APPENDIX B
California Results

Appendix B to Emu's Nov 2023 **Report on Building Standards.**

Emu are experts in the international Passive House standard, the world's most rigorous standardized guideline for envelope efficiency.

The primary report investigates: 2018 IECC, 2021 IECC, 2024 IECC, California Title 24, EnergyStar v3.2, DOE Zero Energy Ready Home, Pretty Good House, 2015 Phius+, 2018 Phius+ Core, 2021 Phius+ Core, 2021 Phius+ Core Prescriptive, PHI Low Energy Building, and PHI Passive House.

This Appendix summarizes the results of the report relative to the 11 projects located in the state of California.

The intent is to allow building owners, project teams, and policy makers to compare building standards as apples to apples, and make informed decisions.

Written by Enrico Bonilauri,
Co-Founder of Emu Passive.
Researched and funded independently.
Monday, November 27, 2023

APPENDIX B - CALIFORNIA RESULTS

Watch this on YouTube

Overview

This Appendix summarizes the results of the report relative to the 11 projects located in the state of California. The Report illustrates how these are actual projects with their own specific characteristics, design, form factor, etc.. This should make the results closer to reality than one would get from using abstract, non-realistic reference buildings (e.g. what is used for ASHRAE Standard 140). The number of projects included should be sufficient to dilute outstanding aspects of individual buildings that could distort the results.

In terms of requirements avoidance of mold and surface condensation (i.e. thermal bridge mitigation), occupants comfort, durability, and resilience, PHI Passive House outperforms all other building standards considered in the Report, including the latest Title 24 and Phius standards.

Some may believe that the latest Title 24 already incorporates many of PHI Passive principles, but the review carried out in this study shows that that is far from the truth. With some exceptions, the latest Title 24 prescriptive performance requirements are actually very similar to the 2018 IECC requirements.

Title 24 improvements over the 2018 IECC performance mostly consist of requiring heat pumps for heating and cooling, and mandating PV systems for projects over a certain size. Other than that, Title 24 prescriptive requirements for the components of the building envelope (i.e. R-values, window U-values, etc.) remain very similar to the 2018 IECC. The IECC requirements outperform the latest Title 24 in that IECC sets a limit to air leakage allowed in buildings.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Projects

As illustrated in depth in the Report, 50 projects from Emu's consulting were selected as the base to compare different building standards.

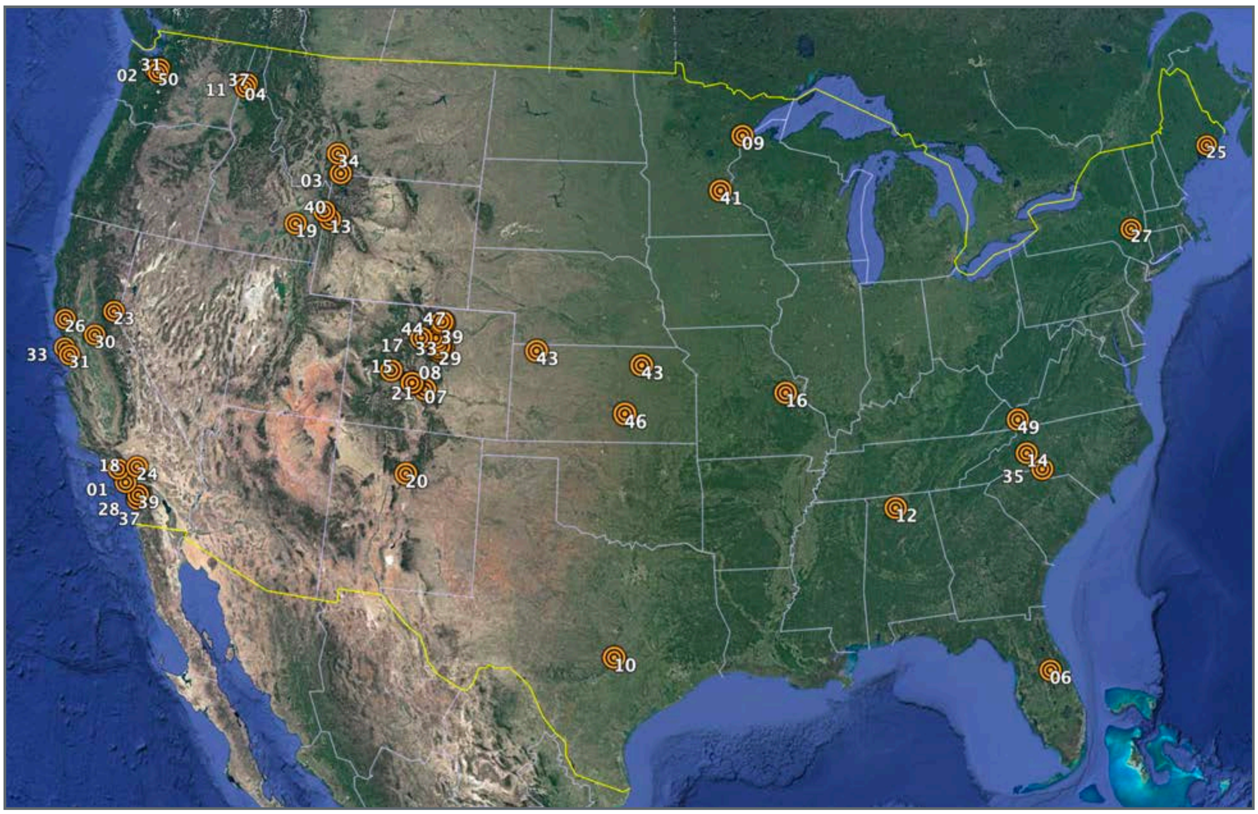

Image B.01: Distribution of the 50 projects across the US.

The number of projects selected was set at 50 in order for the results to have statistical significance.

Intentionally, these are all single family home new construction projects. Multi family, non-residential, and retrofit projects were excluded in order to keep the project pool as consistent as possible.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

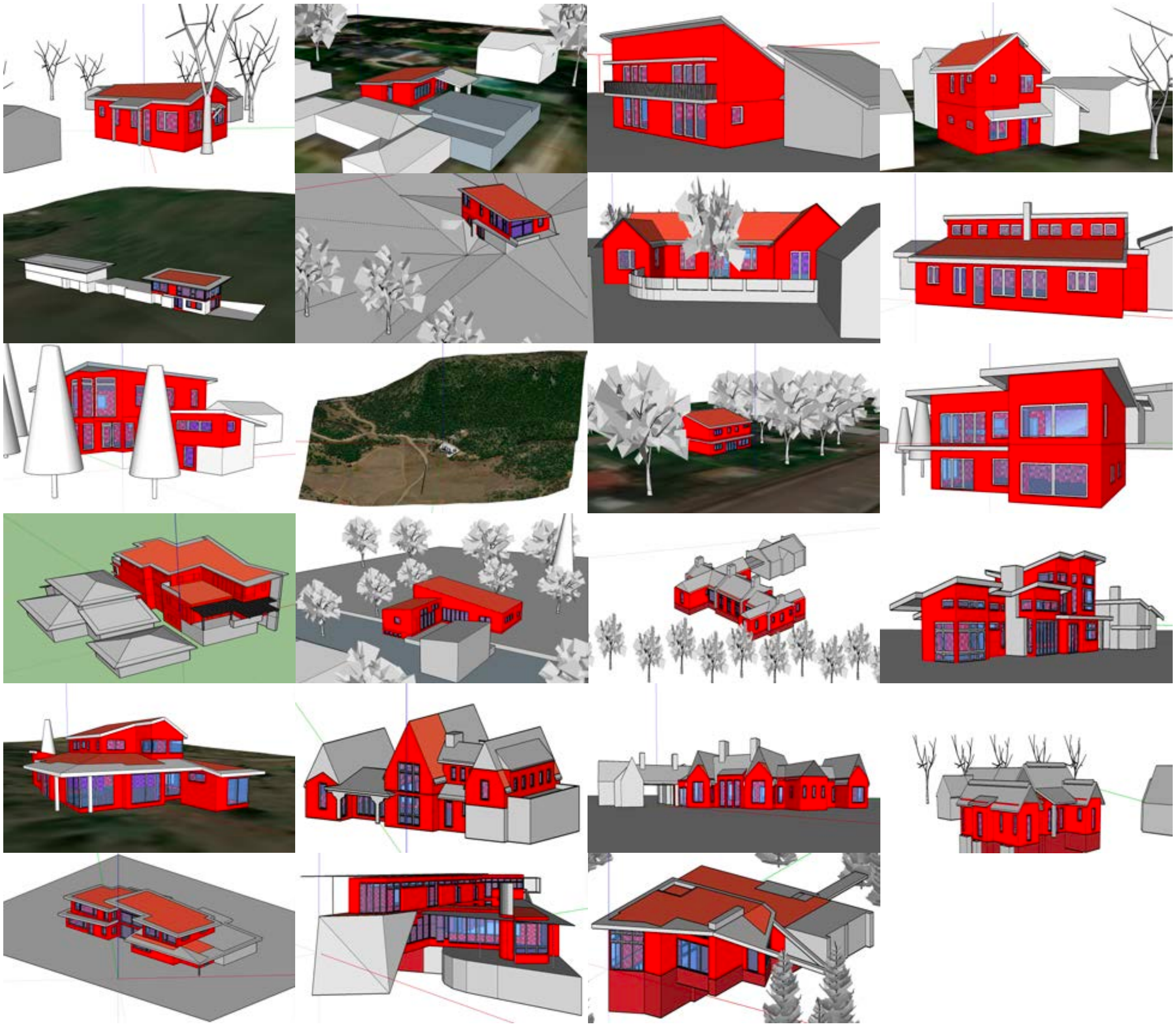

Image B.02: Some of the 50 projects, as modeled in DesignPH before being exported to PHPP for finer analysis. These are real projects, each with its own peculiar conditions, design, and constraints. The number of projects included should be sufficient to dilute outstanding aspects of individual buildings that could distort the results.

Of the 50 projects in the Report, this Appendix summarizes the details and results for the 11 projects located in California. Image B.03 shows the

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

distribution of projects across climate zones defined by Title 24. Image B.04 shows the project locations on a satellite map of California.

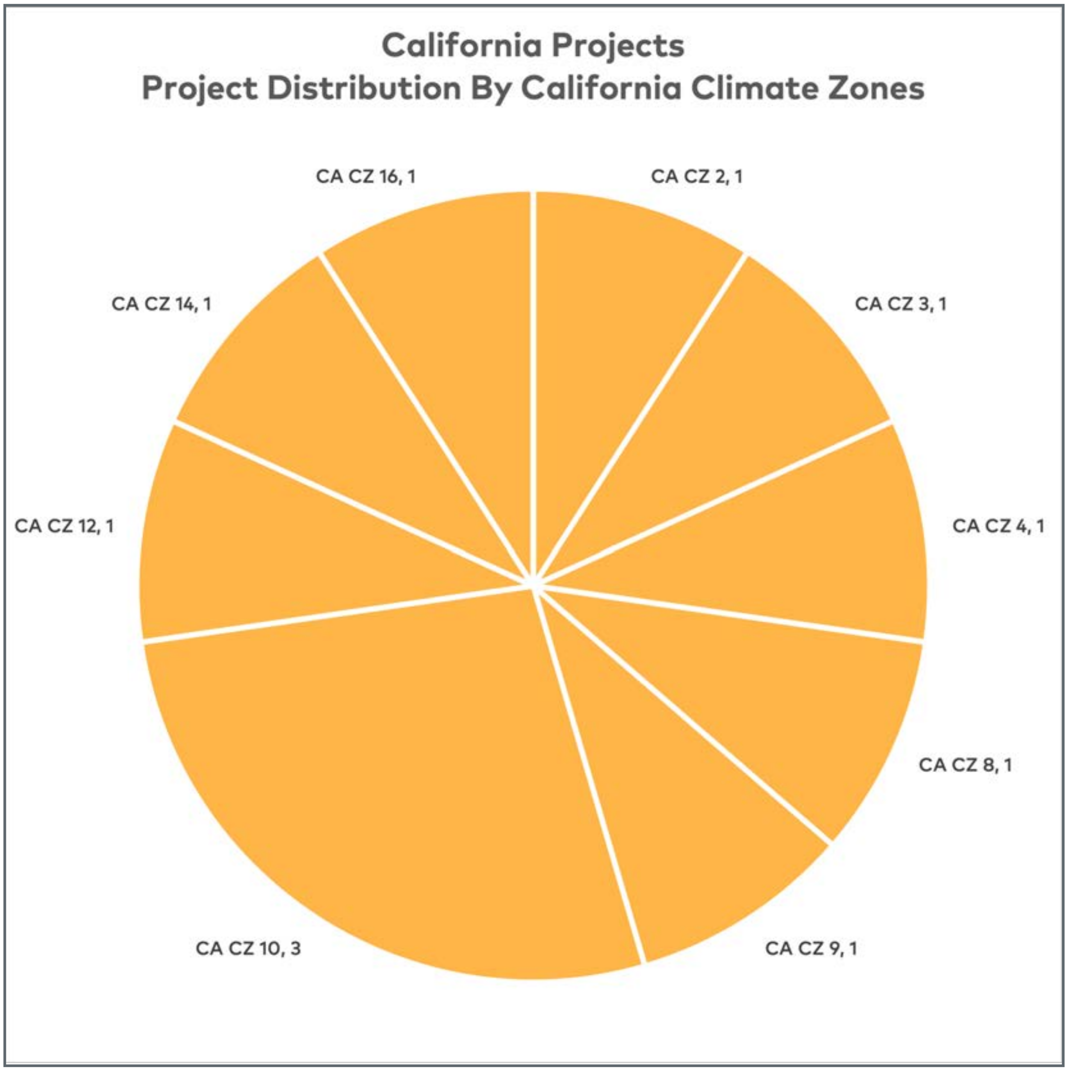

Image B.03: Distribution of the 11 projects across California climate zones as defined by Title 24.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

These project differ in size, shape, orientation, and other details, as they are real life projects. Please refer to the Report for metrics such as treated floor area, form factor, etc..

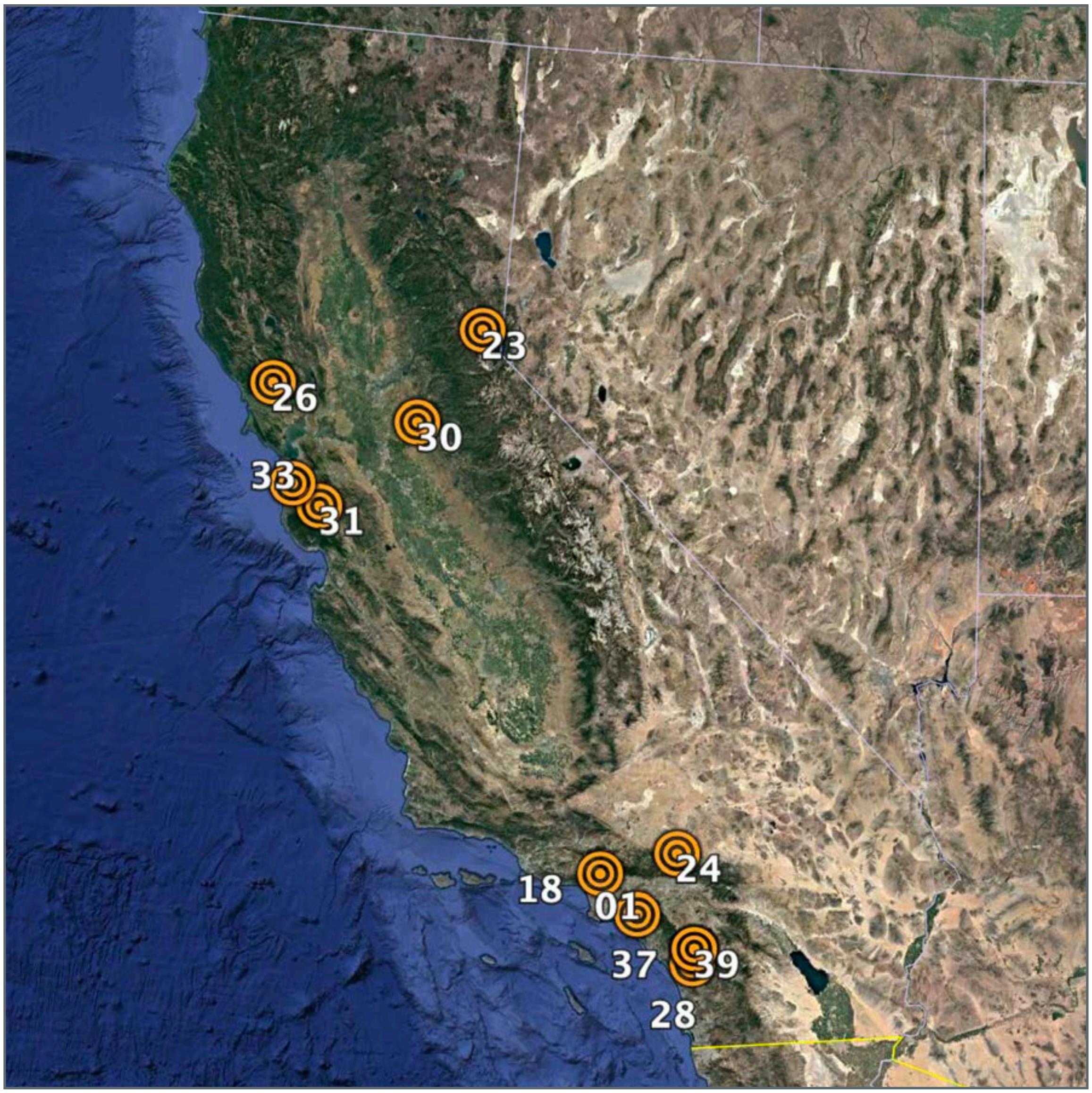

Image B.04: Location of the 11 California projects referred to in this Appendix.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Comparison Method

All projects were modeled in DesignPH and PHPP, according to the prescriptive or performance-based requirements of each building standard considered. For California Title 24, the latest version was used for this research (CEC-400-2022-010-CMF). [More details listed in the Report].

The main assumptions that were used in the models are listed below, with associated comments were applicable.

Assumptions:

1. all buildings to be all-electric
2. all buildings to have active heating and cooling via HP
3. domestic hot water delivered by HPWH
4. interior temperatures: 70˚F heating, 74˚F cooling
5. all buildings to have continuous fresh air ventilation
6. all standards modeled to the minimum allowed performance level
7. effective R-values were modeled per ISO6946 to account for recurring thermal bridging
8. effect of non-recurring thermal briding was not accounted for
9. unless otherwise specified, all prescriptive standards were modeled with low gains glass (SHGC)
10. interior shading was assumed for all openings (per PHPP typ. operation)

Comments To The Assumptions:

1. no comments
2. generous assumption for IECC standards
3. no comments
4. more representative of preferred temperature ranges for US homes than standard PHI and PHIUS modeling conditions (68˚F/77˚F)
5. generous assumption for IECC standards for IAQ, more restrictive for heating/cooling efficiency
6. no comments
7. no comments
8. generous assumption for IECC, California T-24, EnergyStar, DOE ZERH, PGH standards
9. based on Emu's experience working on projects in the American market
10. no comments

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Thermal Comfort

Image B.05 shows the performance of the 11 projects with regards to thermal comfort, and requirements around windows and exterior doors defined by Title 24, Phius, and PHI building standards.

Thanks to California's mild climate, most combinations of project and building standard don't land too far from the target reference threshold temperature. In all locations, PHI outperforms both Phius and the latest Title 24. For about half the projects, Phius underperforms Title 24 for thermal comfort.

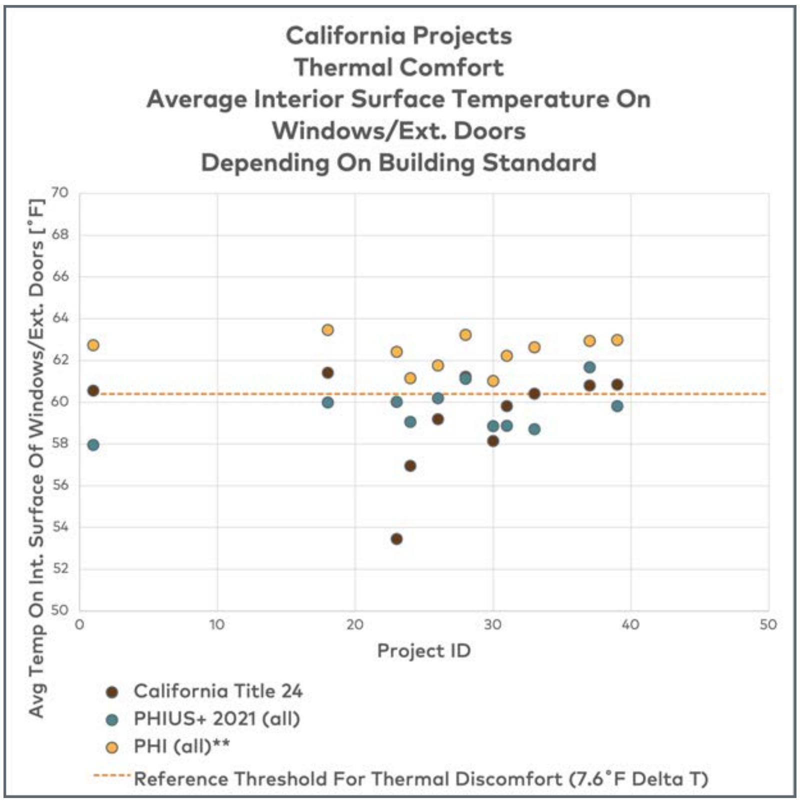

Image B.05: Thermal comfort evaluation for the 11 California projects, depending on which building standard is used.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Indoor Air Quality

Image B.06 shows the performance of the 50 projects of the entire report, with regards to indoor air quality, with regards to airflow rates and CO2 concentration (per EN13779). Because the climate does not have a significant impact on the airflow rates that a building standard prescribes, the 11 California projects were not singled out for this Appendix.

In average, PHI's requirements result in the highest air flow rates per occupant across the projects considered. Title 24 ranks second, and Phius comes in third. All three building standard rank "high" in the air quality grade of EN 13779 for CO2 concentration. [More details in the Report].

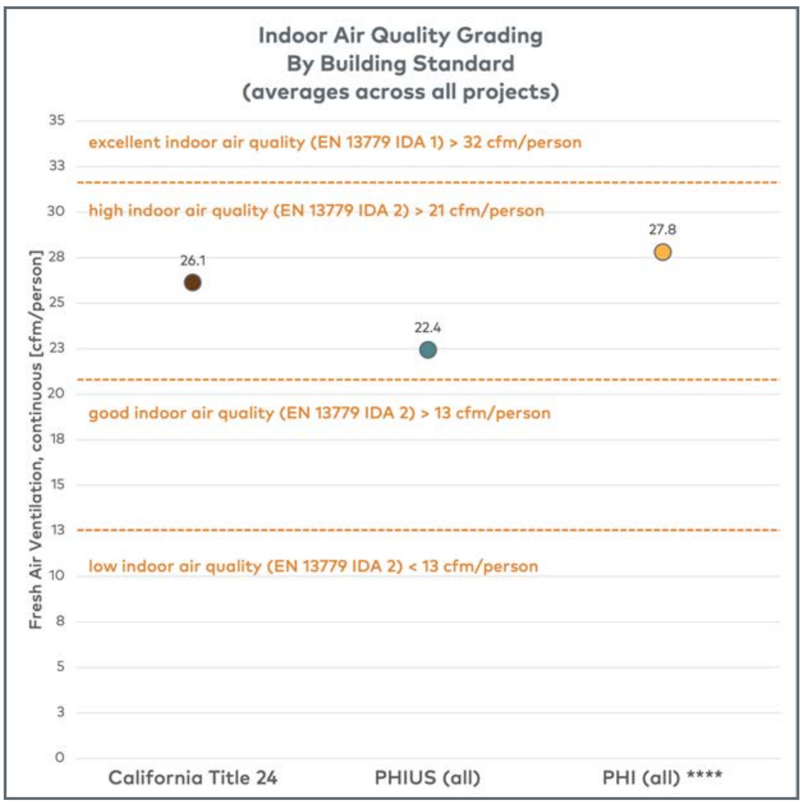

Image B.06: Indoor air quality evaluation for the 50 projects included in the whole Report, based on air flow rates per occupant (per EN 13779).

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Heating + Cooling

Images B.07a and B.07b show the site energy for heating (left hand side graph) and cooling (right), for the latest Title 24 and PHI Passive House.

The site energy was calculated assuming an air-sourced heat pump to provide heating and cooling, using some minimum requirements listed in the latest Title 24 (shown in Image B.08).

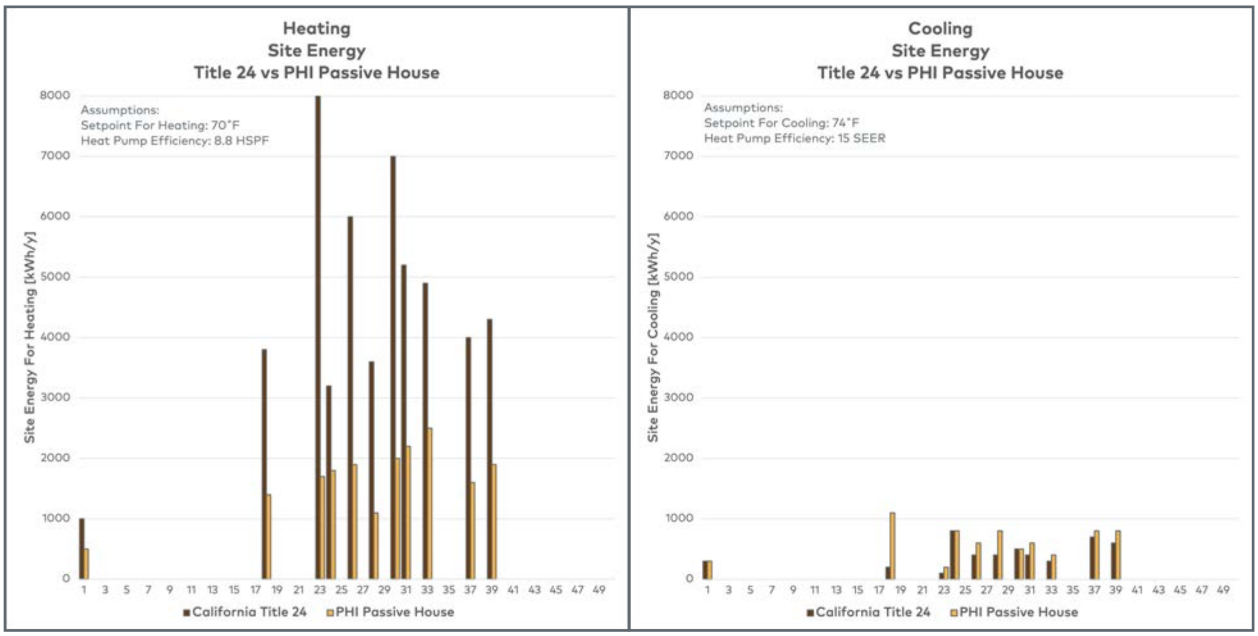

Image B.07a and B.07b: Site energy for heating (left hand side graph) and cooling (right hand side graph), for the 11 California projects modeled to meet Title 24 (brown columns), and PHI Passive House (golden columns).

Images B.07a and B.07b have the same scale. Even in the mild climate zones of California, heating has a significant weight on the overall site energy demand of the building. That is also in part caused by the fact that heat pumps are more efficient in providing cooling, than they are in providing heating. That is evident in Image B.08, which shows a higher efficiency for cooling (SEER) than for heating (HSPF). That is common in heat pump systems. The consequence is that heat pumps swing the needle in favor of cooling, meaning that we need to tackle heating reduction via the building envelope.

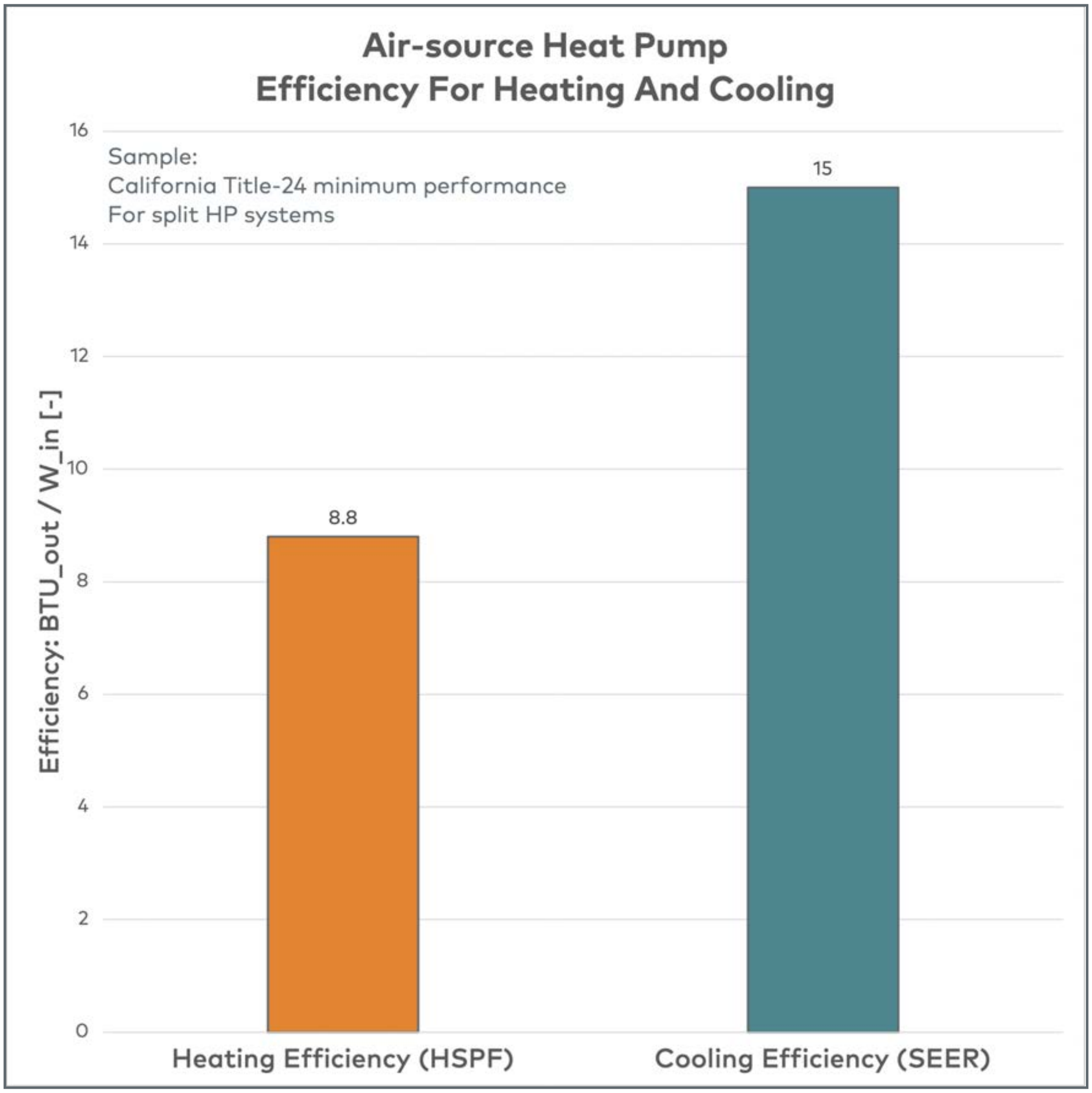

Image B.08: Minimum performance requirements for the air-source heat pump (derived from Title 24), used to calculate the site energy for heating and cooling.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Furthermore, most cooling occurs during the day, at a time when renewable energy systems (e.g. PVs) are likely to generate renewable electricity. Heating on the other hand occurs by a large extent at night, at a time where renewable systems are not generating renewables energy.

In other words even in California, reducing the need for active heating reduces the need to store energy, whether in form of electric batteries of buffer tanks.

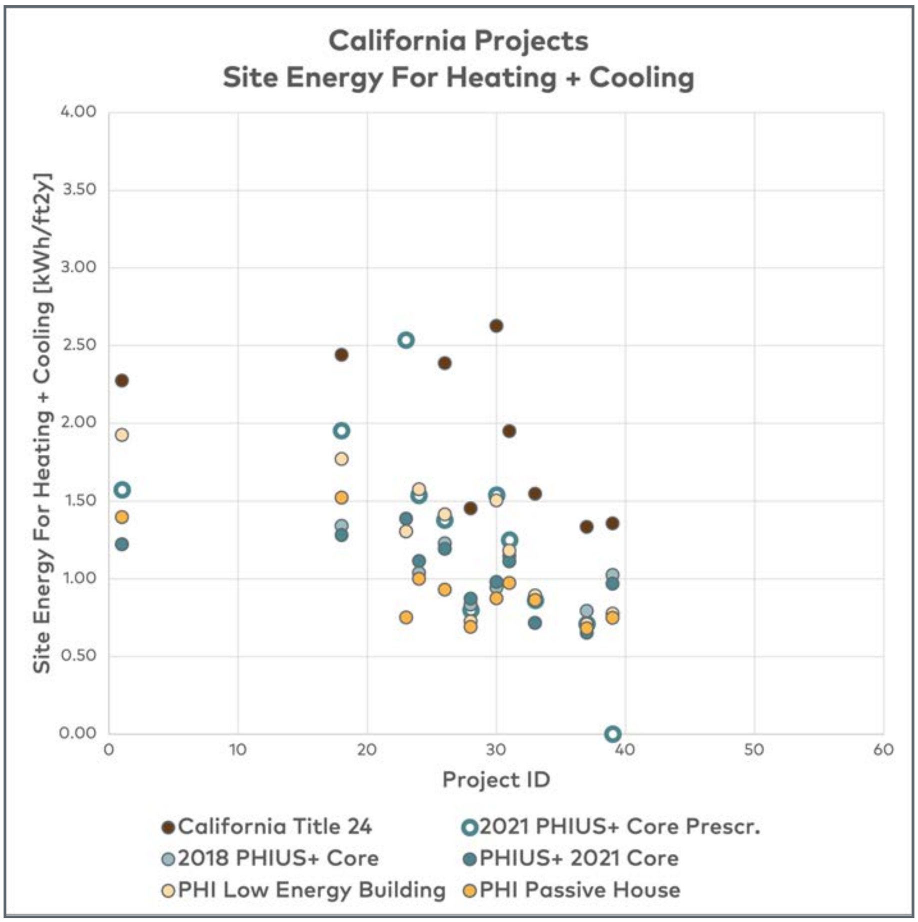

Image B.09: Minimum performance requirements for the air-source heat pump (derived from Title 24), used to calculate the site energy for heating and cooling.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Image B.10 shows the results for heating + cooling site energy for the 11 California projects, depending on the building standard used. In most cases PHI outperforms all Phius standards, while always outperforming the latest Title 24.

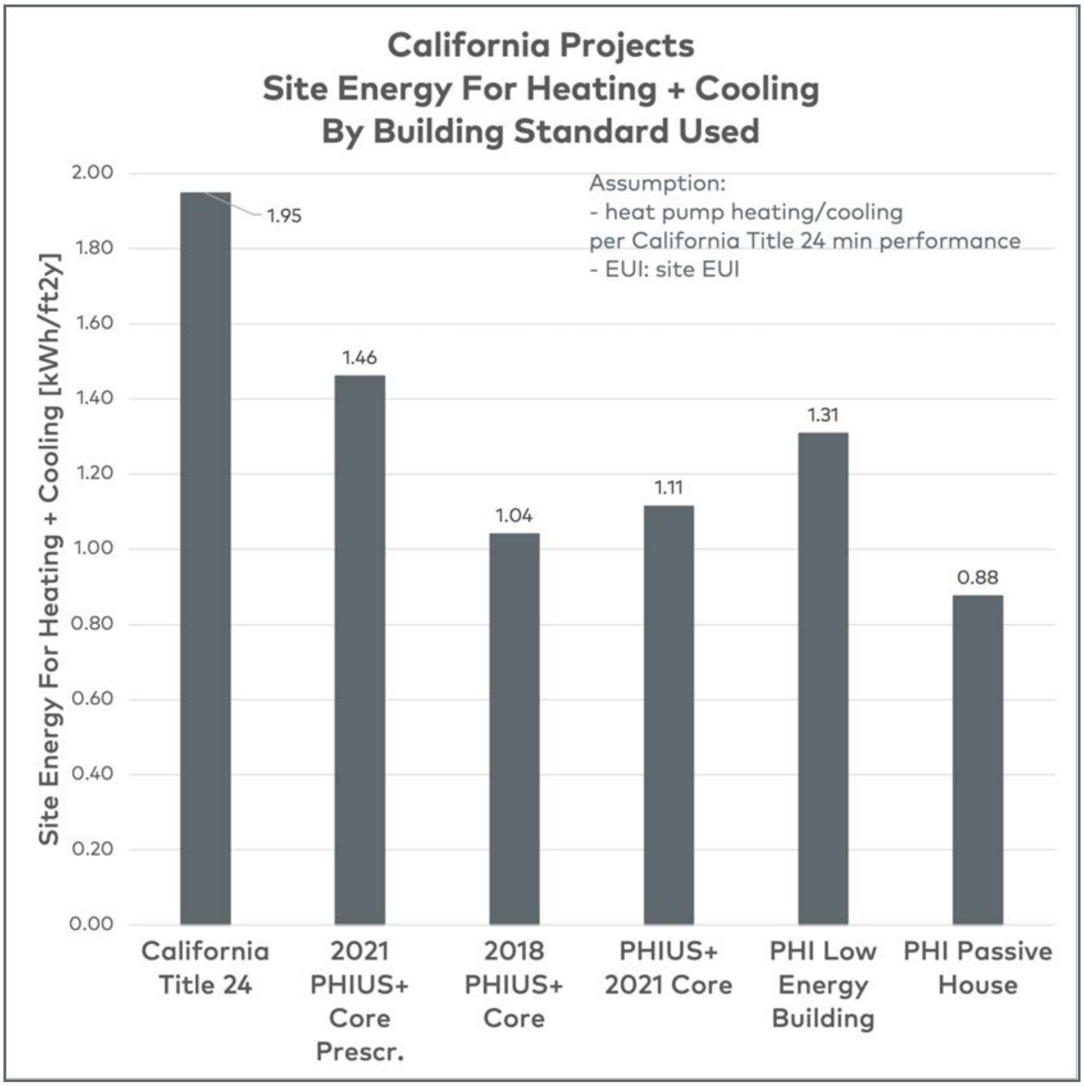

Image B.10: Median site energy for heating and cooling for the 11 California projects included in this Appendix.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

The median values for combined site energy for heating and cooling are shown in Image B.10. PHI Passive House outperforms all other building standards, followed by the 2018 Phius+ Core standard.

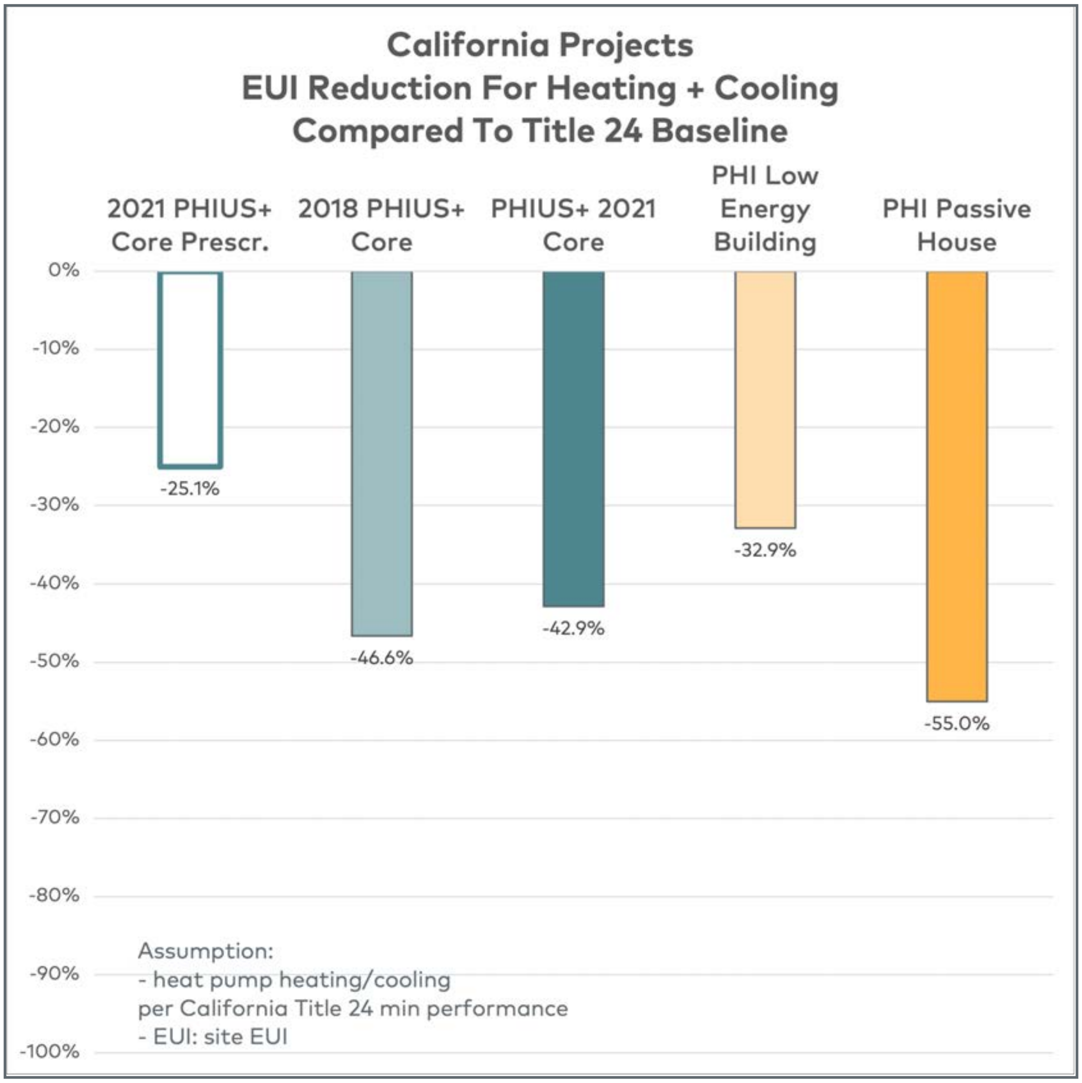

Image B.11: Median reduction of site energy for heating and cooling for the 11 California projects in this Appendix, depending on the building standard considered.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Image B.11 shows the reduction of site energy for heating and cooling for the 11 California projects included in this Appendix, assuming an air-source heat pump used for both services (i.e. heating, and cooling).

The energy use intensity (EUI) for the building standards considered is shown in Image B.12, with a breakdown by energy use. Charging one electric vehicle (EV) per home was included in the EUI, in order to give a reference for when EVs are going to be more widely adopted.

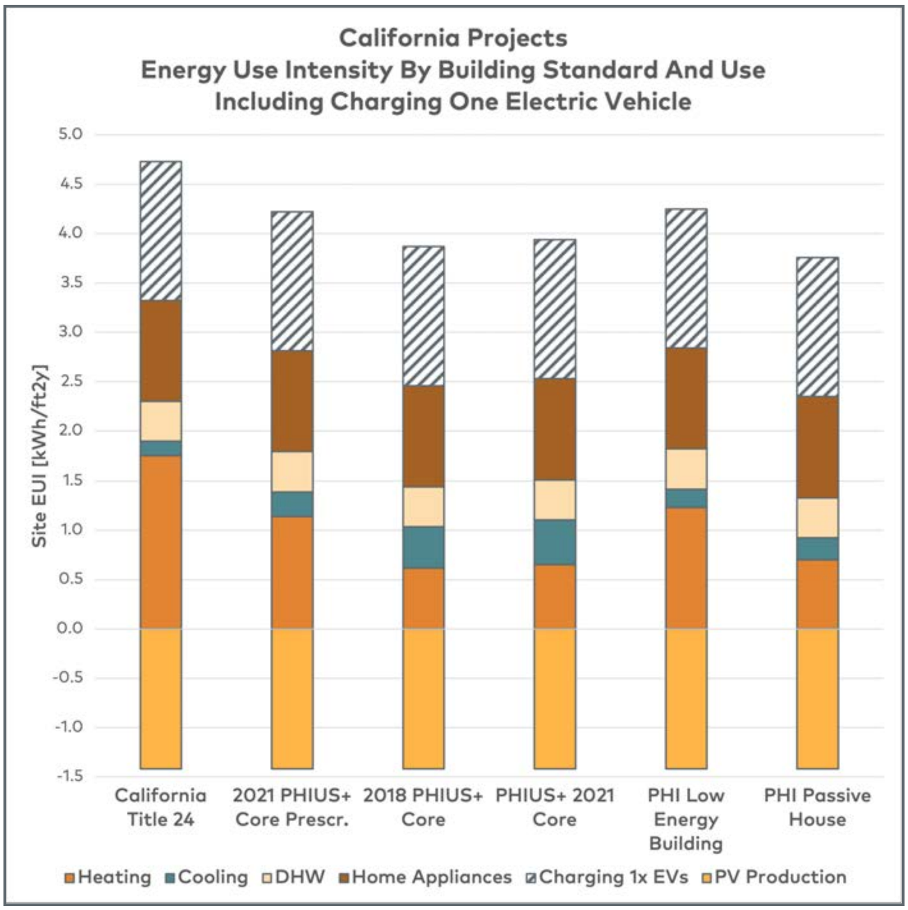

Image B.12: Median energy use intensity (EUI) for the 11 California projects, broken down by energy use.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

From Image B.12, the items worth pointing out are:

- because heat pumps are typically more efficient in providing cooling than heating (see Image B.08), heating exceeds cooling in terms of EUI for all standards considered
- PHI Passive House outperforms all other building standards in terms of energy efficiency. The second most efficiency building standard is the 2018 Phius+ Core standard.
- the reduction of heating and cooling thanks to Passive strategies compared to Code-minimum construction frees up energy capacity to be used to charge EVs. Unlike colder climate zones however, this is more limited in California due to the fact that the milder climate is not that demanding in the first place.

Image B.13 shows the average energy use intensity across the 11 California projects, once the energy produced by the PV systems is subtracted from the total.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

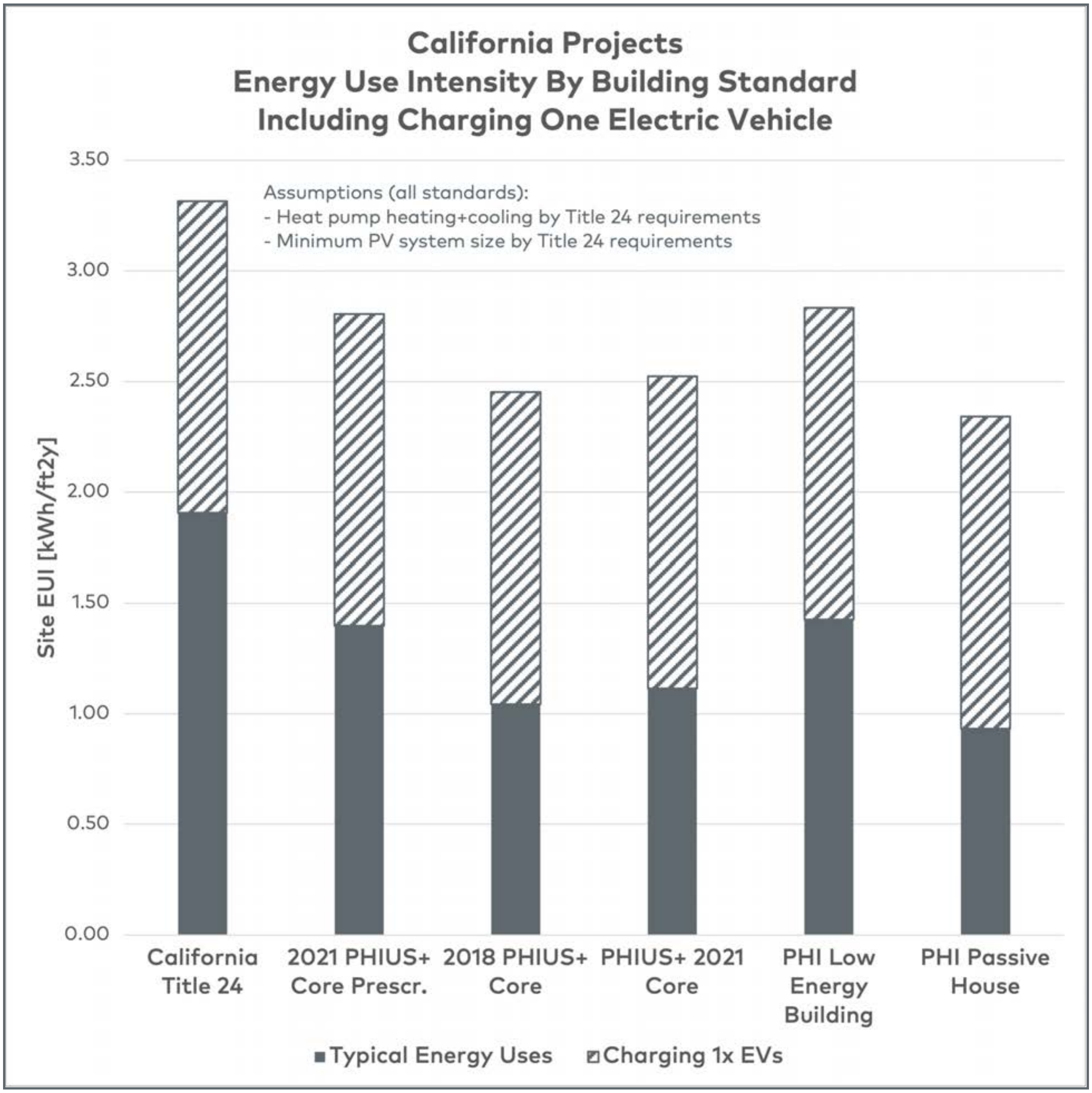

Image B.13: Median energy use intensity for the 11 California projects. These are the same results listed in B.12, once the energy generated by the PV systems are subtracted from the totals.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Other Differences

The research carried out for the Report allowed to identify other key differences among the building standards considered. Among these, the most significant are listed in Table B.01.

Metric	Building Standard				
	California Title 24	2021 PHIUS+ Core Prescr.	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
Maximum Air Leakage, Volume-related (ACH50)	NR	0.9	1.1	1.0	0.6
Maximum Air Leakage, Surface-related (q50)	NR	0.040	0.060	0.055	0.035
Fresh Air System: Minimum Filtration Grade	MERV13	MERV8	MERV8	MERV13	MERV13
Fresh Air System: Maximum Fan Consumption (W/cfm)	1	0.833	0.833	0.757	0.757

Table B.01: More significant differences found between the standards covered in this Appendix.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Minimum Air Filtration Required By Standard				
Building Standard	Minimum Filtration Required	MERV Minimum Required Filtration Grade		
		µm (micron)		
		0.3-1.0	1.0-3.0	3.0-10.0
2018 IRC / IECC	NR	-	-	-
2021 IRC / IECC	NR	-	-	-
2024 IRC / IECC	NR	-	-	-
California Title 24	MERV13	≥ 50%	≥ 85%	≥ 90%
EnergyStar 3.2	MERV6	-	-	≥ 35%
DOE ZERH v2	MERV8	-	≥ 20	≥ 70%
Pretty Good House	NR	-	-	-
2015 PHIUS+	MERV8	-	≥ 20	≥ 70%
2018 PHIUS+ Core	MERV8	-	≥ 20	≥ 70%
2021 PHIUS+ Core Prescr.	MERV8	-	≥ 20	≥ 70%
PHIUS+ 2021 Core	MERV8	-	≥ 20	≥ 70%
PHI Low Energy Building	MERV13	≥ 50%	≥ 85%	≥ 90%
PHI Passive House	MERV13	≥ 50%	≥ 85%	≥ 90%

Table B.02: Filtration grade required by building standard, and the associated ability of filters to remove pollution particles by size (from ASHRAE 52.2).

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

The differences listed in Table B.01 are particularly significant in California, because:

- one of the main concerns for buildings in California is indoor air quality, specially in polluted areas, or in presence of wildfire smoke
- case studies show that the combination of an airtight building envelope, and continuous supply of filtered fresh air, is a winning strategy to ensure high indoor air quality (see Monrore, C., in the Report references)
- the latest California Title 24 addresses fresh air supply and filtration (MERV13), but fails at protecting building occupants from pollutants entering buildings via air leaks (current T24 does not provide any limits to how air leaky buildings may be)
- among the standards considered, PHI provides the highest level of protection as combination of air tightness (0.6 ACH50), fresh air supply, and filtration (MERV13)
- Phius falls in between PHI and T24, with a higher allowance for air leaks (1.1 ACH50 for the performance-based standard), and lower requirements for air filtration even compared to Title 24 (MERV8).

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

CONCLUSIONS

This Appendix summarizes the results for the 11 projects of the Report that are located in California.

While results for individual projects may vary, the pool of projects allows to draw some conclusions on the impact of adopting one building standard over another, and evaluate the benefits for building occupants.

Thermal Comfort

While California climate conditions are fairly mild, the choice of window and door performance still impacts occupant comfort. In this regards, PHI outperforms both the latest Title 24 and Phius. In about half the number of projects, Title-24 outperforms Phius, as Phius requirements (window U-values) were found to be less stringent than Title 24 requirements. [More on thermal comfort in the Report[.

Indoor Air Quality

Air quality ranks high on the priority list in California. In terms of air flow requirements per occupant, filtration grade, and air tightness of the building envelope, PHI outperforms both the latest Title 24 and Phius. Phius outperforms Title 24 in terms of air tightness - 1.1 ACH50 in average for Phius, as opposed to no ACH50 requirements for Title 24. Title 24 outperforms Phius both in terms of air flow rate requirements per occupant, as well as for air filtration grade. [More on indoor air quality in the Report].

A key difference in delivering indoor air quality is the assumptions made for number of occupants. Title 24 follows ASHRAE 62.2 (occupants = # bedrooms +1), Phius considers fewer occupants (occupants = # bedrooms), while PHI determines air flow needs based on a combination of occupancy, extraction, and volume. The resulting air flow rates per occupant are listed in Image B.06.

Durability + Resilience

The Report addresses the matter of durability and resilience in detail. In terms of the air sealing strategy being a major component of durability and resilience, PHI outperforms both Phius and the latest Title 24. Phius outperforms Title 24.

Priorities: Heating vs Cooling

Even in a mild climate like California, heating should not be overlooked or downplayed. Images B.07a and B.07b show the total site energy demand results for the 11 California projects for heating and cooling. These account for heating and cooling being provided by air-sourced heat pumps, which typically perform much better in providing cooling than heating - up to twice as efficient for cooling (or more) than for heating (see Image B.08).

In addition to that, the need for cooling typically occurs at a time (daytime) when renewable energy systems are generating renewable energy (e.g. PV systems). This means that site-produce energy can be used instantly, with no need for storage equipment (and the associated energy losses).

On the other hand, heating often occurs at a time when renewable energy sources are not available (e.g. at night). In order to use renewable energy for heating, storage systems are needed such as electric batteries. To reduce the need for heating leads to reducing the need of batteries and other forms of energy storage.

Once these considerations are taken into account, it's easy to understand how Passive building strategies to reduce the need for heating are a key factor for successful climate strategies even for mild climate zones like California.

Operational Energy Efficiency

Passive building strategies provided by implementing PHI or Phius standards allow to reduce the energy needed to operate buildings.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU

Over the 11 California projects considered in this Appendix, PHI Passive House outperforms all other building standards considered. In terms of operational energy reduction, 2018 Phius+ Core ranks second.

In terms of heating and cooling, adopting PHI Passive House for the building envelope allows a reduction of over 50% site energy compared to the latest Title 24, assuming using the same Code-minimum heat pump.

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
www.emupassive.com
US +1 (833) WILD EMU