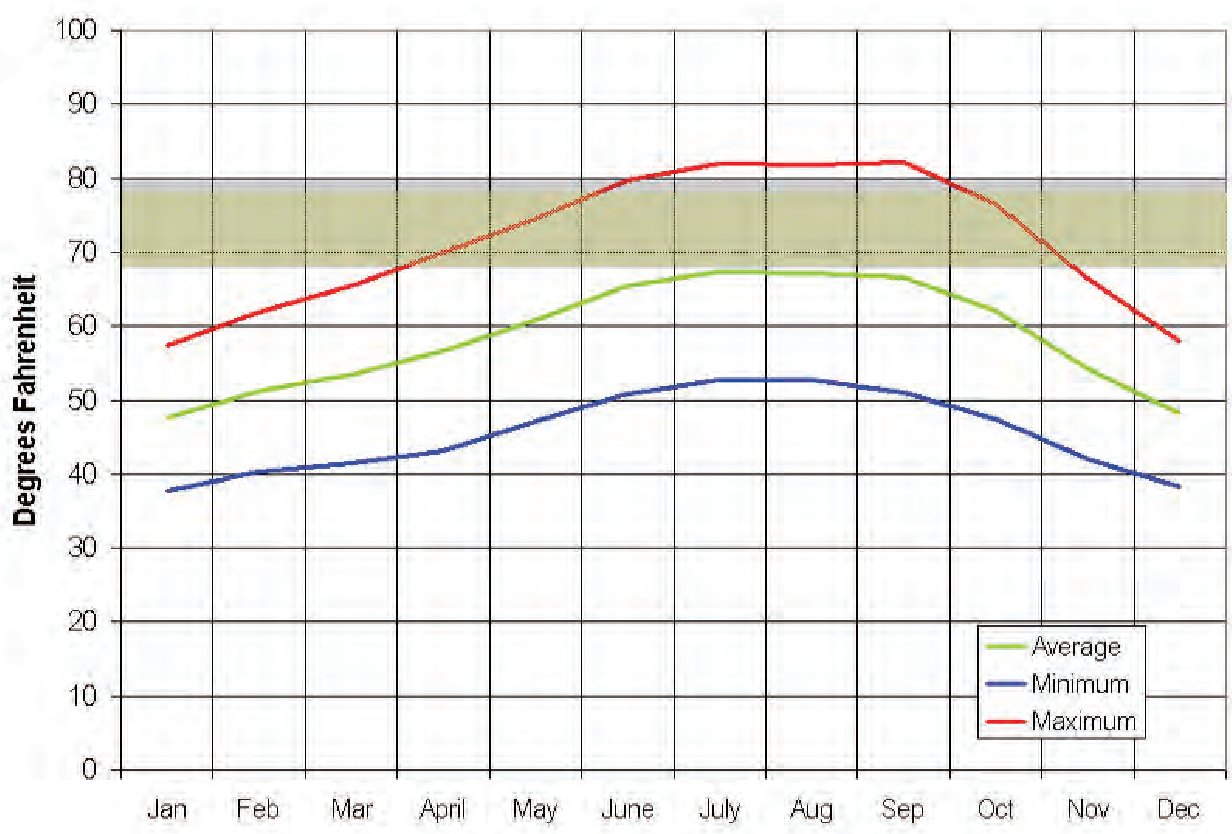
Cold air flows downhill to the valley floors, canyons, and land-troughs. Winters are cool and mild, slightly warmer in comparison to Zone 1. The summers are very comfortable and often windy in the afternoon. Diurnal temperature fluctuates over 20F over the day all year.

Bioclimatic Chart

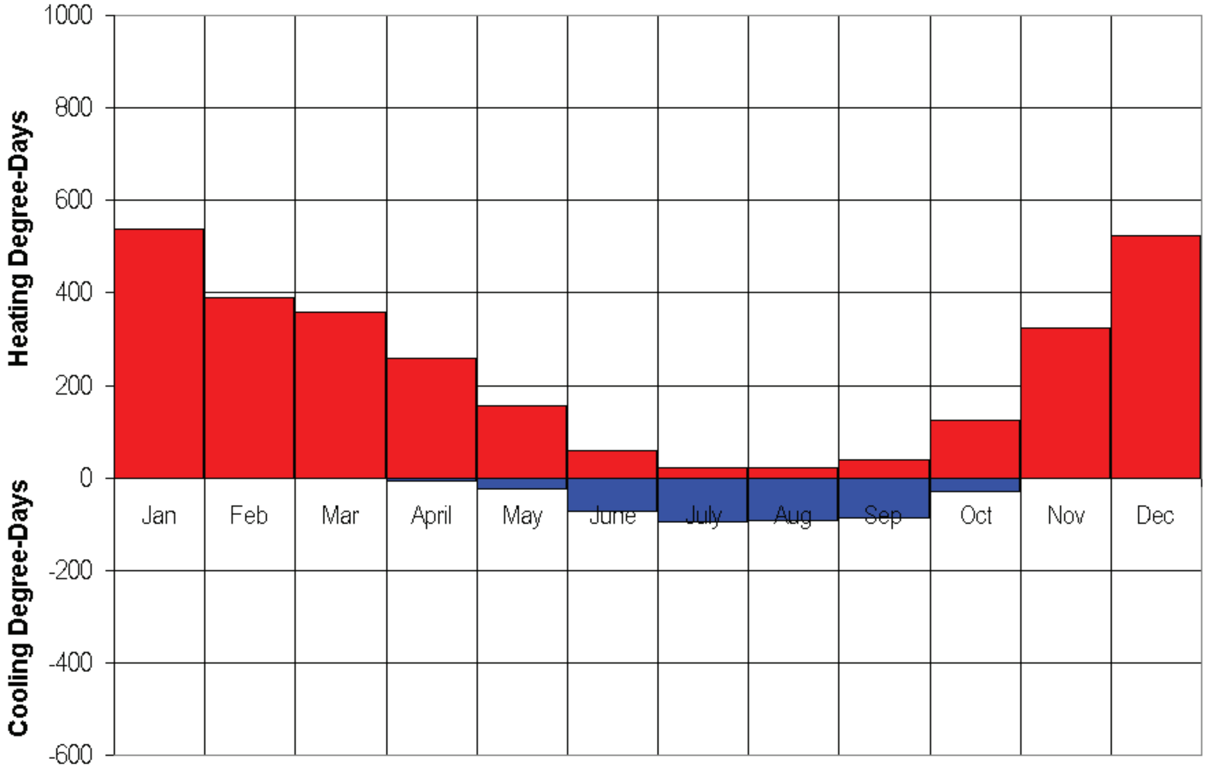


Temperature

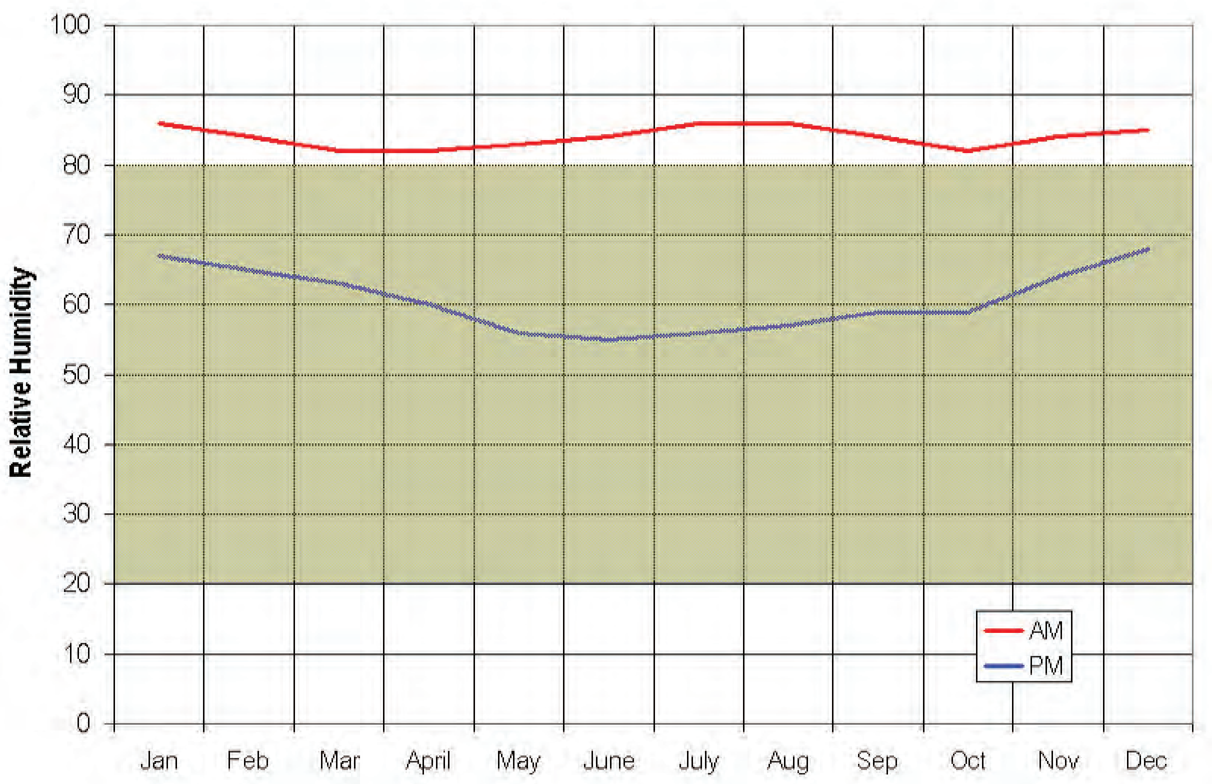
(Typical Comfort Zone: 68-80°F)



Degree Day
(Base 65°)

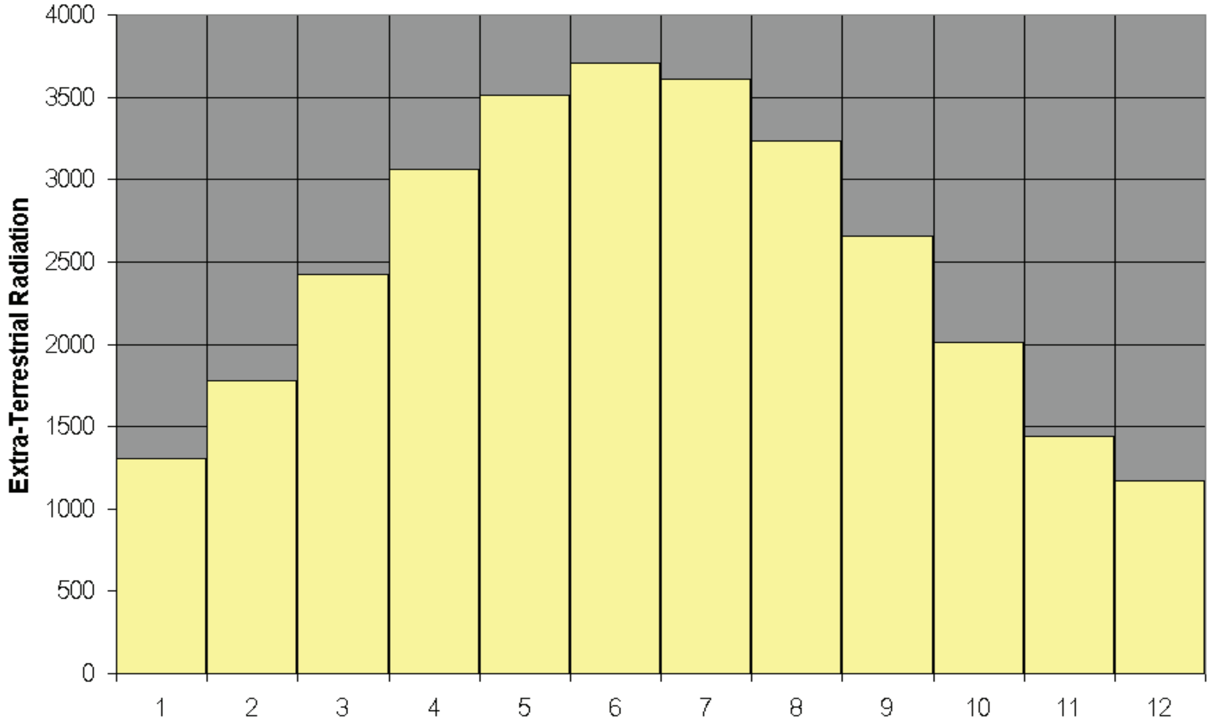


Relative Humidity
(Typical Comfort Zone: 20-80%)

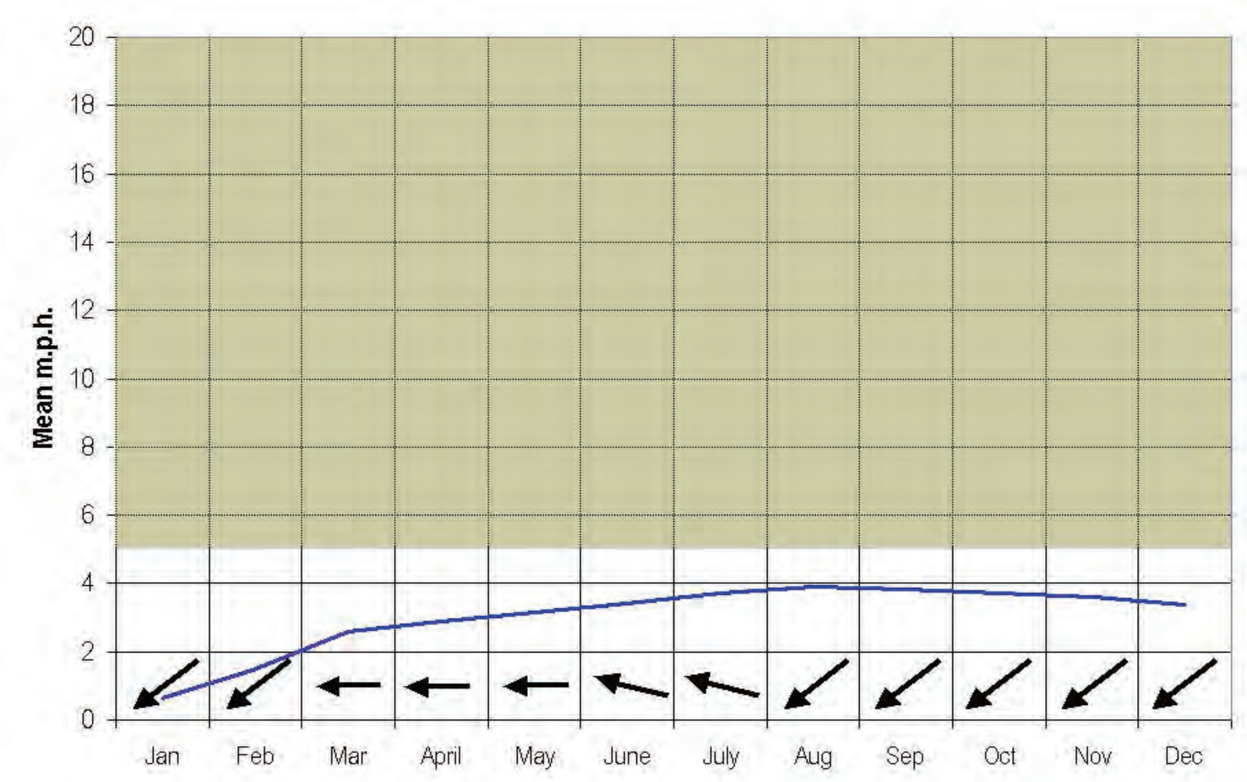


Extra-Terrestrial Radiation

TO BE REPLACED Daily Mean ETR: 2493



Wind Speed



<u>Prevailing Wind Direction</u>
Summer: ESE / NE
Winter: NE

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate Zone 3

Reference City: Oakland
San Francisco
Latitude: 37.75 N
Longitude: 122.2 W
Elevation: 10 ft

Design Day Data

	Oakland (F)	RH	San Francisco (F)	RH
Winter 99%	34		35	
Winter 97.5%	35		38	
Summer 1%	85	MCWB 64	82	MCWB 64
Summer 2.5%	80	MCWB 64	77	MCWB 63

Degree Days

	OAK	*SFO*	*Half Moon Bay*	*Redwood City*
HDD	2909	3042	3770	2563
CDD	128	108	11	486

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days (base 80F)

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar
Summer: Shade
Allow natural ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R38	R30
Wood Frame Walls	R25	R13
Glazing U-Value	0.42	0.67
Maximum Total Area	14%	20%

Basic Climate Conditions

	OAK	SFO
Summer Temperature Range (F)	29	23
Record High Temperature	113 (1960)	106 (1961)
Record Low Temperature	14 (1930)	20 (1932)

Climate

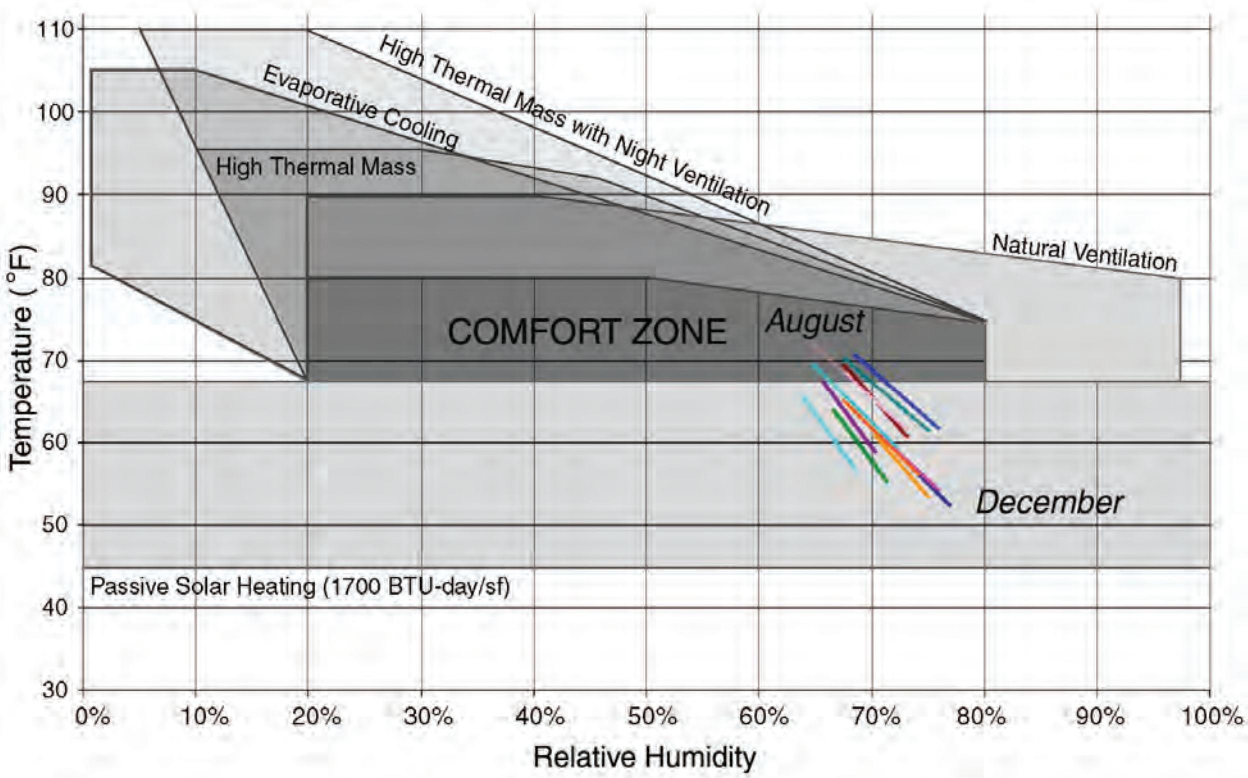
The climate of Zone 3 varies greatly with elevation and the amount of coastal influence. Areas with more coastal influence experience moderate temperatures year round with precipitation in the winter and fog likely from June through mid-August.

Inland from the beaches and sea cliffs, local geography may reduce the fog cover, lessen the winds, and boost summer heat.

Winters are moderately cold with most of the annual rain falling between October and March. Winter sunshine nevertheless is plentiful. Summers are warm and dry, but the nights are cool. Rain is rare during the summer months.

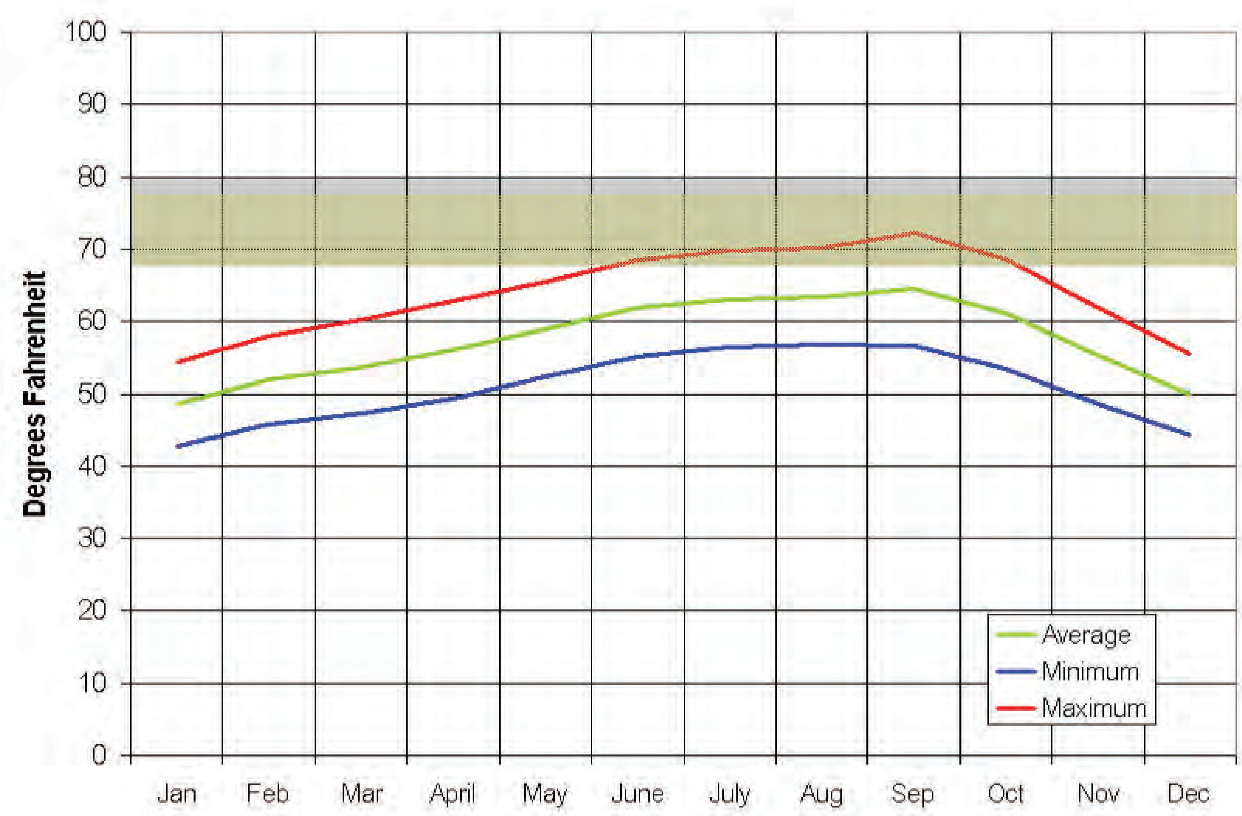
A need for heating is the dominant design concern, but the climate is mild enough that energy consumption is relatively low.

Bioclimatic Chart (Oakland)

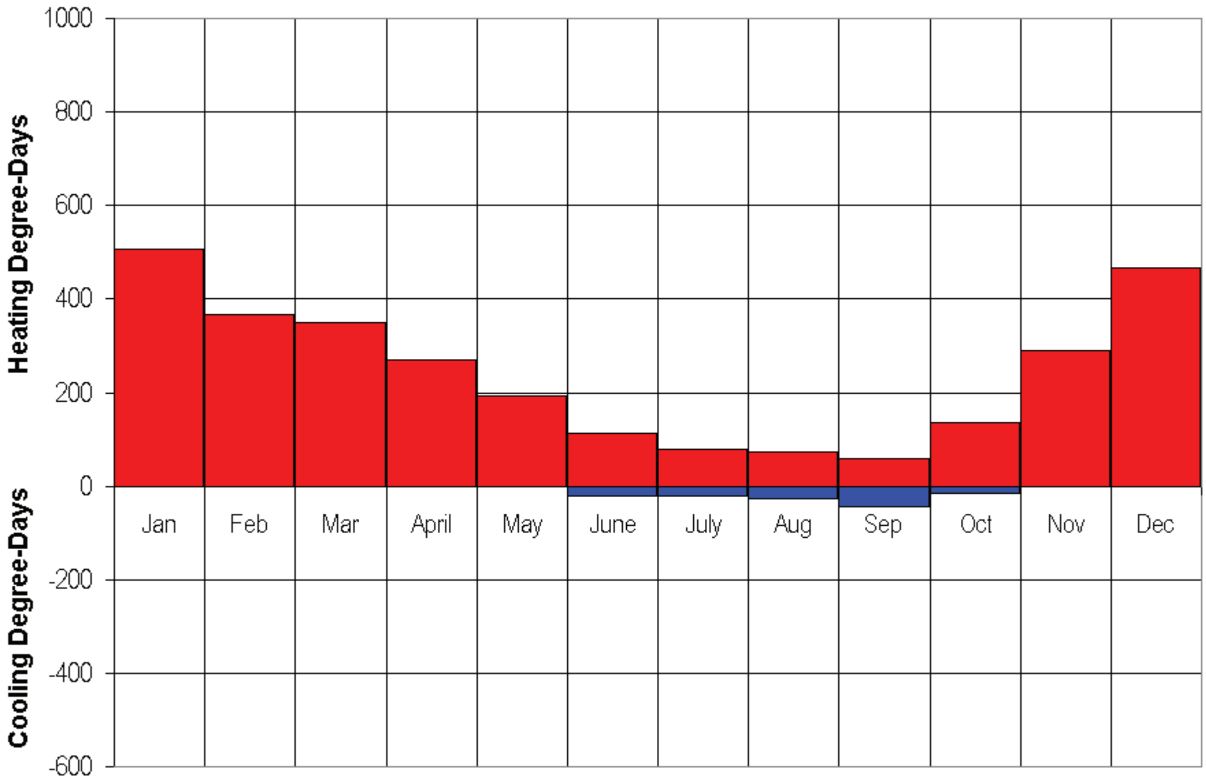


Temperature

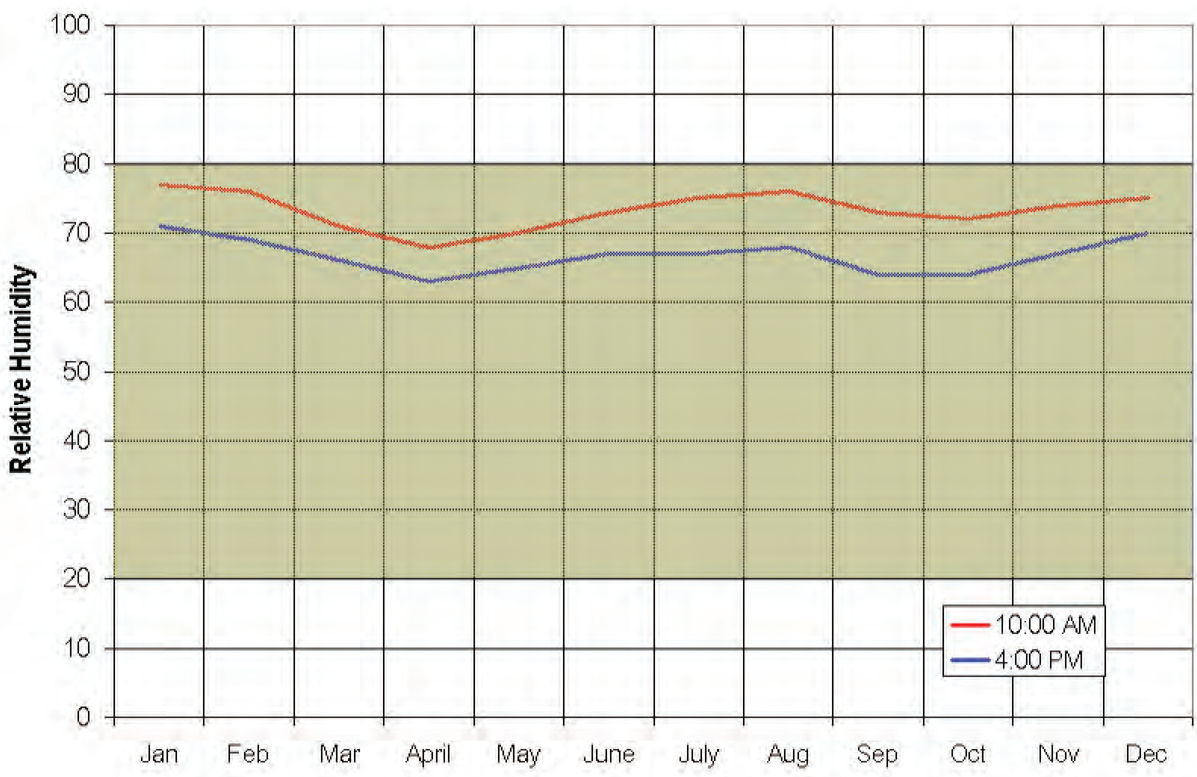
(Typical Comfort Zone: 68-80°F)



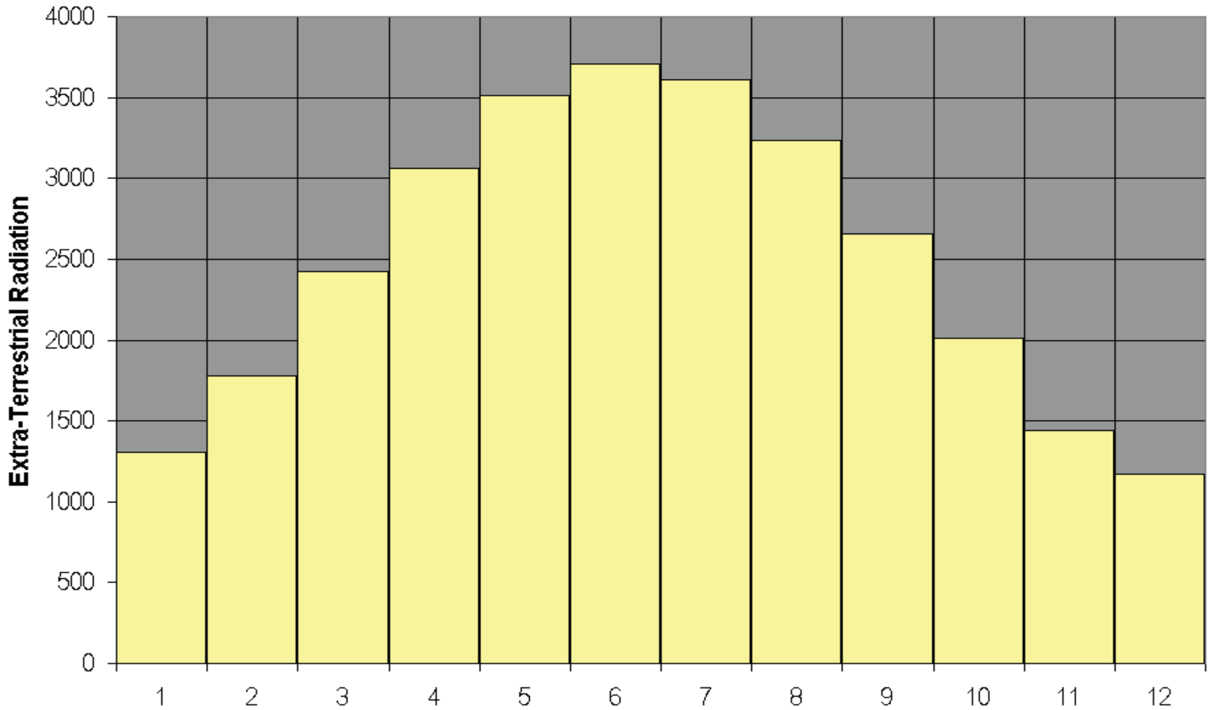
Degree Day
(Base 65°)



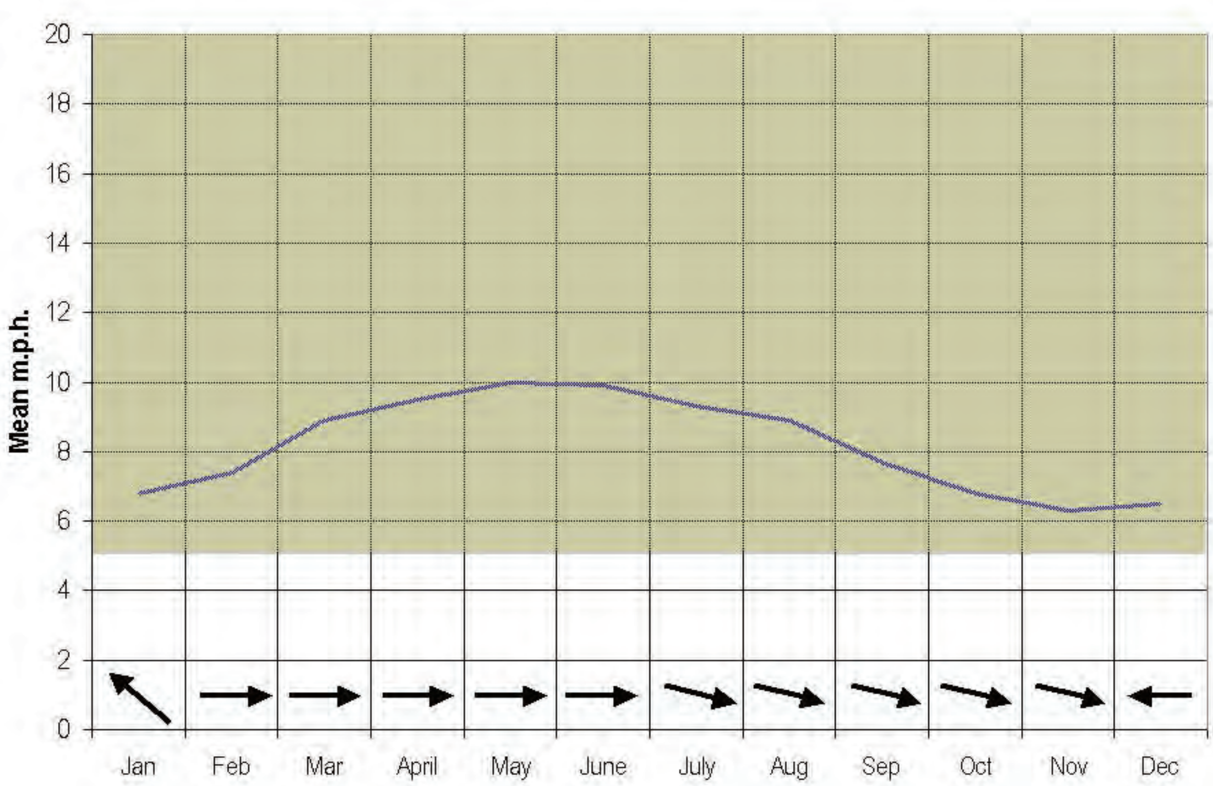
Relative Humidity
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation *TO BE REPLACED* Daily Mean ETR: 2493



Wind Speed



Prevailing Wind Direction
Summer: WNW
Winter: E / W

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate Zone 4

Reference City: San Jose
Latitude: 37.35 N
Longitude: 121.9 W
Elevation: 70 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	23
Record High Temperature (2000)	109
Record Low Temperature (1990)	19

Design Day Data

Winter	99%	34		
	97.5%	36		
Summer				
	1%:	85	MCWB	66
	2.5%:	81	MCWB	65

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Allow natural ventilation
Distribute Thermal Mass
Use Evaporative Cooling

Title 24 Requirements

Package	C	D
Ceiling Insulation	R38	R30
Wood Frame Walls	R25	R13
Glazing U-Value	0.38	0.67
Maximum Total Area	14%	20%

Climate
The Central Coastal Range is inland of the coast but has some ocean influence which keeps temperatures from hitting more extreme highs and lows. This zone covers many microclimates from northern to southern parts of the state. The reference city is in the northern-most part of the zone.

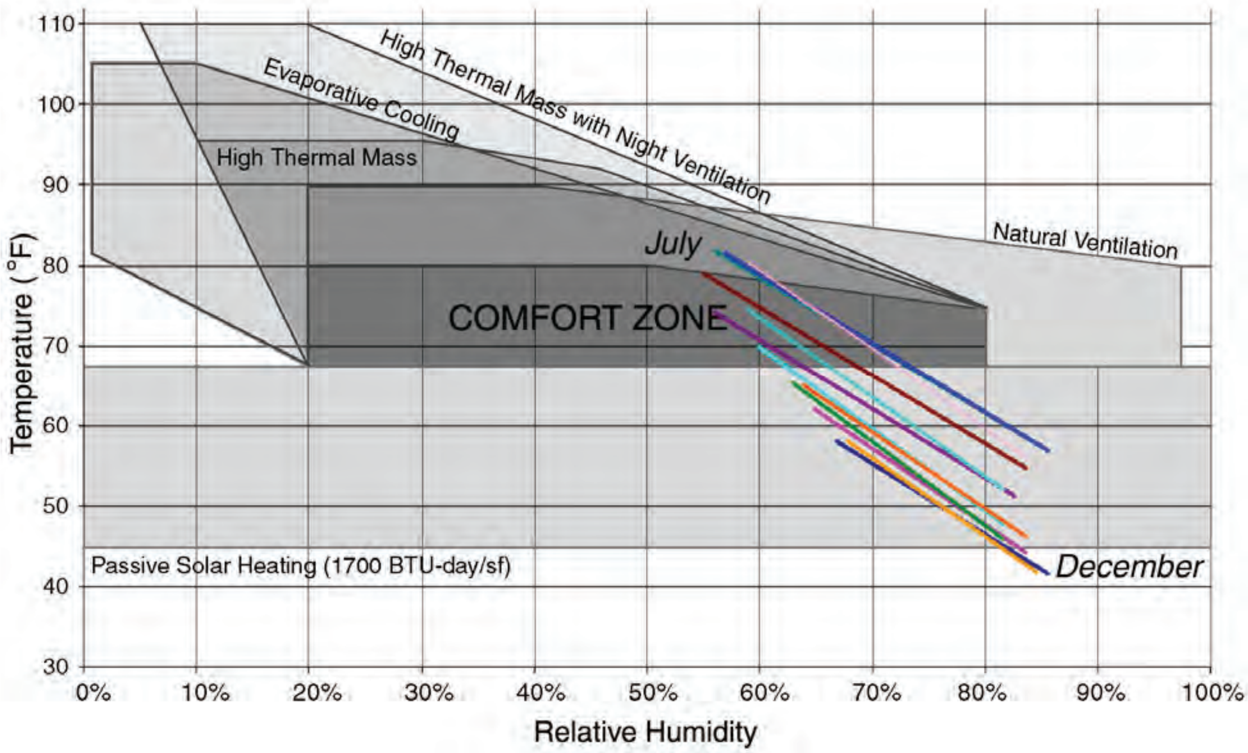
	San Jose	Gilroy	Sunnyvale	Paso Robles
HDD	2335	2278	2643	2934
CDD	574	913	220	956

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

Seasons are sharply defined. Summers are hot and dry with a large daily temperature swing. Summers are hot enough that cooling is necessary. Winters are cool but not severe. Heating is necessary on many days in the winter.

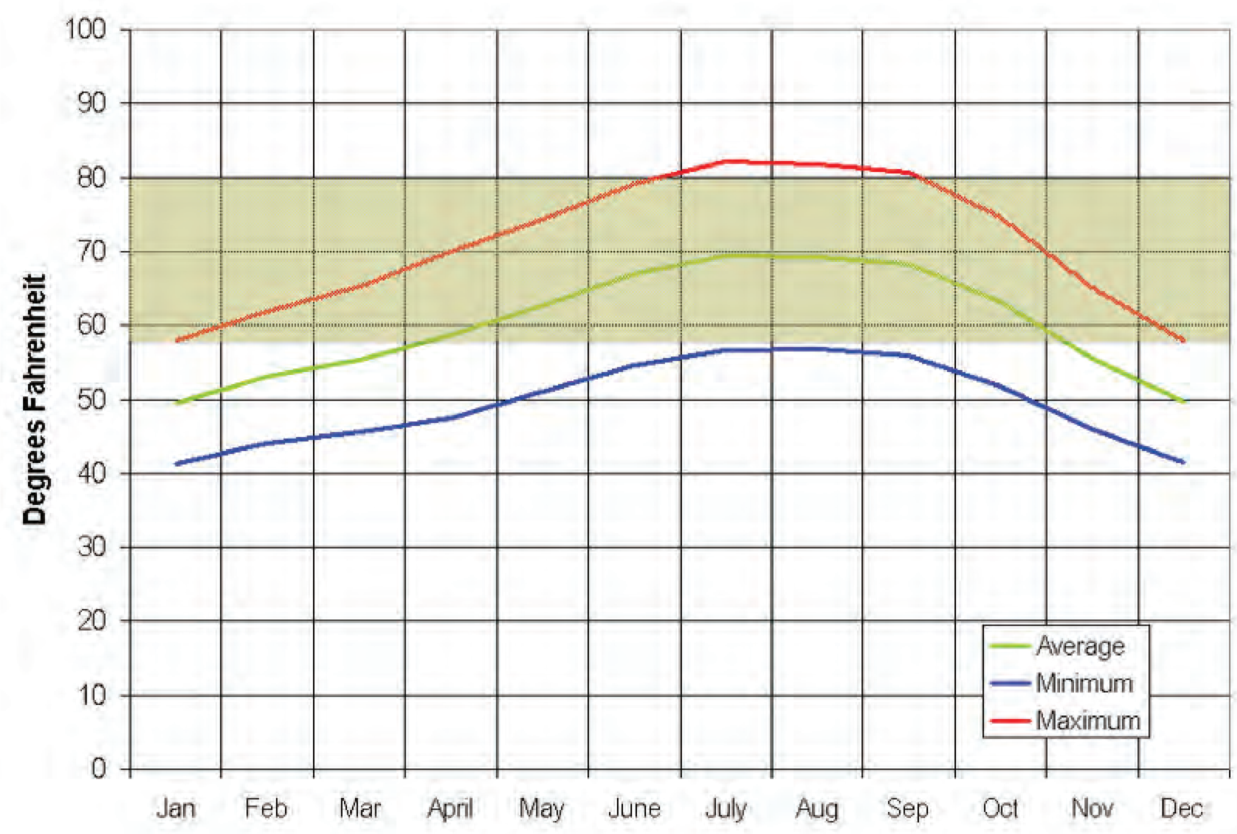
Days are typically clear with the coastal range blocking much of the fog and high winds.

Bioclimatic Chart

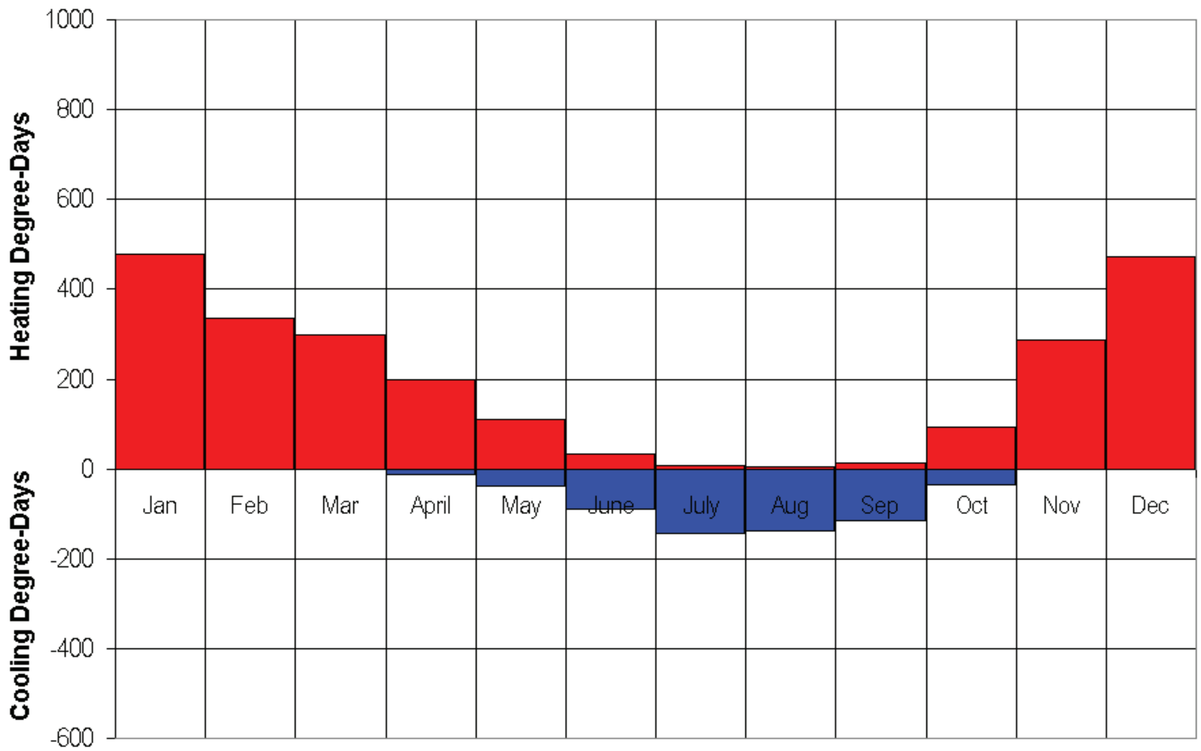


Temperature

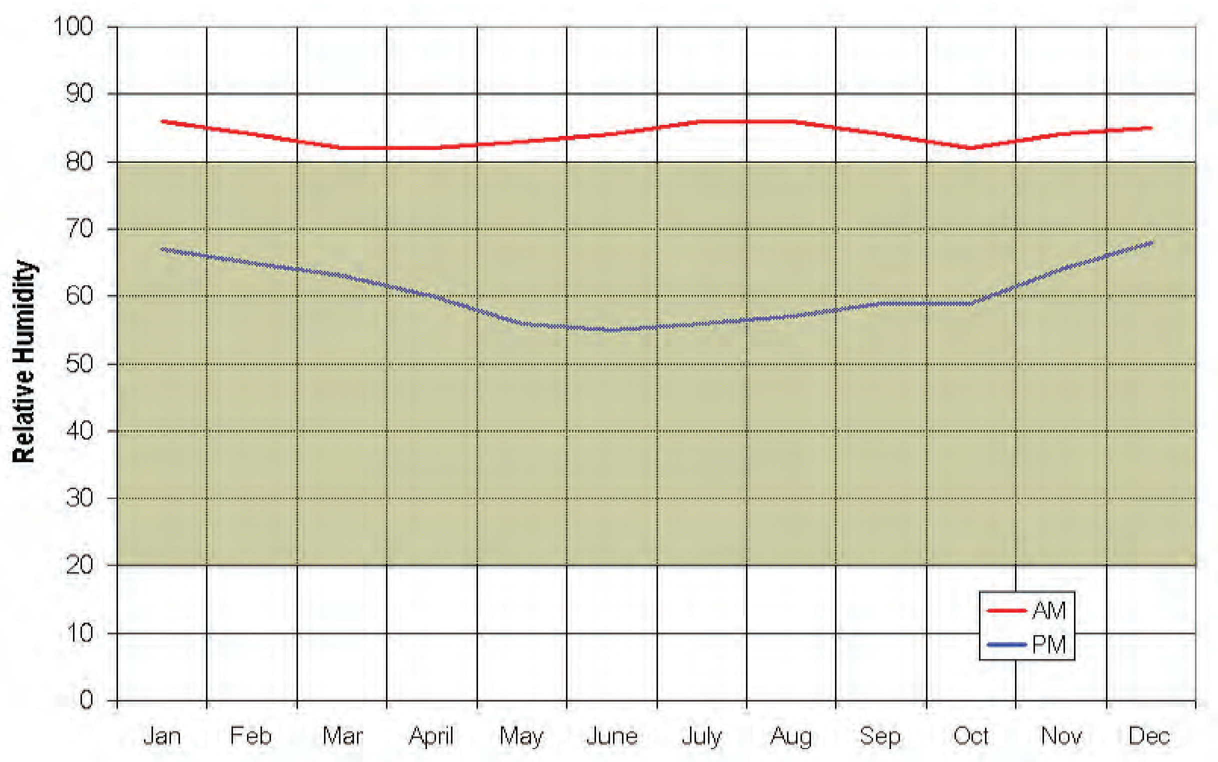
(Typical Comfort Zone: 68-80°F)



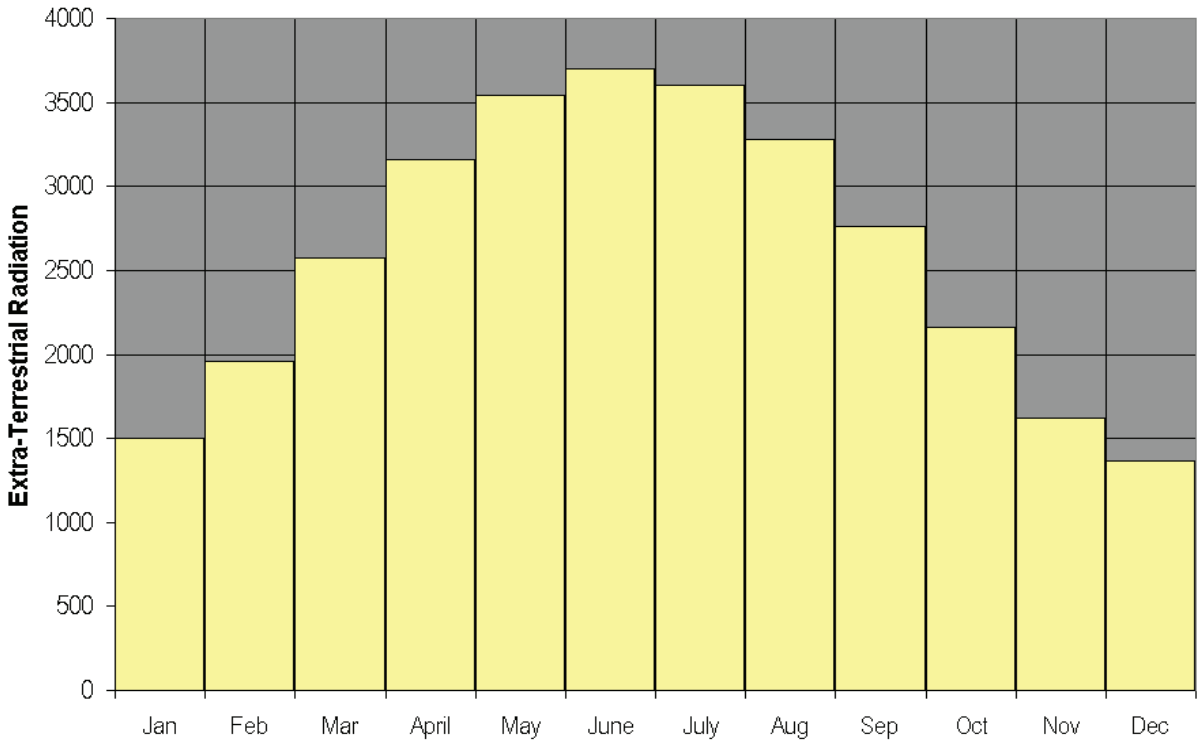
Degree Day
(Base 65°)



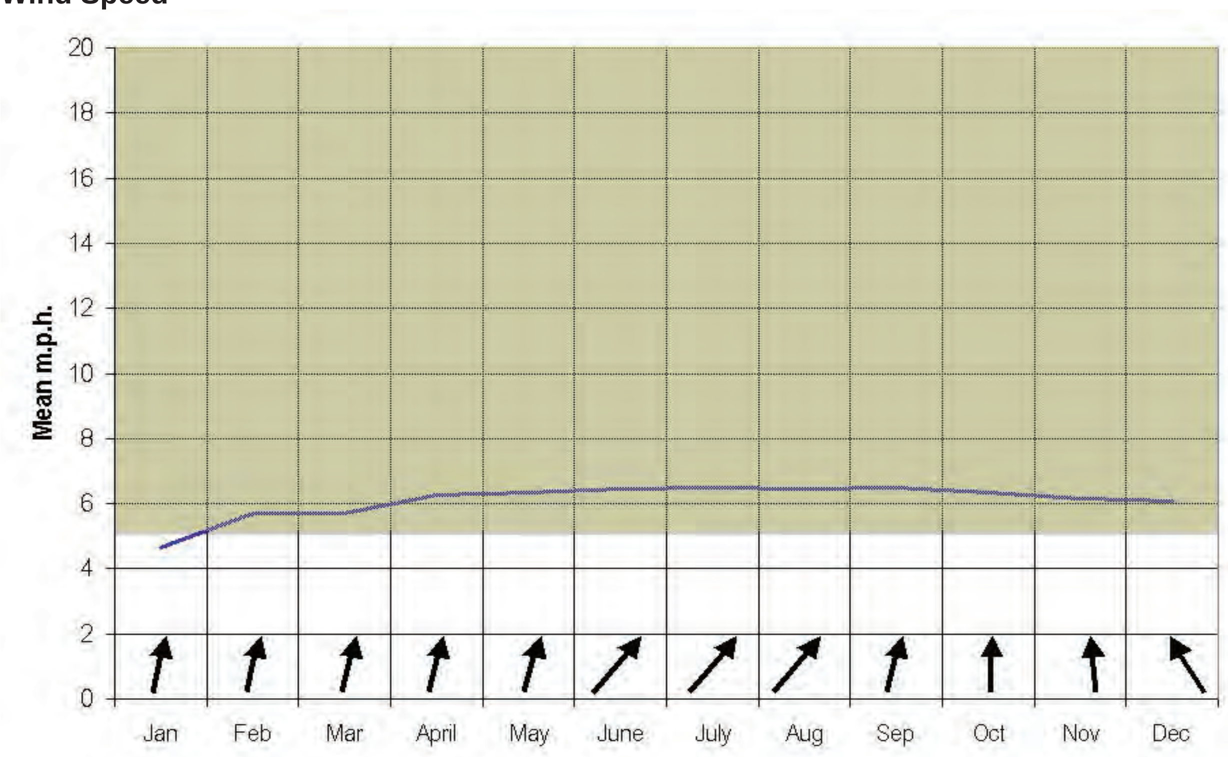
Relative Humidity
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation Daily Mean ETR: 2602



Wind Speed



Prevailing Wind Direction
Summer: NNW
Winter: SE

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate
Zone 5

Reference City:	Santa Maria
Latitude:	34.93 N
Longitude:	120.42 W
Elevation:	230 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	22
Record High Temperature (1987)	108
Record Low Temperature (1976)	20

Design Day Data

Winter	99%	31		
	97.5%	33		
Summer				
	1%:	89	MCWB	68
	2.5%:	76	MCWB	63

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Allow natural ventilation
Distribute Thermal Mass

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R38	R30
Wood Frame Walls	R25	R13
Glazing U-Value	0.42	0.67
Maximum Total Area	16%	20%

Climate

Climate Zone 5 is situated along the coast where ocean temperatures are warmer due to the southern latitude.

Summers are warm with afternoon winds blowing until sunset, which naturally cools the region. The air is usually moist. Fog and cloud cover commonly blocks the sun in the morning and evenings.

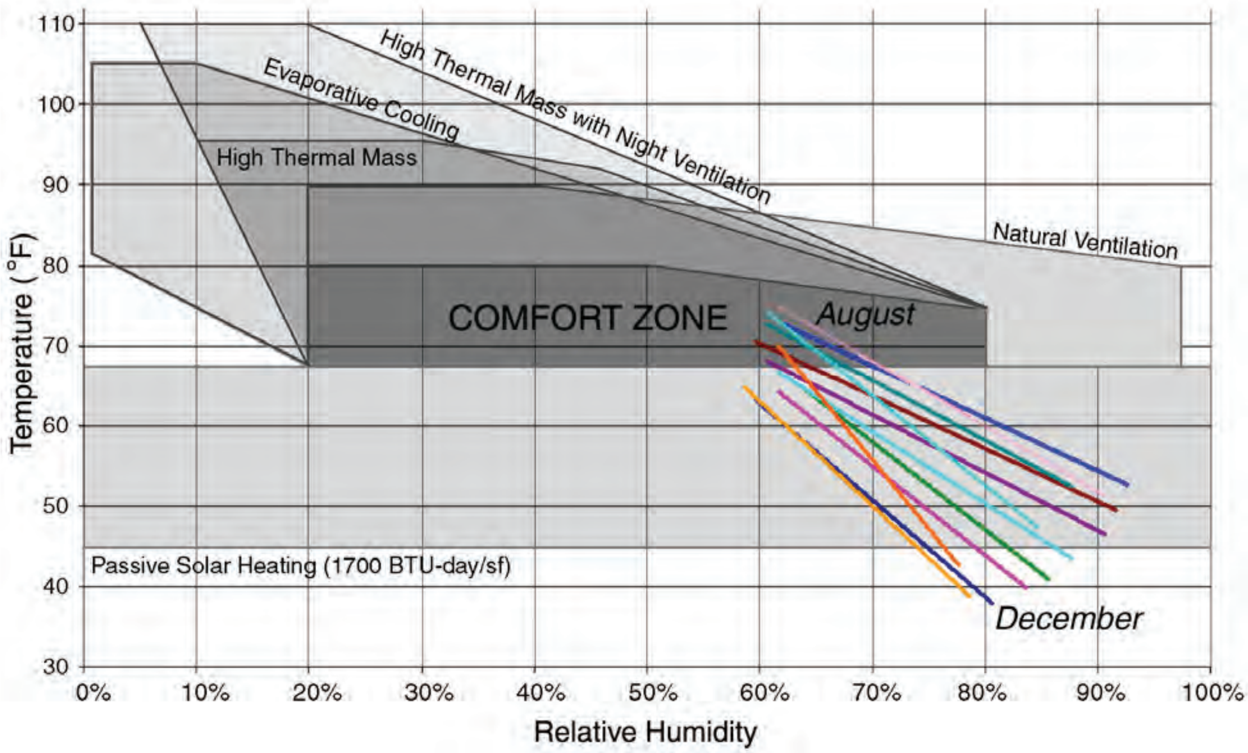
Winters are cold but not severe enough to frost. The coolest parts of this region are the valley floors, canyons, and land troughs.

	Santa Maria	*San Luis Obispo*	*Lompoc*	*Pismo Beach*
HDD	2844	2954	2266	2552
CDD	456	894	332	173

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

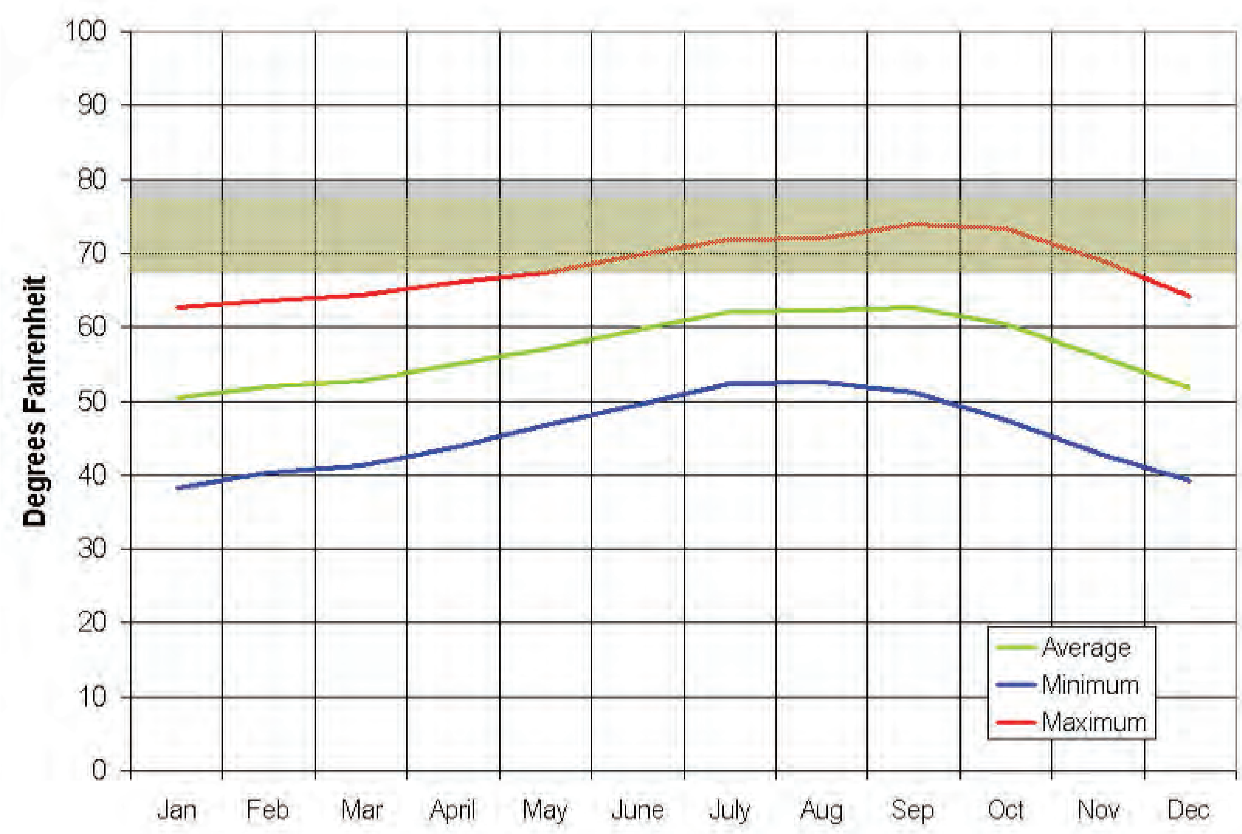
The further inland the location, the fewer HDD and more CDD can be expected. Climate Zone 5 comes close to comfort standards, meaning little cooling is needed and heat is only necessary for part of the day, even in the winter. The mildness of the weather in Zone 5 is reflected in the fact that it is one of the lowest energy consuming climates.

Bioclimatic Chart

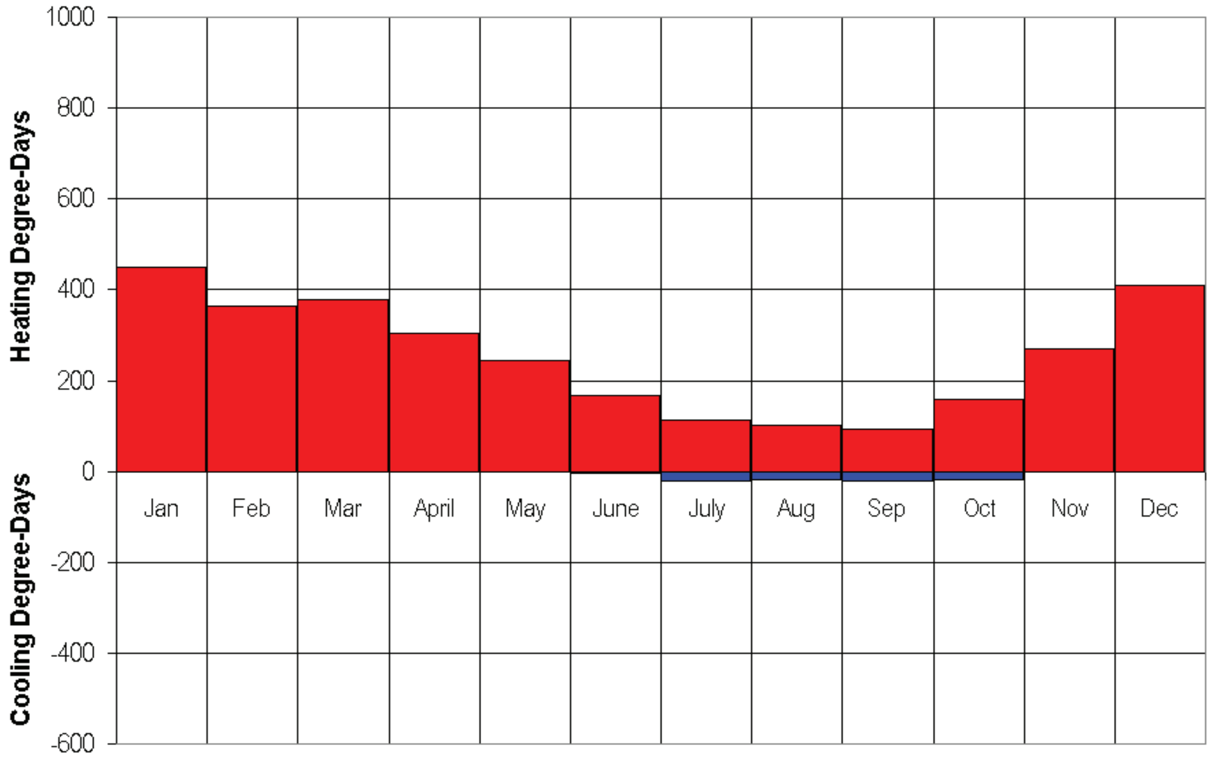


Temperature

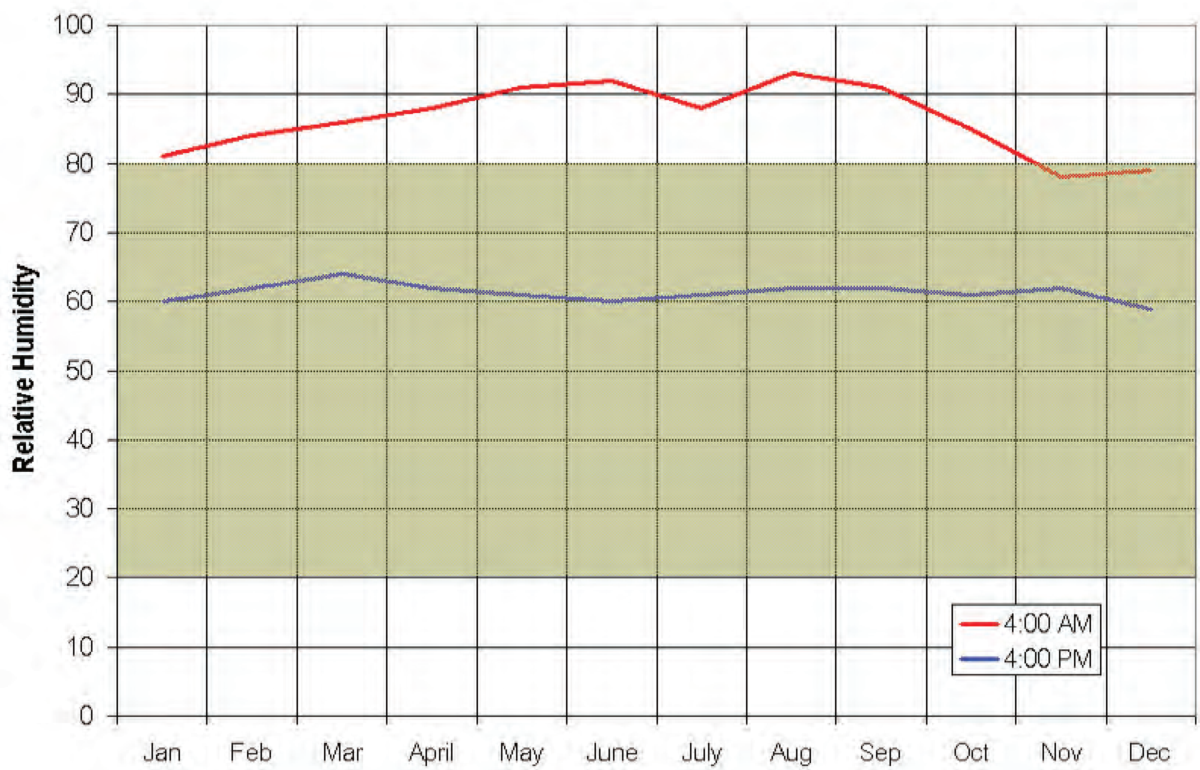
(Typical Comfort Zone: 68-80°F)



Degree Day
(Base 65°)

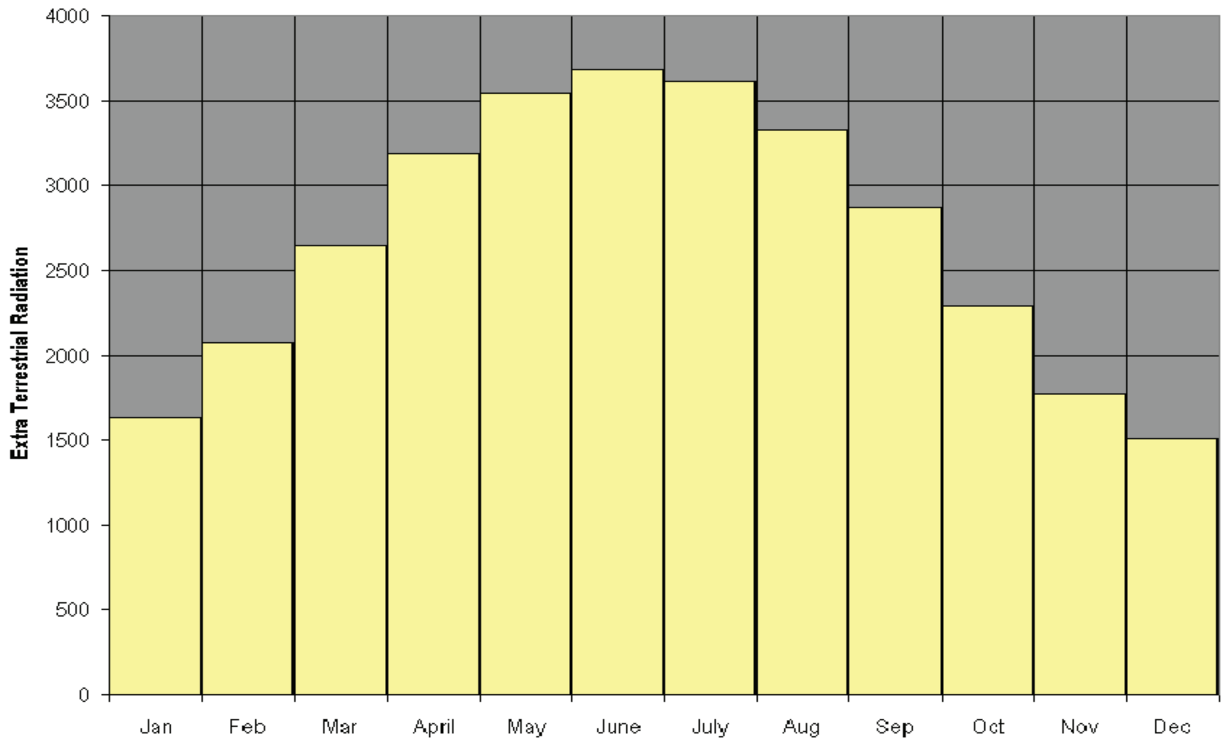


Relative Humidity
(Typical Comfort Zone: 20-80%)

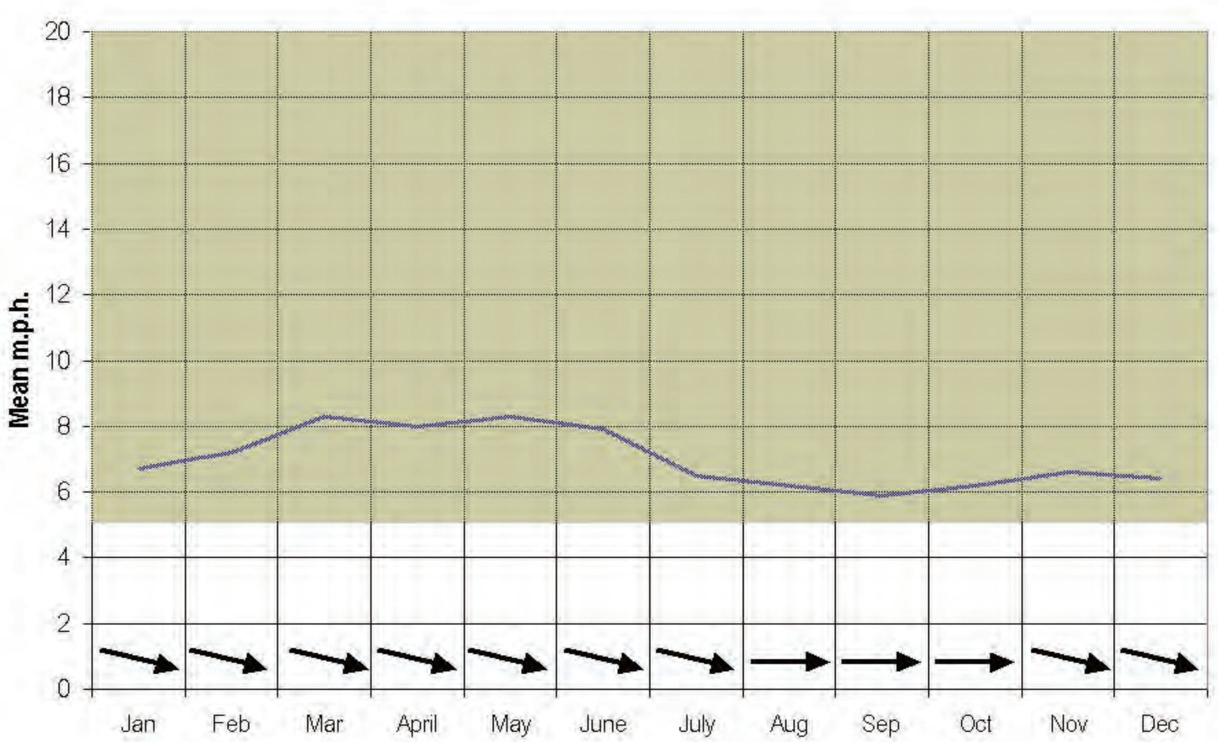


Extra-Terrestrial Radiation

Daily Mean ETR: 2679



Wind Speed



Prevailing Wind Direction
Summer: WNW
Winter: E

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate

Zone 6

Reference City: Los Angeles (LAX)
Latitude: 33.93 N
Longitude: 118.4 W
Elevation: 110 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	15
Record High Temperature (1963)	110
Record Low Temperature (1949)	27

Design Day Data

Winter	99%	41		
	97.5%	43		
Summer	*Mare Island*			
	1%:	83	MCWB	68
	2.5%:	80	MCWB	66

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Allow natural ventilation
Distribute Thermal Mass

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R38	R30
Wood Frame Walls	R21	R13
Glazing U-Value	0.42	0.67
Maximum Total Area	14%	20%

Climate

Climate Zone 6 includes the beaches at the foot of the southern California hills, as well as several miles of inland area where hills are low or nonexistent. The Pacific Ocean is relatively warm in these longitudes and keeps the climate very mild. Most of the rain falls during the warm, mild winters.

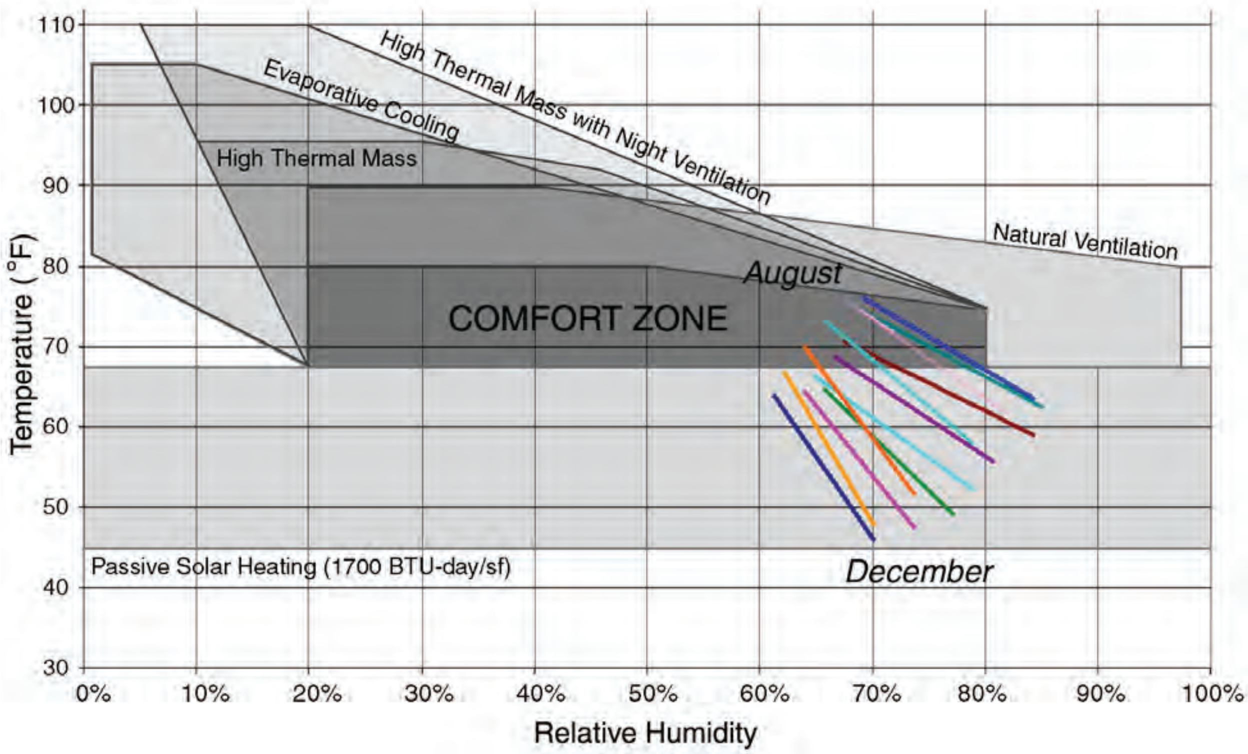
	Santa Barbara	*LAX*	*Long Beach*	*Torrance*
HDD	1902	1458	1430	742
CDD	470	727	1201	568

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

Summers are pleasantly cooled by winds from the ocean. Although these offshore winds bring high humidity, comfort is maintained because of the low temperatures. Occasionally the wind reverses and brings hot, dry desert air.

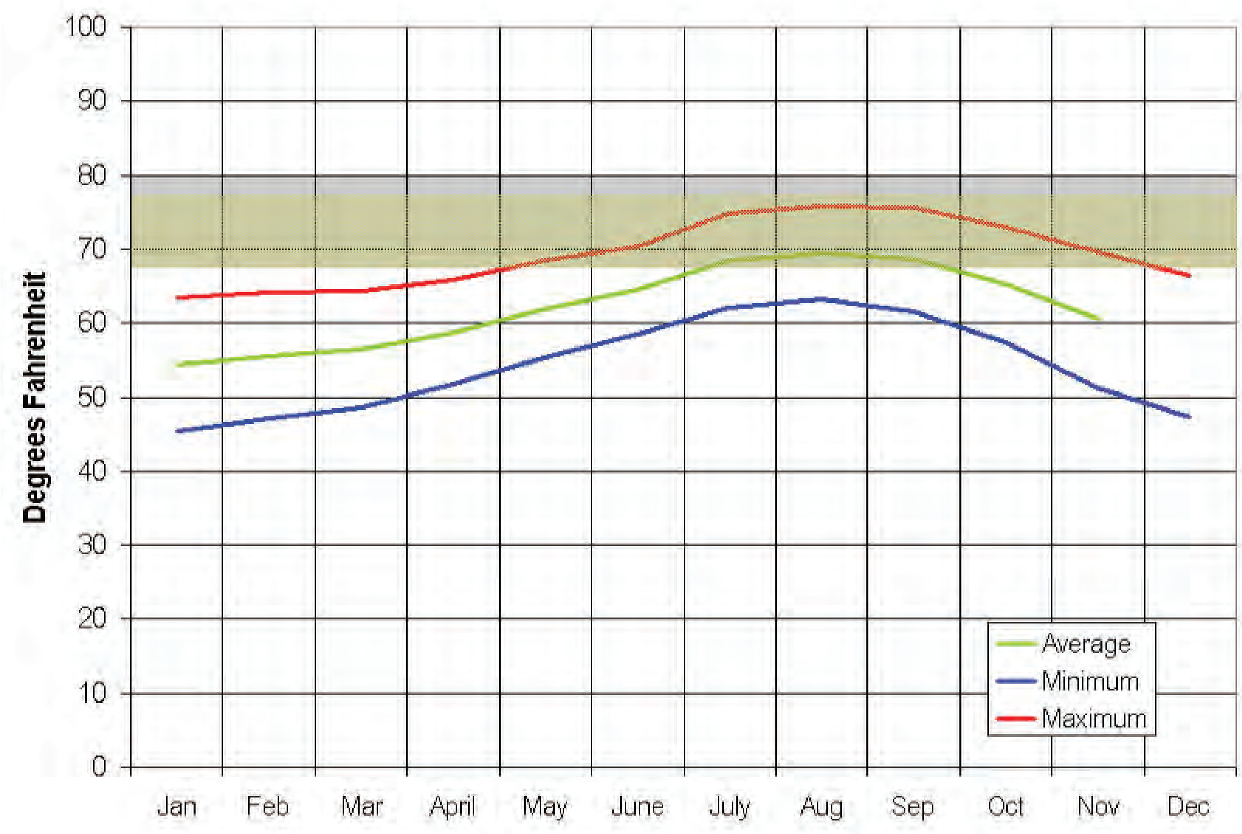
There is a sharp increase in temperature and decrease in humidity as one leaves the coast. Sunshine is plentiful all year, so solar heating, especially for hot water, is very advantageous. Climate Zone 6 is a very comfortable place to live and therefore requires the least energy of any region in California to achieve thermal comfort levels.

Bioclimatic Chart

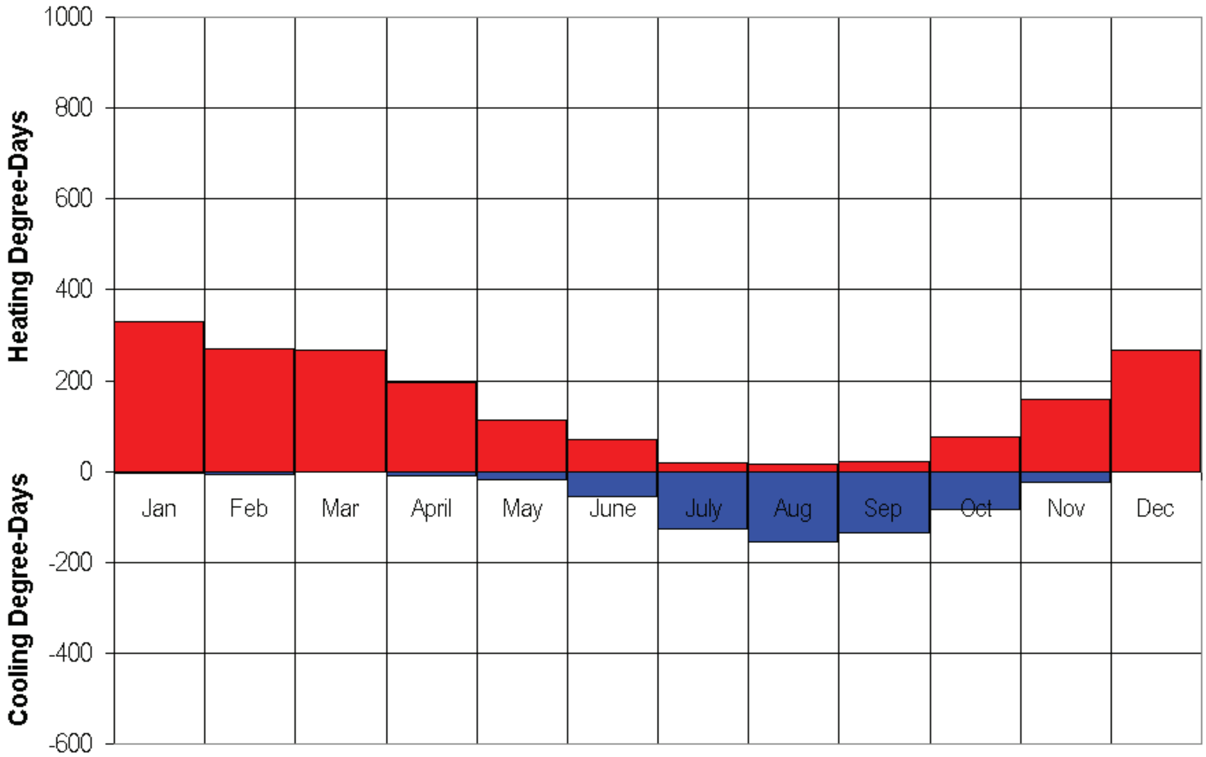


Temperature

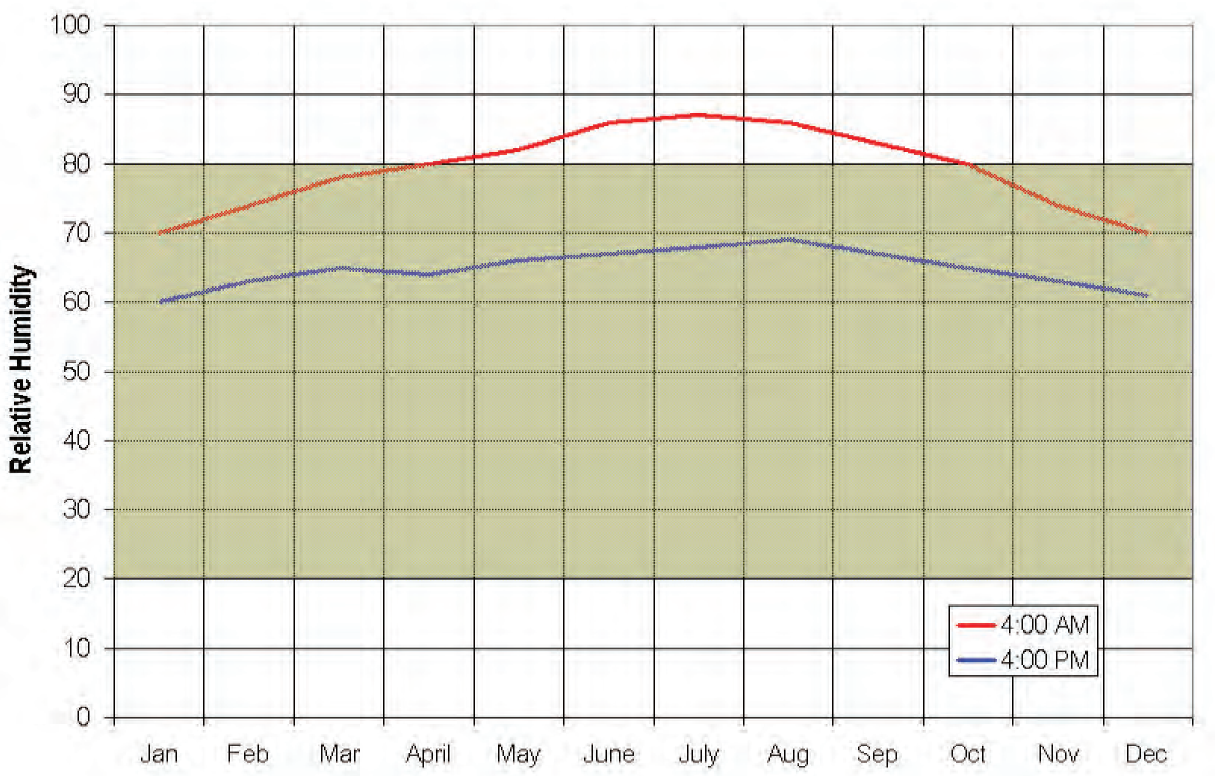
(Typical Comfort Zone: 68-80°F)



Degree Day
(Base 65°)

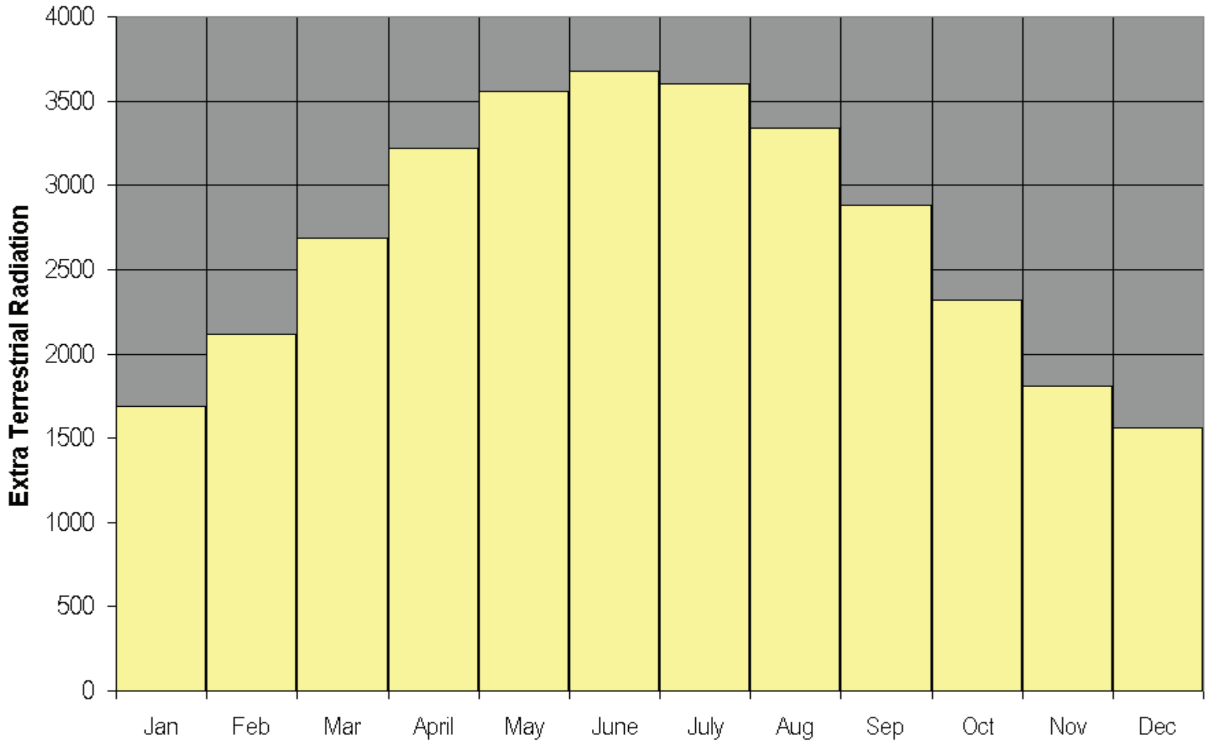


Relative Humidity
(Typical Comfort Zone: 20-80%)

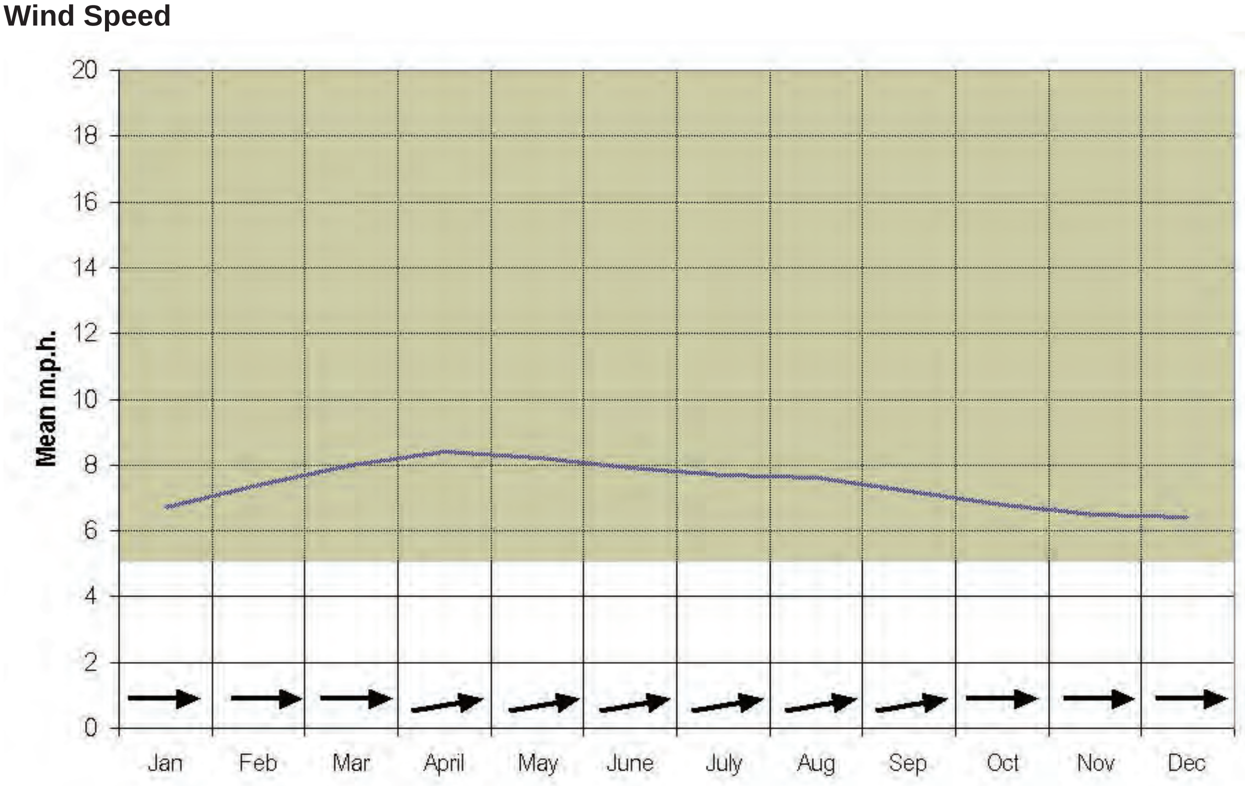


Extra-Terrestrial Radiation

Daily Mean ETR: 2704



Wind Speed



Prevailing Wind Direction
Summer: WSW
Winter: E

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate

Zone 7

Reference City: San Diego
Latitude: 32.73 N
Longitude: 117.17 W
Elevation: 10 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	14
Record High Temperature (1963)	111
Record Low Temperature (1949)	29

Design Day Data

Winter	99%	42		
	97.5%	44		
Summer				
	1%:	83	MCWB	69
	2.5%:	80	MCWB	69

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Allow natural ventilation
Distribute Thermal Mass

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R38	R30
Wood Frame Walls	R21	R13
Glazing U-Value	0.38	0.67
Maximum Total Area	14%	20%

Climate

Climate Zone 7 is the southernmost coastal region of California. The warm ocean water and latitude make this climate very mild. The temperature of the ocean water affects the air temperature over it, and this in turn moderates temperatures over the coastal strip.

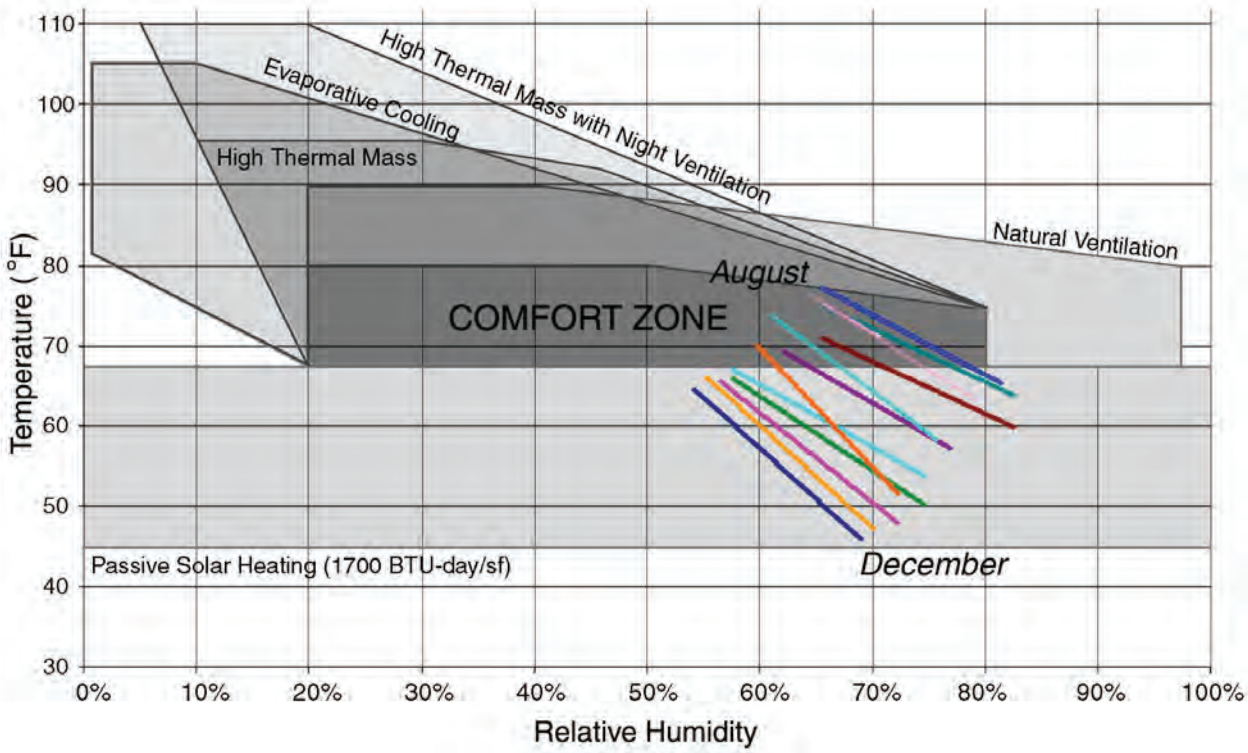
The ocean influences the weather most of the time, however the wind changes sometimes, bringing in the hot and extremely drying Santa Ana winds. The weather in the summer is warm and comfortable, and hot enough that cooling is necessary on some days.

	Oceanside	*Chula Vista*	*San Diego*	*La Mesa*
HDD	2009	1321	1256	1400
CDD	505	862	984	1110

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

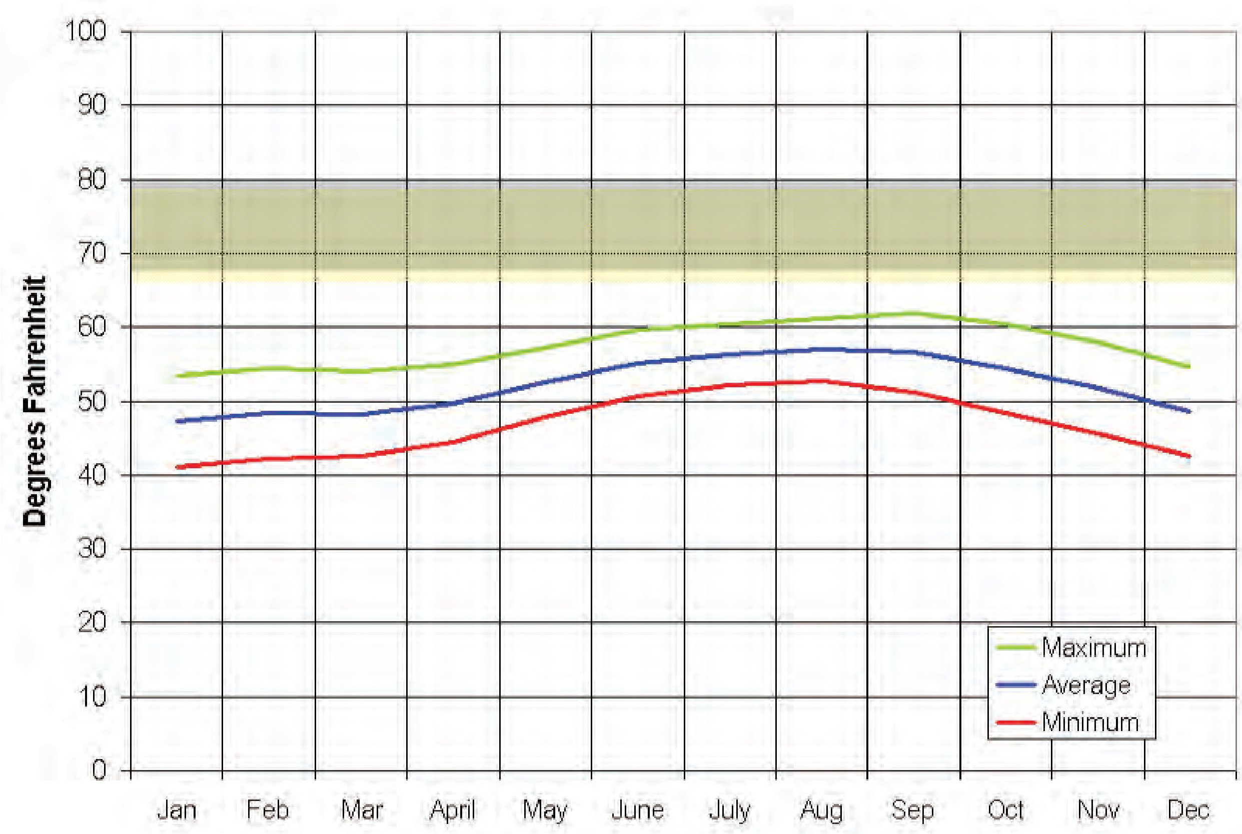
However, daily high fogs naturally cool the area at night. The winters are cool and heating is necessary sometimes. The weather and comfort standards in this region are in concurrence as shown by the low consumption of energy use.

Bioclimatic Chart

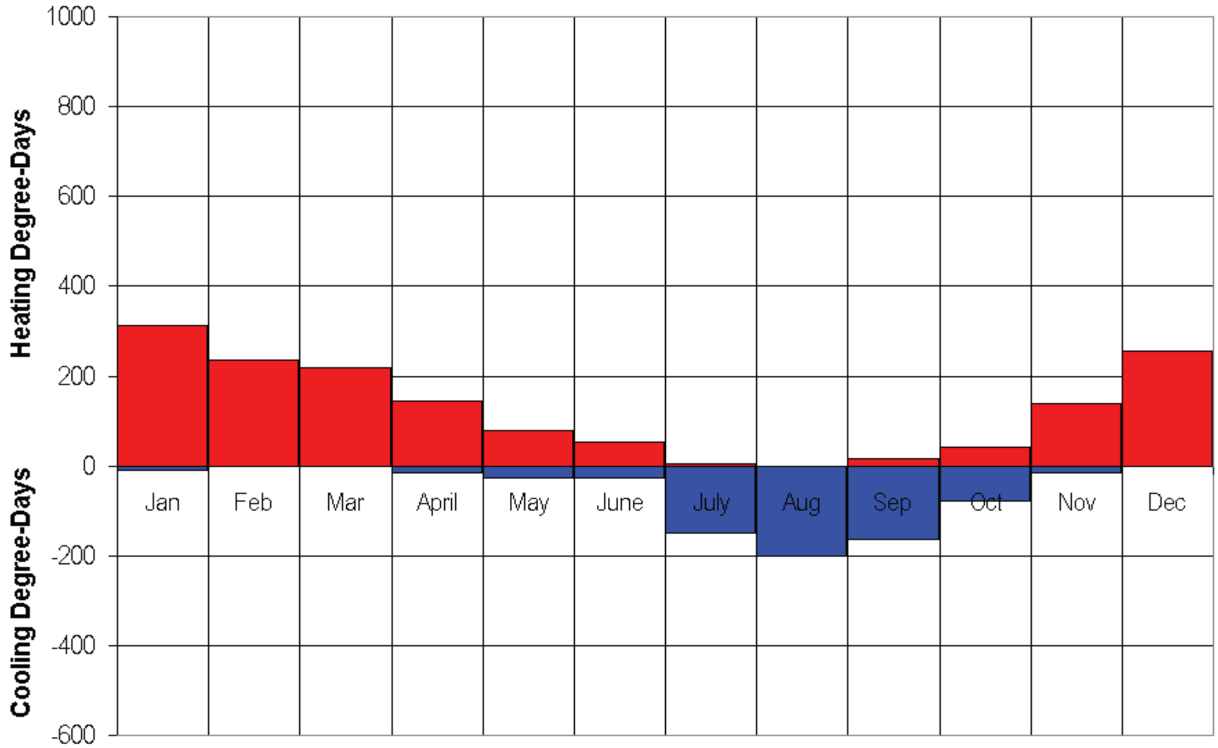


Temperature

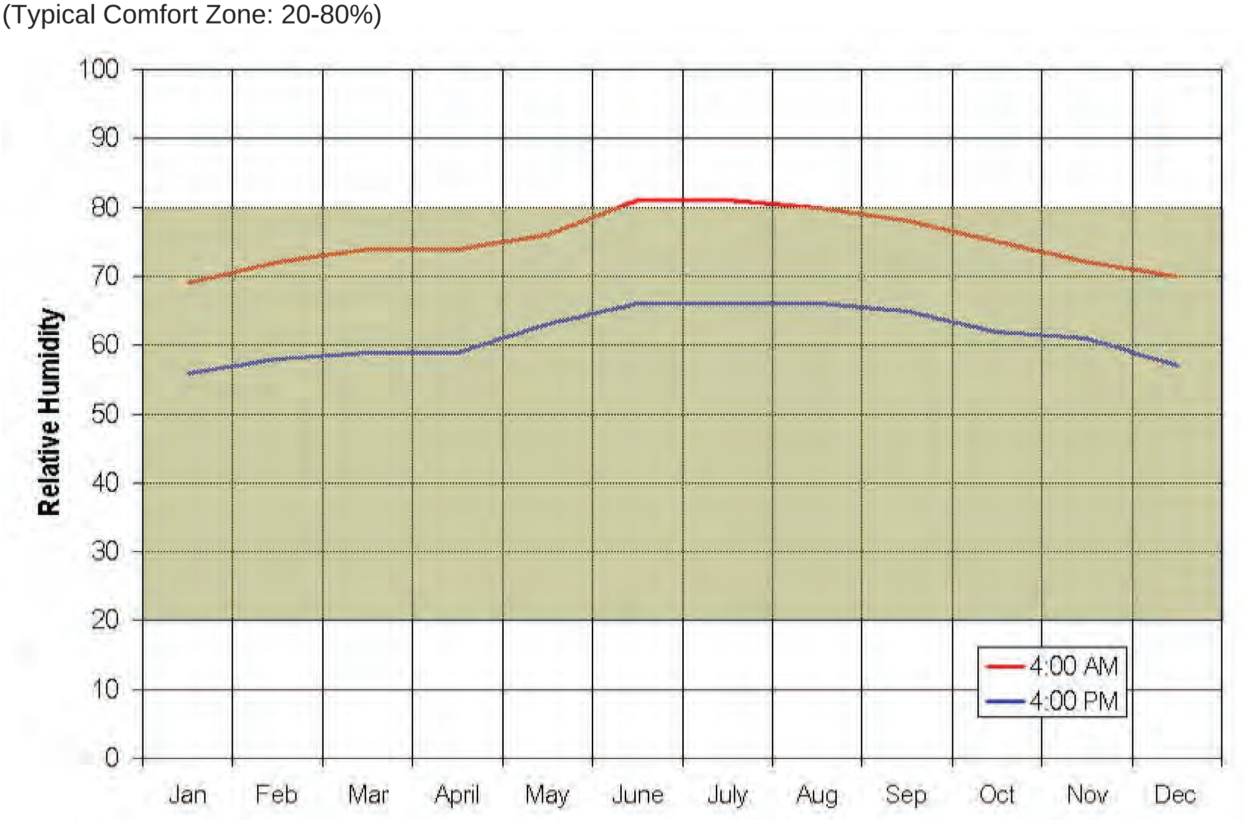
(Typical Comfort Zone: 68-80°F)



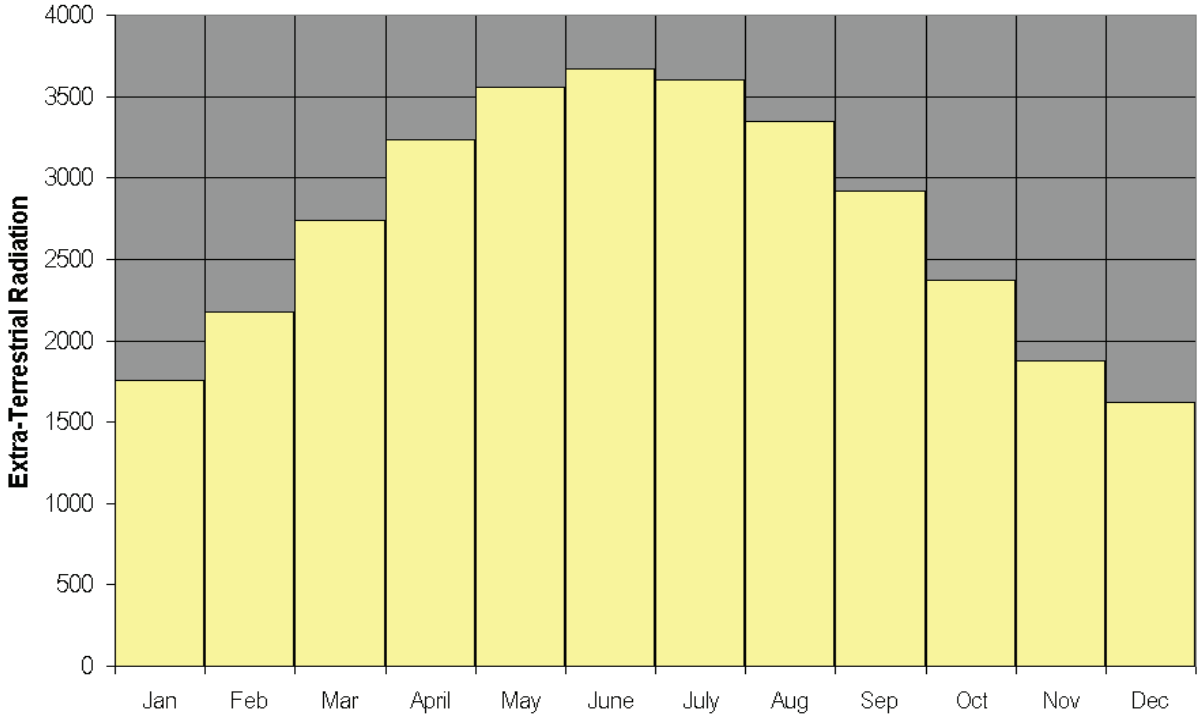
Degree Day
(Base 65°)



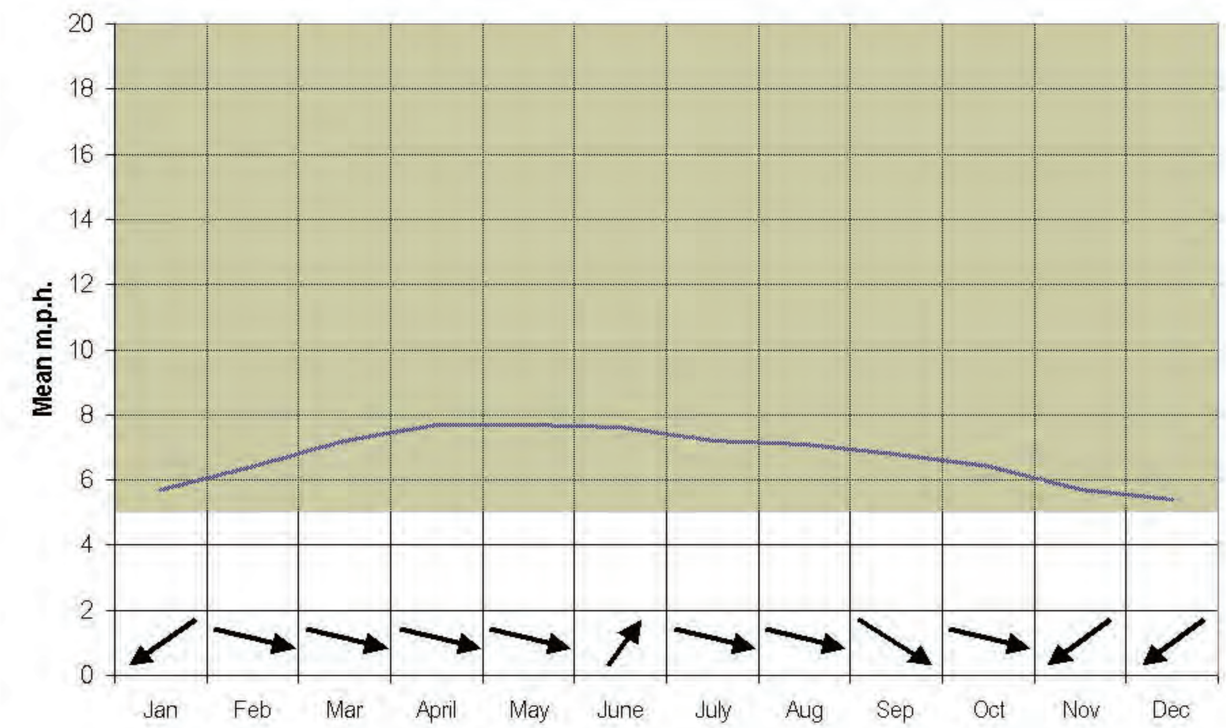
Relative Humidity
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation Daily Mean ETR: 2739



Wind Speed



Prevailing Wind Direction
Summer: WNW
Winter: NE

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate

Zone 8

Reference City:	Long Beach
Latitude:	33.82 N
Longitude:	118.15 W
Elevation:	30 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	15
Record High Temperature (1961)	111
Record Low Temperature (1963)	25

Design Day Data

Winter	99%	41		
	97.5%	43		
Summer	*Mare Island*			
	1%:	83	MCWB	68
	2.5%:	80	MCWB	68

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Allow natural ventilation
Distribute Thermal Mass

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R38	R30
Wood Frame Walls	R21	R13
Glazing U-Value	0.38	0.67
Maximum Total Area	14%	20%

Climate

Though inland from the coast, Zone 8 is still influenced by marine air. The ocean influence controls temperature keeping it from being more extreme.

Since this zone is not directly on the coast the temperatures in the summer are warmer, and in the winter, cooler. Cooling and heating are necessary in this climate to achieve comfort standards.

	Long Beach	*Anaheim*	*Tustin*	*El Toro*
HDD	1430	1286	1794	1413
CDD	1201	1294	1102	691

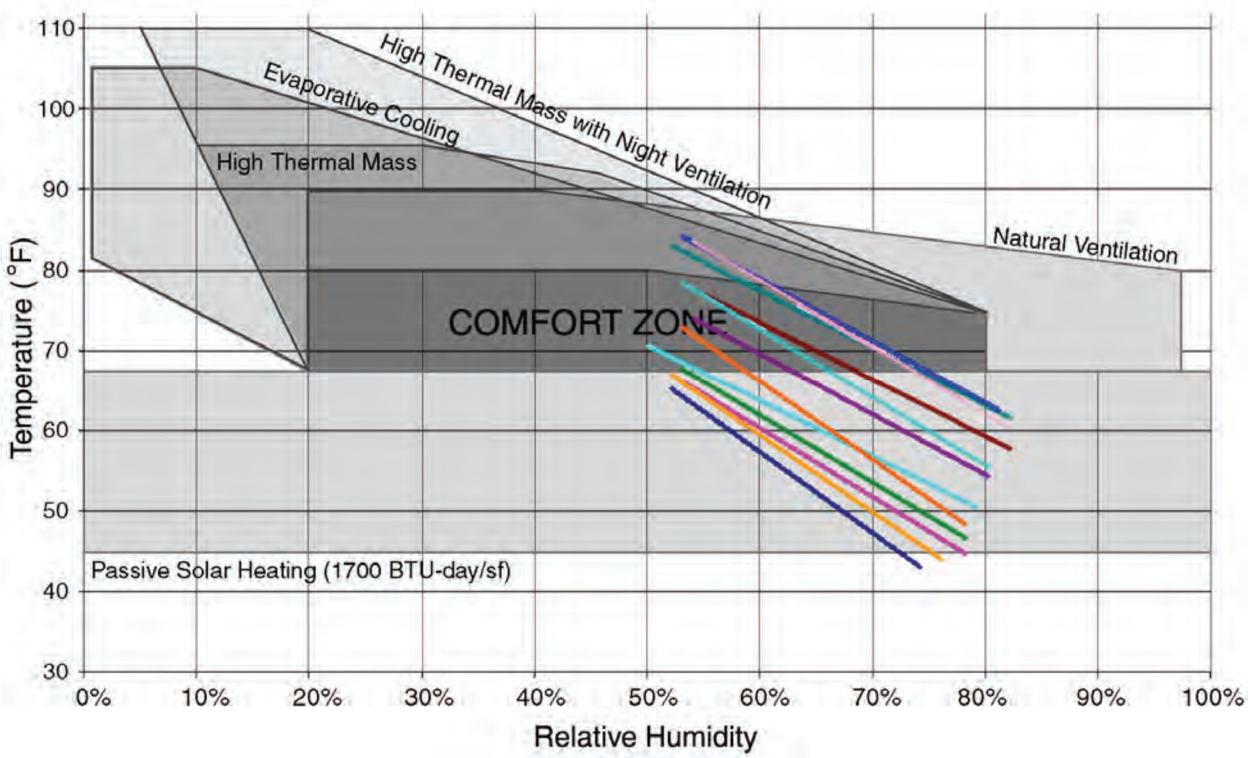
HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

Most of the rain falls in the winter and frosts are not a threat. Coldest temperatures are experienced in the canyons and near canyon mouths.

This are is ideal for growing subtropical plants, such as the avocado. Winters are not cold enough to grow apples, peaches or pears.

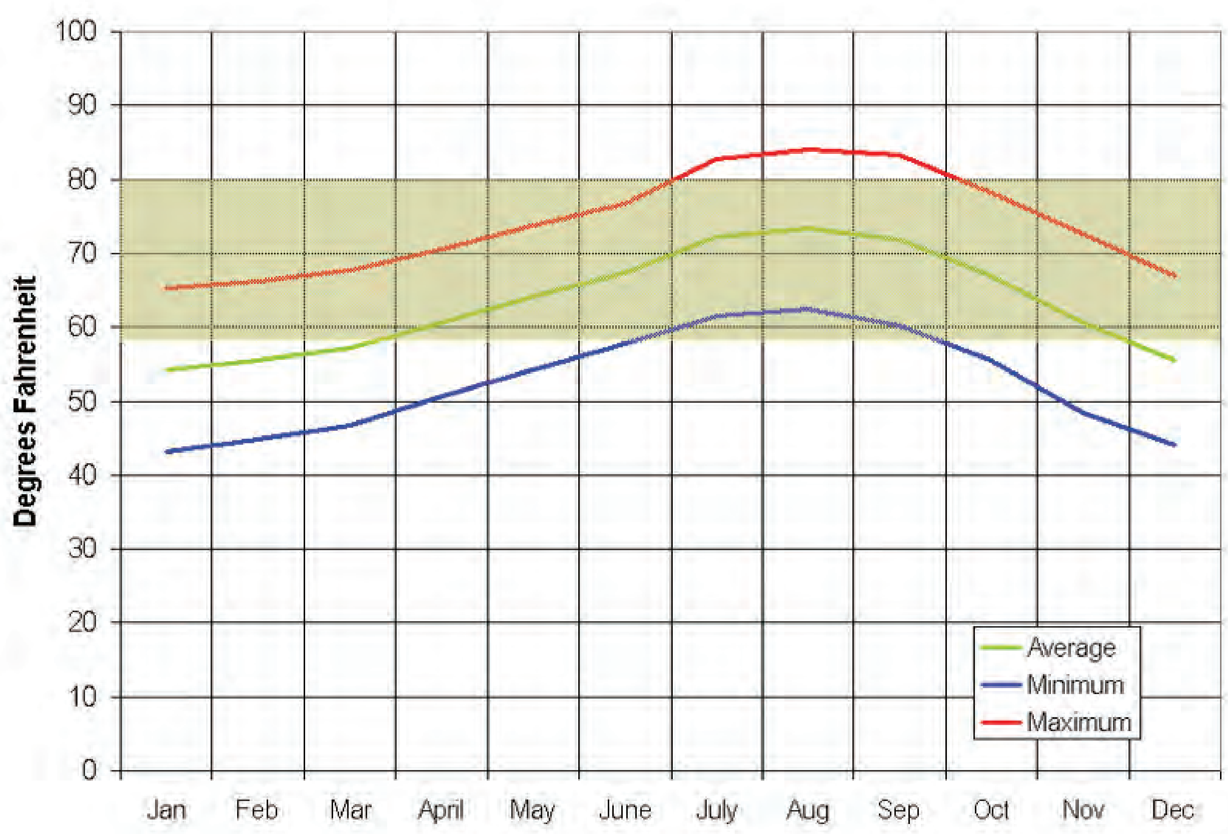
Sunshine is plentiful in this region since it is far from coastal daily fog.

Bioclimatic Chart

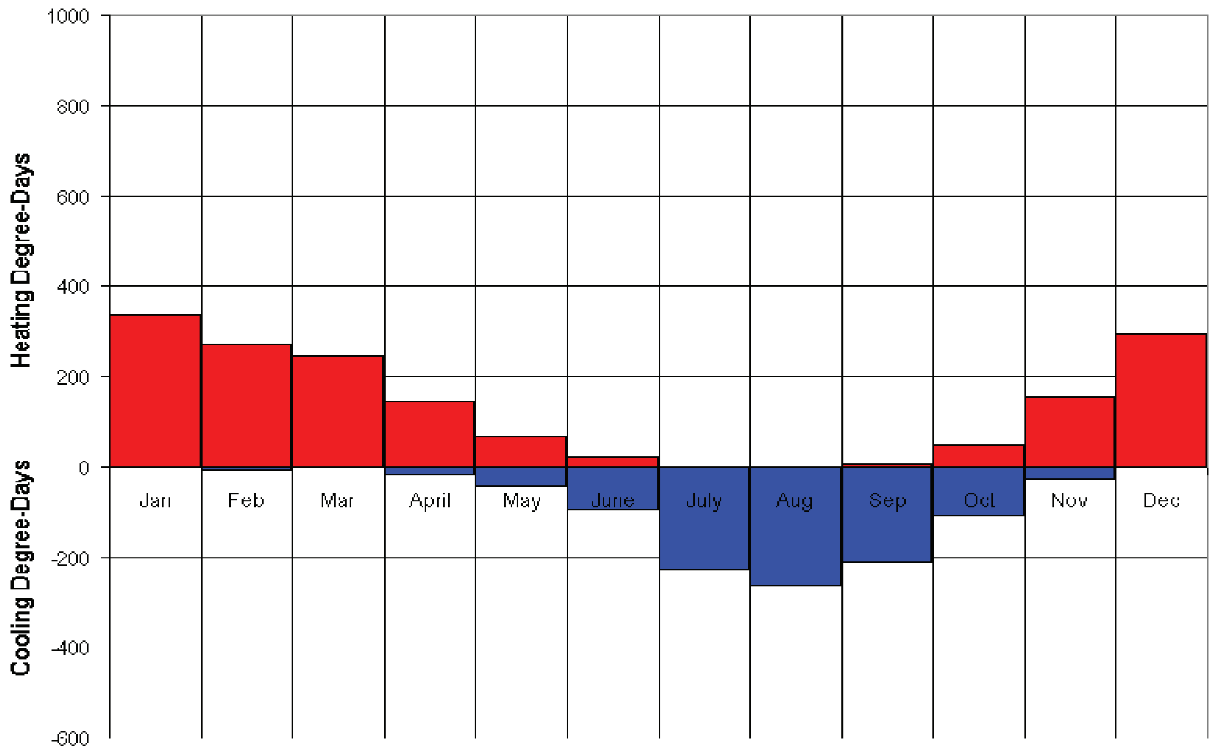


Temperature

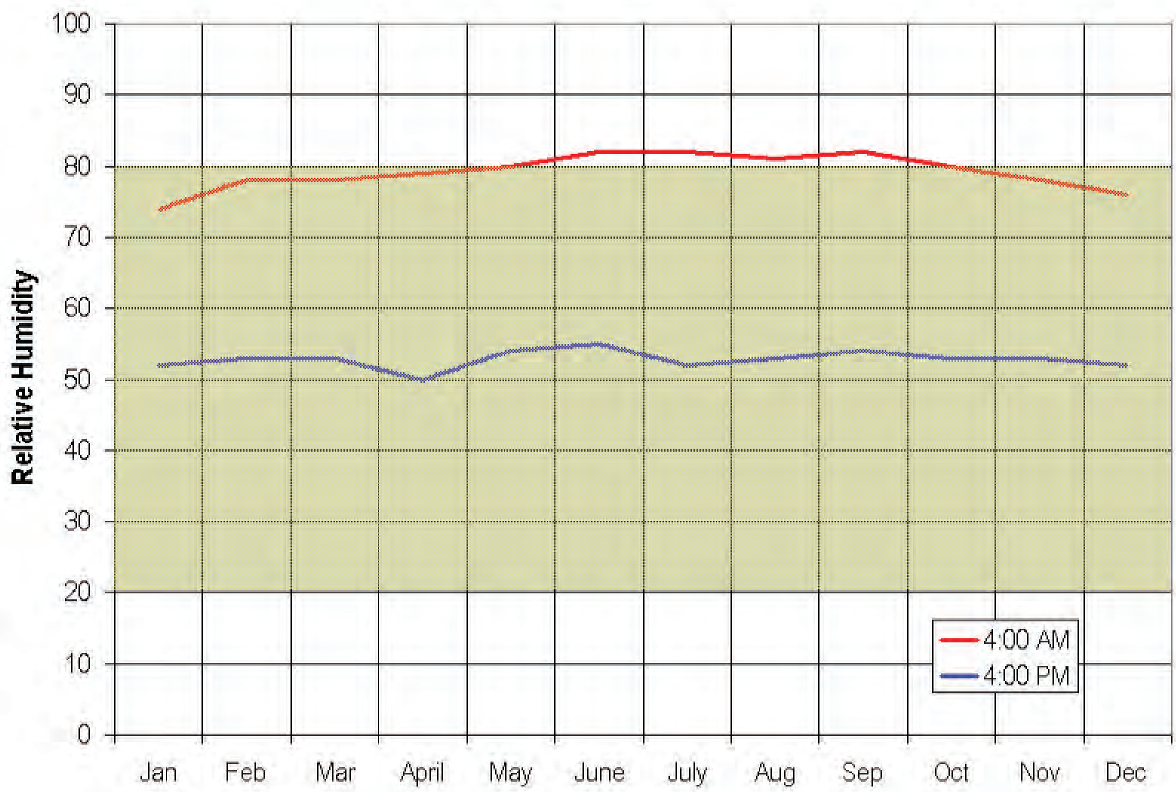
(Typical Comfort Zone: 68-80°F)



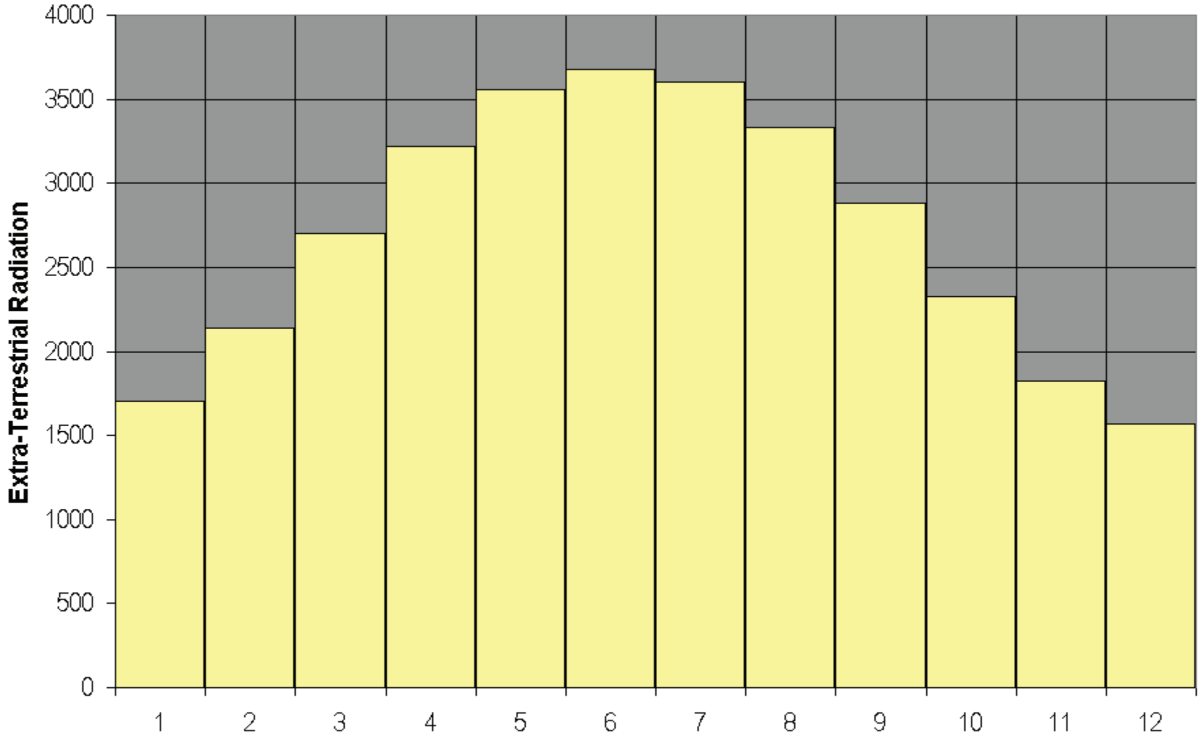
Degree Day
(Base 65°)



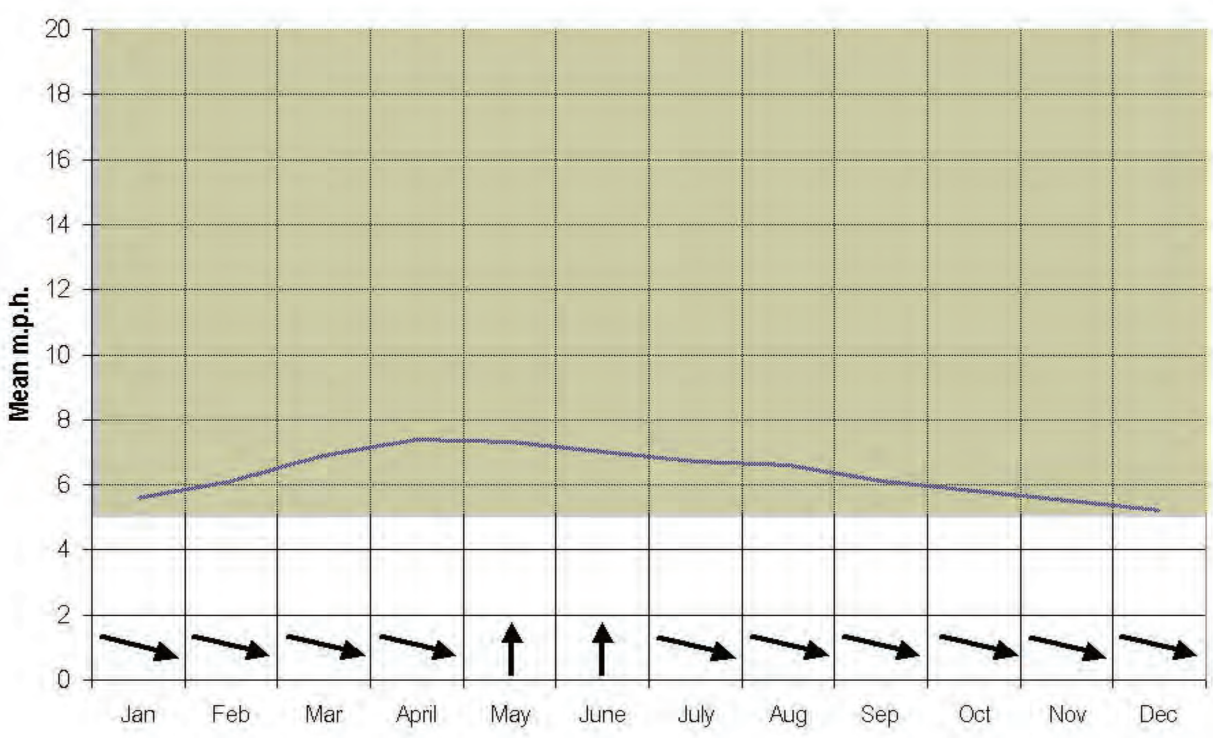
Relative Humidity
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation Daily Mean ETR: 2712



Wind Speed



Prevailing Wind Direction
Summer: WSW
Winter: E

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate

Zone 9

Reference City:	Los Angeles (Civic Center)
Latitude:	34.05 N
Longitude:	118.23 W
Elevation:	270 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	19
Record High Temperature (1955)	110
Record Low Temperature (1949)	28

Design Day Data

Winter	99%	37		
	97.5%	40		
Summer				
	1%:	93	MCWB	70
	2.5%:	89	MCWB	70

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Use Evaporative Cooling
Distribute Thermal Mass

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R38	R30
Wood Frame Walls	R21	R13
Glazing U-Value	0.38	0.67
Maximum Total Area	14%	20%

Bioclimatic Chart

Climate

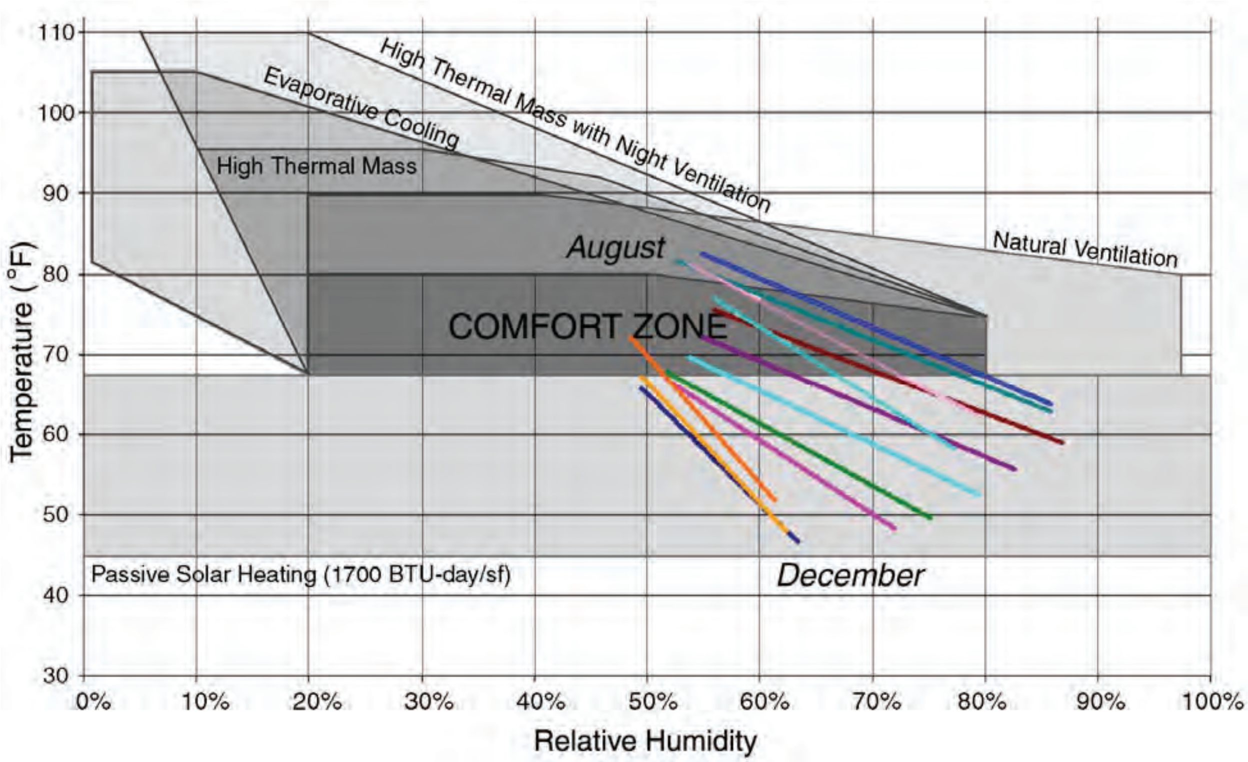
Both coastal and interior weather influences the Southern Californian inland valley climate zone. The inland winds bring hot and dry air, and marine air brings cool and moist air.

This area is famous for growing citrus because the summers are hot and winters never frost. This area has as many HDD as CDD.

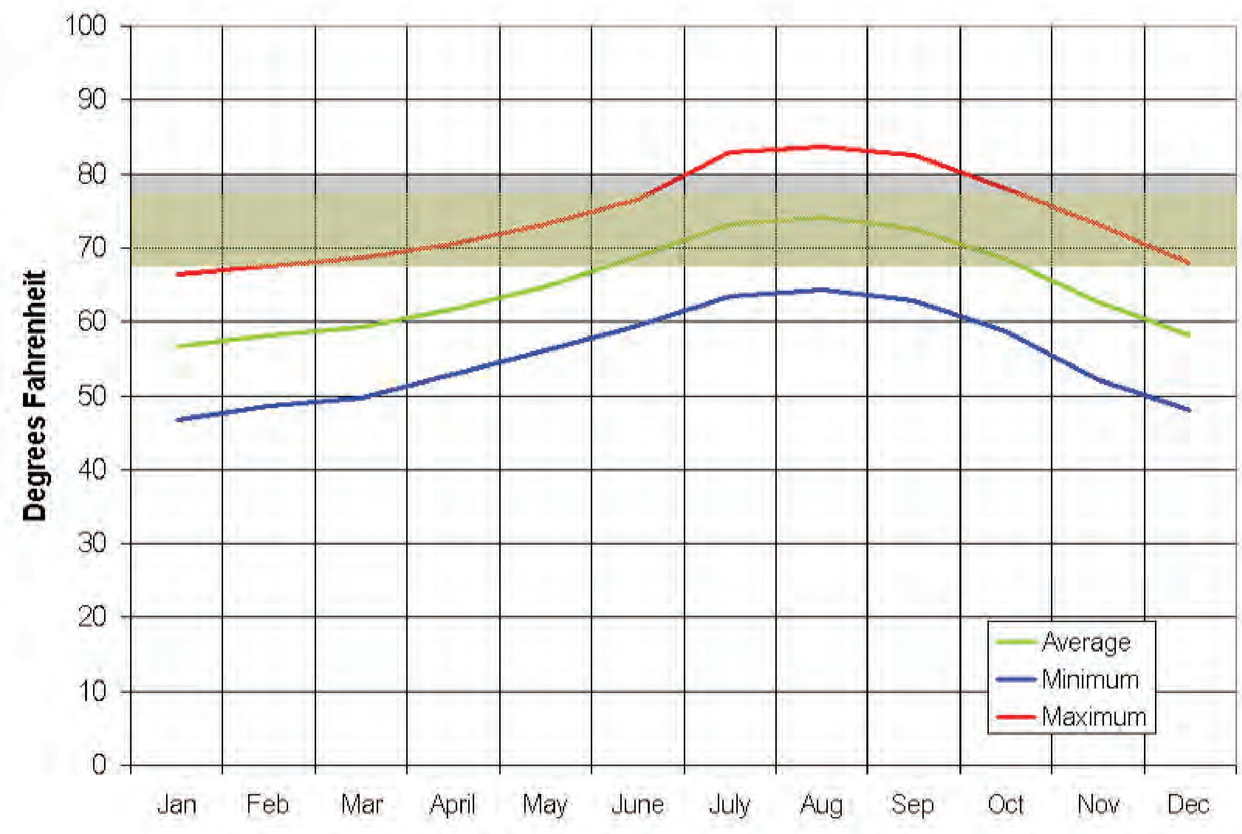
	LA Civic Center	*Pasa-dena*	*Burbank*	*Pomona*
HDD	1154	1398	1575	1713
CDD	1537	1558	1455	1273

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

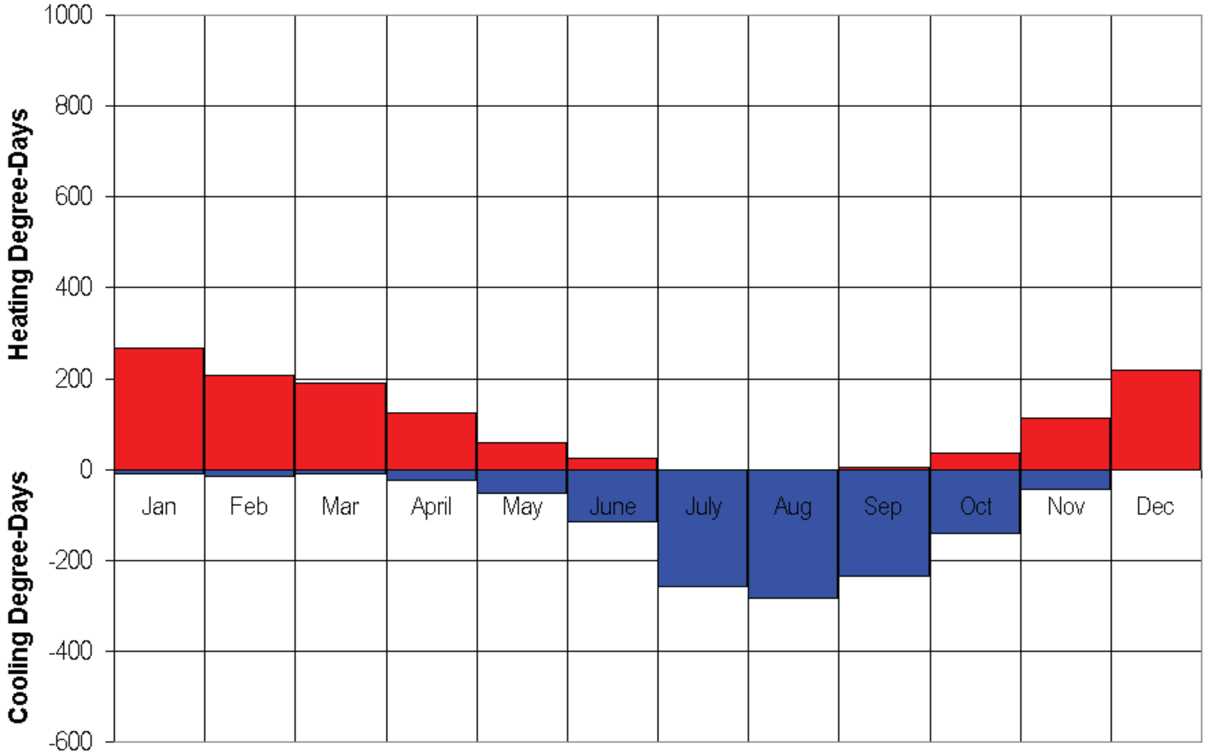
Compared to the coast, summers are warmer and winters are cooler. Rain falls in the winter averaging around 2" per month between November and April. More than 50% of the time skies are clear or partly cloudy.



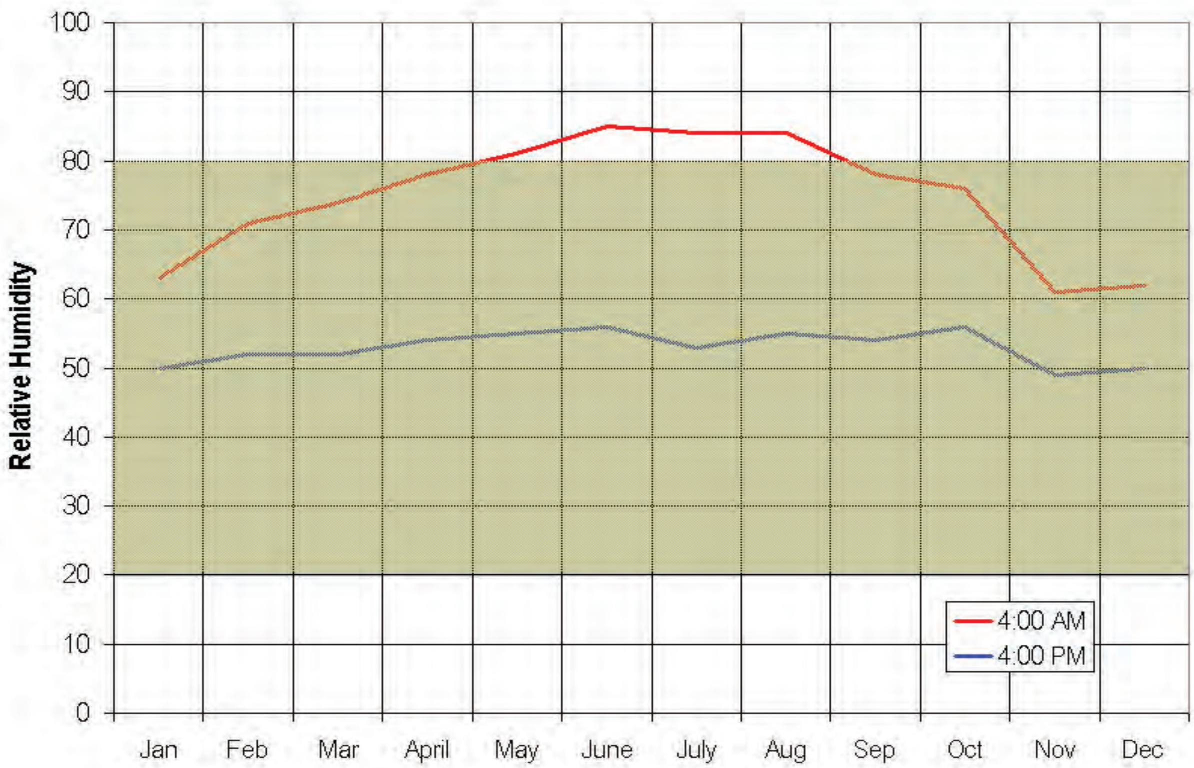
Temperature
(Typical Comfort Zone: 68-80°F)



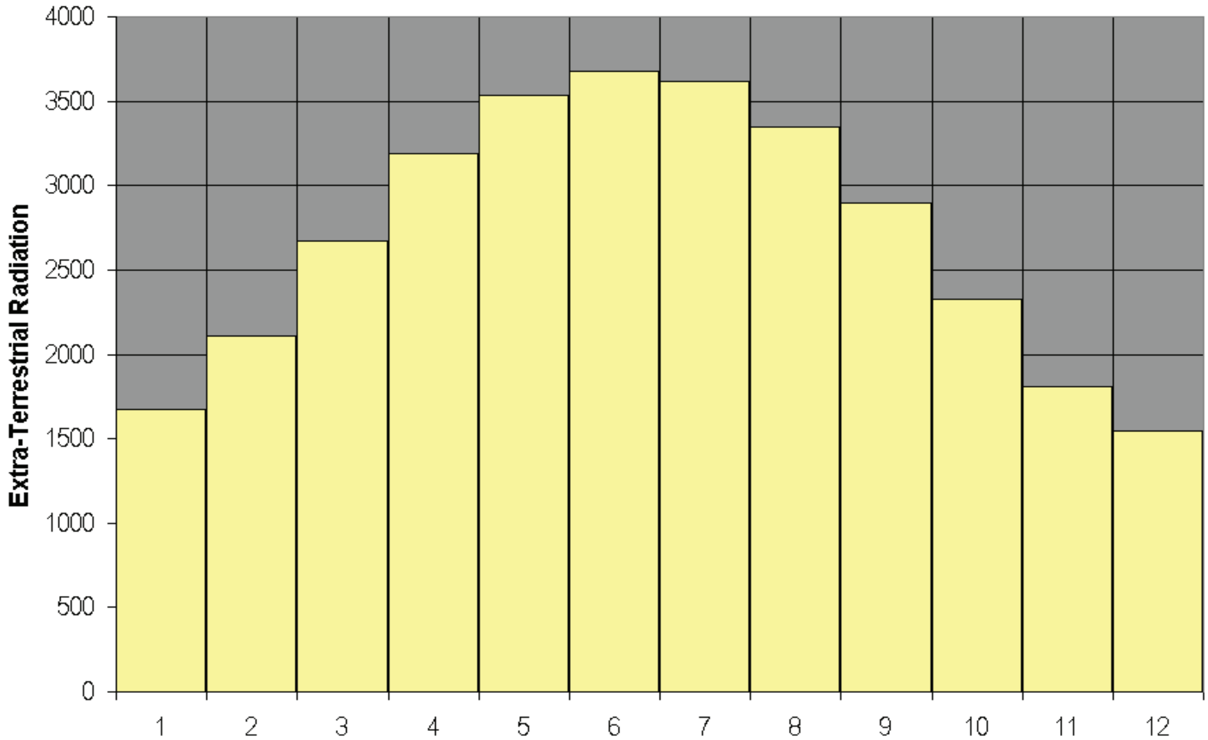
Degree Day
(Base 65°)



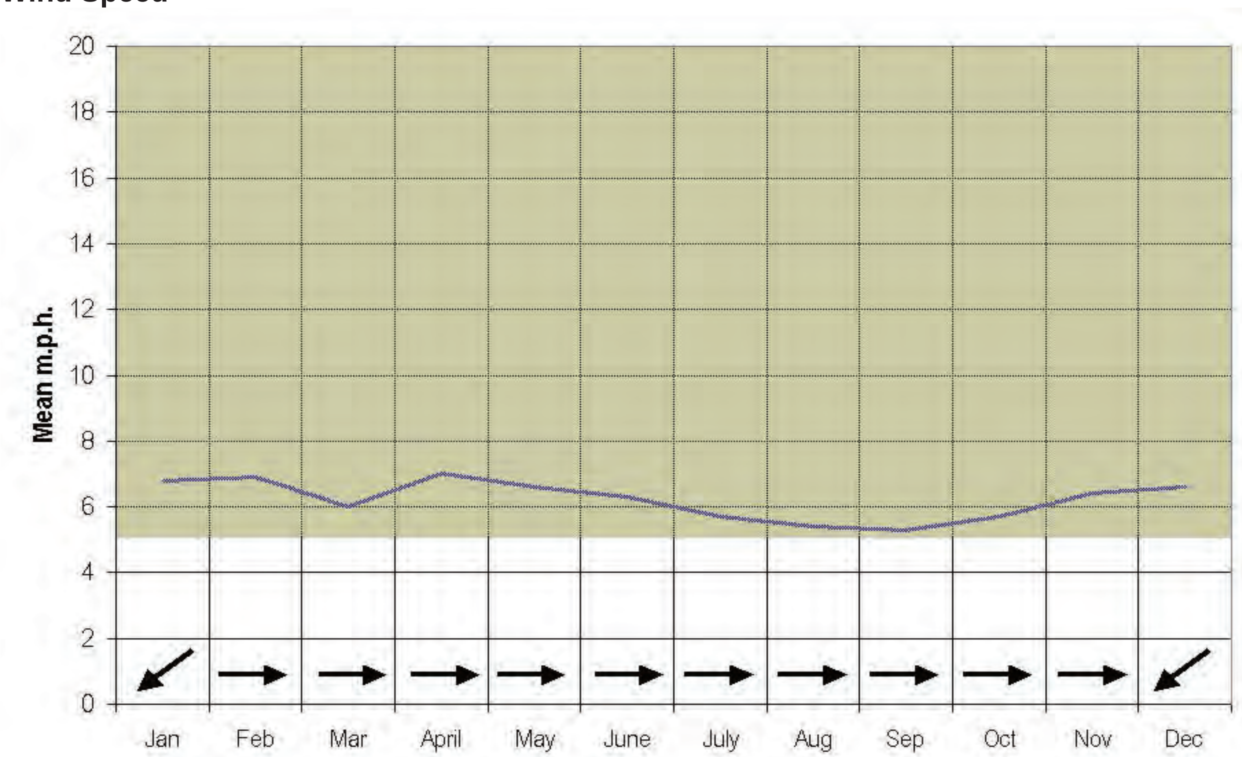
Relative Humidity
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation Daily Mean ETR: 2699



Wind Speed



Prevailing Wind Direction
Summer: NW
Winter: NW

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate

Zone 10

Reference City:	Riverside
Latitude:	33.95 N
Longitude:	117.38 W
Elevation:	840 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	32
Record High Temperature (1934)	116
Record Low Temperature (1950)	19

Design Day Data

Winter	99%	29		
	97.5%	32		
Summer				
	1%:	100	MCWB	68
	2.5%:	98	MCWB	68

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Allow natural ventilation
Distribute Thermal Mass

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R30
Wood Frame Walls	R25	R13
Glazing U-Value	0.38	0.57
Maximum Total Area	16%	20%

Climate

The Southern California interior valleys are hilly and effected by thermal belts. Hilltops and valleys get more cold in the winter (with the possibility of frost) and warmer in the summer than the slopes and hillsides from which cold air drains.

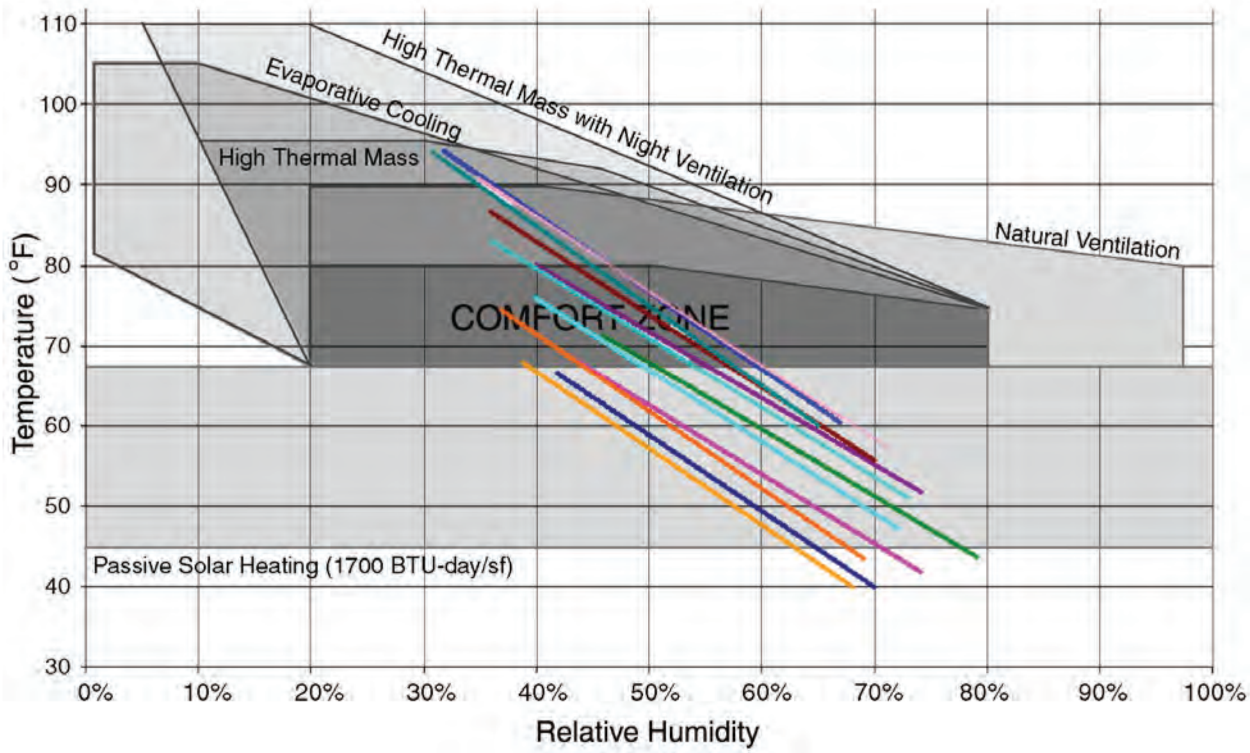
This climate is little influenced by the ocean. The days are quite sunny with most of the rain falling in the winter.

	Red-lands	*El Cajon*	*River-side*	*San Berna-dino*
HDD	1904	1560	1678	1599
CDD	1714	1371	1456	1937

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

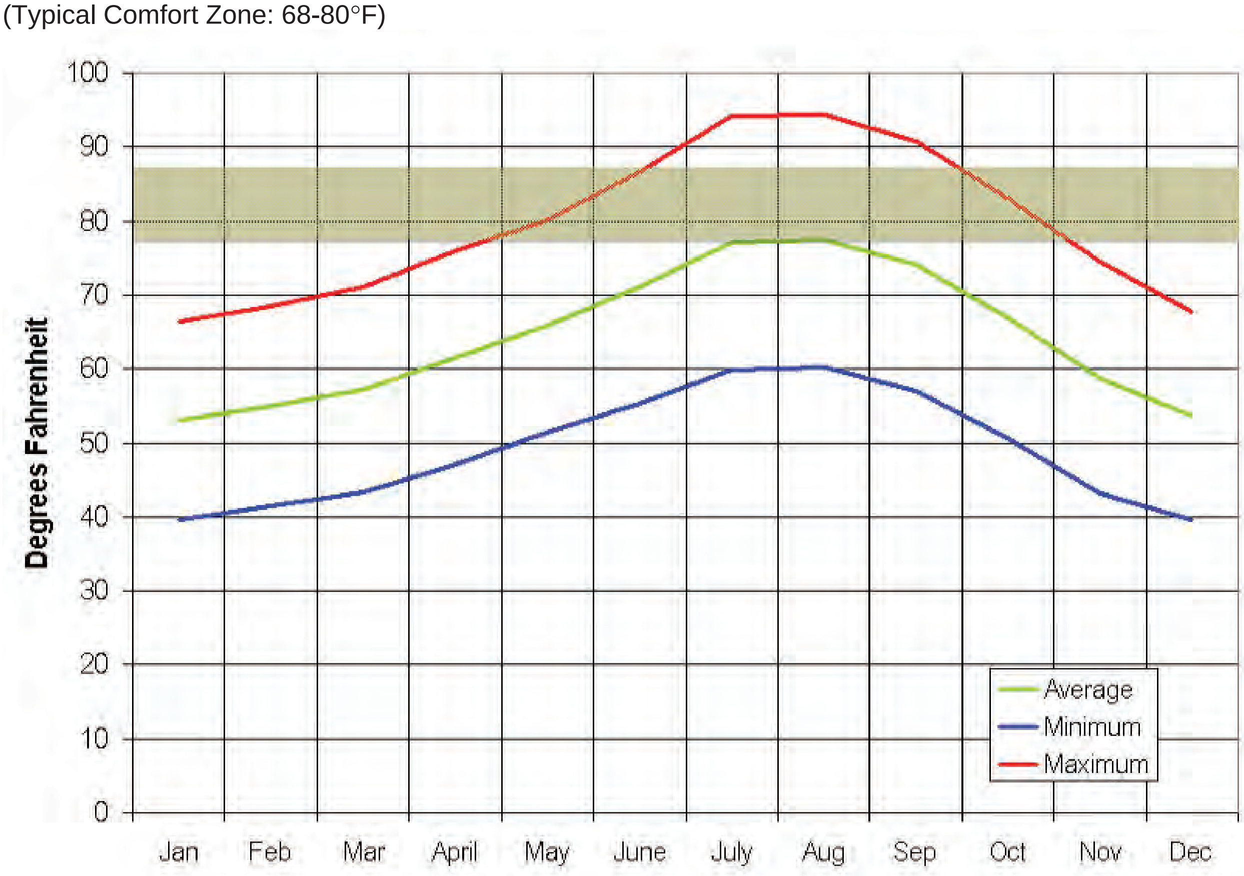
The temperature swing over the year is more extreme, with hotter summers and colder winters than the coastal climates to its west. Cooling and heating is necessary to maintain thermal comfort.

Bioclimatic Chart

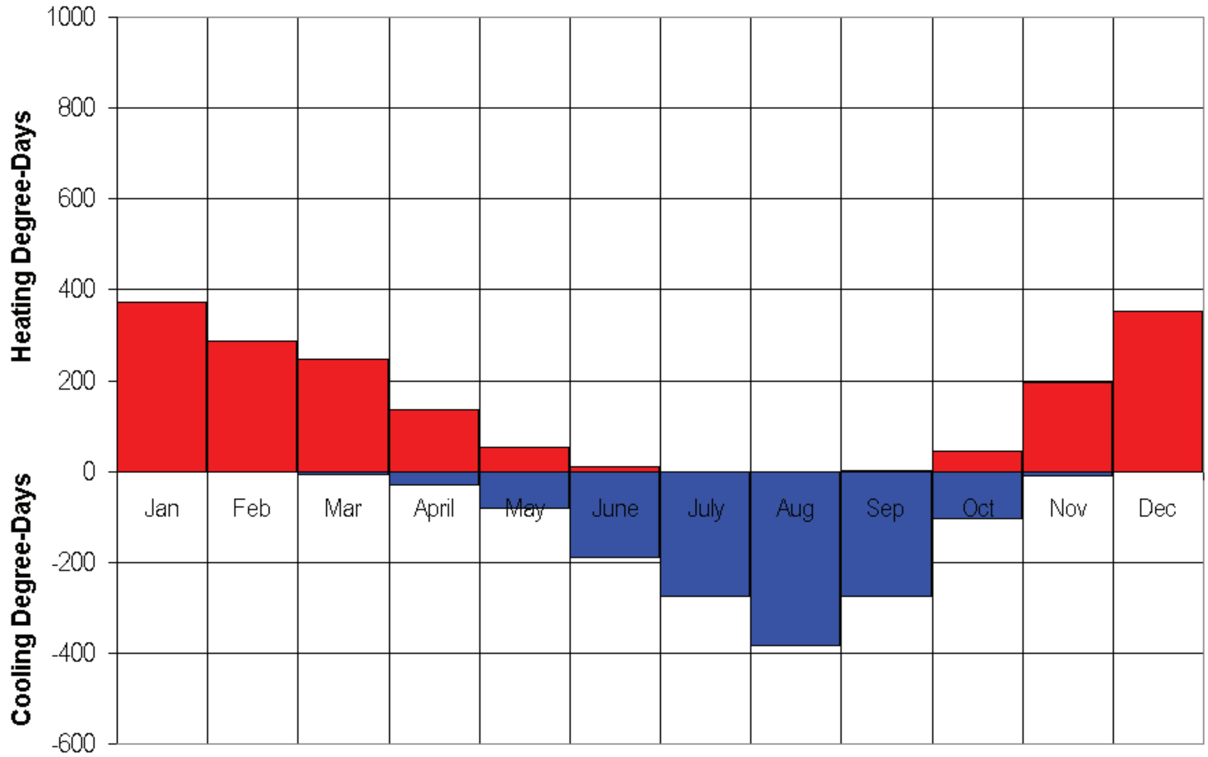


Temperature

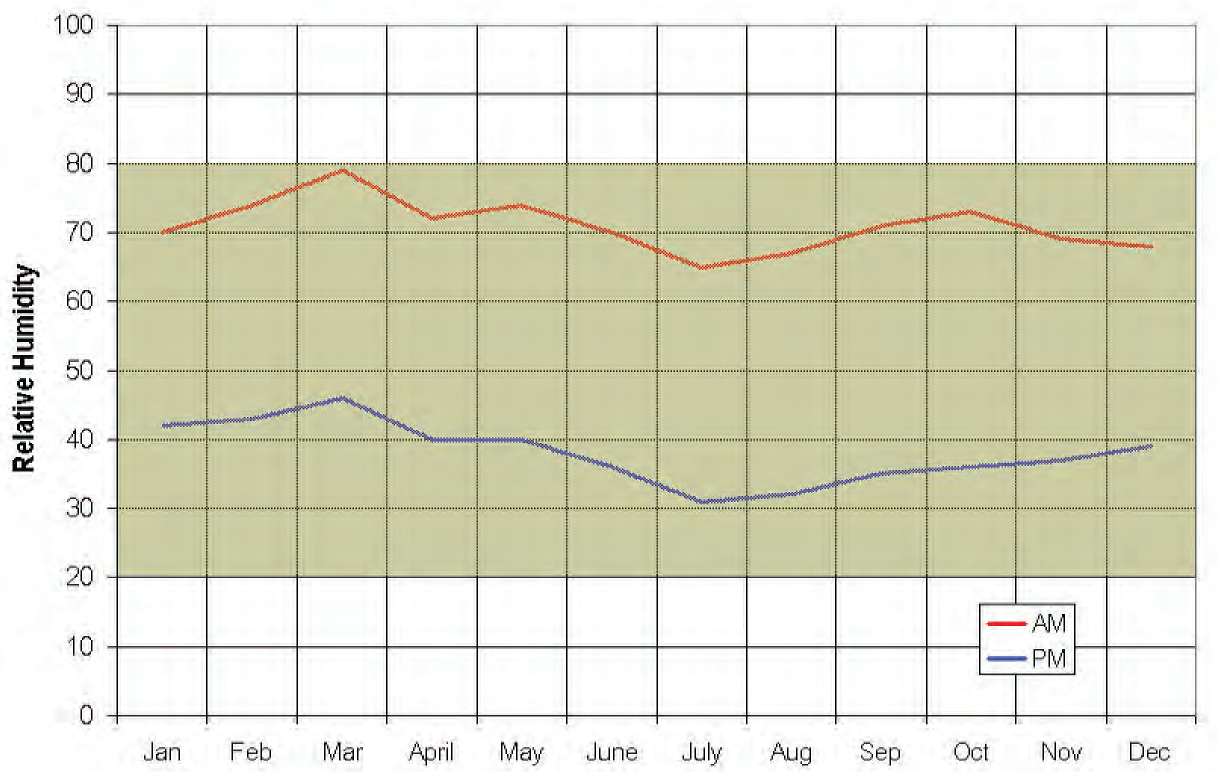
(Typical Comfort Zone: 68-80°F)



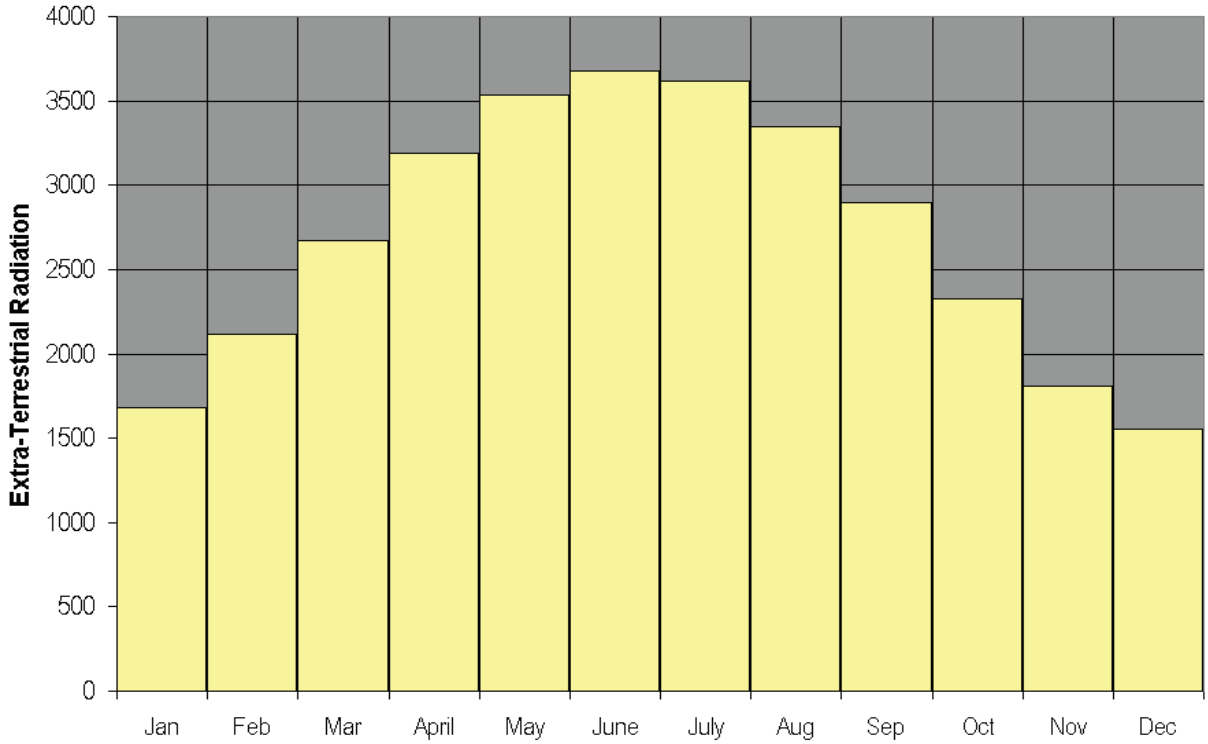
Degree Day
(Base 65°)



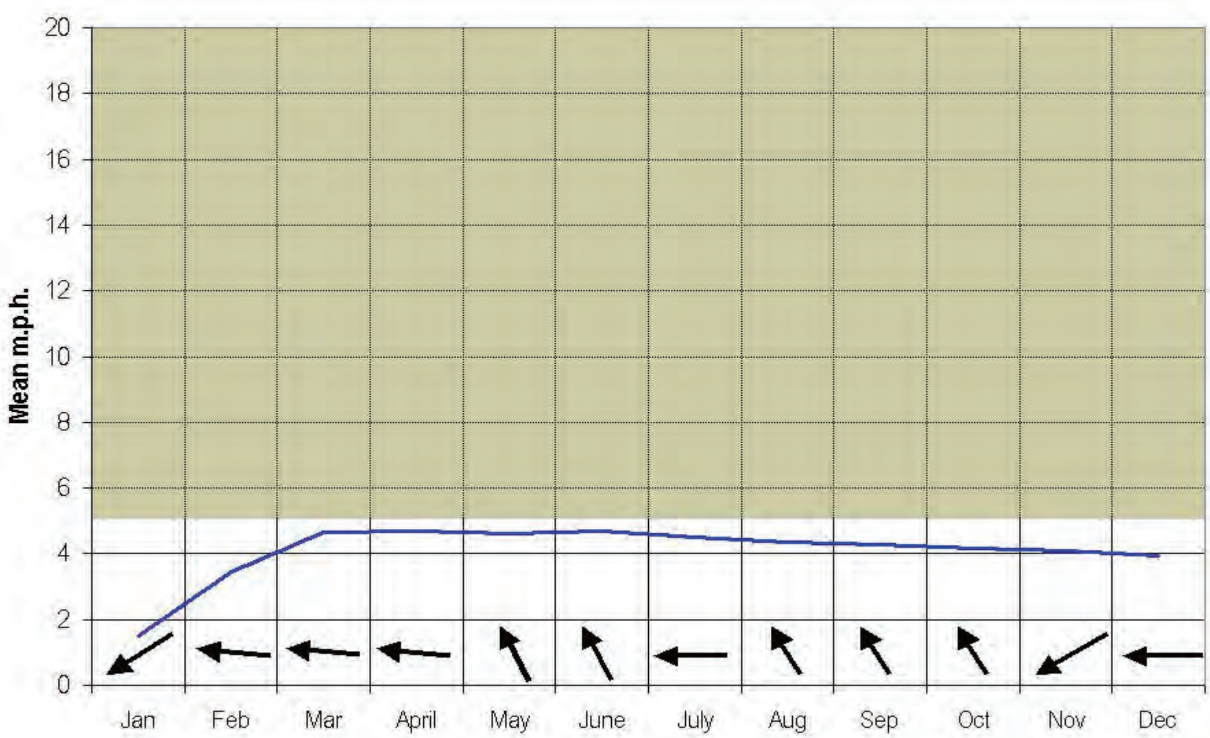
Relative Humidity
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation Daily Mean ETR: 2701



Wind Speed



Prevailing Wind Direction
Summer: SE
Winter: E

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate Zone 11

Reference City: Red Bluff
Latitude: 40.09 N
Longitude: 122.15 W
Elevation: 342 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	32
Record High Temperature (1978)	119
Record Low Temperature (1975)	20

Design Day Data

Winter	99%	29		
	97.5%	31		
Summer				
	1%:	105	MCWB	68
	2.5%:	102	MCWB	67

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Use Evaporative Cooling
Use High Thermal Mass with Night Ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R38
Wood Frame Walls	R29	R19
Glazing U-Value	0.38	0.57
Maximum Total Area	16%	20%

Climate

Climate Zone 11 is the northern California valley, south of the mountainous Shasta Region, east of the Coastal Range, and west of the Sierra Cascades.

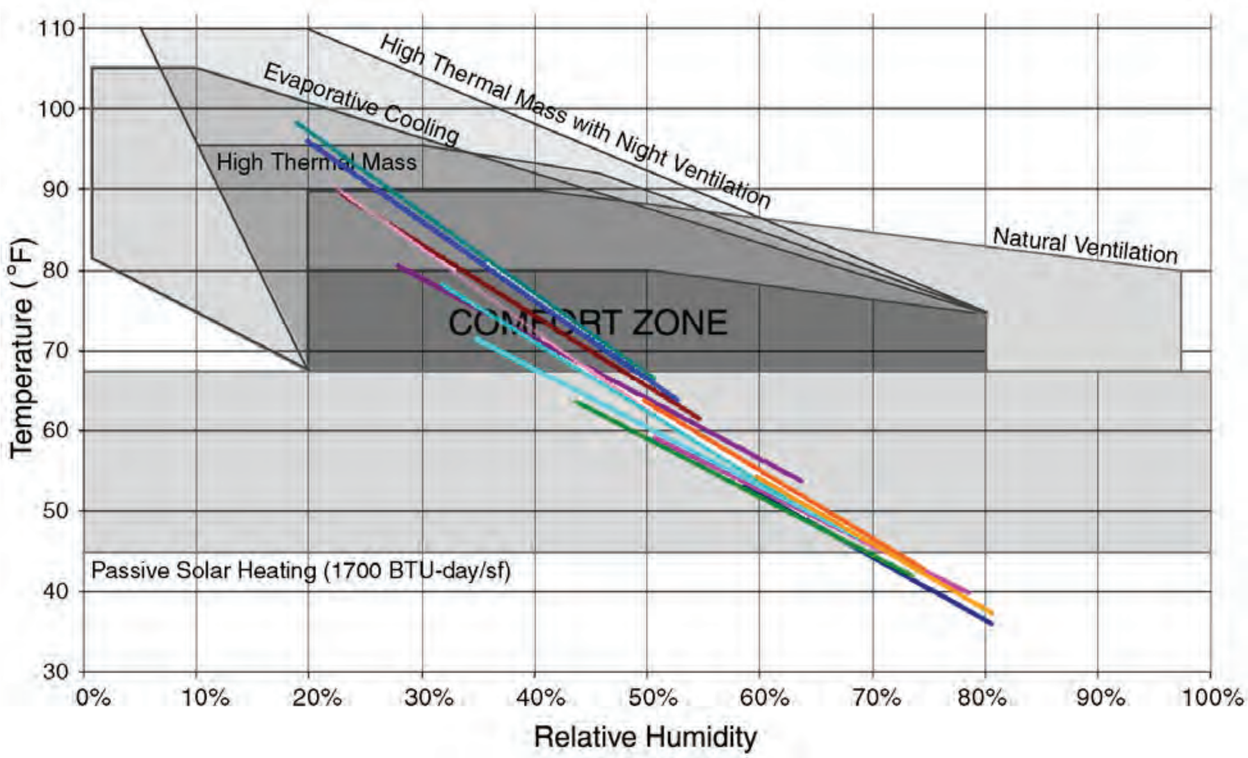
Seasons are sharply defined. Summer daytime temperatures are high, sunshine is almost constant, and the air dry. Winters are very cold with piercing north winds, possibility of snow and thick Tule fog. Cold air rolls off the hillsides on winter nights and pools in the colder flatlands. Quite a bit of rain falls between October and March, as much as 4.75" per month.

	Red Bluff	*Auburn*	*Grass Valley*	*Marys-ville*
HDD	2688	3095	4287	2524
CDD	1904	1292	612	1607

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

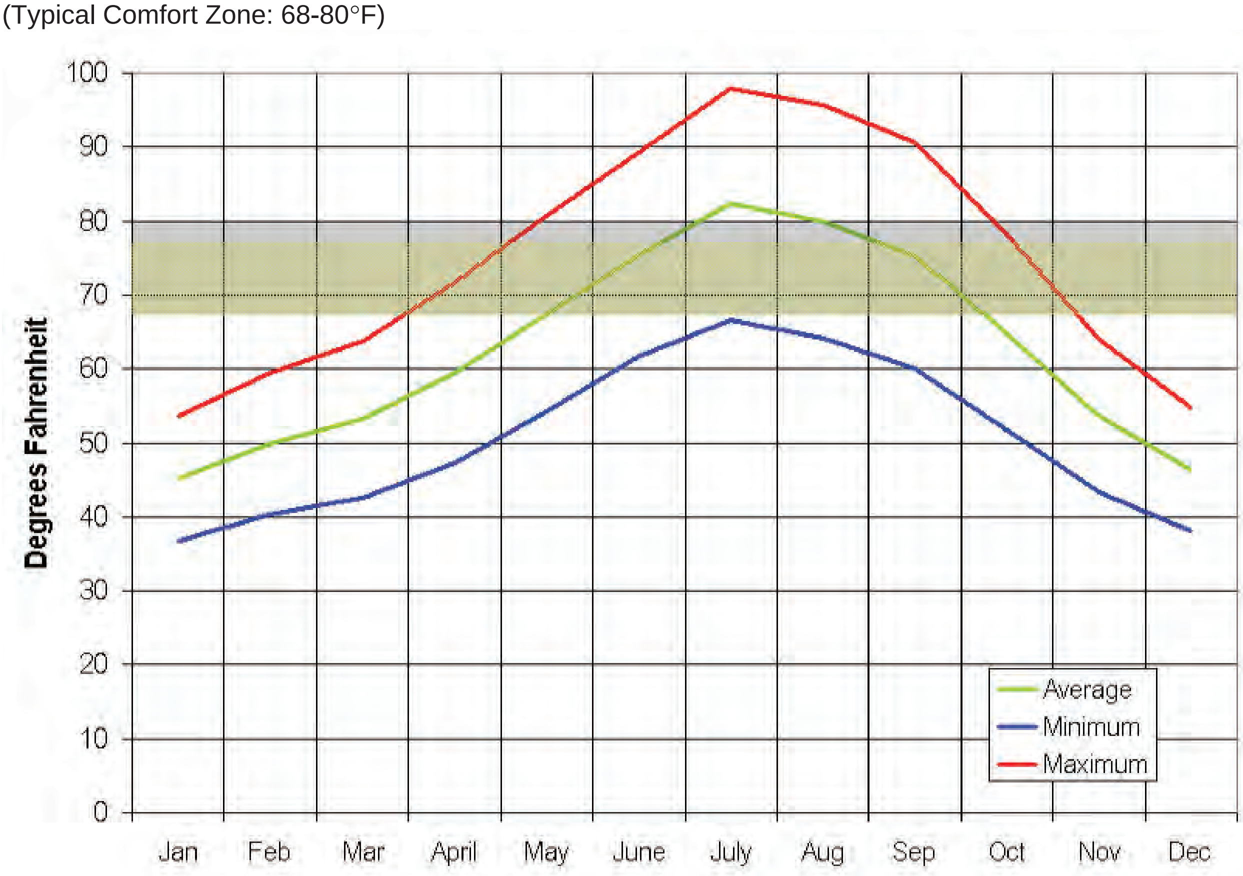
Because there is extreme weather, cooling and heating is necessary. Climate Zone 11 consumes a lot of energy consumption to meet comfort standards.

Bioclimatic Chart

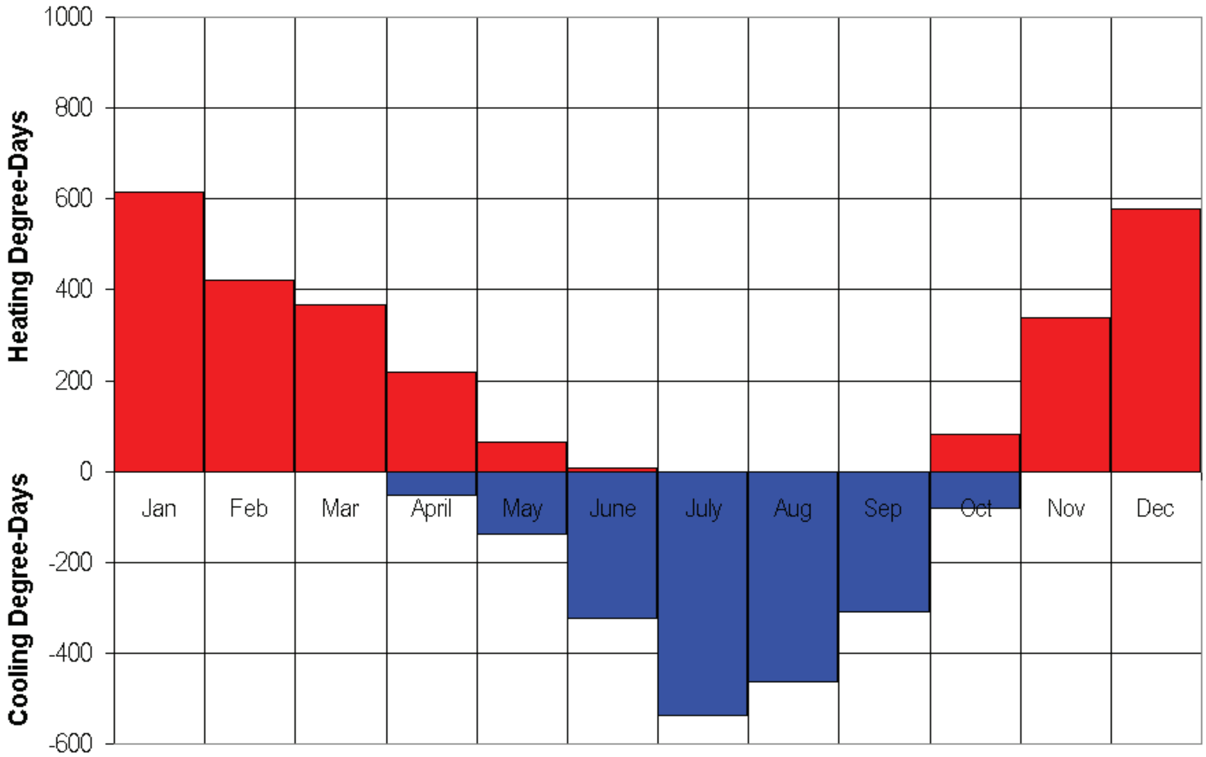


Temperature

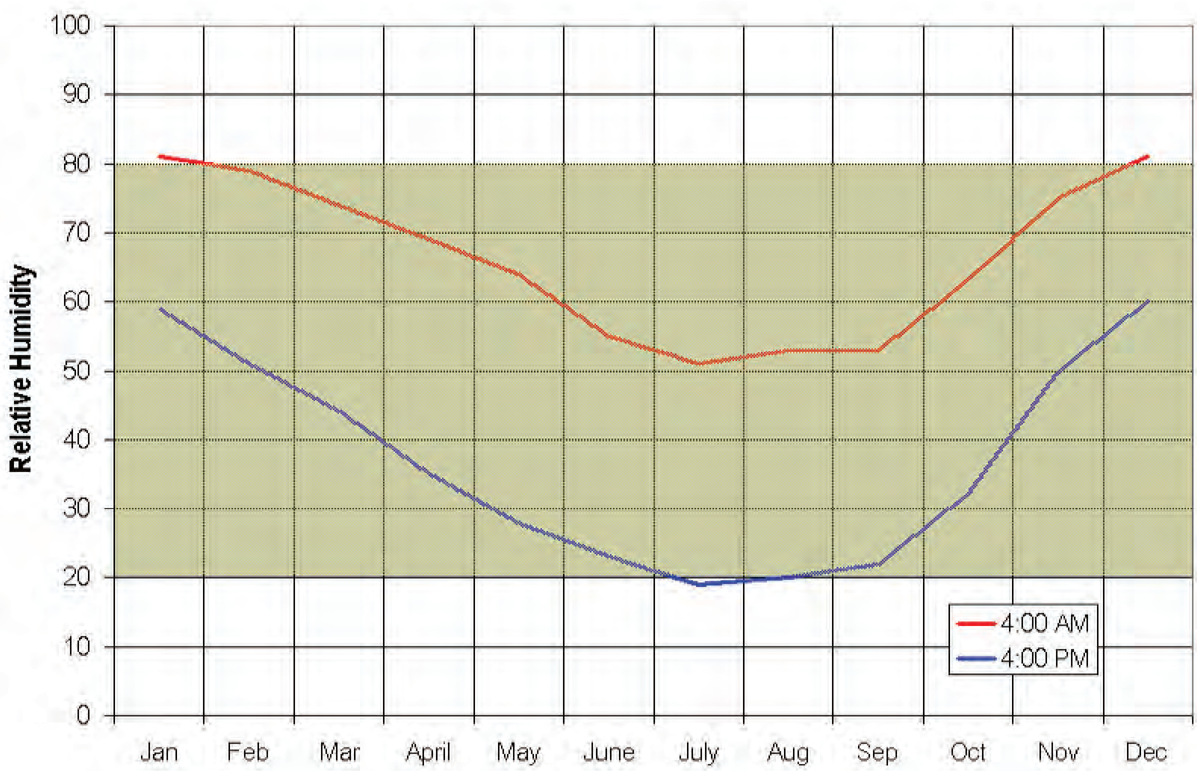
(Typical Comfort Zone: 68-80°F)



Degree Day
(Base 65°)

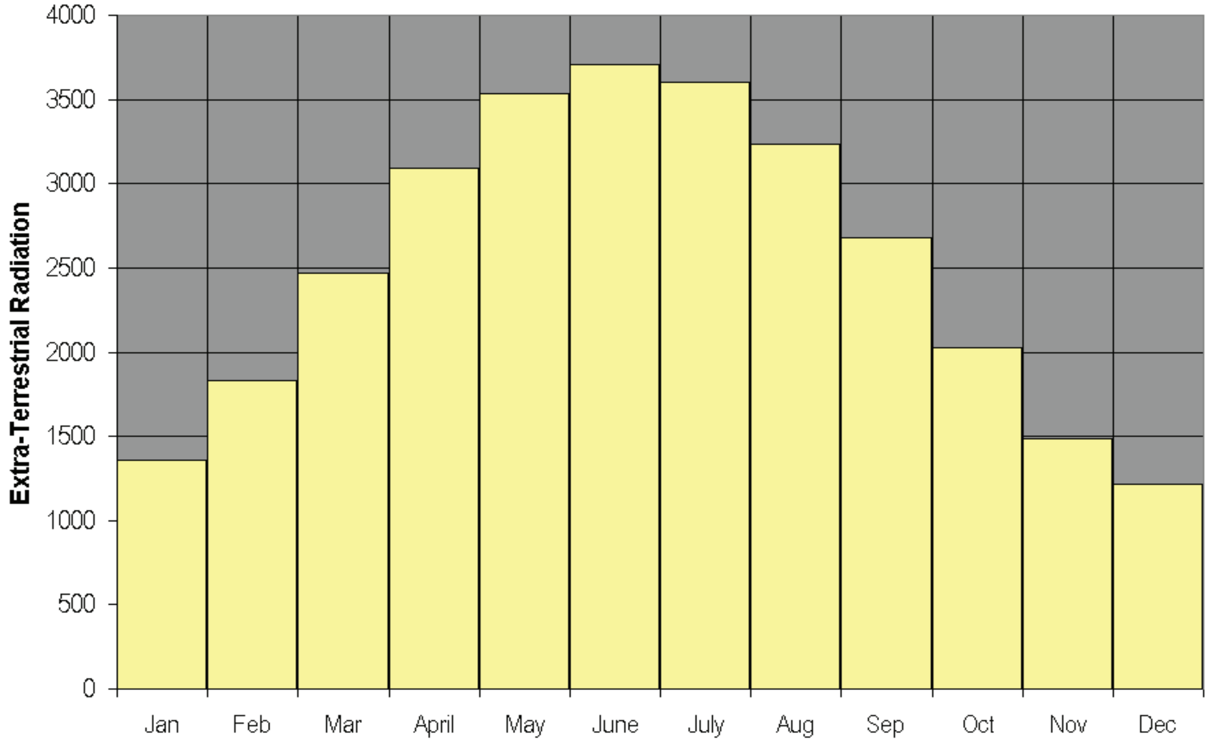


Relative Humidity
(Typical Comfort Zone: 20-80%)

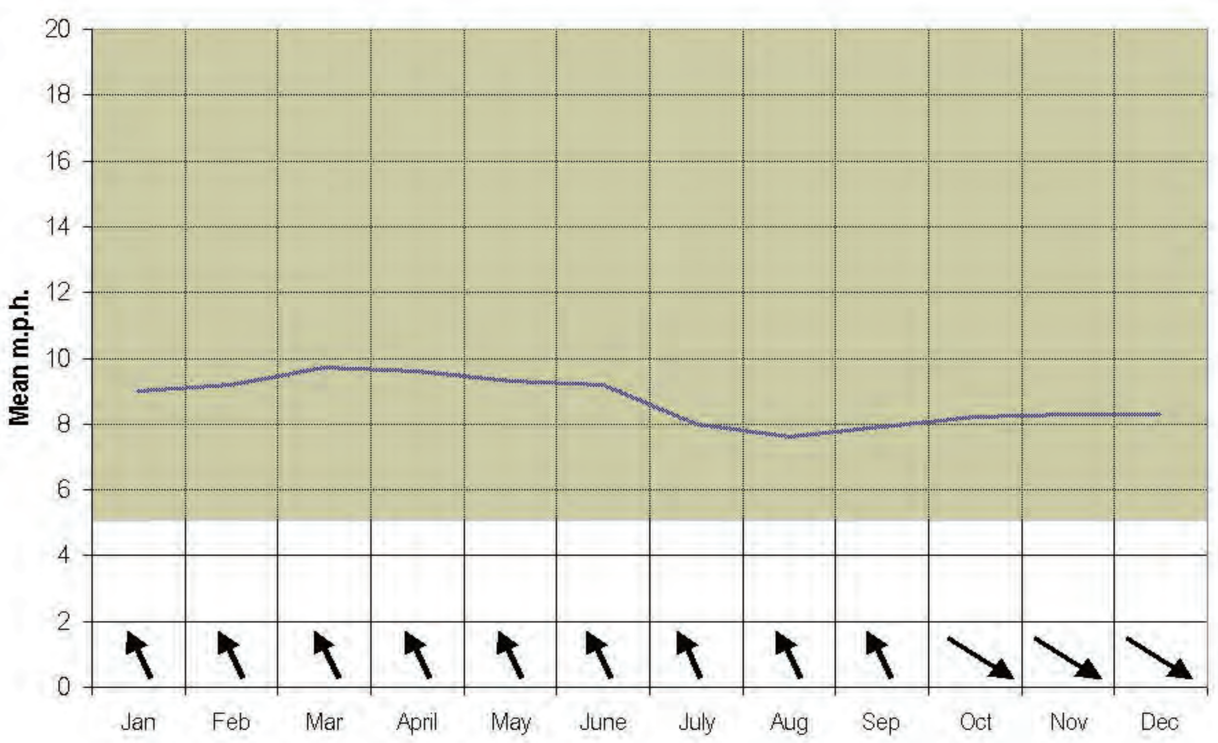


Extra-Terrestrial Radiation

Daily Mean ETR: 2519



Wind Speed



Prevailing Wind Direction
Summer: SSE
Winter: NW

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate Zone 12

Reference City: Stockton
Latitude: 37.54 N
Longitude: 121.15 W
Elevation: 22 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	35
Record High Temperature (1972)	114
Record Low Temperature (1963)	19

Design Day Data

Winter	99%	28		
	97.5%	30		
Summer				
	1%:	100	MCWB	69
	2.5%:	97	MCWB	68

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Use Evaporative Cooling
Use High Thermal Mass with Night ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R38
Wood Frame Walls	R29	R19
Glazing U-Value	0.38	0.57
Maximum Total Area	16%	20%

Climate

This part of the Northern California Central Valley is situated just inland of the Bay Area. Parts of Contra Costa County east of the Caldecott Tunnel are also part of Zone 12.

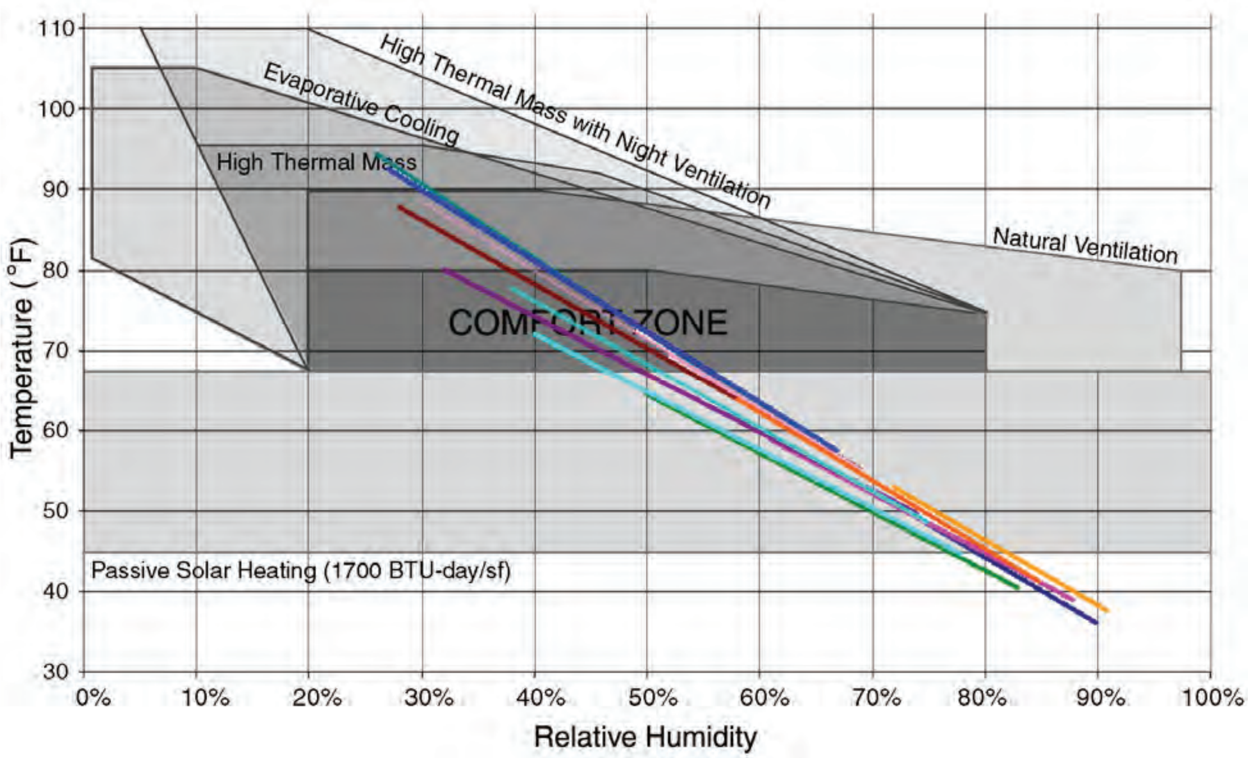
This climate zone experiences cooler winters and hotter summers than Climate Zone 3 (Bay Area). Winter rains fall from November to April. Tule fog is common in the winter east of Mount Diablo. Some lower areas receive frost on winter nights.

	Stockton	*Merced*	*Concord*	*Lafayette*
HDD	2702	2430	2751	2602
CDD	1470	995	860	1578

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

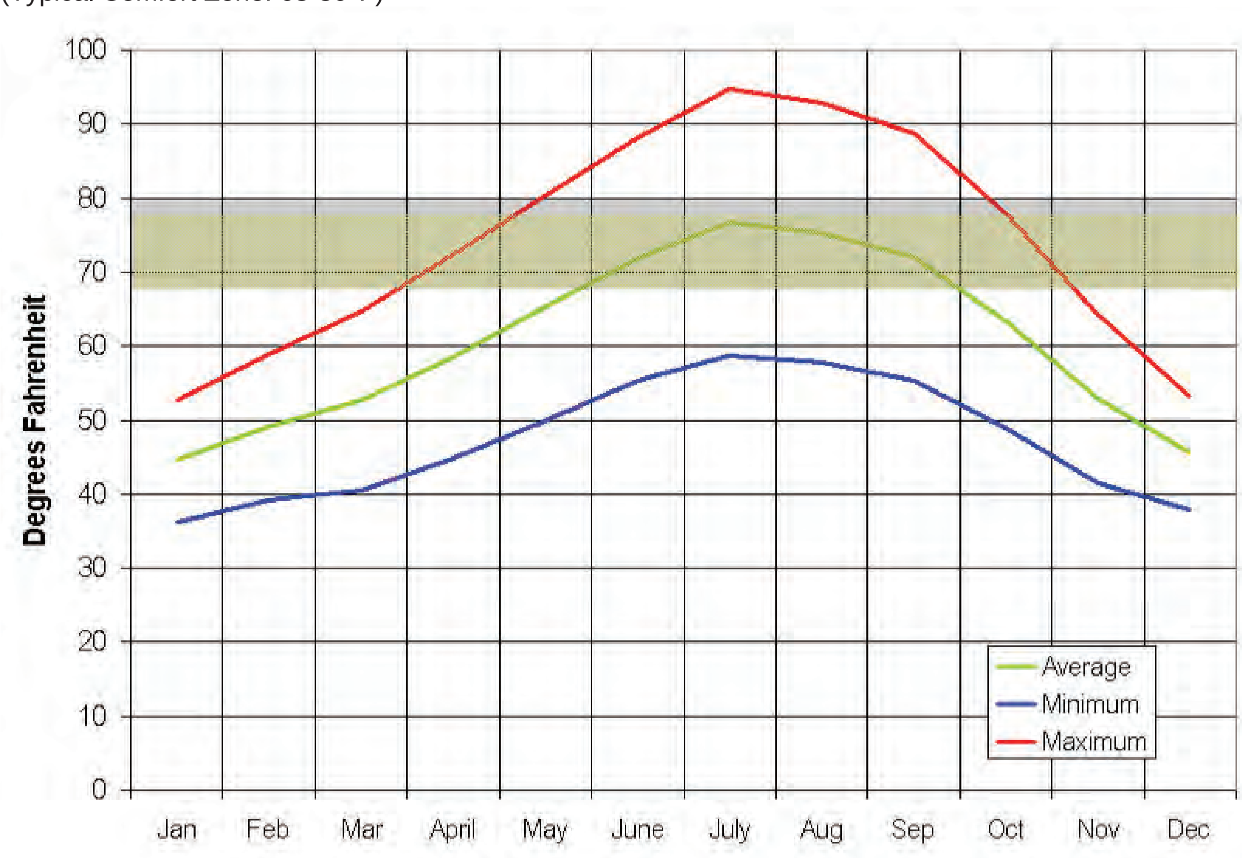
There are more HDD to design for than CDD. High temperatures are usually over 100F. While the marine air may influence temperatures in the areas closest to the Bay Area, the ocean influence is negligible on the hottest days when blinds blow off shore.

Bioclimatic Chart

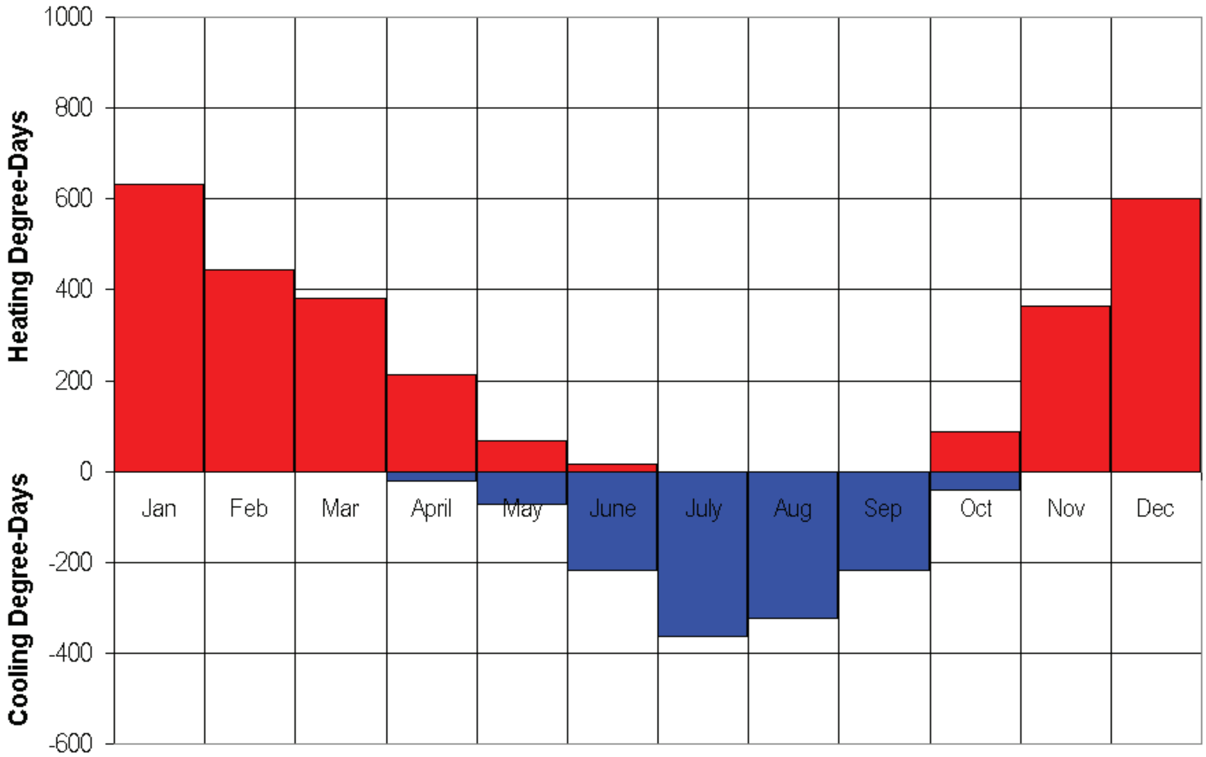


Temperature

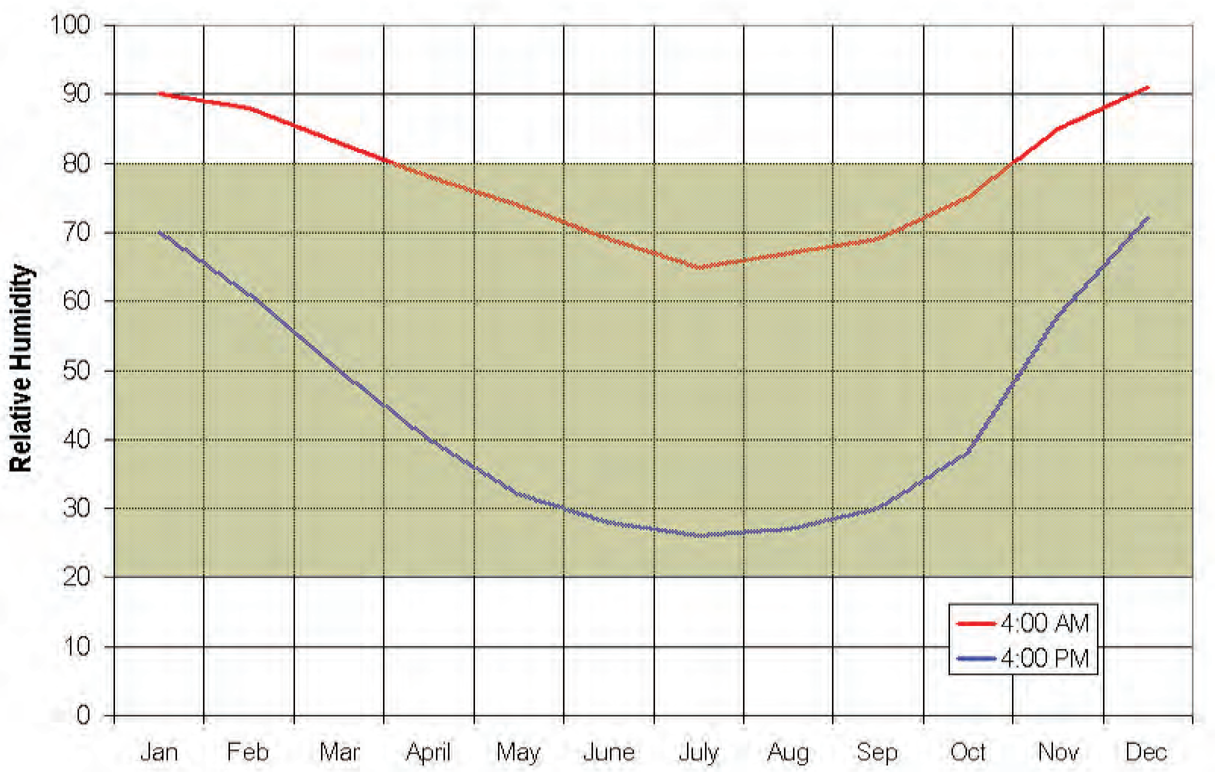
(Typical Comfort Zone: 68-80°F)



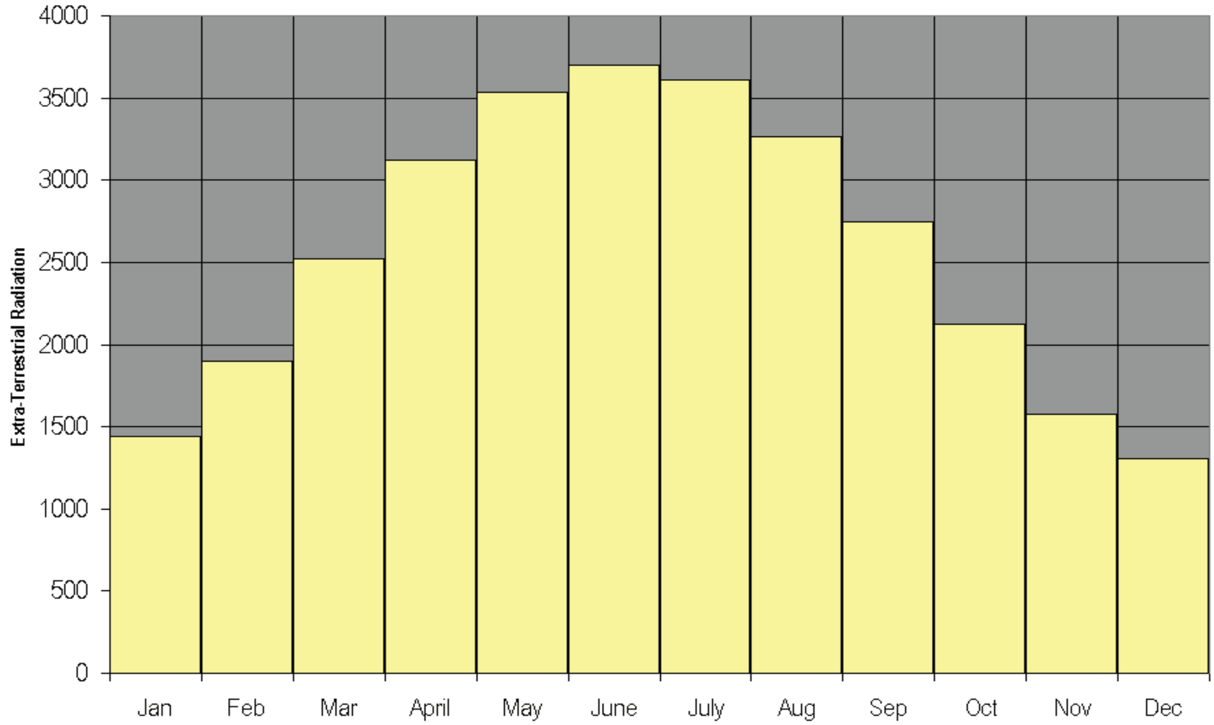
Degree Day
(Base 65°)



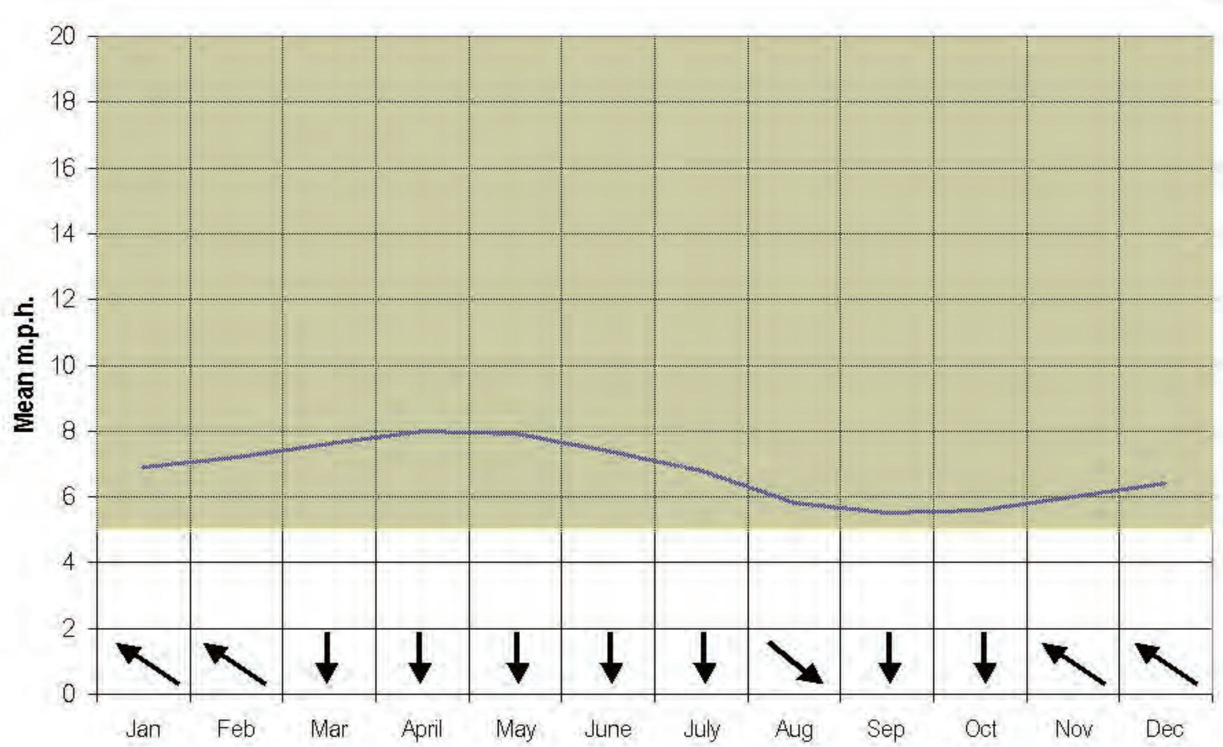
Relative Humidity
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation Daily Mean ETR: 2570



Wind Speed



Prevailing Wind Direction
Summer: NW
Winter: WNW

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate

Zone 13

Reference City:	Fresno
Latitude:	36.46 N
Longitude:	119.43 W
Elevation:	328 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	34
Record High Temperature (1980)	111
Record Low Temperature (1963)	19

Design Day Data

Winter	99%	28		
	97.5%	30		
Summer				
	1%:	102	MCWB	70
	2.5%:	100	MCWB	69

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Use Evaporative Cooling
Use High Thermal Mass with Night ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R38
Wood Frame Walls	R29	R19
Glazing U-Value	0.38	0.57
Maximum Total Area	16%	20%

Climate

California's Central Valley in this southern location is an ideal place to farm citrus trees. Summer daytime temperatures are high, sunshine is almost constant during growing season, and growing season is long.

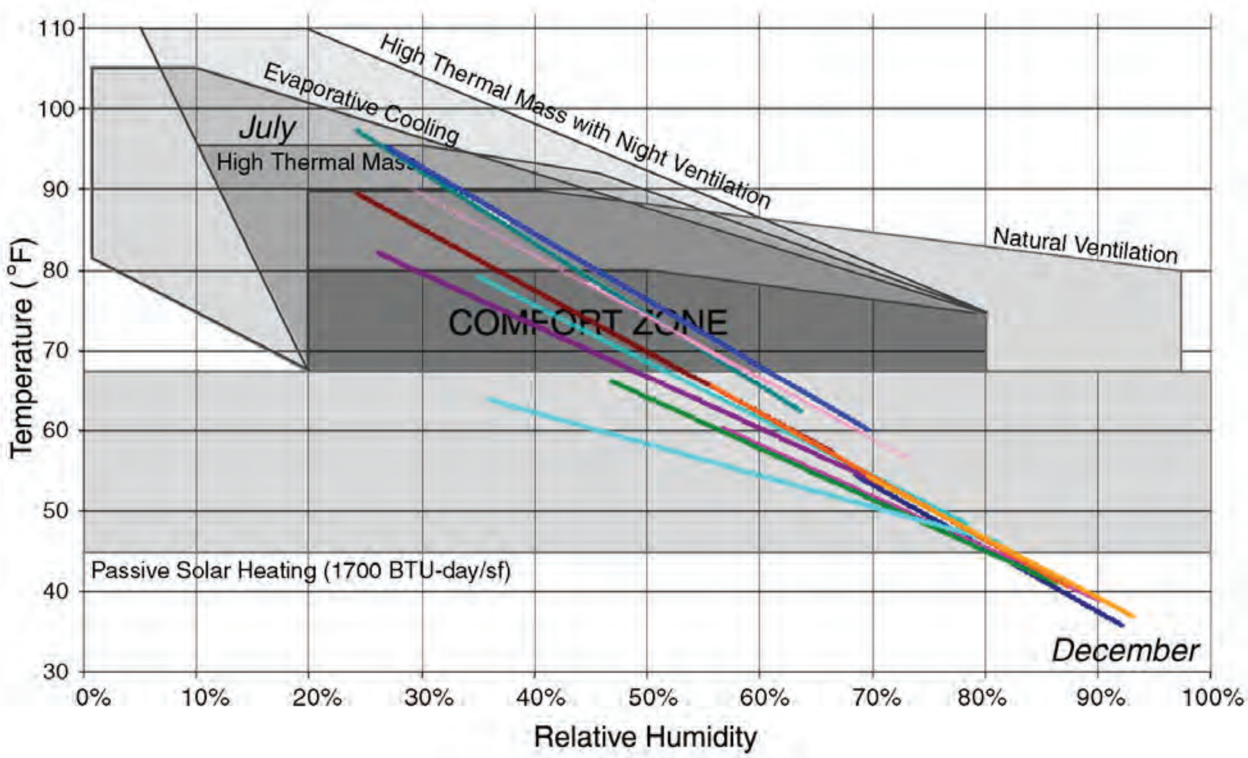
Summer humidity is higher here, than in other parts of the Central Valley, making cooling energy consumption higher in comparison. Winter rains fall between November and April on average 1.5"(+) per month. The winter cold can be quite intense, and piercing north winds can blow for several days at a time in the winter. Tule fog (extremely thick low fog) blankets the region for days in the winter.

	Fresno	*Bakers-field*	*Visalia*	*Porter-ville*
HDD	2702	2430	2588	2053
CDD	1470	995	1685	2246

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

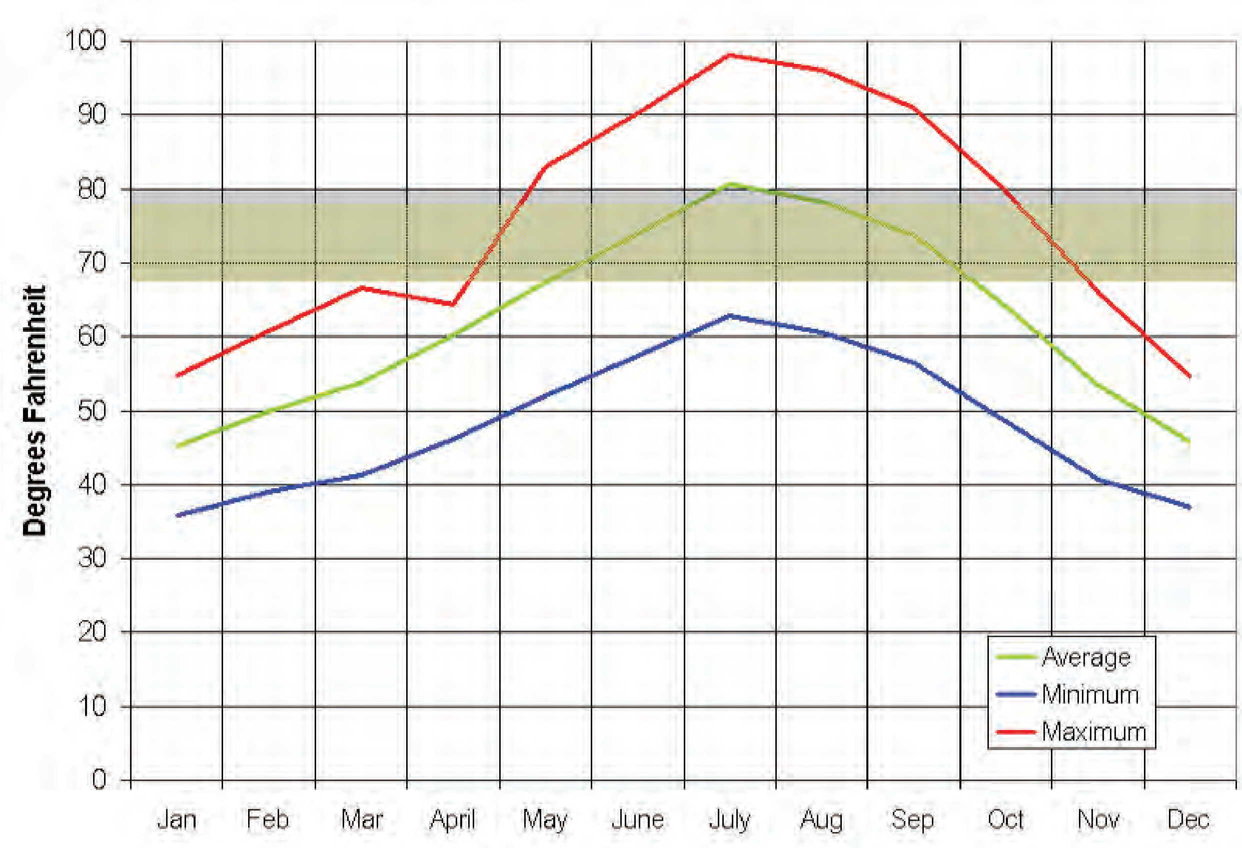
There are almost as many CDD as HDD in this high energy consuming Climate Zone 13.

Bioclimatic Chart



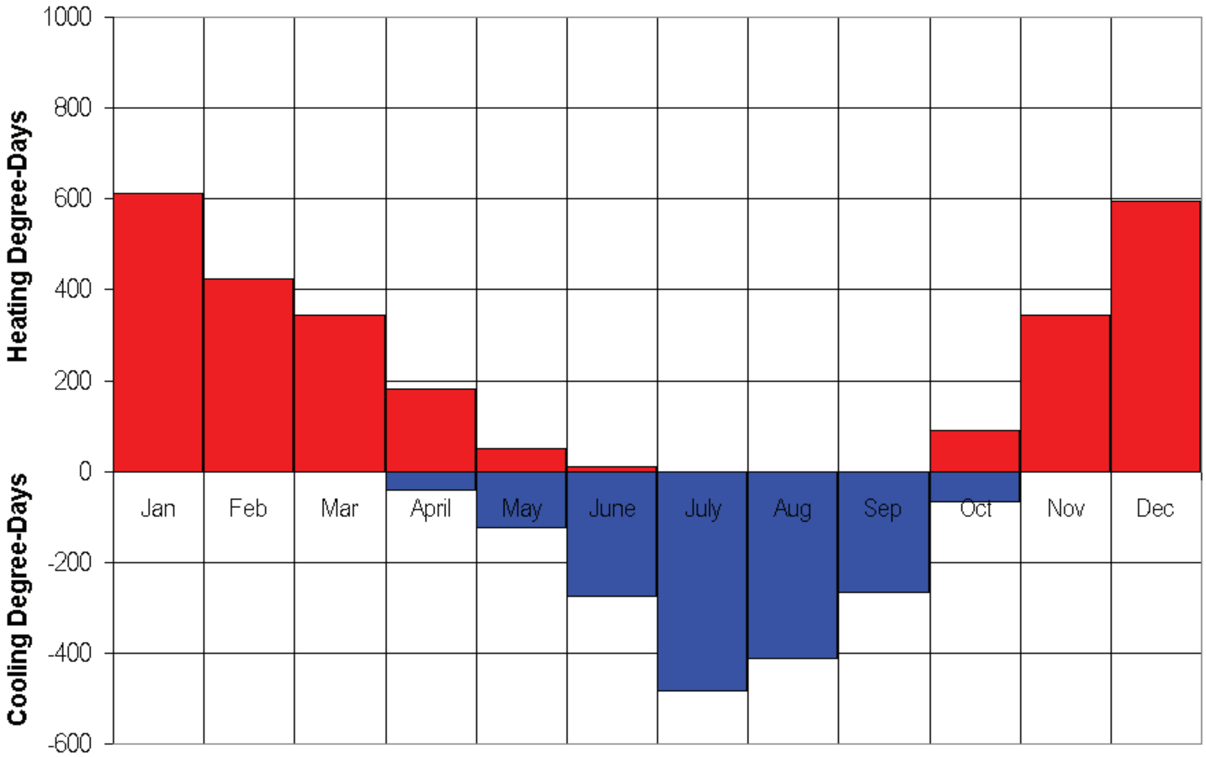
Temperature

(Typical Comfort Zone: 68-80°F)



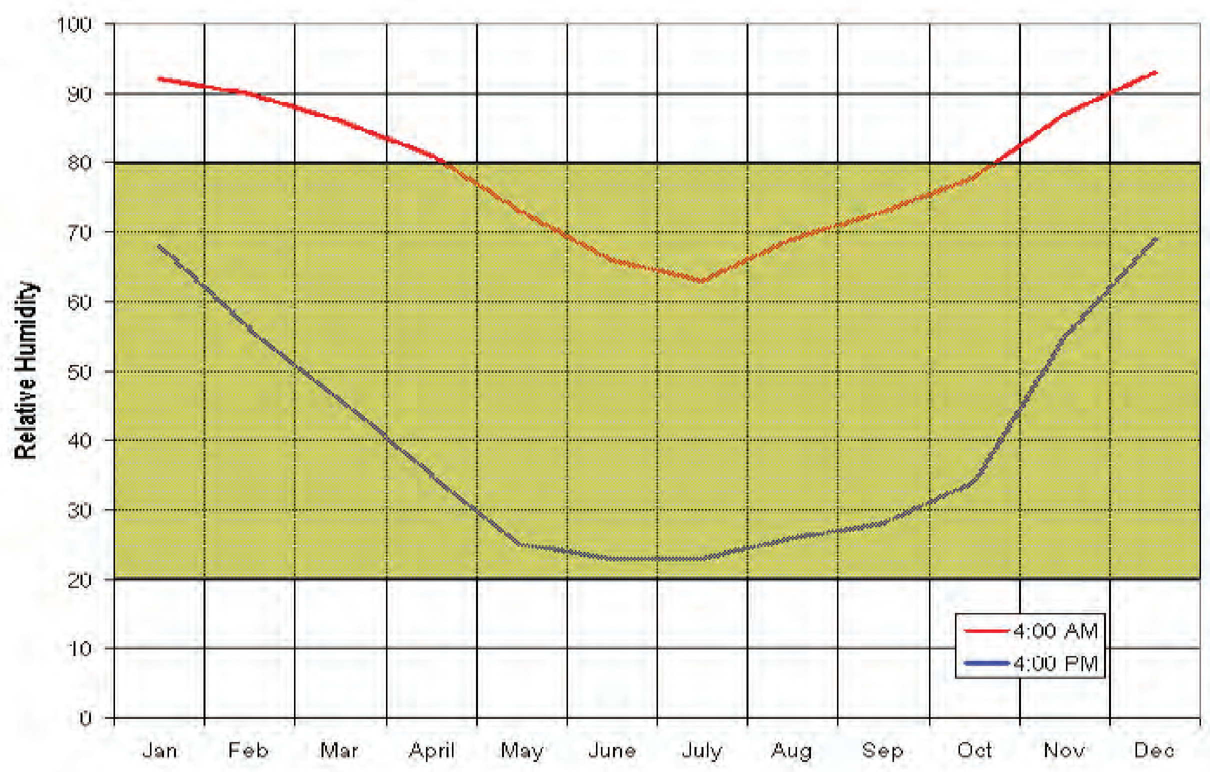
Degree Day

(Base 65°)

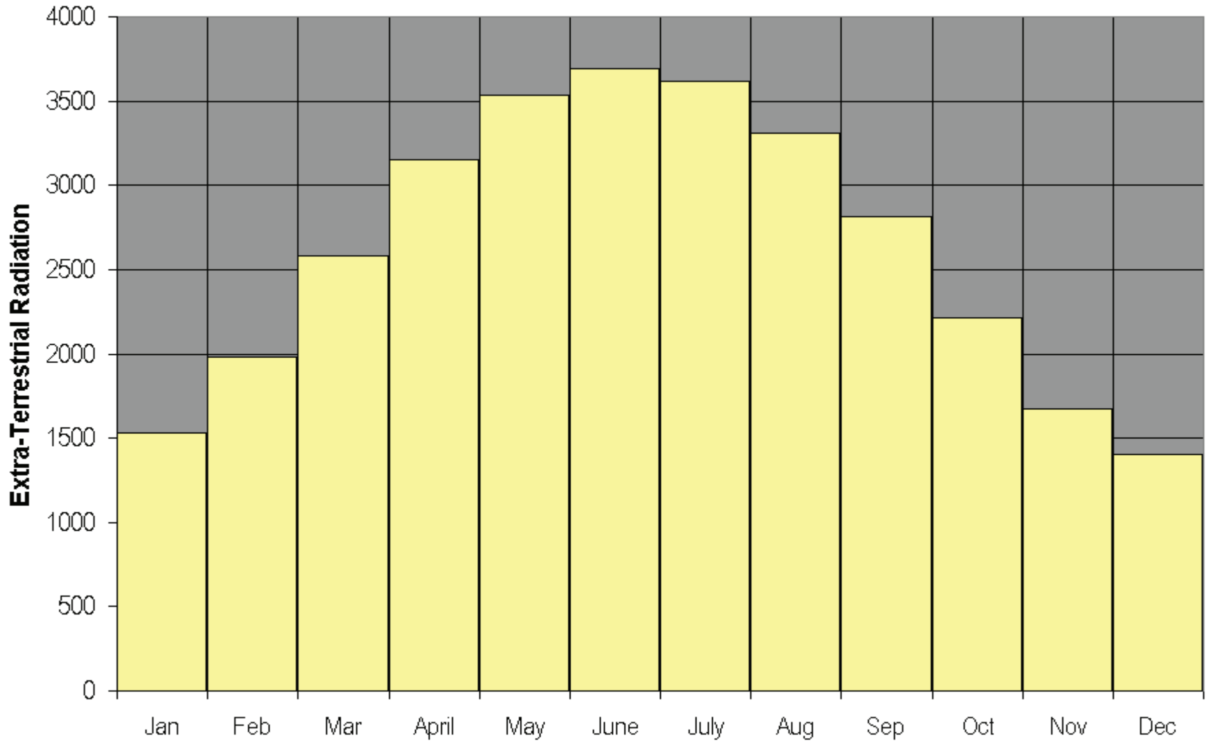


Relative Humidity

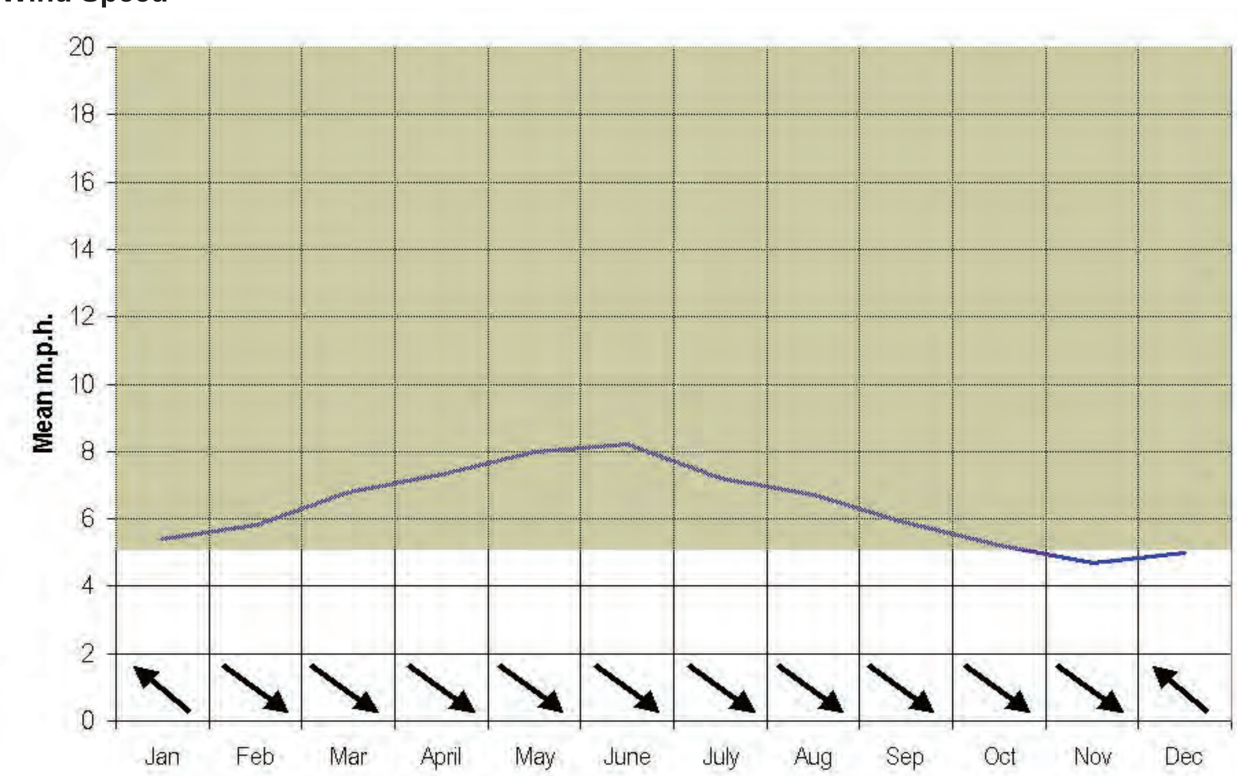
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation Daily Mean ETR: 2594



Wind Speed



Prevailing Wind Direction
Summer: WNW
Winter: E

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate

Zone 14

Reference City: Barstow
Latitude: 35 N
Longitude: 116.47 W
Elevation: 1927 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	30
Record High Temperature (1972)	116
Record Low Temperature (1963)	3

Design Day Data

Winter	99%	26		
	97.5%	29		
Summer				
	1%:	106	MCWB	68
	2.5%:	104	MCWB	68

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Use Evaporative Cooling
Use High Thermal Mass with Night ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R38
Wood Frame Walls	R29	R21
Glazing U-Value	0.38	0.57
Maximum Total Area	14%	20%

Climate

The climate of this medium to high desert is similar to neighboring cold winter zone 16 and subtropical low desert zone 15. Here, the continental mass influences this interior climate more than the ocean.

Zone 14 Climate is characterized by wide swings in temperature, both between summer and winter and between day and night. Hot summer days are followed by cool nights; freezing nights are often followed by 60F days.

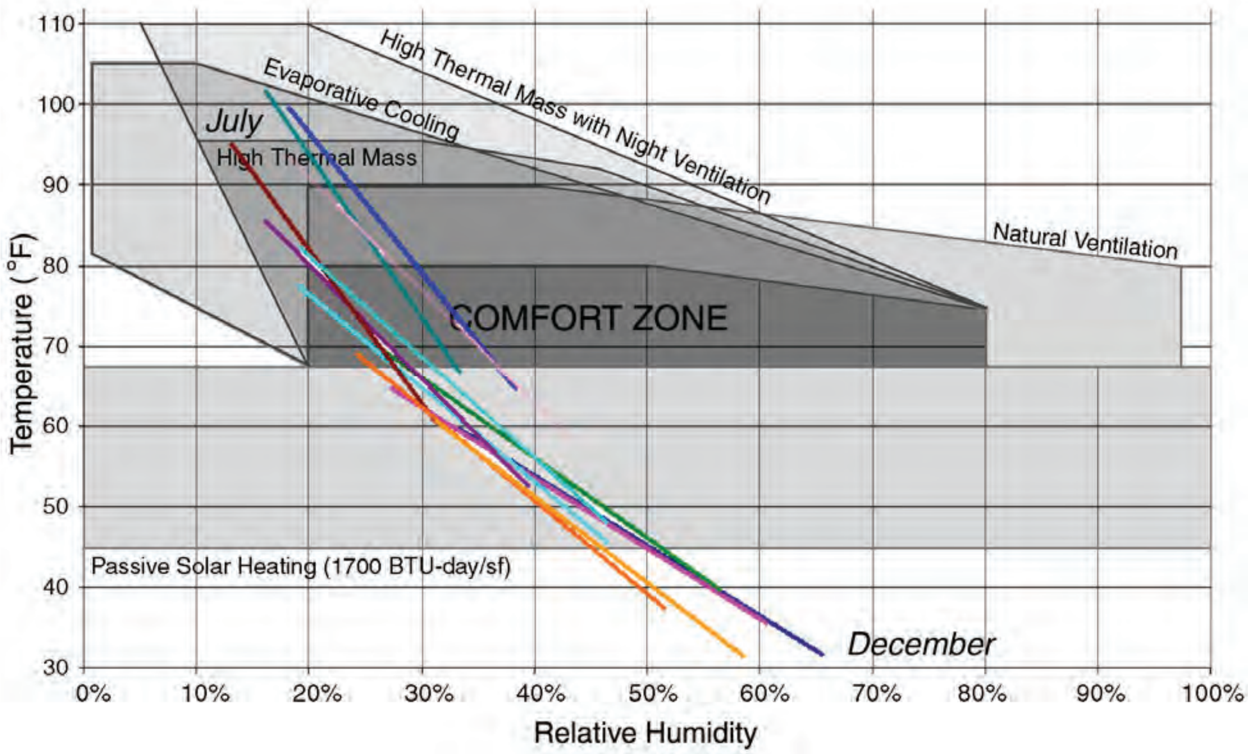
	Barstow	*Trona*	*Palmdale*	*Twenty-nine Palms*
HDD	2581	2492	2704	1910
CDD	4239	2922	1998	3064

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

There are almost as many CDD as HDD. The hazards of this climate to plants are late spring frosts and desert winds.

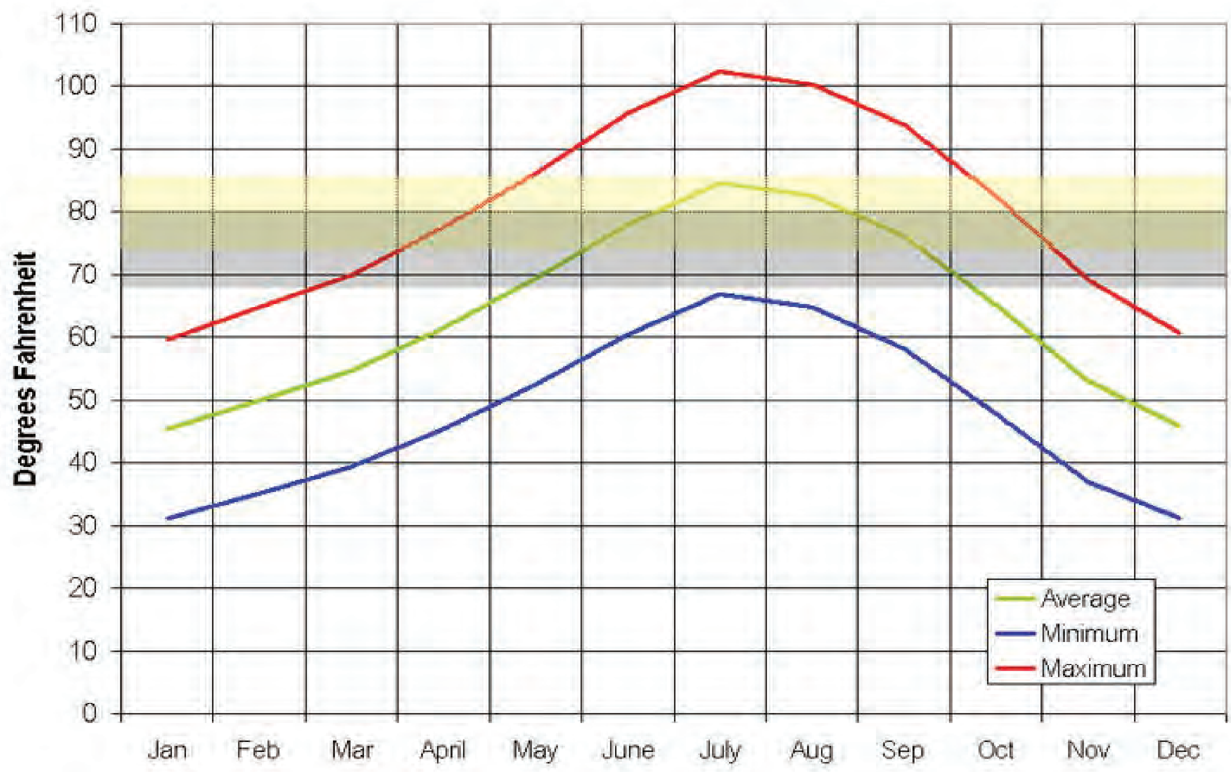
Summers are hot and dry. Does not rain (or snow) more than 1" per month. Winters are cold, especially on the slopes and hillsides where cold air drains off on winter nights. Zone 14 is a high energy-consuming climate, where cooling and heating is needed to maintain comfort.

Bioclimatic Chart

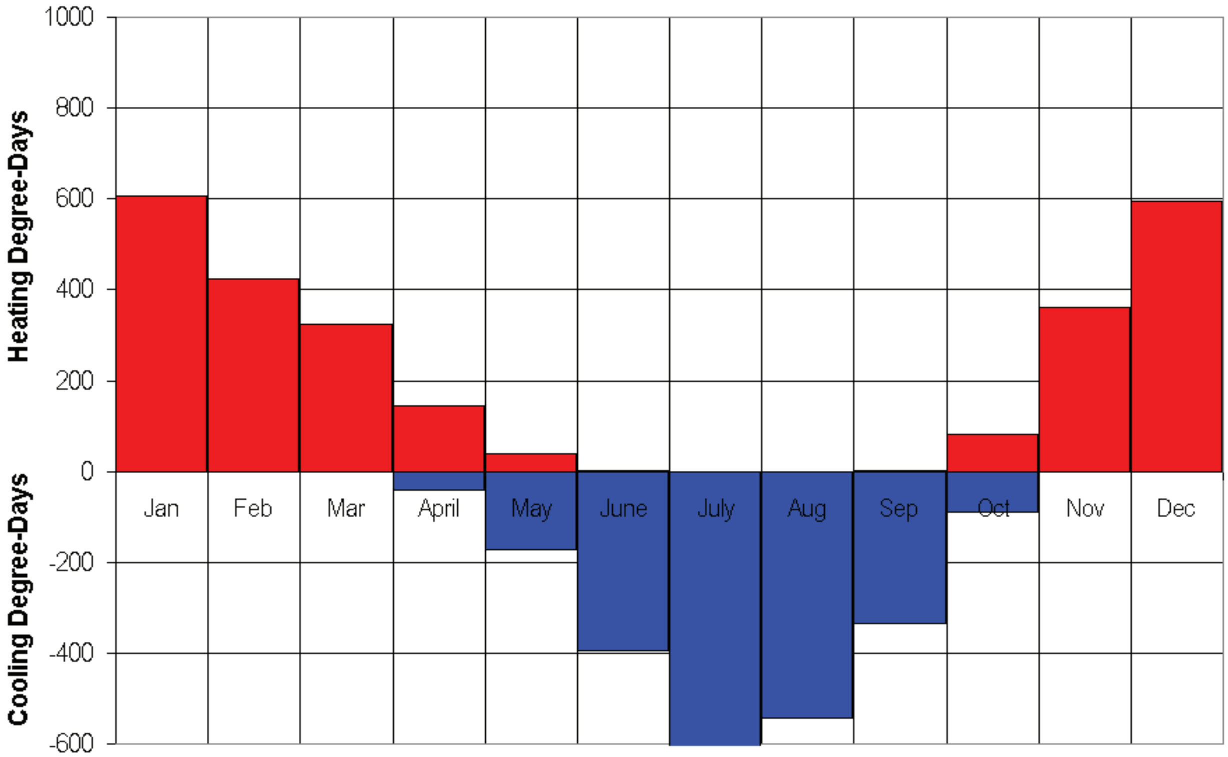


Temperature

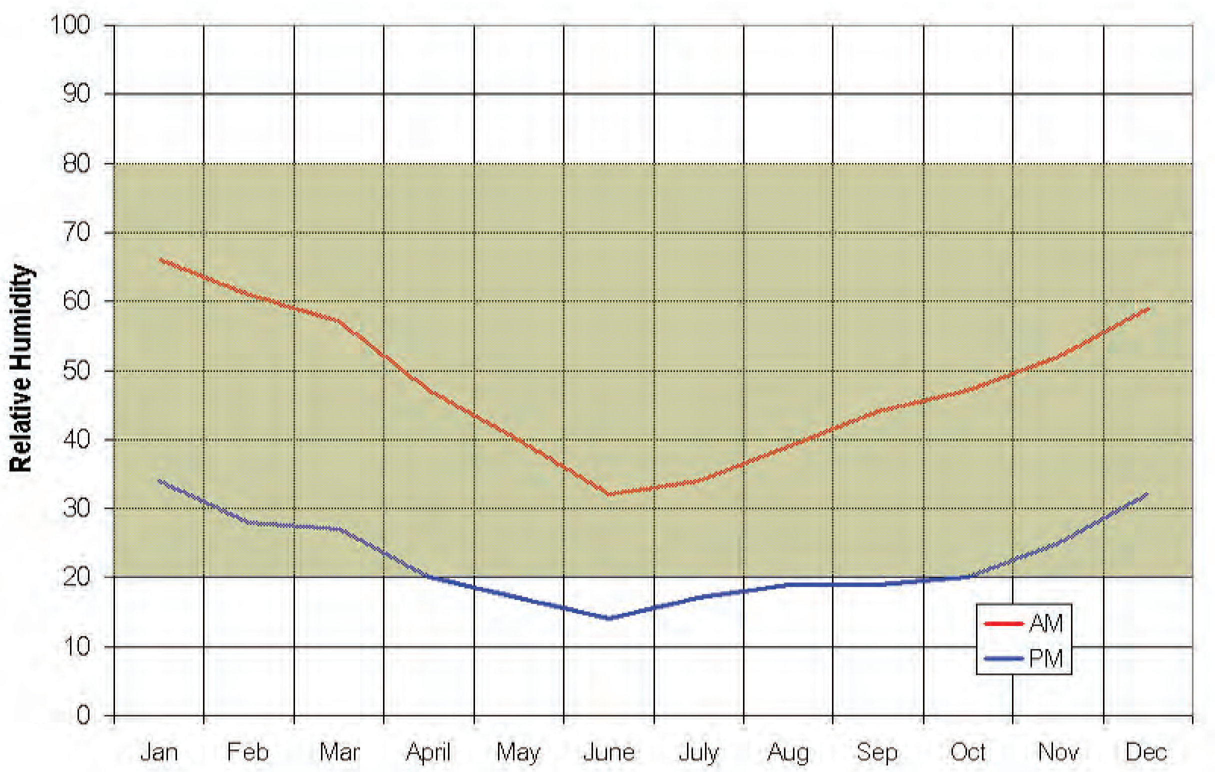
(Typical Comfort Zone: 68-80°F)



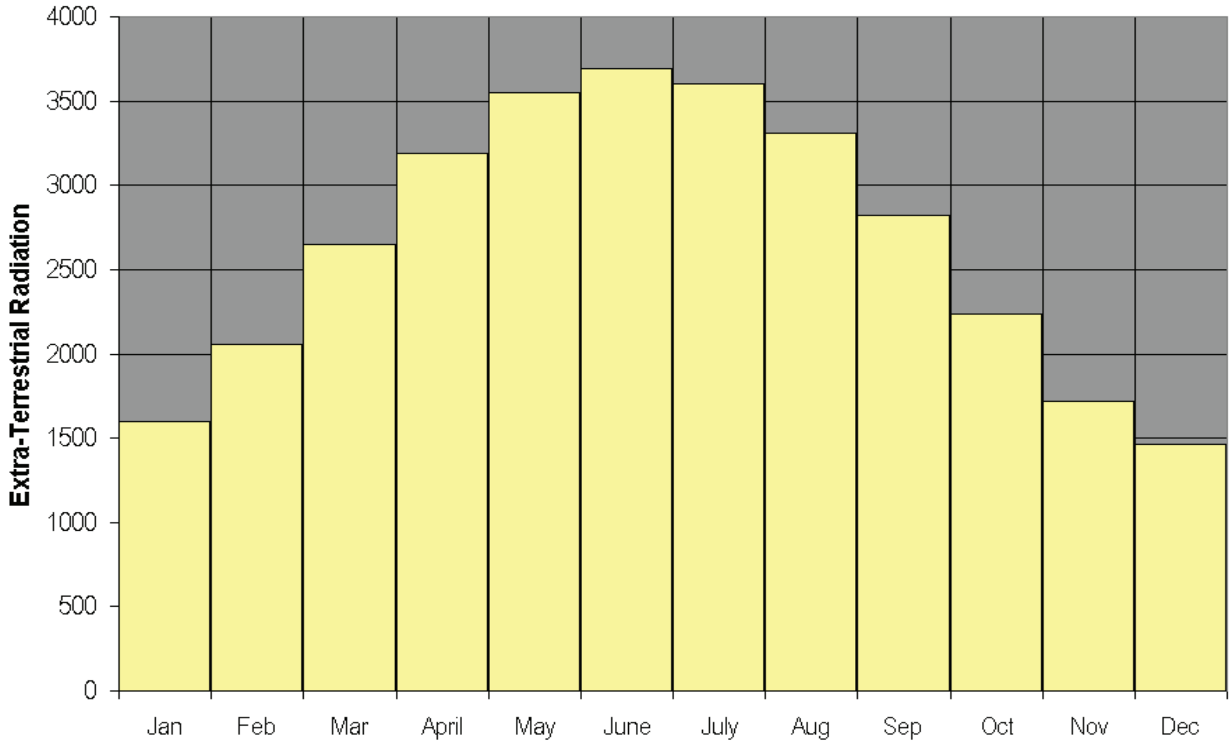
Degree Day
(Base 65°)



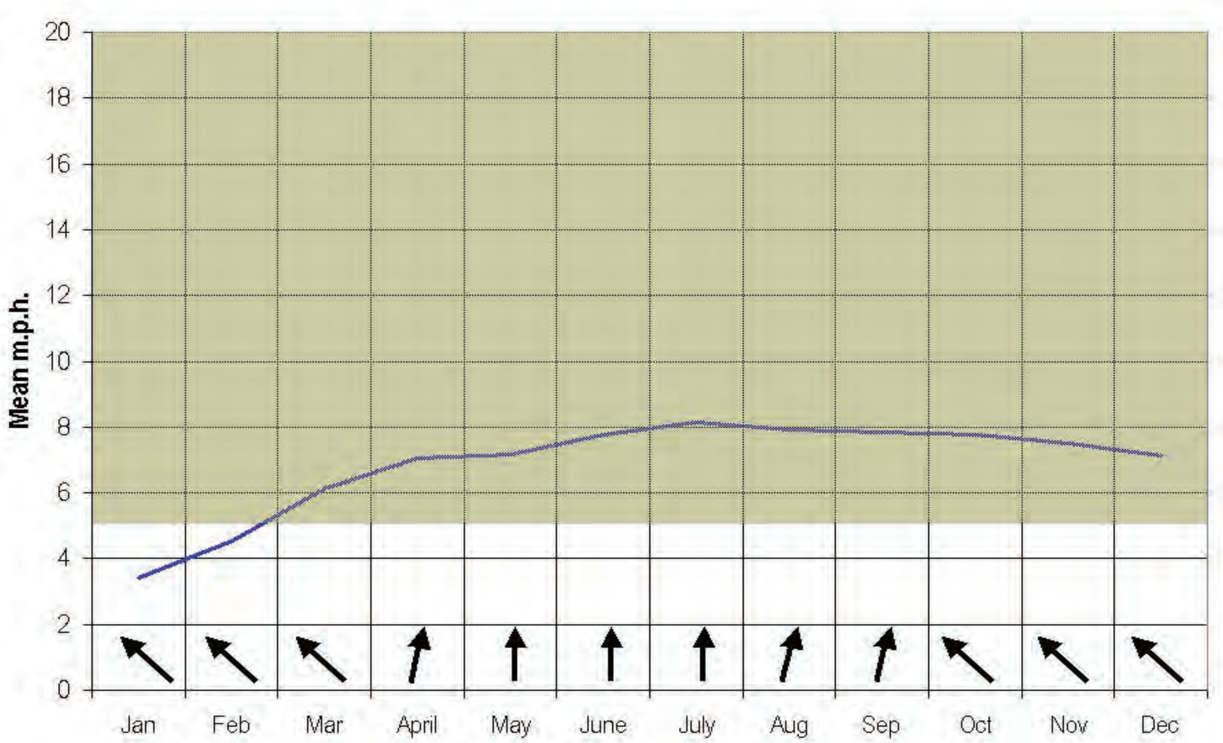
Relative Humidity
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation Daily Mean ETR:2626



Wind Speed



Prevailing Wind Direction
Summer: W
Winter: WNW

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate

Zone 15

Reference City:	Brawley
Latitude:	32.95 N
Longitude:	115.55 W
Elevation:	0 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	18
Record High Temperature (1950	122
Record Low Temperature (2000)	2

Design Day Data

	El Centro			
Winter	99%	35		
	97.5%	38		
Summer				
	1%:	112	MCWB	74
	2.5%:	110	MCWB	74

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Use Evaporative Cooling
Use High Thermal Mass with
Night ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R38
Wood Frame Walls	R29	R21
Glazing U-Value	0.38	0.55
Maximum Total Area	16%	20%

Climate

Zone 15 is the low desert and is characterized by extremely hot and dry summers and moderately cold winters.

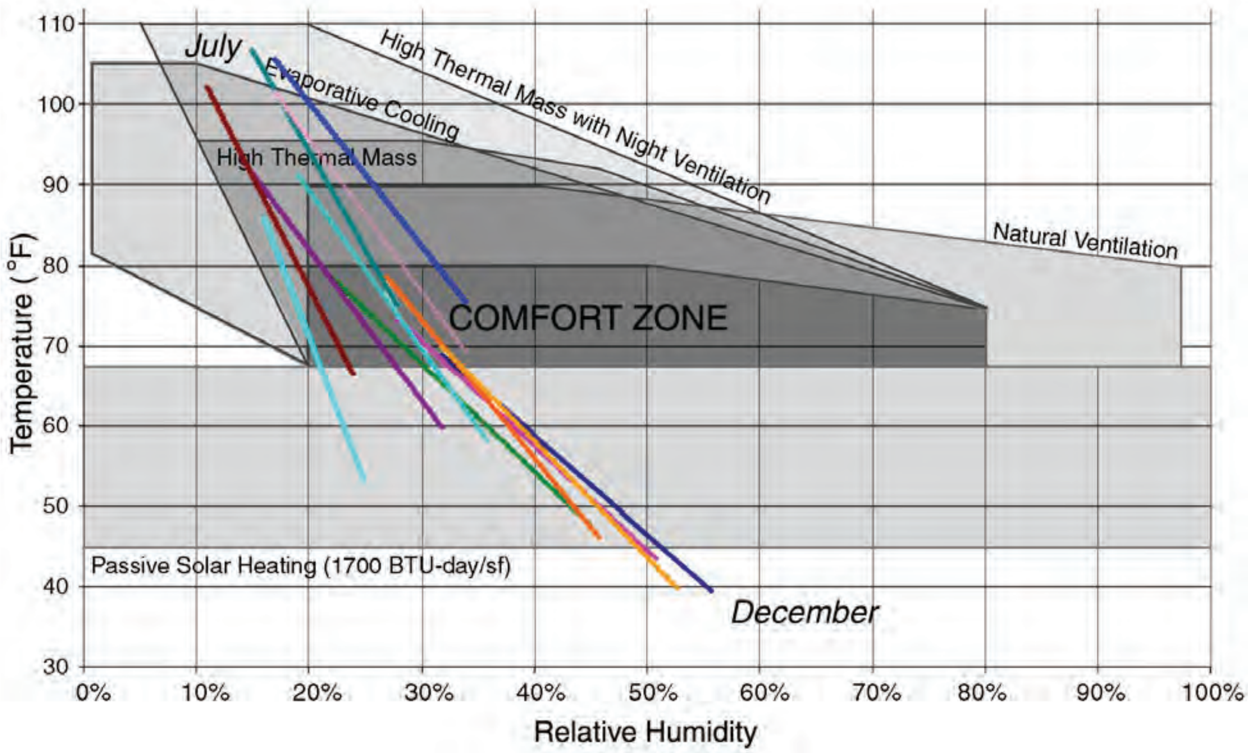
The average temperature in Climate Zone 15 is much higher than any other zone in California, especially in the summer. The humidity is below the comfort range much of the year, which results in a large diurnal temperature range and very cool nights.

The skies are clear most of the year with an annual sunshine of about 85%. Summer storms bring most of the annual precipitation. August is the wettest month, with 1 inch of rain The winters are short and mild, and can bring short frosts. While some heating is required during the winter, cooling is the overwhelming concern for designing within Zone 15.

	Brawley	*Blythe*	*El Centro*	*Needles*
HDD	1106	1295	1080	1227
CDD	6565	3977	3952	4545

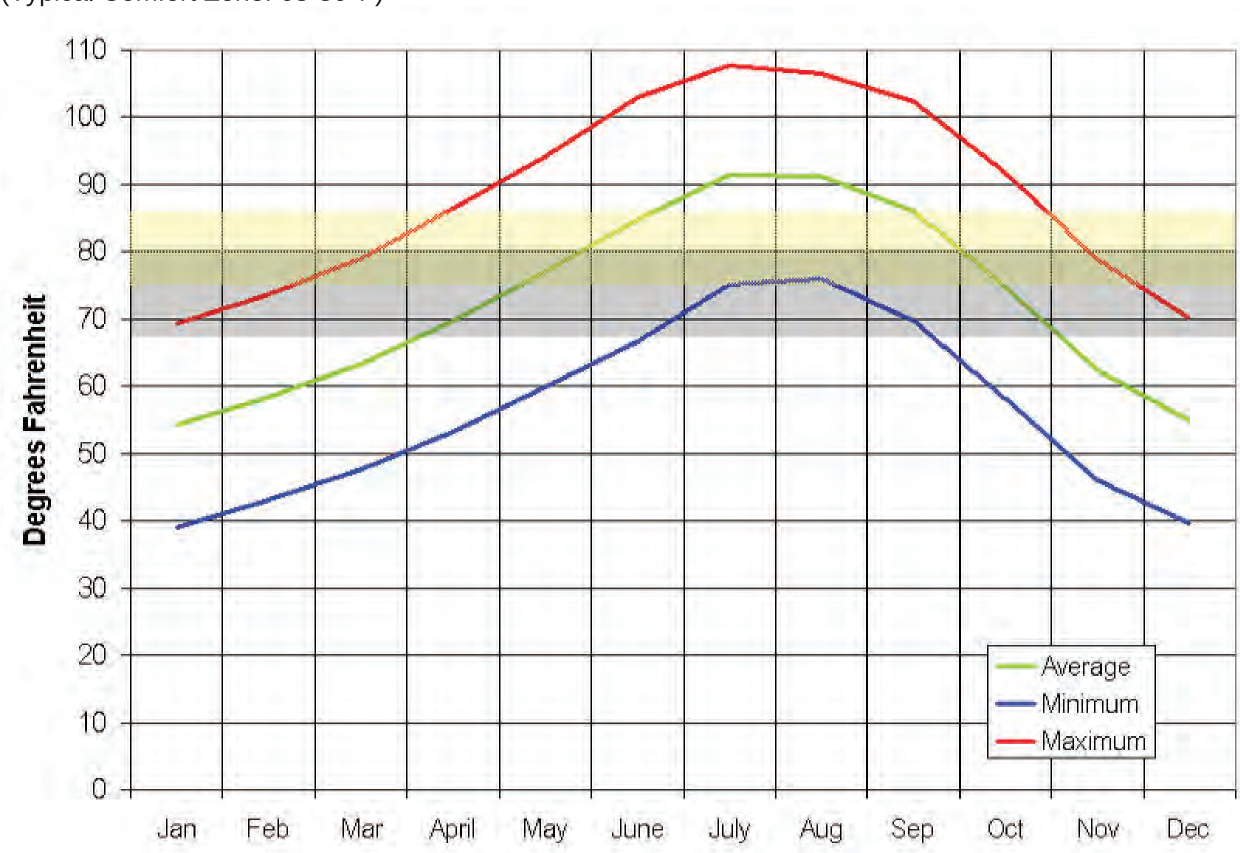
HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

Bioclimatic Chart

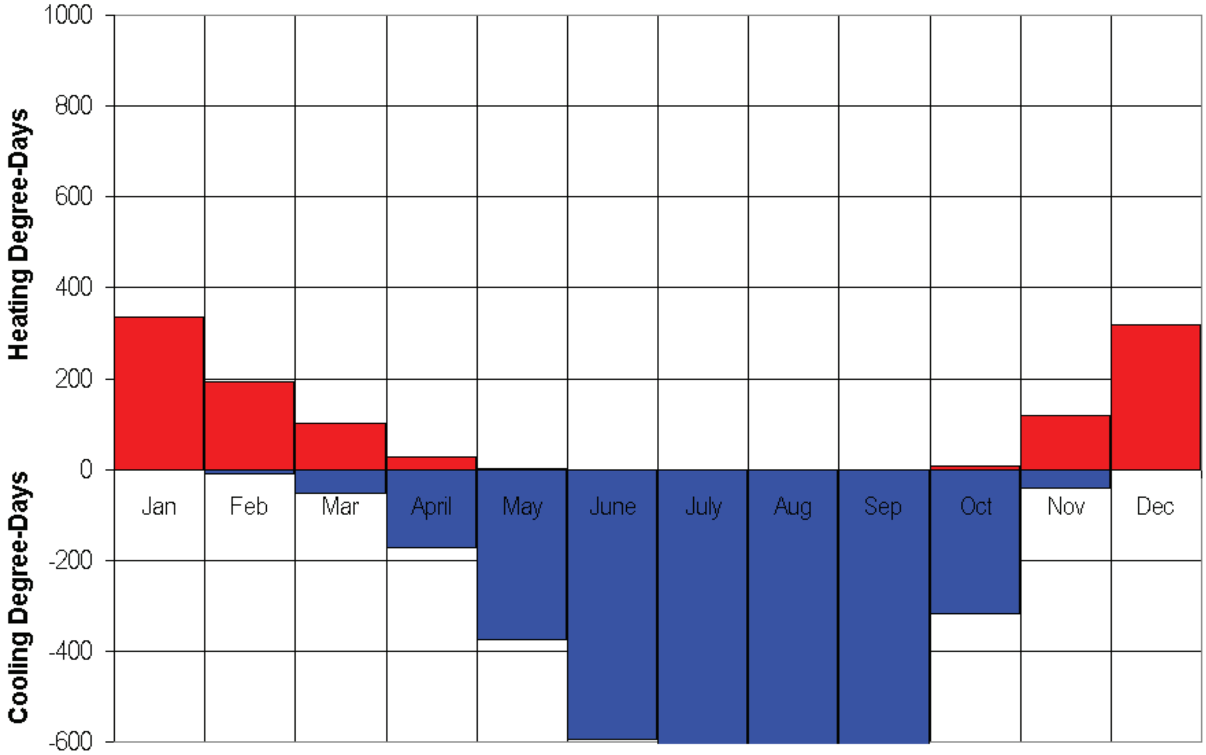


Temperature

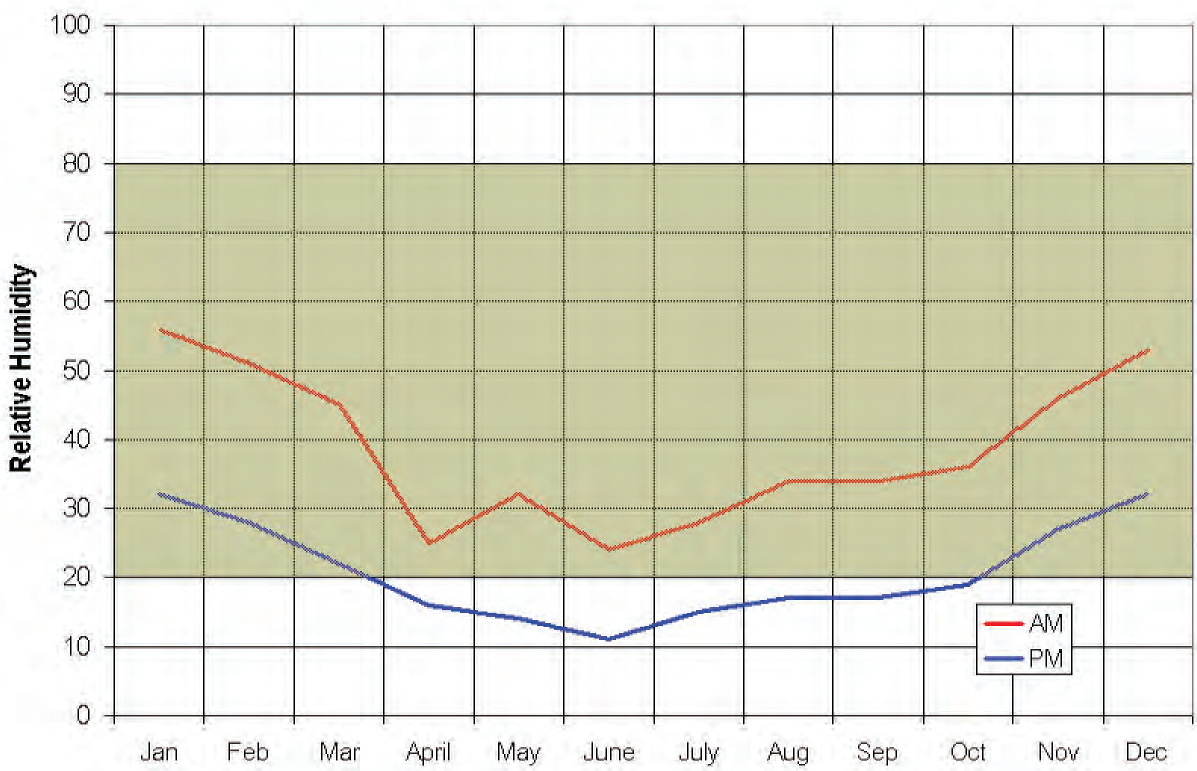
(Typical Comfort Zone: 68-80°F)



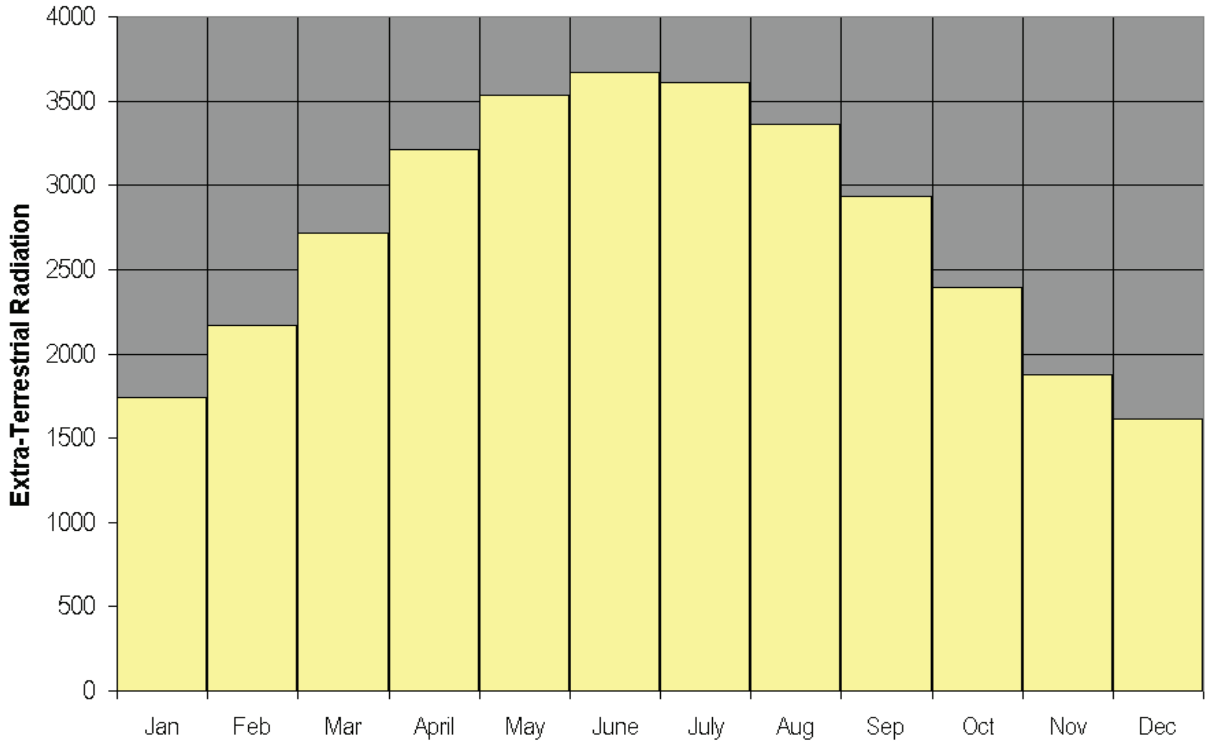
Degree Day
(Base 65°)



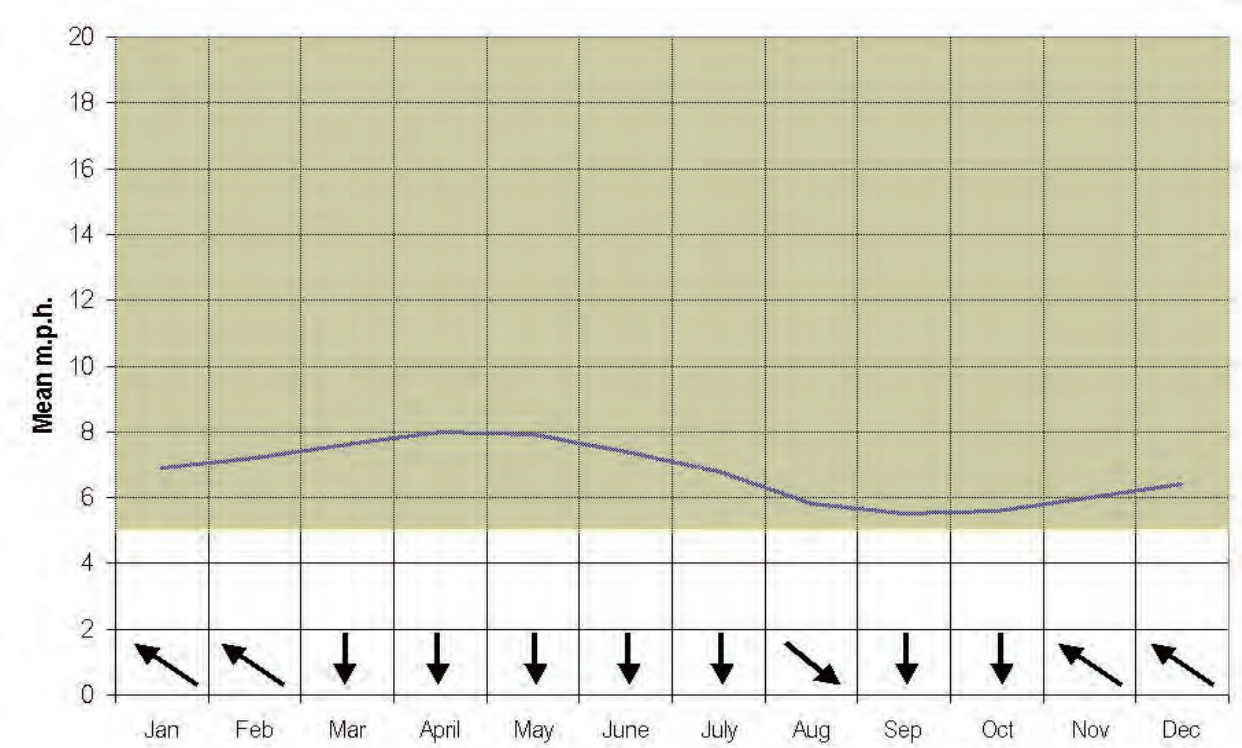
Relative Humidity
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation Daily Mean ETR: 2735



Wind Speed



Prevailing Wind Direction
Summer: N
Winter: SE

Natural Ventilation is most effective when wind speed is 5 mph or greater.

California Climate Zone 16

Reference City:	Bishop
Latitude:	37.22 N
Longitude:	118.22 W
Elevation:	4108 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	34
Record High Temperature (1972)	109
Record Low Temperature (1974)	-7

Design Day Data

Winter	99%	11		
	97.5%	15		
Summer				
	1%:	102	MCWB	61
	2.5%:	100	MCWB	61

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Use Evaporative Cooling
Use High Thermal Mass with Night ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R38
Wood Frame Walls	R29	R21
Glazing U-Value	0.42	0.55
Maximum Total Area	14%	20%

Climate

Climate Zone 16 is a high, mountainous and semiarid region above 5,000 feet in elevation. It covers a large area from the Oregon Border to San Bernadino county.

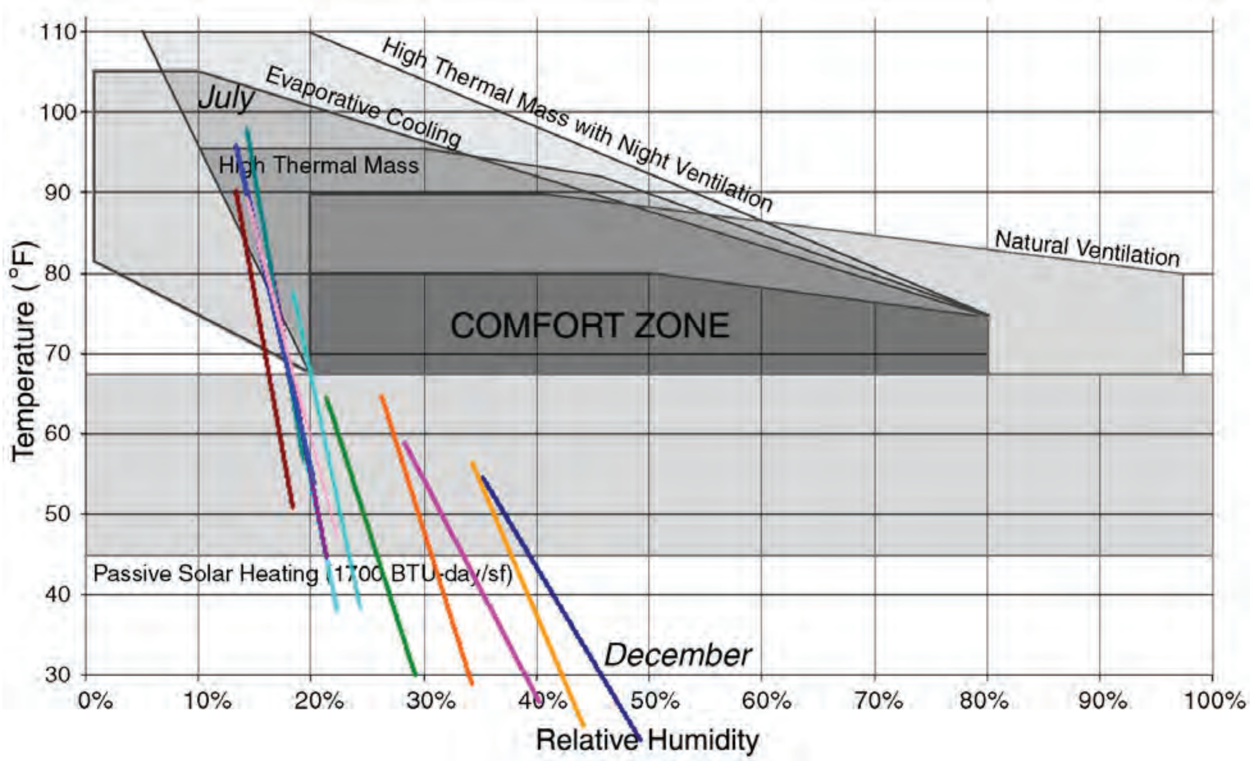
The climate is mostly cold, but seasonal changes are well defined and summer temperatures can be mild. Temperature varies tremendously with the slope orientation and elevation, but cool temperatures and snow cover predominate for more than half of the year. Fortunately, summer temperatures are modest, although the nights are cool. The annual precipitation can between 30-60 inches a year in this large geographic region, 90% of which falls in the winter.

	Bishop	*Sierra City*	*Mount Shasta*	*Hetch Hetchy*
HDD	4313	5183	5991	4740
CDD	1037	492	235	619

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

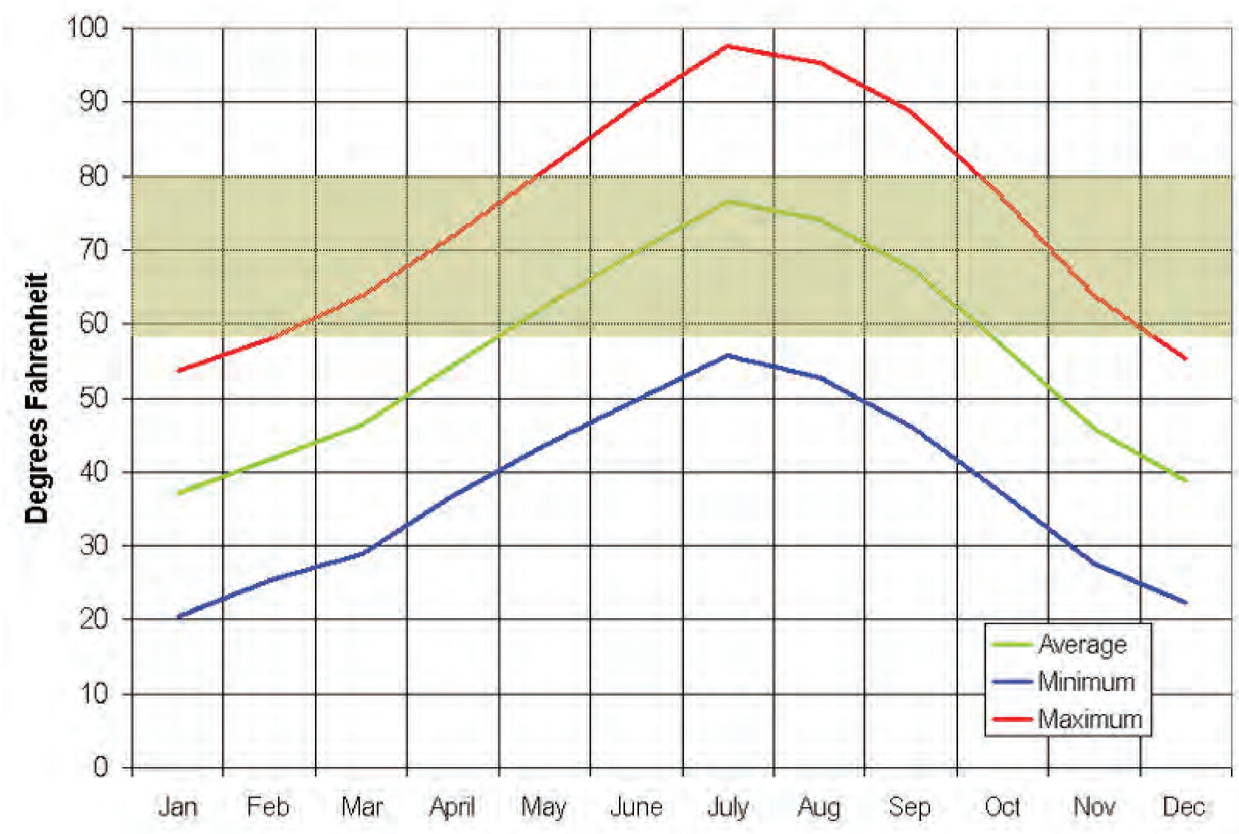
Since this zone experiences the most extreme range of temperatures, the energy consumption, especially for heating, is the highest in the state.

Bioclimatic Chart

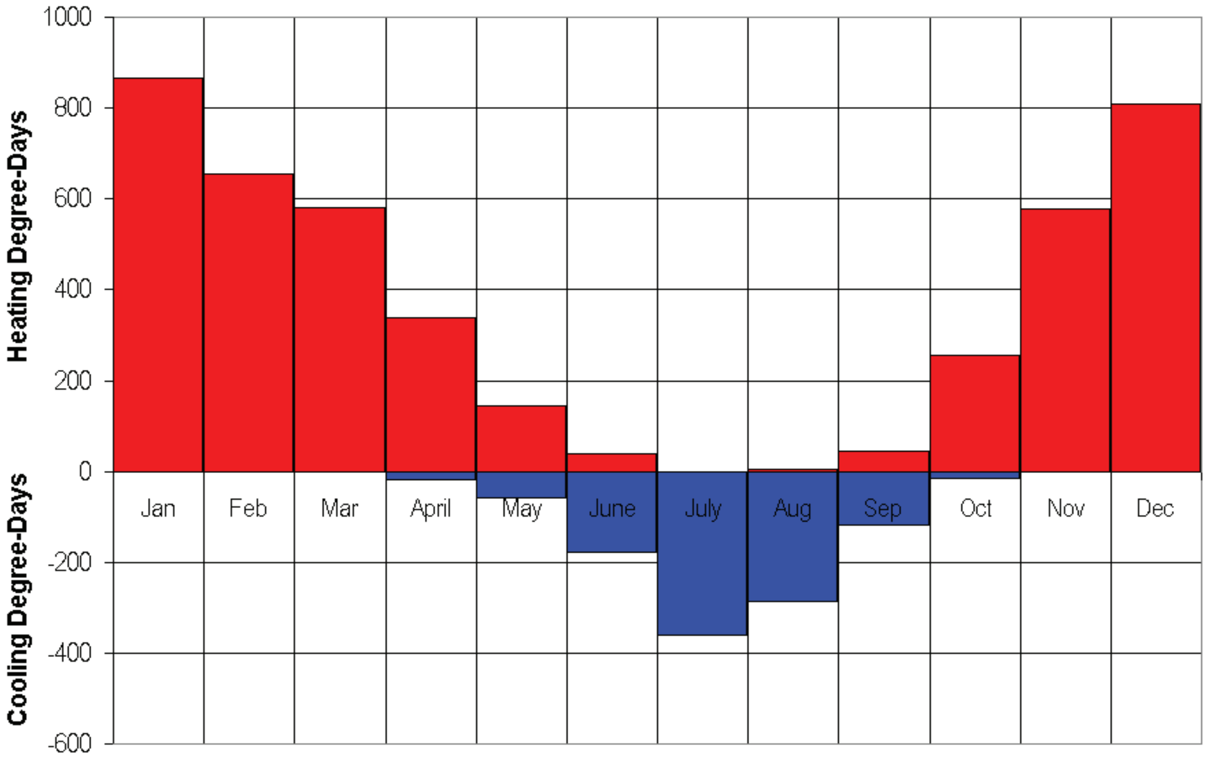


Temperature

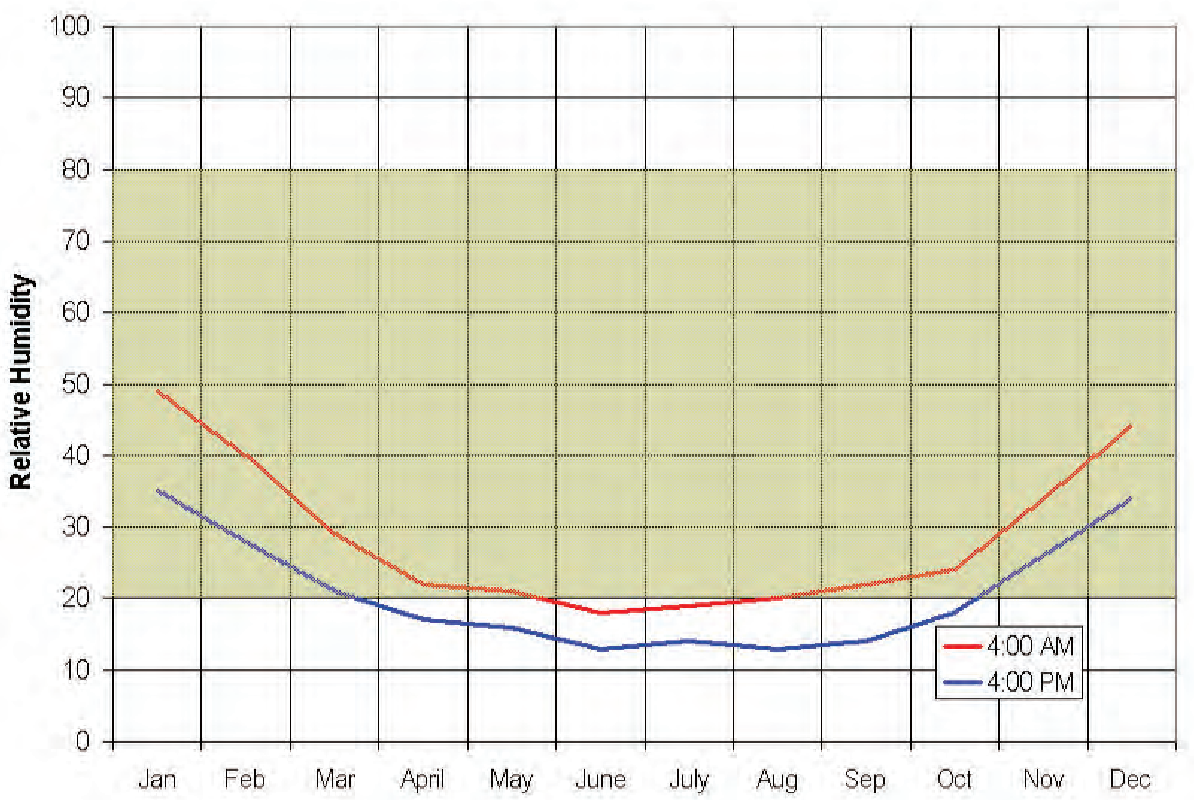
(Typical Comfort Zone: 68-80°F)



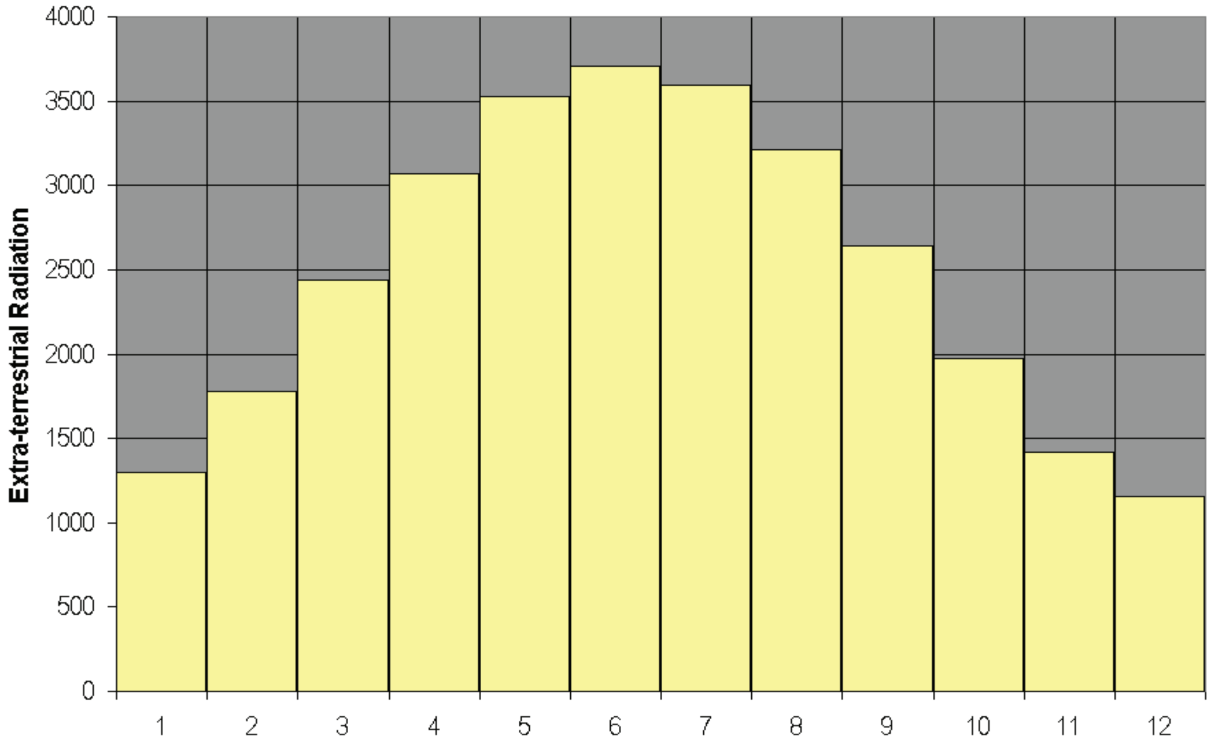
Degree Day
(Base 65°)



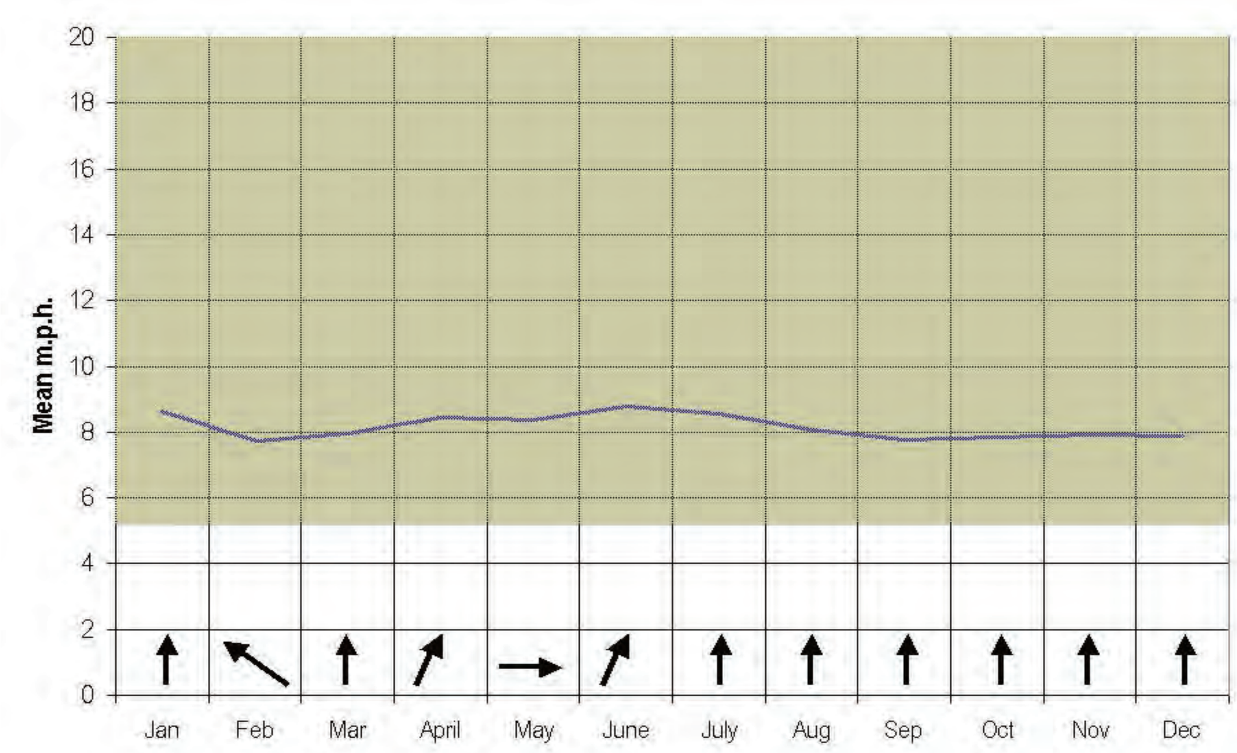
Relative Humidity
(Typical Comfort Zone: 20-80%)



Extra-Terrestrial Radiation Daily Mean ETR: 2484



Wind Speed



Prevailing Wind Direction
Summer: S
Winter: NW

Natural Ventilation is most effective when wind speed is 5 mph or greater.

NewSecurityBeat
The blog of the Wilson Center's Environmental Change and Security Program

The Dark Side of the Sun: Avoiding Conflict Over Solar Energy’s Land and Water Demands

October 2, 2018 | *By Olivia Smith*

Solar farms—just like regular farms—cover large swaths of land, requiring between 3.5 to 16.5 acres per MW of generating capacity. The largest solar plant in the world, the 648 MW Kamuthi facility in Tamil Nadu, India, covers ten square kilometers. But it will be dwarfed by the 3,450 MW facility under construction on China’s Tibetan Plateau, which will span 298 square kilometers when completed. Building these large plants requires fundamentally changing how the land they sit on is used, which—without careful planning—could have negative impacts on the environment and local communities that could potentially lead to conflict. The backlash could not only derail solar projects, but could also fuel resistance to future renewable energy development.

Competing Demands: Water, Energy, and Food

Solar energy is increasingly affordable- in fact the price of utility-scale generation has dropped by 86% since 2009. As costs fall, many countries plan to expand solar generation dramatically to meet international climate commitments; China alone added 52.8 GW of solar generation last year. But there are challenges with integrating solar generation into the grid, since it is dependent on sunlight and is thus an intermittent source. Photovoltaic (PV) panels stop producing when the sun stops shining, while concentrated solar power harnesses thermal energy from the sun's rays, allowing generation to continue only briefly after sunset. These limitations could impede development or make other power sources more attractive. Some new solar facilities are built on agricultural land, eliminating livelihoods and reducing local food production. This land-use change can stir tensions in rural communities, as happened in Connecticut where farmers who leased land found themselves in competition with clean energy. And especially in poorer and marginalized communities, it could change food production for decades. One state-run solar company in India leases farmland for 28 years, paying farmers much more than they would have made from their harvests.

Often, the land most suitable for solar energy is in dry climates where water is extremely scarce. While solar photovoltaic facilities use little water, solar thermal plants use vast quantities of water for cooling and cleaning. In the North African desert, Morocco's enormous $9 billion Noor solar thermal complex competes with local agriculture for water from the El Mansour Eddahbi dam, consuming about six million cubic feet of water each year. As Tunisia and other countries throughout the arid Middle East consider building solar thermal plants, they must figure out where the water will come from.

Equity, the Environment, and the Exploited

Although solar generation is emissions-free, the construction process can have detrimental effects on the environment. The process of producing raw materials and siting facilities disturbs local ecosystems. PV panels require some rare materials, like silver, whose extraction is energy intensive and polluting. In the "rare earths kingdom" of Ghanzou, China, the 190 million tons of waste from abandoned mines will take 70 years to address. And efforts to recycle inputs for both solar thermal and PV solar facilities are under-developed.

Solar farms can also reinforce inequality. Subsidies and carbon taxes have made cleaner energy cheaper. In Germany, a backlash against renewable energy has mounted in opposition to the high costs these measures impose on poorer consumers who remain dependent on utilities and the grid. Similarly, the poor and even communities where solar energy is produced may not receive the electricity. A massive solar plant proposed for Tunisia was branded "neocolonialist" because it would have delivered electricity straight to Europe through undersea cables.

In the Mojave Desert, the Colorado River Indian Tribes are protesting the development of utility-scale solar facilities, which they argue will disturb archaeological sites and harm biodiversity. The tribes claim that the project developers did not adequately consult with them, as required by federal law.

Other renewable energy projects, such as hydroelectric dams and wind farms, have faced similar opposition from local communities concerned about environmental impacts or land rights. Sometimes the resistance is successful; in the Mexican state of Oaxaca, the federal court blocked a large wind project due to inadequate consultation with indigenous Zapotecs. In other instances, the local communities lost their battles—and even their lives, as in northeast India in 2016, when anti-dam protestors were killed.

The Bright Side

If planned thoughtfully, solar projects can avoid land-use conflict. The built landscape offers major opportunities for siting small-scale solar, including on roofs and walls. New programs like RE-Powering America's Land have converted abandoned industrial sites and defunct landfills into solar farms. Combining wind and solar generation into one facility can reduce the space and infrastructure required as well as help balance intermittency issues. And solar farms can even co-locate with real farms: Agricultural researchers have found that crops grow beneath solar panels—and the plant can provide cheap electricity to power farm operations.

Solar energy could help alleviate, rather than exacerbate, countries' water problems. Solar PV, which is more common and less water-intensive than solar thermal, uses water only in manufacturing and periodic cleaning. For some developing countries facing water stress, solar PV's efficiency is pivotal. A World Resources Institute report found that switching to solar PV and wind energy would significantly reduce India's water-energy nexus challenges by reducing the need for thirsty fossil fuel plants.

Furthermore, solar facilities could power energy-intensive activities such as crop irrigation or water pumping, reducing their carbon footprint. Solar-powered drip irrigation can be more water-efficient and more cost-effective than traditional methods, as demonstrated by a pioneering project in Benin. Water pumps powered by solar panels, which are widespread in the Asia-Pacific region, make fresh water supply possible for rural developing communities not connected to the main grid. The power of the sun is being harnessed to power street lamps and trash compactors, and even to create drinking water from the air.

Some countries have recognized the importance of participatory planning and democratic management to ensure a sustainable, conflict-free solar strategy. Solar projects are booming in Kenya, where the constitution mandates that energy sector decisions are made at the county level. Two companies plan to invest $23 million in solar-storage micro-grids, using blockchain and micro-funding to further democratize and increase access to Kenya's energy sector.

For solar energy to be successful at the scale required by climate change mitigation, solar facilities must be harmonized with the ecosystem, agriculture, and human needs. If local communities are excluded, and knock-on effects are overlooked, the benefits of renewable energy could be outweighed by negative consequences. But if innovative strategies and inclusive approaches continue to gain momentum, the future of solar energy will be bright.