Can California decarbonize electricity without improving Building Energy Codes?

As California's policymakers celebrate SB100, a landmark bill that requires utilities to deliver carbon-free electricity by 2045, the details on how this will be delivered are yet to be disclosed. Buildings in California currently use electricity for approximately 48% of their total energy demand. The remaining 52% leans heavily on carbon-intensive sources such as propane and natural gas. Organizations such as the American Council for an Energy-Efficient Economy (ACEEE) have noted that California "must go big on energy efficiency to be carbon-free by 2045."[1] This means that despite a building energy code that is widely admired and stricter than many other states, we'll need to wring much more efficiency out of our buildings. But can this be done and how much room for improvement is there?

In February of 2018, the City of Palo Alto released a ground-breaking report, innocuously titled: "Buildings Baseline Study and Roadmap for Zero Net Energy Buildings."[2] This report, while attempting to adhere to the State's previously mandated Zero Net Energy (ZNE) goals, inadvertently exposed a more urgent priority for buildings. The release of Palo Alto's report arrived barely a month prior to the California Energy Commissions' (CEC) announcement of their proposed updates to the 2019 Title 24 Energy Efficiency Standards.[3] This CEC announcement made headlines nationally due to a new requirement to include solar panels for all residential buildings by 2020. However, more significant than the 'bling' of the required PV, was a careful walk-back from an earlier push towards Zero Net Energy buildings. The CEC's deft side-stepping of their previous ZNE targets was easy to miss as it was mentioned only at the very end of their FAQ,[4] camouflaged under the sub-title "Do the 2019 residential standards get us to zero net energy?"

There's much to unpack in these two documents, which serendipitously serve to reinforce and clarify each other. In order to further clarify them, we'll measure them against the energy models of a cluster of seven recent Palo Alto projects. These will be used to explore where the CEC could potentially take residential code updates in the future and illustrate just how much ‘wiggle’ room remains to increase residential building efficiency. We’ll close with the sobering reality of the measured performance data for a project similar to those we’ll review in Palo Alto. Our goal is to support the CEC’s pivot towards building decarbonization and point out where they could potentially take California’s energy codes in the near future.

Learning from Palo Alto

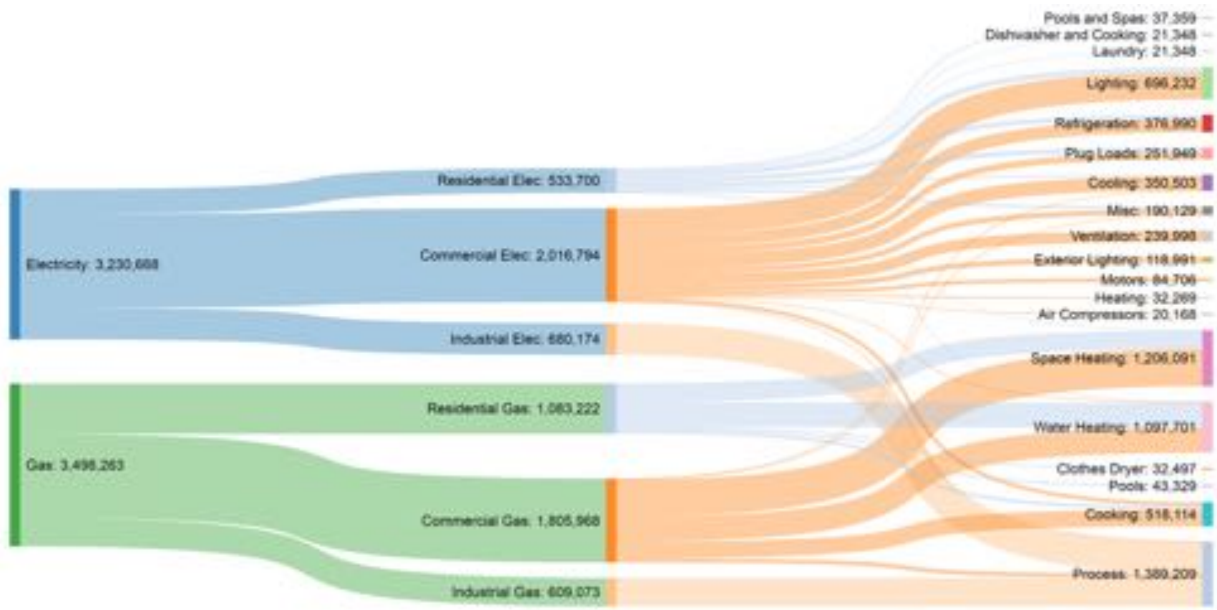

Figure 1. 2016 Palo Alto Building Energy Use Breakdown, disaggregated by type, source and end use. Source: Residential Appliance State Survey (RASS) and California Commercial End Use Survey (CEUS.) Graphic use by kind permission from DNV-GL.

Palo Alto enjoys the good fortune of a municipally owned utility, which was able to provide energy use data for this study. Their report begins with a great Sankey diagram, illustrating overall source energy use that aligns with much of the State of California, which leans heavily on natural gas and accounts for just over half of total energy use. The next pie graph shows a total energy use breakdown similar to some of California’s larger cities, with commercial buildings consuming the lion’s share of Palo Alto’s energy. At the third level of energy use disaggregation, the information gets interesting: this is where we can start to identify exactly how and where building energy in Palo Alto is being spent. This granular view allows a better perspective on what needs fixing, and where the best opportunities may lie for achieving deep carbon emissions reductions. This report is notable in that it provides a comprehensive overview of the energy use of one of California's mid-sized cities. While it's hard to define Palo Alto as 'average,' we could be forgiven for calling its built environment 'typical.' For this reason, we're using this report to provide generalized insight into the energy use of 'every town' California.

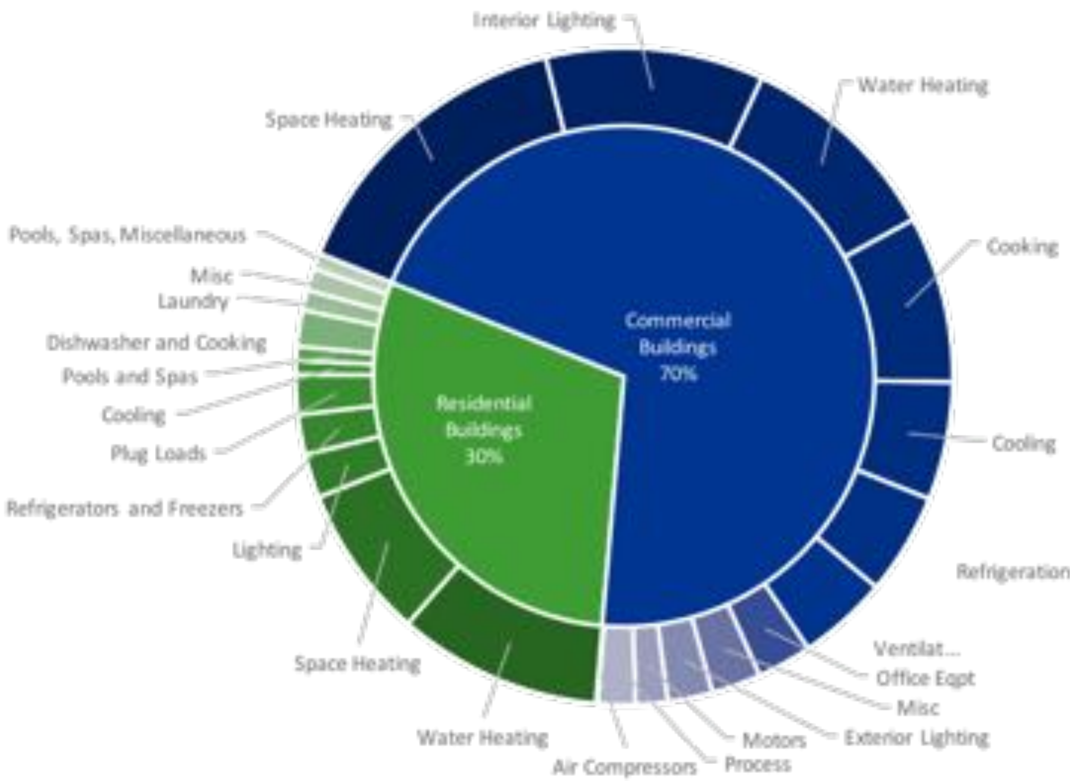

Figure 2. Palo Alto Utilities Data 2016 (inside pie chart), with Residential Appliance Saturation Study 2009 (RASS) and California Commercial End-Use Survey 2006 (CEUS) used to determine end use breakdown by building sector. Source: DNV-GL.

Shifting our policy focus

By far the most eye-opening information exposed in this report is an innocent-looking set of bar-chart graphs, comparing the results of annual energy use through the three frameworks of Zero Net Carbon, Zero Net Energy and Zero Net Electricity. These simple bar graphs reveal *a stark divergence of weighted priorities,* when looking at energy use through these three specific lenses, prompting the question: ***What is the target we're really aiming for with our buildings?***

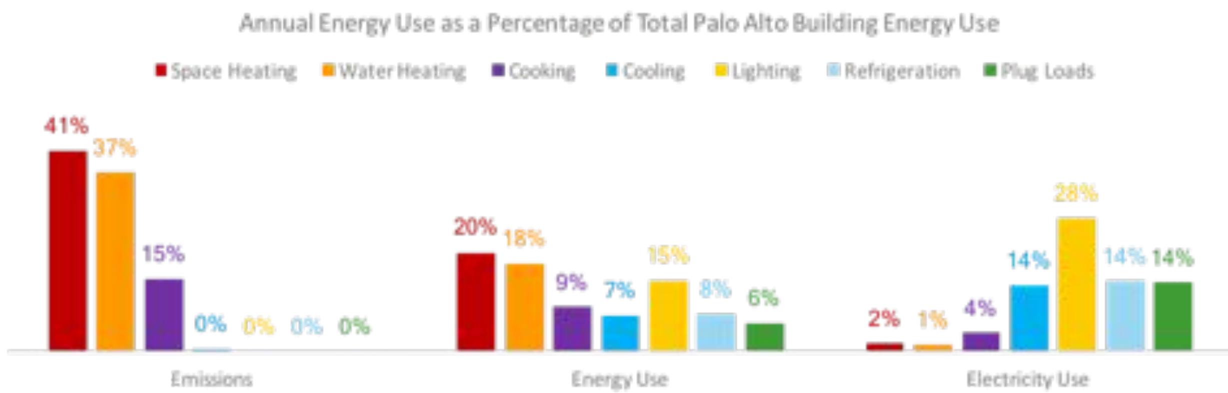

Figure 3. Summary of Building Energy Usage (Total BTU). Source: Data compiled from RASS and CEUS data by DNV-GL.

This is where the CEC's recent leap-frog over Zero Net Energy, in favor of a carbon reduction focus, starts to make more sense. This comparison graph reveals that if we look only through the Zero Net Electricity lens, we'd be led towards heavily promoting daylighting and lighting efficiency measures, likely with minimal outcomes for carbon emissions reductions. Similarly, the Zero Net Energy lens offers a broader distribution of possible policy incentive options. Some positive impact on carbon emissions reduction could be expected, but *it's clearly the Zero Net Carbon lens that we simply cannot ignore*. Even in the bucolic, and supposedly 'mild' climate enjoyed by Palo Alto, the highest building carbon emissions come from energy used for space heating.[5] Water heating follows closely behind, offering policymakers two unassailable choices: space heating and water heating. If policy is focused on only these two things, we'll have a much higher chance of significantly reducing our carbon emissions from buildings.[6]

So, how do we achieve this most effectively?

Fortunately for us, the CEC's FAQ already has much of this covered. Special mention is made of the new residential standards encouraging "demand responsive technologies including battery storage and heat pump water heaters."[7] This is big. It signals a clear move towards the electrification of buildings – a big step for California where gas has been the fuel of choice for many years. With this combination of electrification, storage and heat pump technology, hot water energy use will mostly be covered by renewable energy. Less clear in the CEC's FAQ is a clear plan for how they'll be reducing building space heating demand. Fortunately, space heating demand happens to be a particular specialty of the Passive House standard. For this reason, the modeled data from a cluster of buildings, all located in and around Palo Alto provides a helpful comparison.

Palo Alto’s (mostly) Passive House Cluster

The population of Palo Alto is known for their innovation and willingness to explore new technologies. This pioneering spirit extends to their built environment where the largest cluster of (mostly) Passive House projects in California is located. The projects we’re looking at here are not all certified Passive House buildings, but all of them used the Passive House Planning Package (PHPP) energy model to guide their design and construction. Two of these projects are certified: the multigenerational home and the larger SFR- Luxury home. Their teams were kind enough to share the energy models for their projects with us and we’ve been able to generate a few simple comparisons of their assembly R- and U-values. The modeled performance metrics of these diverse buildings is instructional and provides insight on where the code may have room to move towards high performance targets such as those required by the Passive House standard.[8]

Diverse Building types and sizes

Figure 4 (above): Treated floor area (interior conditioned space) of buildings in Palo Alto's Passive House Cluster plus CA T-24 house based on Palo Alto average house size, reduced by 15% for fair approximation.

These projects represent a diverse range of sizes and use-types, ranging from a 252 SF tiny house (1) to two luxury-homes of 4,687 SF, (4) and 5,341 SF, (7) respectively. They include a multigenerational single-family home (3), where an aging grandparent occupies an attached accessory dwelling unit (ADU) and an intentional community (6), housing a small commercial kitchen, full basement of shared community space and eight dormitory-style bedrooms. Project five (5) in this cluster is a small commercial office building. One of the smaller residential projects, project #2, is a retrofit of an old 1920's holiday cottage. With the exception of the larger office buildings, this mix of buildings offers reasonable representation of Palo Alto's diverse building types.

Figure 5 (above): Wall assembly insulation values all include a framing factor reduction and are shown as 'effective,' as opposed to 'nominal.' (eg. R-19 'nominal' - 15% ff = R-16 effective.)

When comparing the R-values of the primary building envelope assemblies it is interesting to note the remarkable similarity in wall and roof insulation values for all seven projects. (Note: they were all designed and modeled by completely separate teams.) While the code-compliant wall insulation does not lag too far behind the PHPP-compliant projects, the fact that exterior walls are always the largest surface area of any building, makes this a key issue.

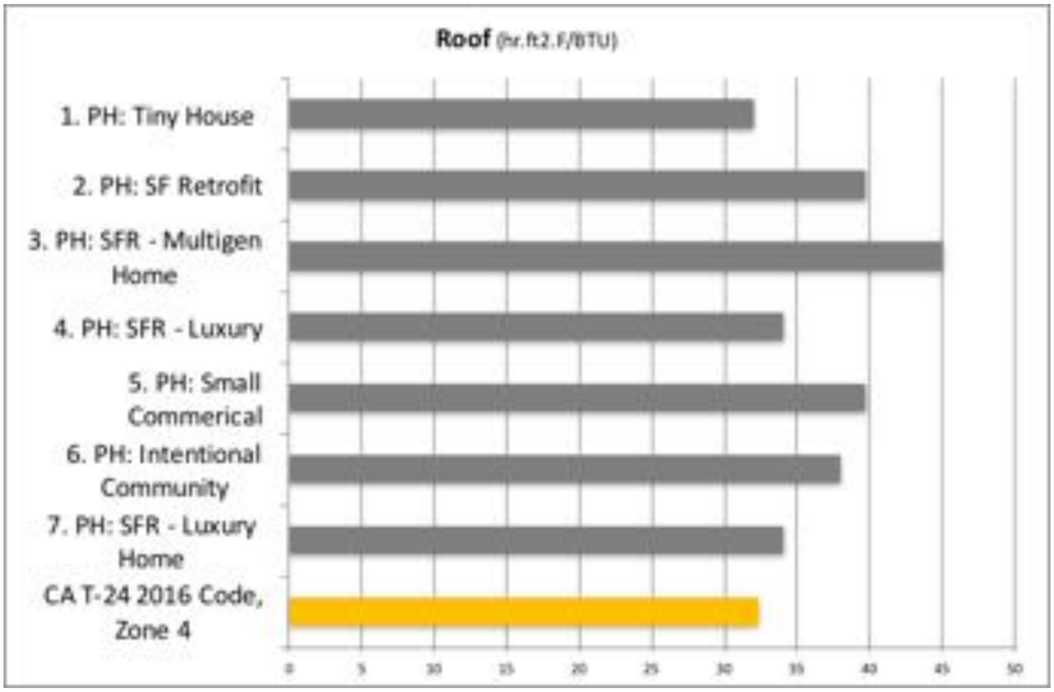

Figure 6. Roof insulation levels shown as 'effective.' (See note in Fig.5)

While walls still offer room for improved insulation, roof insulation levels are clearly well aligned. (Nothing to see here!)

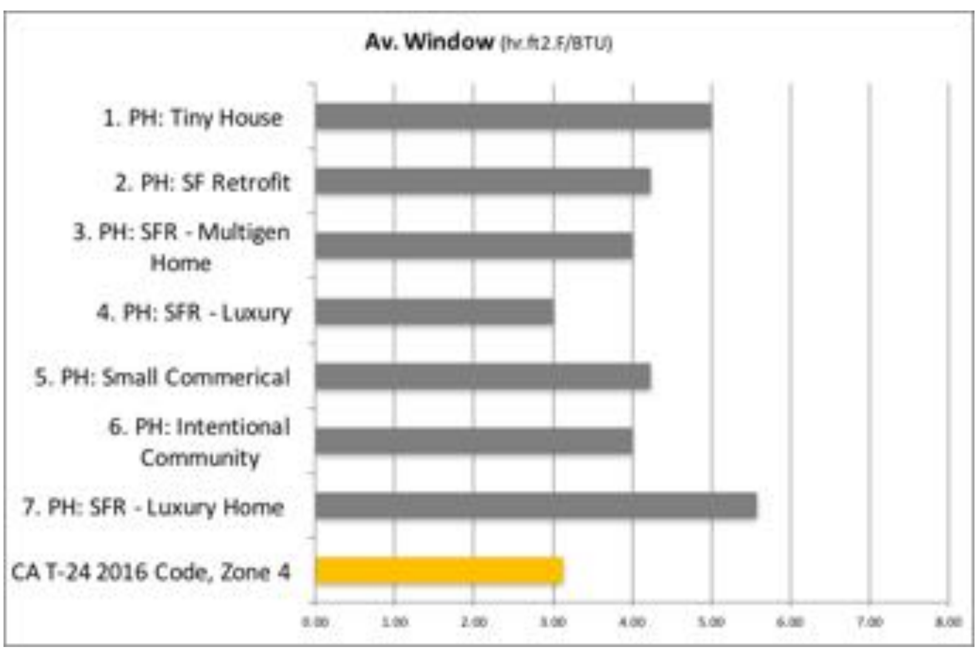

Figure 7. Window U-values converted to R-values for simplicity. PHPP projects show avg. window performance values; T-24 code value is a 'worst allowable' performance value.

A larger divergence starts to emerge in the average window R-value comparison. The design team for Project 4 were the only ones who opted for double-glazed windows. All other projects selected triple-glazed windows, indicating that, while it is possible to meet PHPP targets with double-glazing, triple-glazing may offer other advantages in this ‘borderline’ climate. The T-24 compliant windows in this comparison are represented as the ‘worst allowable’ compliance value. We could reasonably assume that a code compliant project with these windows should meet PHPP performance targets.

Caveat emptor: this particular comparison is somewhat complicated. Without going too far into the weeds here, it’s enough to say that a significant difference exists in how window performance is calculated via the PHPP, compared to most other energy models. NFRC and the ISO 10077 testing protocols used by the PHPP have been shown to further muddy this comparison, so it may be safest to not draw any solid conclusions from this particularly simplistic comparison. (Windows are complicated and this graph isn’t.)

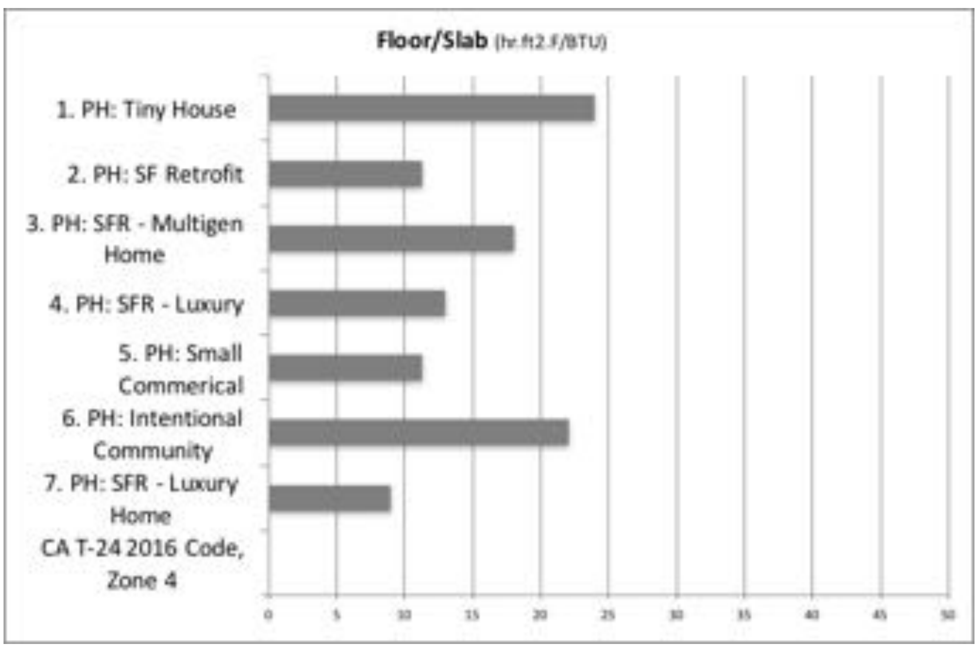

Figure 8. Floor/Slab values all shown for slab-on-grade, except for project #1 - Tiny House

It’s at the Floor/Slab comparison where the largest differences appear. All but one of the PHPP-modeled projects employed a slab on grade floor assembly. The exception was (1), the Tiny House, which required almost double the floor insulation than that of its peers. This is due to both its diminutive size and more vulnerable exposure to ambient temperature.[9]

Notably, the hypothetical T-24 project shows *no sub-slab insulation is required to meet code*.[10]

Shifting Code Compliance

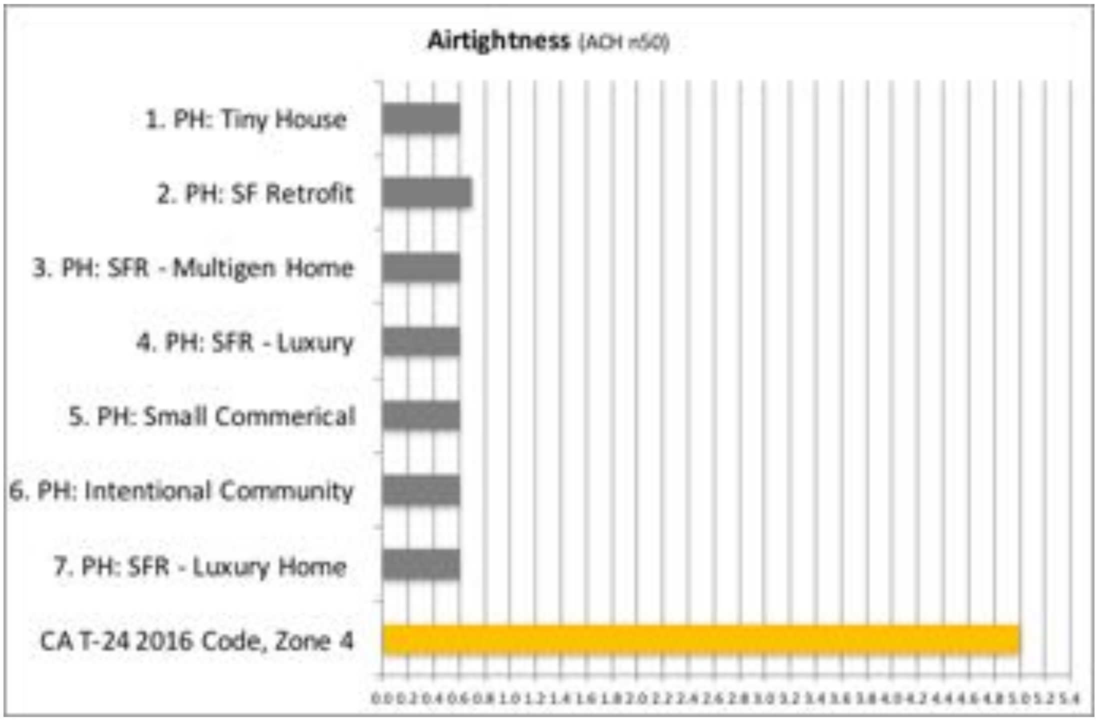

Figure 9. Airtightness metrics compared with 2016 T-24 Residential Code Compliance.

A final, glaring omission in the code compliance option shows up in a comparison of the airtightness testing for all these projects. They all met the required threshold for Passive House certification, including the retrofit, which is allowed slightly more leakage than its new-build counterparts (up to 1ACH/n50.) This indicates requiring airtightness *is not an impossible task.* Passive House projects delivered by experienced teams now routinely achieve airtightness testing results between 0.2 and 0.3ACH so we know that meeting air-tightness targets is not difficult. Code enforcement agencies across the country[11] are increasingly recognizing tightened envelopes as an easy, cost-effective measure to drastically improve the performance of our buildings.

Measured performance

Unfortunately, we don't yet have the measured performance metrics for this set of projects to enable a full comparison of their predicted and measured performance. We hope to extend this study in future to include that information.

Targeting Loads

We do have a robust set of performance data for another Passive House project located not too far away in neighboring Climate Zone 12, just across the Bay in Alamo, California. Despite being outside Palo Alto, this ~3,000 SF project shares many of the same features and assemblies as the multigenerational single-family home Project (3) in the Palo Alto cluster. It has a Treated Floor Area of 2,342 SF, wall assembly of R-28, roof assembly of R-46, windows of R-3.3, Floor/Slab of R-14 and a slightly better airtightness reading of 0.3 ACH n50. This is an all-electric home, utilizing heat pump-technology for both hot water and space conditioning. It boasts a 7.5 kW solar PV array installed on the south-facing roof that powers both the house and an electric vehicle. While not certified, we're reasonably confident this building meets the requirements of the Passive House standard.

Figure 9 composite: Alamo Passive House by One Sky Homes is an all-electric home. The project includes a 7.5kW PV array on the south-facing roof that generated 12,767 kWh of energy to offset a net annual energy use of 10,707 kWh by the house and electric vehicle.

Time of Use Matters

Monitoring of energy use of this building began in earnest by May 1st, 2016. The daily energy use of the building since then has been remarkably stable but it's the bigger picture overview of energy use vs generation that provides the most insight here (and reaffirms our conclusions drawn from the three framework comparison graphs generated in the Palo Alto report.)

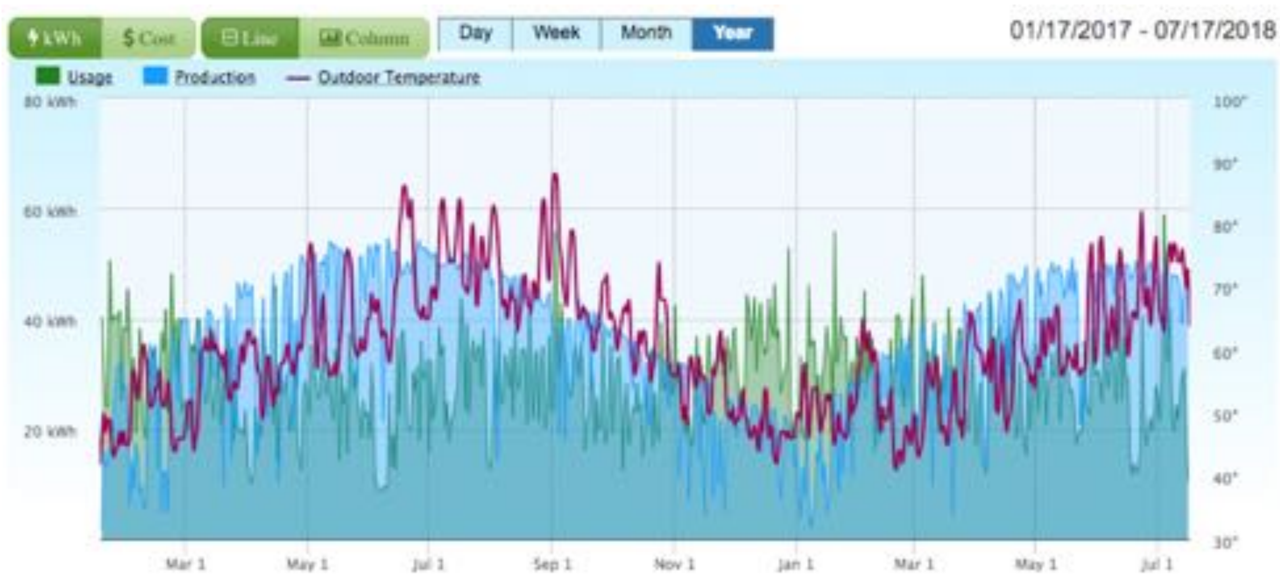

Figure 10: Alamo Passive House Total energy demand vs energy production, courtesy of One Sky Homes

When we look at the graph plotting a full year of daily outdoor temperature (red line), against electric usage (green line) overlaid with energy production (blue line), we start to identify crucially important information. Even in our sunny California climate, in a house with incredibly low overall demand (including an electric vehicle), a 7.5 kW array is unable to meet all of its energy needs between the months of November and February. It shows that *without battery storage, this house still requires a utility*. This not only means time of use matters, but that *seasonal use matters and* ***confirms that our most critical variable is in fact winter space heating demand – large portions of which cannot be covered by short-term battery storage.***

Refocusing on Emissions Reductions

The information revealed by this monitored data, combined with the Palo Alto report supports the new direction being taken by the CEC in their updates to our

Title 24, Part 6 energy code. This direction was clearly outlined in the closing paragraph of their FAQ document:

"Looking beyond the 2019 standards, the most important energy characteristic for a building will be that it produces and consumes energy at times that are appropriate and responds to the needs of the grid, which reduces the building's emissions." ***[12]***

Passive House California is in full support of this revised focus on building emissions reductions. However, the information we have shared here provides evidence that there is still plenty of room (and opportunity) to improve building envelope efficiency and **to focus particularly on space-heating energy use reduction.** We're pleased to support the California Energy Commission's efforts pointing our State in the right direction.

- *PHCA is grateful to the owners and project teams who contributed their PHPP files to support this study.*
- *To find out more about the work of Passive House California, visit our website at:* http://passivehousecal.org/
- *To learn more about the Passive House Standard, join us at the 2018 North American Passive House Network Conference (#NAPHN18) in Pittsburgh on October 17-21st: https://naphnconference.com/*

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September 2018

References:

· City of Palo Alto Development Services, "Buildings Baseline Study and Roadmap for Zero Net Energy Buildings." Released February 2018. Authors: Blake Herrschaft and Betty Seto, DNV GL.

· California Energy Commission, "2019 Building Energy Efficiency Standards, Frequently Asked Questions." Released March 2018.

California Energy Commission, "2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings." Pg

Footnotes:

[1] http://aceee.org/blog/2018/09/california-must-go-big-energy

[2] https://www.cityofpaloalto.org/civicax/filebank/documents/63492

[3] http://www.energy.ca.gov/title24/2019standards/documents/2018_Title_24_2019_Building_Standards_FAQ.pdf

[4] http://www.energy.ca.gov/title24/2019standards/documents/2018_Title_24_2019_Building_Standards_FAQ.pdf

[5] Space Heating demand is also the highest energy user in commercial buildings, challenging the commonly held notion that commercial buildings in this region are 'cooling load dominated.'

[6] Early projections indicate this same approach applies equally to our warmer, southern Californian climates where summer peak load reduction offers the same opportunities for full electrification. (More on this in future articles.)

[7] http://www.energy.ca.gov/title24/2019standards/documents/2018_Title_24_2019_Building_Standards_FAQ.pdf

[8] To clarify, we refer here to the targets of the international standard set by the Passive House Institute as these are universal for all seven projects and were the targets aimed for by these project teams.

[9] It's not clear why project (6) required so much more insulation than the other PHPP-modeled projects. (We'd hazard a guess that this anomaly may be due to other factors, and was not necessary to meet a performance target, given that this project has a basement slab.)

[10] Not included in this graph is the perimeter slab insulation required for all these projects, including the code compliant building.

[11] https://cdn.ymaws.com/www.nibs.org/resource/resmgr/BEST/BEST2_022_WB6-5.pdf

[12] http://www.energy.ca.gov/title24/2019standards/documents/2018_Title_24_2019_Building_Standards_FAQ.pdf