REPORT

Building Standards

Investigating the ability of 12 building standards to deliver resilient, healthy, and efficient buildings.

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

This 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.

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

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

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Fort Collins, CO, USA 80524
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US +1 (833) WILD EMU

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Fort Collins, CO, USA 80524
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Watch This On YouTube

A walk-through of this paper is covered in a series of topic-specific videos on Emu Passive's YouTube Channel.

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Fort Collins, CO, USA 80524
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WHY THIS MATTERS

The American economy has started its journey on the path of electrification. This is true for the auto industry, with electric vehicles on the rise. This is also true for the construction industry. PV panels are now commonly installed in million of buildings, and heat pumps and electric batteries are the next step in the process.

Electrification is great in many ways. It streamlines the adoption of renewables, and the Biden administration has set the goal to cover 80% of demand with renewables by 2030 [3]. By the same date, the goal is for one in every three cars sold to be electric, and for residential heat pump sales to quadruple.

Electrification also poses some serious challenges. With multiple industries converging to one energy vector, it's only natural to expect the price of electricity to increase. As we put all our eggs in the basket of electricity, we expose our economy to a greater risk of failure. Furthermore, we are a whole generation away (at least) from covering 100% of the energy demand with renewables [96].

In building better buildings, electrification helps mitigating the environmental impact our buildings, but it won't necessarily make buildings better for people.

Why did we (Mankind) invent buildings in the first place?

A building's job it to protect people, to provide comfortable, healthy shelters. If buildings fail at that, it won't matter if they are all-electric, Net Zero, or have low embodied carbon. No PV panel has ever solved a mold problem, ever. Furthermore, if buildings are energy inefficient, they depend on energy supply to maintain livable conditions. With a more loaded energy grid, this expose people to the risk of more likely and dramatic shelter failures and unlivable conditions.

This Report covers how current building codes fail at delivering resilient and healthy buildings. It also covers how Passive building standards today provide a verified alternative path to delivering dependable and efficient shelters.

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Fort Collins, CO, USA 80524
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US +1 (833) WILD EMU

SUMMARY

This research investigates the ability of twelve building standards to deliver resilient, healthy, and efficient buildings.

In order to have statistical relevance, 50 projects were selected from Emu's consulting practice as the basis for the research. To ensure consistency in the project pool, the projects selected were single family, new construction projects. Also, to ensure that the results would be representative of different climate zones of the US, 1/4 of projects were selected from Hot / Warm climate zones, 1/2 from Mild climate zones, and 1/4 from Cold climate zones.

The research was developed by determining the minimum compliance requirements for each of the twelve building standards considered, and to model each project to those requirements in the Passive House energy modeling software (PHPP). This report assumes all buildings are all-electric, using heat pumps for heating, cooling, and domestic hot water.

The research investigates how these building standards address a number of challenges that buildings face in delivering a healthy, resilient shelter to people, including among others:

- Thermal Comfort
- Indoor Air Quality
- Avoidance Of Mold/Condensation
- Durability
- Thermal Resilience
- Operational Energy Efficiency
- Performance Gap
- Reduction Of Embodied Carbon
- Resource Efficiency
- Future Proofing

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The research investigates the building standards, and how they address each of these challenges. Depending on individual metrics, quantitative and/or qualitative evaluations were provided for each standard and topic.

As different metrics don't lend themselves to being combined (e.g. one cannot add a % reduction in energy consumption, to a more stringent fresh air filtration requirement), a scoring system was developed to simplify the communication of the results to a broader audience.

With regards to mainstream building codes (IECC, California Title 24, EnergyStar, DOE ZERH), the following takeaways emerged from the research:

- Current building codes (IECC, California Title 24) fail in delivering healthy, comfortable, and resilient buildings
- The evolution of said building codes (2024 IECC draft) seems to indicate those values are not on the agenda for current code developments
- Mainstream "high performance" building standards (EnergyStar, DOE ZERH) also fail at delivering buildings that are substantially better than code-minimum for the health of their occupants.
- Compared to code-minimum requirements (in this paper, prescriptive 2018 IECC), improvements on the building energy performance are achieved by implementing heat pumps for heating and cooling (EnergyStar, DOE ZERH), and/or PV systems (California Title 24). Neither strategies prioritize core values of buildings (i.e. indoor air quality, comfort, resilience).

Such failures in delivering healthy, comfortable buildings impact people's quality of life for a long time. Contrary to popular belief, an American family stays in a house for 13 years on average before they move out again [59, 98].

The research investigated a number of "Passive" building standards available in the American market, curated by the International Passive House Institute (PHI) and Phius. From investigating these Passive standards, the takeaways include:

- Compared to code-minimum built buildings (2018 IECC), Passive building standards greatly reduce the need for active heating and cooling. In terms of site energy demand, the best performer is PHI Passive House (70.6% reduction), followed by 2018 Phius+ Core (57.8%), PHI Low Energy Building (56.6%), and 2021 Phius+ Core (55.7%).
- In terms of energy use intensity (EUI) reduction compared to the 2018 IECC, PHI Passive House is also the best performer. Results for the California Title 24 standard appear good, but that's thanks to 1) the fact that California climate conditions cause less need for heating and cooling in the first place, and 2) Title 24 mandates energy compensations through PV systems. If that were not the case, Title 24 would perform fairly similarly to the 2021 IECC.
- In the context of market electrification, the greater energy efficiency of Passive buildings should not be disregarded. The results of this research show that with the same EUI of a 2018 IECC-built home, on average it's possible to power a Passive home (PHI Passive House), and charge two electric vehicles with little or no increase in demand for the grid.

With regards to building quality metrics, the takeaways from comparing Passive building standards are listed below (based on the scoring system):

- PHI's Comfort Criterion and air tightness requirements deliver the greatest level of thermal comfort of all standards investigated. Among Phius' standards, the 2021 Phius+ Core Prescriptive achieves a greater level of comfort thanks to the more stringent air tightness requirements compared to Phius' performance-based standards.
- In terms of indoor air quality, PHI Passive House has the most stringent requirements for building air tightness, fresh air filtration, mold avoidance, and requires higher fresh air flow rates compared to any other standards considered. 2021 Phius+ Core Prescriptive delivers the second highest performance due to the adoption of the EPA indoorAir Plus requirements, and the more stringent air tightness requirements compared to the performance-based Phius standards.

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- For durability and resilience, PHI Passive House ranks first, followed by PHI Low Energy Building.

In this context, probably one of the greatest challenges the American construction industry faces is to start setting specific goals to how a building performs. That is, instead of setting prescriptive requirements for individual building components.

A common perception is that the energy modeling may be an unnecessary expense for projects.

On the contrary, the findings from this research (see "Resource Efficiency") prove how the energy analysis can pay for itself. Performance based approaches can avoid hundreds of cubic feet of unnecessary insulation compared to prescriptive approaches that aim for the same level of energy performance.

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INTRODUCTION

"Voluntary Prisoners Of Architecture"

As graduation thesis work for my first Master's degree, I investigated the state of architecture theory, critics, and sustainability in Italy at the time (2005-06).

In doing that, I came across the concept of "Voluntary Prisoners Of Architecture", expressed by Rem Koolhaas in his book S, M, L, XL. At the time, I was graduating from architecture school, and had received zero training in thermal comfort, indoor air quality, and health risks associated with buildings. Koolhaas' book did not address any of those either, but the concept resonated with me.

Several sources show how in Western countries, people spend over 90% of their time indoors, meaning the quality of the buildings that they occupy has a great impact on their health and wellbeing.

Among the findings from my thesis research project was the disconnect between what was considered to be an award-winning design, and how good or bad that building actually was for its occupants. That was almost 20 years ago, well before Covid, and before indoor air quality, comfort, and other parameters became more popular in architects' and designers' circles.

One can only hope that things are better now. To test that, please answer the following question:

On average, how long do you think an American family stays in a home, before they move out again?

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We ask this question to hundreds of American builders, architects, and other professionals at the beginning of our Passive House training. If your answer was 5-7 years, your answers falls within the average of what we hear.

In reality, American families spend over 13 years on average in one home [59, 98]. This means that for an average of 13 years, you and your family commit to be voluntary prisoners of whatever conditions exist in your home. With the current conditions in the construction industry (inflation, high interest rates, etc.), that is likely to increase.

This also means that most professionals are disconnected from the reality of the market they operate in. If you're advising clients and base your recommendations on a 5-year time span instead of 13 or more, you're failing at doing your job well.
As professionals, we have the responsibility of determining what prisons our clients will "do time" in. In these terms, any design award that does not prioritize health and comfort among the evaluation criteria can become a shallow exercise in vanity.

Beautiful buildings are loved and therefore can last longer (which makes good design a key component of sustainability), but the first job of a building is to provide a healthy shelter that protects its occupants. That is why we (Mankind) invented buildings in the first place.

Building standards are created to provide guidelines and enforceable metrics to the design and construction of buildings. In doing so, they allow the establishment of minimum requirements for all buildings, as well as of goals for buildings to go above and beyond minimum building performance practices.

The intent of this paper is to investigate building standards that are common in the US, and to verify their ability to deliver on not only energy efficiency, but also (and more importantly) on metrics that make buildings good for their occupants (i.e. indoor air quality, thermal comfort, etc.).

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The paper also compares these standards to one another, and provides the results to the public so that informed decisions can be made for adoption on a project-specific basis, or by municipality or state.

Image 01 - Rem Koolhaas, "Voluntary Prisoners Of Architecture"

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About Emu Passive

Emu was originally founded in 2009 in Italy as an architecture practice (Emu Architetti). We found Passive House building science to be the handrail to direct our decisions as architects, from concept design to construction details.

After a number of years of practicing as Passive House architects, we asked ourselves:

"Are we having enough of an impact?"

At the time, we were designing a few Passive House projects a year, and the answer we gave to that question was "No".

We found education to have a greater, longer lasting impact than working on individual buildings, so we re-wrote our mission to be:

To close the gap between mainstream construction practices and advanced, proven building science, and to empower our industry to build for the future and for resiliency through builder training and simple, standard, Passive systems.

At about the same time (2016-17), we moved Emu from Italy to Colorado, and we became accredited Passive House education providers.

Today, Emu trains more builders in hands-on construction techniques for Passive standards than any other workforce training provider in the US.

Emu's vision is to make research-based Passive design/build as <u>the</u> industry standard for mainstream construction.

This paper is part of that vision.

About This Paper

This paper was not indented to be extensive, initially. Actually, this was intended to be a short Instagram post to be published in the Summer of 2021, comparing the volume-related air leakage requirement of PHI, to the surface area-related requirement of Phius. Then, comparing project-specific heating and cooling requirements sounded like and interesting topic to be added. So, too, did thermal comfort requirements. And how about adding indoor air quality?

Two and a half years later, this paper compares key metrics across a dozen building standards used in the US. The intent is to allow building owners, project teams, and policy makers to compare building standards as apples to apples, and make informed decisions.

About The Author

Enrico Bonilauri holds two Masters Degrees — one in Architecture from the University of Parma, Italy, and one in Sustainable Design from the University of Sydney, Australia. As a registered Italian Architect and Certified Passive House Trainer, Designer, and PHI Certifier, he has worked in Australia, Europe, and North America. He specializes in building envelope analysis, informed by the thousands of hours spent on construction sites. Speaker experience includes conferences in Germany, Austria, China, US, Canada, Spain, Australia, and New Zealand. He's the Co-Founder of Emu and has been the scientific curator of their Passive House training curriculum, teaching American builders since 2017.

BUILDING SCIENCE BACKGROUND

Glossary

We see a lot of confusion on the market with regards to language, definitions, and goals. We felt it was necessary to provide a basic glossary, in the hope this would help navigating this paper.

Cooling + Dehumidification Demand (CD)

The amount of energy consumed by the building over a typical year, for the purpose of cooling and dehumidification (as applicable). It directly contributes to the total energy to be offset for goals e.g. Net Zero.

Cooling Load (CL)

The peak of sensible and latent cooling that the cooling system of the building is required to provide for the building to remain comfortable during the worst case design conditions in Summer. It does not directly contribute to the total energy to be offset for goals e.g. Net Zero.

Heating Demand (HD)

The amount of energy consumed by the building over a typical year, for the purpose of heating. It directly contributes to the total energy to be offset for goals e.g. Net Zero.

Heating Load (HL)

The amount peak of heating that the mechanical system of the building is required to provide for the building to remain comfortable during the worst case design conditions in Winter. It does not directly contribute to the total energy to be offset for goals e.g. Net Zero.

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Heating/Cooling Demand (net)

The amount of energy needed for heating/cooling of the building as a combination of climate, occupancy, architectural design, and quality of the building thermal envelope (incl. ventilation and air leaks). It refers to the efficiency of the building thermal envelope, i.e. it is net of any inefficiencies of the mechanical systems used to deliver the heating and cooling, and of the grid.

Site Heating/Cooling Demand

It corresponds to the net heating/cooling demand, once all inefficiencies of the heating and cooling systems are accounted for all the way up to the meter. It does not account for district grid inefficiencies - that is accounted for in the Source Energy (Primary Energy), which is not addressed in this study.

Net Zero Energy / Net Zero Carbon Building

The most common definition of Net Zero we can refer to is a building that over a typical year produces as much energy - or more - than it consumes [19].

A more recent definition of Net Zero Energy has extended the energy balance to include the energy used to charge electric vehicles on-site, for transportation off-site[14].

R-value

Thermal resistance provided by a building assembly to the transfer of heat from one side to the other. It is a misleading value, as it does not directly represent heat losses occurring through an assembly.

U-value

Also called 'thermal transmittance', it represents the heat losses occurring through an assembly (per degree of temperature difference between the two sides of the assembly).

U-value, uninstalled (U-factor, aka Uw)

For fenestration components, the U-value provided by the manufacturer, consisting of the heat losses occurring through the frame, glass, and glass edge of the fenestration product.

U-value, installed (Uw_inst)

For fenestration components, the U-value consisting of the heat losses occurring through the frame, glass, glass edge of the fenestration product, as well as the heat losses occurring at the interface between the fenestration product and the assembly it is installed in (e.g. for windows, the heat losses at the interface between the window frame and the wall). In

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Passive building standards, the Uw_inst value is used to calculate the surface temperature on the interior surfaces of windows and exterior doors, for the purpose of thermal comfort analysis.

SHGC - Solar Heat Gains Coefficient

Mostly used in the context of glazed components (e.g. windows), it represents the amount (as a percentage) of the solar radiation being let through the glass compared to the total radiation the glass is exposed to. In other words, it describes the total amount of passive solar gains that a glass surface lets into the building (in form of daylight, heat, and other radiation). In this report the SHGC refers to the center of glass SHGC.

Air Tightness

The degree of how tight the building is with regards to the unintentional flow of air through its thermal envelope, i.e. from the inside to the outside (and vice versa).

ACH50 - Air Changes Per Hour at 50 Pa (volume-related metric)

An air tightness testing protocol based on a volumetric calculation. Where a physical pressurization test of the building is carried out to measure the leakage rate, this rate is then divided by the net volume of the building.

q50 - Air Changes Per Surface Area at 50 Pa (surface area-related metric)

An air tightness testing protocol based on the surface area of a building. Where a physical pressurization test of the building is carried out to measure the leakage rate, this rate is then divided by the net total area of the building envelope (i.e. roof + walls + ext. floors + windows/doors etc.). The q50 is a surface-specific result.

Building Thermal Envelope

Assemblies (ext. floors, walls, roof), windows, doors etc. that enclosed the portion of the building that is conditioned, and separate if from other parts of the building that are unconditioned, as well as from the ground and the exterior ambient.

Prescriptive Method

A set of compliance requirements that apply to individual components of a building. That is, instead of mandating a specific minimum performance for the building as a whole. A typical case is compliance with minimum energy code requirements by means of meeting all the minimum R-values etc.. It may or may not require a whole building energy model, depending on the standard.

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Performance Method

An approach to compliance that requires achieving a certain degree of performance for the building as a whole. This is typically done with the support of a building energy model.

PHI EnerPHit Standard:

A Passive standard developed by PHI specifically for the retrofit of the existing buildings, including step-by-step remodeling. It includes a Performance Method as well as a Prescriptive Method. Because the projects covered in this paper are new buildings, EnerPHit is not addressed in this paper.

PHI Low Energy Building Standard

A Passive standard developed by PHI specifically for new builds that cannot achieve the full PHI Passive House standard, either due to climate, size/orientation, or other constraining conditions.

PHI Passive House

The main Passive building standard developed by PHI since the mid 1990s. It applies to residential as well as non-residential buildings (the term 'House' is sometimes source of misunderstanding). It can be applied to all construction types both for new build and retrofit projects.

PHPP - Passive House Planning Package

The building energy modeling software developed by PHI for the design of Passive buildings. It is used to calculate heating and cooling demand on the basis of ISO 13790, with the support of data collected from occupied Passive buildings over decades. It can be used to calculate loads as well, as it is validated according to ASHRAE Standard 140. All projects in this study were modeled using PHPP v9.6.

DesignPH

SketchUp plug-in developed by PHI to allow architects to execute preliminary Passive House calculations at early design stages. All projects covered in this study were first modeled in DesignPH for accurate calculation of exterior shading by means of ray tracing.

bim2PH

BIM plug-in for Revit, Archicad etc., developed by PHI to allow architects to execute preliminary Passive House calculations at early design stages.

Phius+ 2015, 2018, 2021

Building standards curated by Phius.

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WUFI: Wärme Und Feuchte Instationär

Software originally developed by the Fraunhofer Institut to determine the one-dimensional dynamic heat and moisture transfer through a building assembly, as an alternative to the dewpoint method. The software is now called WUFI Pro.

WUFI Passive:

Software developed by the Fraunhofer Institut to calculate the heating and cooling demand of buildings in compliance with ISO 13790. The software is validated for ASHRAE Standard 140 load calculation. WUFI Passive has been adopted by Phius as the building energy modeling software to be used in their certification program. To the extent of our knowledge, Phius used to use PHPP in the past, but that is no longer the case.

Abbreviations And Acronyms

BTU	British Thermal Unit
CD	Cooling Demand
CL	Cooling Load
DOE	Department Of Energy
EPA	Environmental Protection Agency
ERV	Enthalpy Recovery Ventilator (aka Energy Recovery Ventilator)
EUI	Energy Use Intensity
EV	Electric Vehicle
GFA	Gross Floor Area
HD	Heating Demand
HL	Heating Load
HP	Heat Pump
HRV	Heat Recovery Ventilator
HSPF	Heating Seasonal Performance Factor
ICC	International Code Council
IECC	International Energy Conservation Code
IRC	International Residential Code
PGH	Pretty Good House
PH	Passive House
PHI	International Passive House Institute
Phius	Passive House Institute US (PHIUS)
PHPP	Passive House Planning Package
PV	Photovoltaic System
SEER	Seasonal Energy Efficiency Ratio
TFA	Treated Floor Area
WUFI	Wärme Und Feuchte Instationär
ZERH	Zero Energy Ready Home

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COMPARISON METHOD

Comparison Goals

The goal of this research was to compare different building standards, and evaluate their ability to improve the quality of buildings.

Goal:

1. evaluate a range metrics for quality and sustainability
2. use actual projects modeled by Emu
3. keep project pool consistent
4. number of projects high enough to be statistically significant
5. locations to be representative of different climates of the US

Measures Taken:

1. thermal comfort, indoor air quality, durability+resilience, operational energy efficiency, embodied carbon
2. developed detailed analysis using designPH and PHPP software
3. single family homes, new construction
4. 50 individual projects were included in the research
5. almost all US climate zones are represented in this study

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Reference Projects

For this research, 50 projects from Emu's consulting portfolio were selected as the basis to compare different building standards. The number of projects selected was intended to be high enough 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.

In detail, the project selection criteria included:

- actual projects from Emu's consulting (*as opposed to abstract, sample buildings as what is used for reference in testing standards [12])
- single family home projects, new construction
- building sizes ranging from approx. 500 ft2 to approx. 6000 ft2 TFA
- 1/4 projects located in Warm Climate (ASHRAE Climate Zones 2-3)
- 1/2 projects located in Mild Climate (CZ 4-5)
- 1/4 projects located in Cold Climate (CZ 6-7)

Images 03 and 04 show the project distribution by state. Images 05 and 06 show the project distribution by ASHRAE climate zone [13]. and by Warm/Mild/Cold climate (this grouping was determined for the purposes of this research).

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The projects included in this research are actual projects, each with its own peculiarities, constraints, architectural design, form factor, actual owners, street addresses, and surrounding environments. Some of the 3D model views of the projects are shown in Image 07. Details for each projects are listed in Table A.01 in Appendix A, including among others TFA, form factor, building volume, etc..

The decision to use actual projects was driven by the aim for results to be as representative of real life conditions as possible. If taken individually, the peculiarities of each project may warp results in one way or another. However once taken collectively over a large number of projects, these peculiarities dissolve into larger conclusions and trends.

The alternative path would have been to model one or more reference buildings, similar to what is used used in research studies and software validation [12]. Such reference buildings could be described as "big unrealistic boxes", and were deemed too unrepresentative of real life projects to yield reliable results.

Images 08 and 09 show the distribution of projects by size (Treated Floor Area, TFA [69]), and a scatter between TFA and Form Factor. The project selection was conducted to have a consistent gradient of project sizes in order to avoid skewing the data, For this reason significant size outliers were not included in the project pool. Emu is located in CO and therefore many projects are at high elevations (up to 10,000 ft above sea level).

The draft of the 2024 IECC includes significant exceptions to requirements for projects located at elevations greater than 4,000 ft elevation, which was implemented in the modeling for this research project.

The distribution of the 50 projects by site elevation is shown in Image 10. This is relevant for exceptions to U-value requirements included in the 2024 IECC draft (and other reasons).

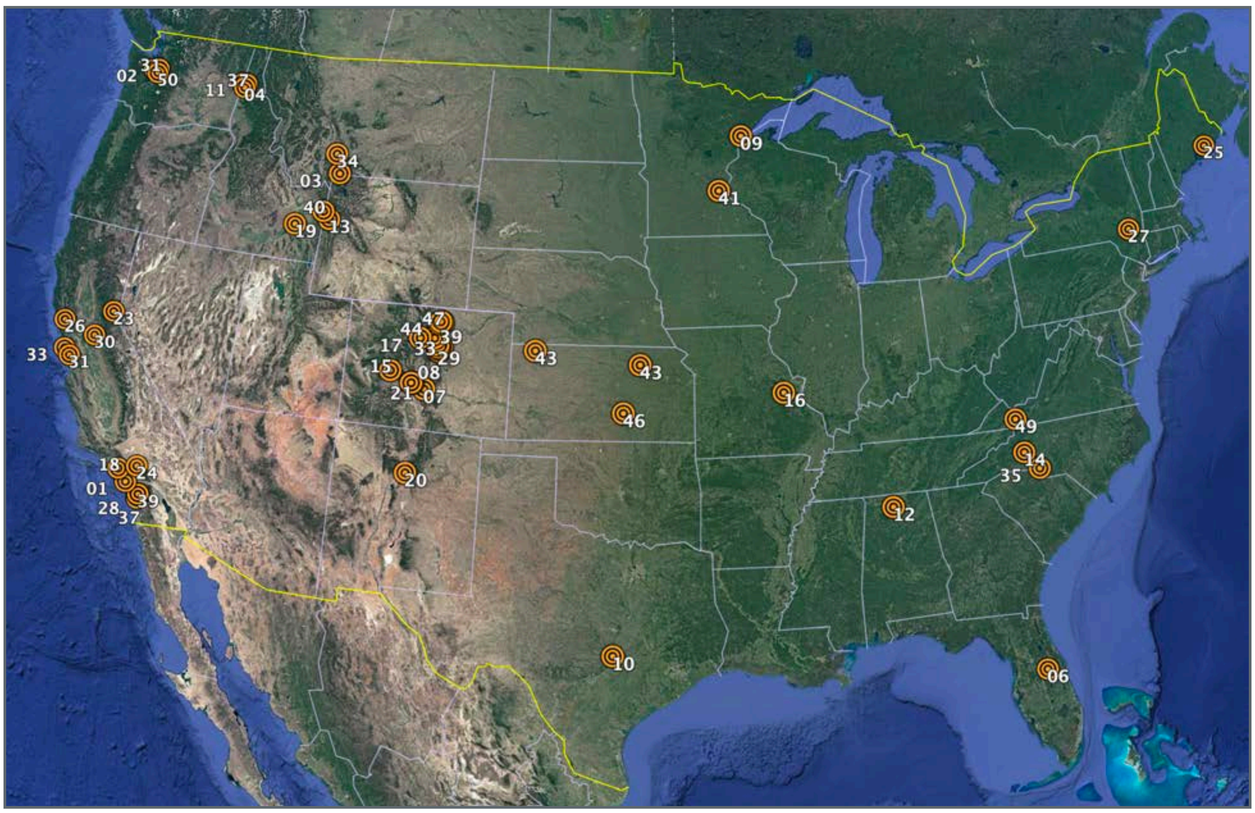

Image 02: Satellite view of the US with the location of the 50 projects included.

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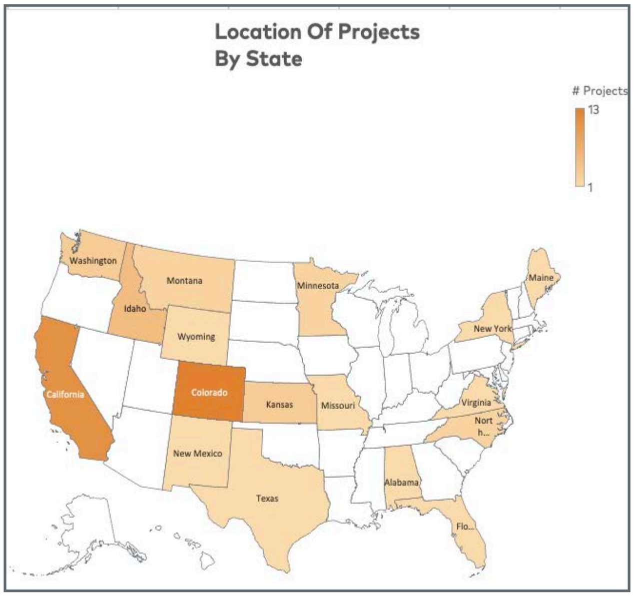
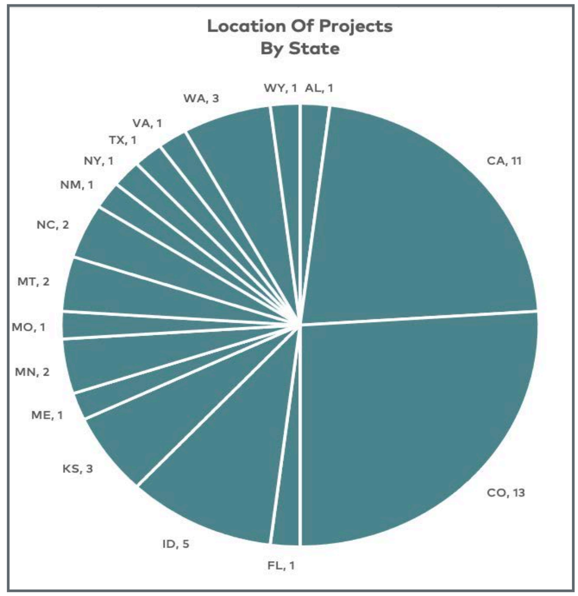




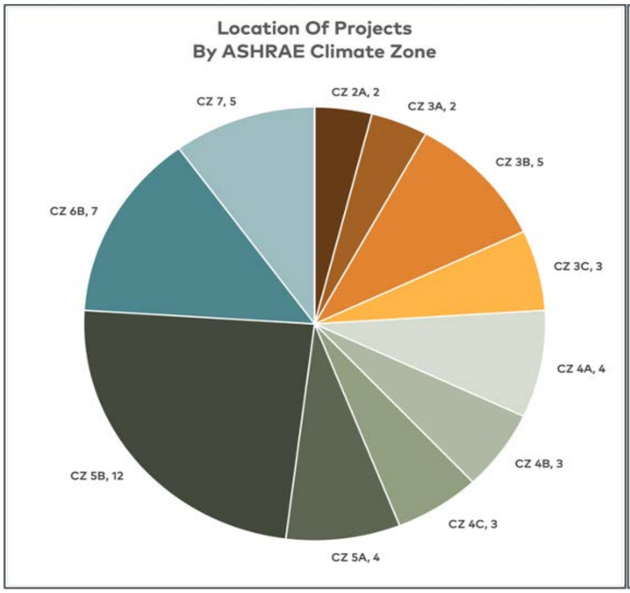
Images 03, 04: Distribution of projects by state - map and pie chart.

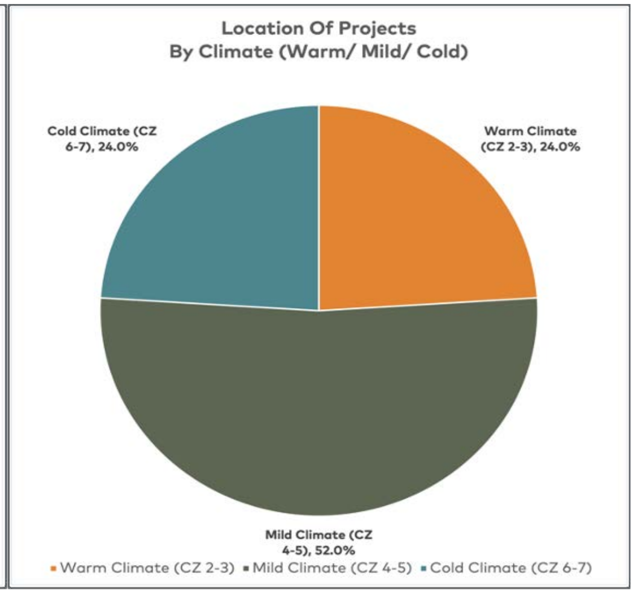
Applicability

The applicability of some building standards is subject to specific conditions, such as:

- California Title 24: applicability limited to projects located in California
- 2021 PHIUS+ Core Prescriptive: applicability limited by building size
- Pretty Good House: no real limitation on applicability. However, guidelines are only available for climate zone 5 and 6, which constituted the limitation on applicability within this study.

Table A.02 in Appendix A lists applicability of the standards considered to the projects included in this research.





Images 05, 06: Distribution of projects by climate zone -ASHRAE climate zones (left), Warm/ Mild/Cold climate zone (right)

Analysis Tool

In order to quantify difference in building performance, all projects were modeled per the applicable building standards.

The analysis was developed as follows, and for the following reasons:

- DesignPH and PHPP softwares used for the energy analysis [68, 74]
- Convenience – Emu had the models already built from Emu's consulting
- PHPP excel format allows easy data processing and export
- Both PHPP and WUFI Passive [35] are based on the same ISO13790 standard [52], so the difference between the results from the two are expected be limited

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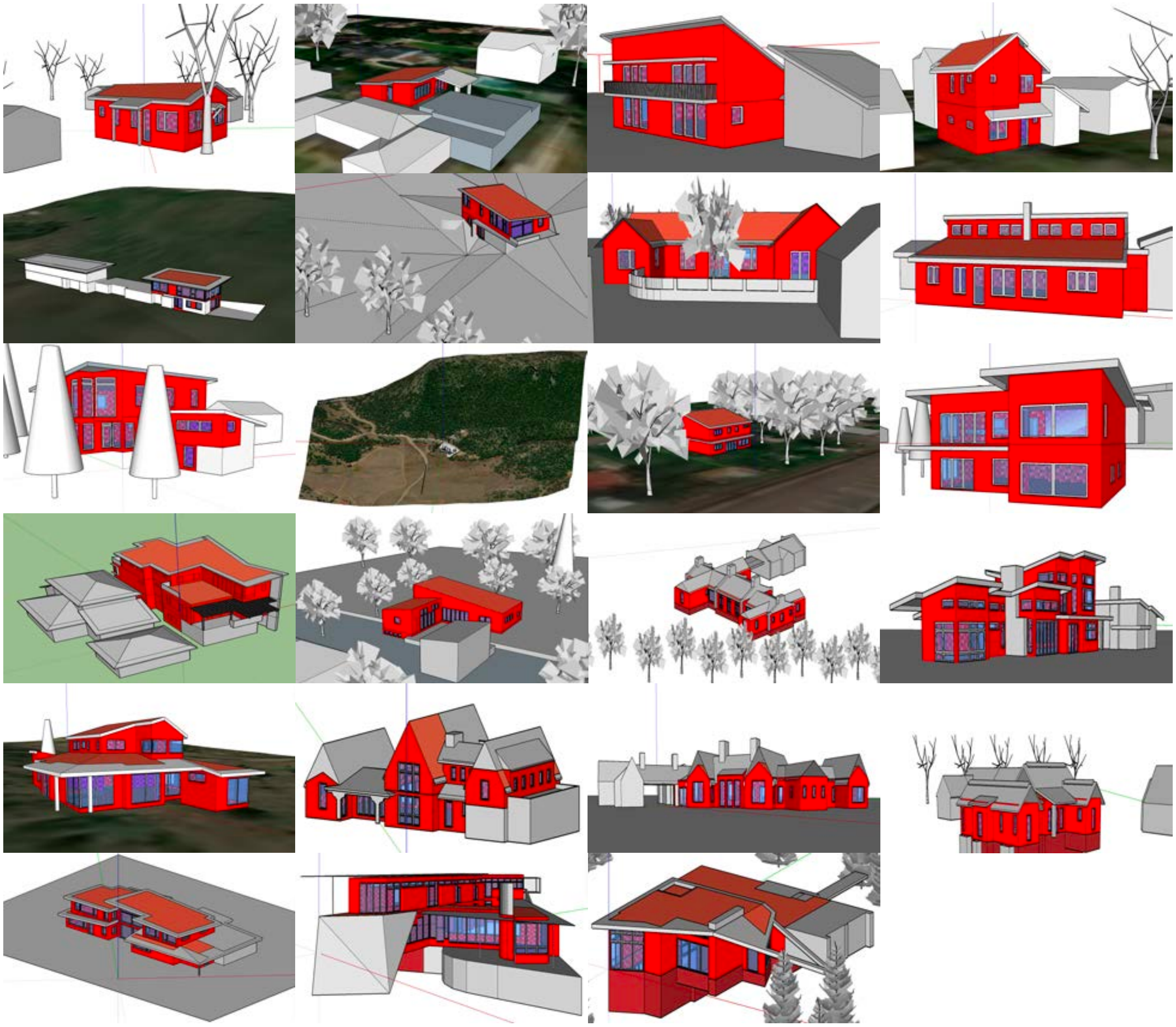
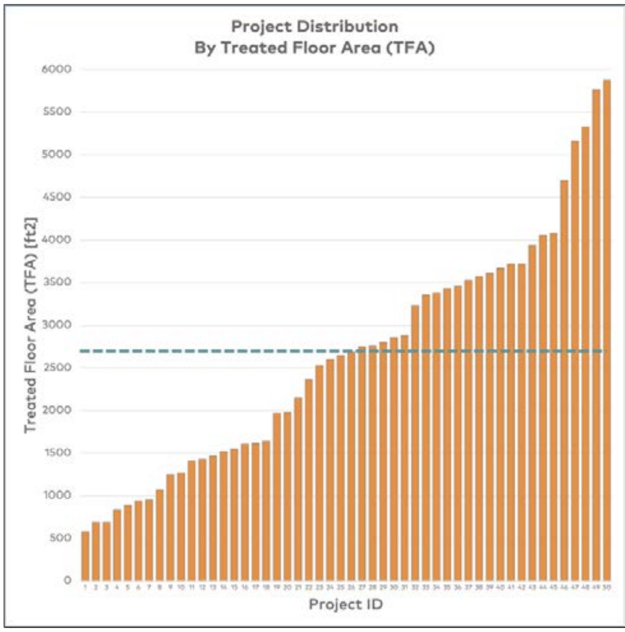
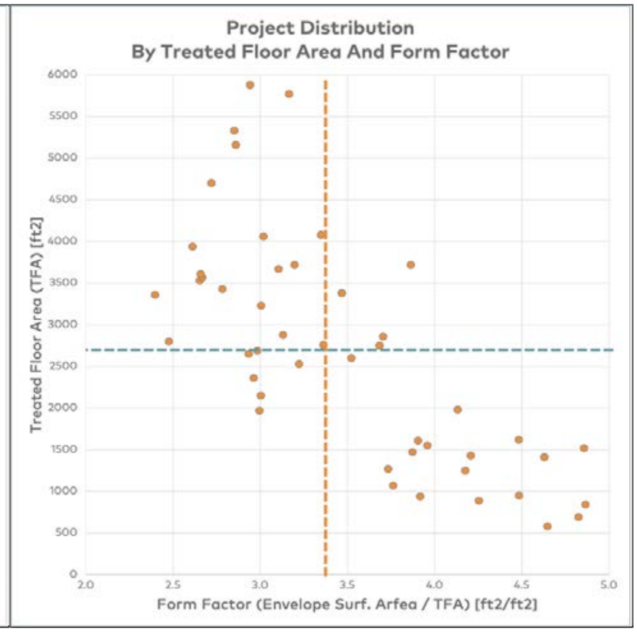


Image 07: Some of the 50 projects, as modeled in DesignPH before being exported to PHPP for finer analysis. These are real projects, each with its own peculiar conditions, design, and constraints. The number of projects included should be sufficient to dilute outstanding aspects of individual buildings that could distort the results.

- The modeling was kept as consistent as possible across building standards,





Images 08, 09 - Left: Distribution of projects by size (TFA), and TFA / Form Factor scatter (right)

errors in the analysis tool would affect all results in a similar way. For modeling conditions and assumptions, see following section.

- The goal of the research was to compare different building standards, not to compare different softwares.

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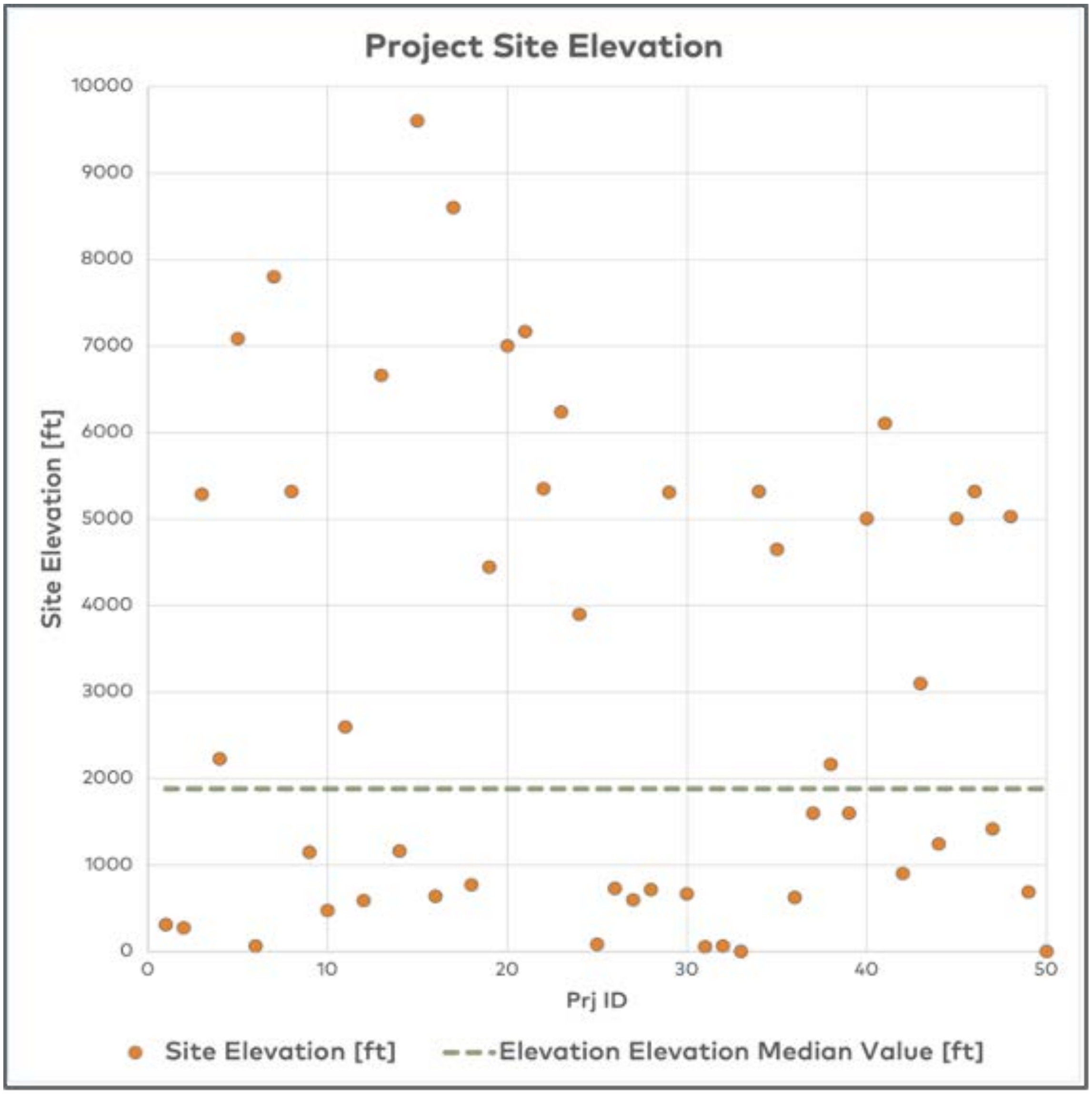

Image 10: Distribution of projects by site elevation.

Modeling Assumptions

The building standards included in this research were modeled in designPH and PHPP according to the specific requirements of each standard. These are listed in Appendix A.

In addition to the requirements of each standard, the following assumptions were made in the modeling:

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 bridging 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

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Comparison Metrics

To limit the comparison between building standards to a single metric, e.g. energy performance, would provide very limited feedback on the improvements provided by that standard on the quality of a building. To draw an analogy to cars, it would be like comparing different cars just by the miles per gallon metric, overlooking other key metrics such as safety, noise control, and other aspects that make cars "good" for people.

The following metrics were included in the research, as a way to obtain a more rounded comparison between different building standards.

1. Thermal Comfort
2. Indoor Air Quality
3. Resilience + Durability
4. Operational Energy Efficiency
5. Embodied Carbon

Images 11, 12, 13: From top to bottom, logos o DesignPH [68], PHPP [74], and WUFI Passive [35]

These are significantly different metrics, and their evaluation is impacted by factors including among others:

- Climate
- Occupancy (in the case of the projects selected, number of occupants)

- Building Size (treated floor area, envelope surface area, building volume)
- Building Form Factor

Table 01 provides a preview of what the Summary Results Table looks like. In other words, given the scope of the research, the metrics considered, and the number of projects used, this multi-faceted question will receive a multi-faceted answer.
It is however impossible to compare the impact of a higher filtration grade filter used in a ventilation system, to the embodied carbon of a project, to the thermal comfort achieved by using better windows. In other words, an absolute apples to apples comparison across the metrics listed above is not possible.

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Proposed Scoring

In order to make the results easier to communicate, a scoring system was developed for the purposes of this research. There is no expectation of this scoring to be absolutely accurate or universally accepted. It is a simplification of reality, as it is often needed in communicating technical metrics to the greater public.

Each of the five metrics listed earlier were allocated 20 points, for a total of 100 points. These are just points, with no equivalent physical attributes (e.g. CO2e, or other units of measurements).

For each Metric, a number of Criteria was identified as ways to evaluate the impact of each building standard. The breakdown of the Criteria for each Metric is shown in Table 02.

Intentionally, the allocation of points was kept even across all Metrics, and for each Metric, across all its Criteria. As there is a fair amount of personal opinion involved in allocating points to e.g. EUI Reduction as opposed to Thermal Comfort, this was deemed to be a way to remove one's personal opinions from the scoring system.

To be noted that some Criteria are associated with more than one Metric. This is intentional, as some Criteria contribute to more than one metric in improving the quality of a building. An example of this is the reduction of air leaks, which enhances the durability and resilience of a building, improves thermal comfort, and it reduces operational energy for heating and cooling.

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Comparison Metrics						
Building Standard	Value Metrics					
	Thermal Comfort	Indoor Air Quality	Resilience	Durability	Operational Energy Efficiency	Embodied Carbon
2018 IRC / IECC						
2021 IRC / IECC						
2024 IRC / IECC						
California Title 24						
EnergyStar 3.2						
DOE ZERH v2						
Pretty Good House						
2015 PHIUS+						
2018 PHIUS+ Core						
2021 PHIUS+ Core Prescr.						
PHIUS+ 2021 Core						
PHI Low Energy Building						
PHI Passive House						

Table 01 - Preview of the Summary Results Table.

BUILDING STANDARDS

Metrics: Absolute, Statistical, and Arbitrary

In investigating building standards, it's helpful to understand how metrics are determined.

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Absolute Metrics

Absolute metrics are the ones that are driven by simple cause and effect, i.e. *"if A happens, we can expect B as a consequence"*. A typical example of an absolute metric used in building standards is the risk for condensation, based on the combination of temperature and relative humidity. Absolute metrics are often based on physics - see [51] for reference.

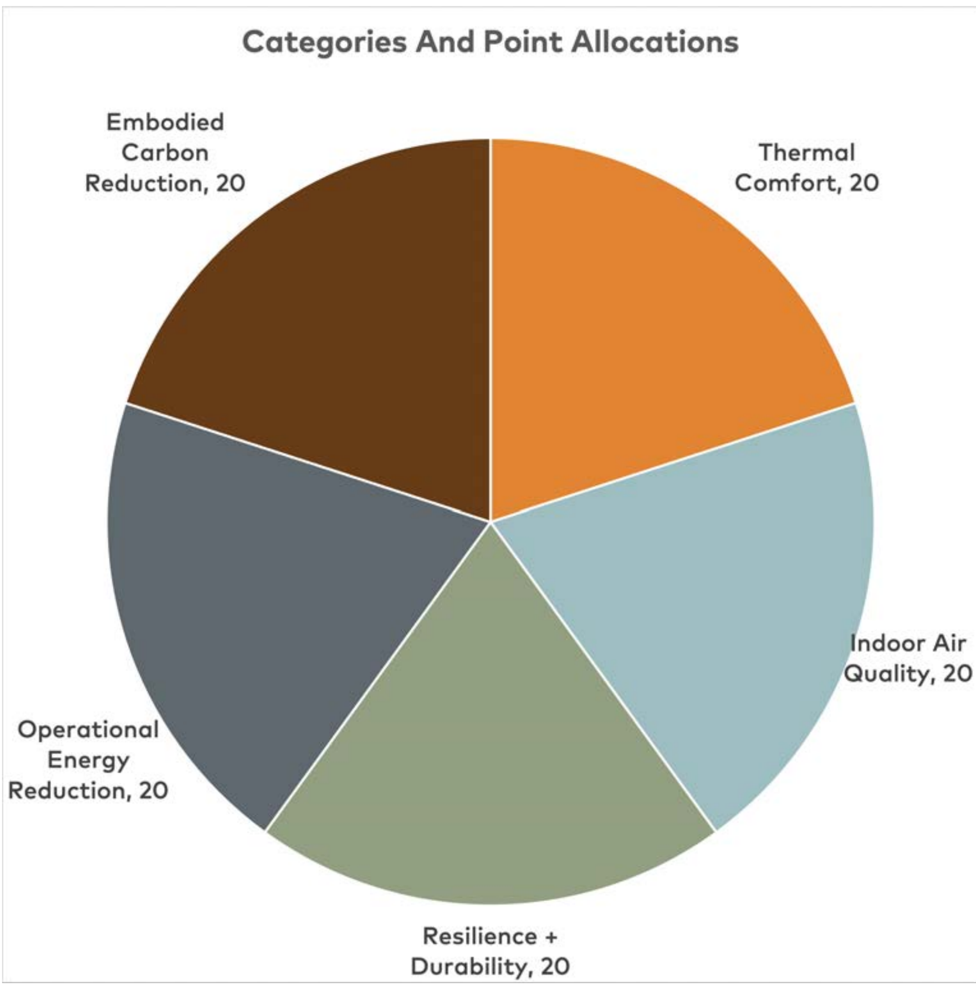

Image 14: Breakdown of points available for the five metrics considered in the research.

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Statistical Metrics

As the name describes it, statistical metrics are based on statistical expectation of an outcome, i.e. "if A happens, there's an X percent chance that B will happen". Typical example of statistical metrics is thermal comfort [7, 45].

Arbitrary Metrics

Having reviewed a number of building standards for this study, the following metrics and criteria (among others) appear arbitrary:

- Minimum R-values,
- Maximum uninstalled U-factors (fenestration)
- Maximum air leakage allowance
- Minimum performance requirements for heat pumps (HSPF, SEER)
- ERI Targets
- PHI's heating and cooling demand maximums
- Phius' heating and cooling demand maximums
- Wether to use volume-related or surface-area-related metrics for maximum air leakage (ACH50, q50)

Most of metrics and requirements included in building standards are arbitrary, meaning that they are agreed upon on grounds that are neither absolute nor statistical.

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Scoring Breakdown

	Value Metric	Points	Criteria				
Scorecard 1	**Thermal Comfort**	20	Delta T: Window Surface vs Room Average	Air Leakage Reduction			
			10	10			
Scorecard 2	**Indoor Air Quality**	20	Coverage Of Fresh Air Need	Air Leakage Reduction	Minimum Air Filtration	Avoidance Of Mold And Surface Condensation	EPA AirPlus Required
			4	4	4	4	4
Scorecard 3	**Resilience + Durability**	20	Air Leakage Reduction	Avoidance Of Interstitial Condensation	Avoidance Of Mold And Surface Condensation	Thermal Resiliency	
			5	5	5	5	
Scorecard 4	**Operational Energy Reduction**	20	EUI Reduction	Verifiable Reuslts	Resource Efficiency	Future Profing For EV Adoption	
			5	5	5	5	
Scorecard 5	**Embodied Carbon Reduction**	20	Embodied Carbon Reduction	Resource Efficiency			
			10	10			

Table02: Breakdown of points available for the five metrics considered in the research.

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Building Standards Included

In the American market, a number of building standards provide guidance to guide policymakers, municipalities, and project teams, in setting parameters and goals for building performance. Among these, the following standards were chosen for the development of this research.

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2018 IECC
A current version of the International Energy Conservation Code [39]. The prescriptive version of this Code was used in the research, as it seems to be the most common implementation method in the market. This was also used as the baseline for comparison of all other standards.

2021 IECC
The more recent version of the International Energy Conservation Code [41]. The prescriptive version of this Code was used in the research, for the reason listed above.

2024 IECC
At the time this research was executed, this version had not yet been published. In order to show the overall direction of IECC development, an official draft of this version was used in the research [43]. The prescriptive version of this Code was used in the research, for the reason listed above.

California Title 24
The current energy code used in the State of California [16].

EnergyStar v3.2
A voluntary program run by the Environmental Protection Agency, with the goal to reduce energy usage and environmental impact. Version 3.2 was used in this study, although it is not mandated yet [30]. For simplicity, the national requirements were applied to all projects, regardless of local programs.

DOE Zero Energy Ready Home (ZERH)
A voluntary program run by the Department Of Energy. *"High performance home that is so efficient that a renewable energy system could offset most or all the home's energy annual energy usage"*. Version 2 was used in this study [22].

Pretty Good House (PGH)
PGH is "a framework and guidelines to focus on the core issues that should be the front and center when designing and building a high quality home or

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renovation" [55, 91] It's not an actual program, but it was included in this research due to its popularity on the internet.

2015 Phius+

Image 15: Building standards included in this research.

A Voluntary program run in the US and Japan by Phius [81]. It defines goals for comfort, IAQ, and energy efficiency by prioritizing the building envelope (Passive approach). Version 2015 was included only for reference in this research.

2018 Phius+ Core
This version was announced in 2021, and became effective in the Spring of 2019 [82].

2021 Phius+ Core
The most recent version of the Phius standard in its performance-based form [85].

2021 Phius+ Core Prescriptive
A prescriptive form of the current Phius standard [85].

PHI Low Energy Building (PHI LEB)
A building standard curated by PHI for new buildings that cannot meet the full PHI Passive standard [69]. It includes more relaxed goals for energy efficiency and air leakage compared to the PHI Passive standard, while maintaining its quality assurance for comfort, IAQ, mold avoidance, etc..

PHI Passive House
A Voluntary program run internationally by PHI [69]. It defines goals for comfort, IAQ, and energy efficiency by prioritizing the building envelope (Passive approach).

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Applicability Of Building Standards

The applicability of a few building standards was constrained by e.g. location, building size, and available information:

- California Title 24: applies to projects located in California
- 2021 Phius+ Prescriptive: application is limited by building size
- Pretty Good House: information available was limited to Climate Zones 5-6

See Appendix A for the applicability of these standards to individual projects.

These applicability constraints impact the results to some degree.

For example in terms of thermal comfort, it may look like California Title 24 is able to provide comfortable conditions to building occupants. The reality is that it is applicable only in the state of California, where the mild climate conditions are not demanding at all in terms of comfort.

Adoption Timeframe And Home Rule

For non-IECC standards, the list above describes which version of the standard was included in this research.

For IECC standards, the actual adoption is subject to individual states and municipalities adopting a version of the code, or not. To complicate things, home rule states allow municipalities to amend and modify an IECC code as it gets adopted.

For the purpose of this research, the IECC standards were applied per the original standard verbatim, regardless of timeframe and amendment in the actual adoption by the municipality of the individual projects.

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Co-Certification Requirements

In terms of building certification, some programs come with nested co-certification requirements, such as:

EPA Indoor airPlus program requires:

- EnergyStar

DOE Zero Energy Ready program requires:

- EPA Indoor airPlus
- EnergyStar

Phius programs require:

- DOE Zero Energy Ready
- EPA Indoor airPlus
- EnergyStar

Prescriptive Requirements

For prescriptive building standards, Appendix A provides detailed lists of requirements as they applied to the individual projects used in this research.

Performance-based Requirements

For standards including 2018 Phius+ Core, 2021 Phius+ Core, PHI Low Energy Building, and PHI Passive House, requirements for individual components of the building envelope were determined as follows:

- windows/ext. doors: U-value calculated to meet the Comfort Criterion for each standard [74, 84]
- air leakage: maximum allowed per building standard [69, 82, 85]

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For heating and cooling demand, both PHI and PHIUS use 68˚F reference temperature for heating, and 77˚F for cooling [69, 82, 85]. For this study, 70/74˚F was deemed to be a more representative set of conditions for heating and cooling in homes in the US.

For each PHI and Phius standard, the heating and cooling demand targets were determined on a project-specific basis [74, 83, 86]. These are listed in Appendix A. The average values are listed above in Table 03.

In the research, the PHPP models for PHI and Phius performance-based standards were developed to meet the heating and cooling allowances with the standard 68/77˚F conditions. Then, they were set to the 70/74˚F conditions in order to compare results with the other building standards modeled.

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METRICS: BUILDING QUALITY

Maximum Allowed Heating Demand (net)											
	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2018 PHIUS+ Core	2021 PHIUS+ Core	2021 PHIUS+ Core Prescr.	PHI Low Energy Building	PHI Passive House
	kBTU/ft2y											
Median	NR	NR	NR	NR	NR	NR	NR	9.30	8.90	NR	9.50	4.75
Average	NR	NR	NR	NR	NR	NR	NR	8.49	9.86	NR	9.50	4.75
Comp to PHI PH	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.8	2.1	N/A	2.0	1.0

Maximum Allowed Cooling Demand (net)												
	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2018 PHIUS+ Core	2021 PHIUS+ Core	2021 PHIUS+ Core Prescr.	PHI Low Energy Building	PHI Passive House
	kBTU/ft2y											
Median	NR	NR	NR	NR	NR	NR	NR	13.00	7.25	NR	9.50	4.75
Average	NR	NR	NR	NR	NR	NR	NR	14.04	9.06	NR	9.92	5.04
Comp to PHI PH	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.8	1.8	N/A	2.0	1.0
NR	No Requirements											

Table 03: Maximum allowed heating and cooling demand for PHI and Phius performance-based standards (average values across all projects).

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This section addresses metrics that contribute to the building having a better impact on their occupants - as opposed on the environmental impact (embodied and operational) of building and operating the building.

Thermal Comfort

Passive Building standards, including PHI and Phius, base most of their comfort concepts on ASHRAE 55 and ISO 7730 [7, 45]. This results in PHI and Phius having similar, yet different requirements for minimum performance for windows and exterior doors (aka Comfort Criterion), and maximum allowed air leakage.

Most of the other building standards address air tightness by setting maximum air leakage requirements (except California Title 24, which sets no maximum air leakage for buildings).

No standards other than PHI and Phius address thermal comfort by means of an analytical method (Comfort Criterion).

Passive House Comfort Criterion

The Comfort Criterion (which is different for PHI and Phius) addresses thermal comfort by containing radiant asymmetry and downdrafts within the thermal comfort limits identified in ASHRAE 55 and ISO 7730 [77, 78].

As this research was started in the Summer of 2021, the Comfort Criterion was evaluated in PHPP v9.6. Current PHI and Phius Comfort requirements have both since evolved in a more detailed evaluation of downdrafts and radiant asymmetry. Nonetheless, the results listed here are indicative of the comfort conditions inside buildings adopting one building standard or another.

Image 16 shows the thermal comfort evaluation for each project, depending on the building standard followed in the selection of windows and exterior doors. For California Title 24, see Appendix B. For EnergyStar and DOE Zero Energy Ready Home programs, the results are fairly similar to what shown for the 2024 IECC.

The requirements for uninstalled and installed U-factors (Uw, Uw_inst) for each project and building standard are listed in Appendix A. The installed U-factors (Uw_inst) were calculated in PHPP, assuming an installation Psi value of 0.040 W/mK for all building standards.

The design temperature for thermal comfort for each project is listed in Table B.00. The same table also lists the calculated average temperature on the interior surface of windows and ext. doors for each project and building standard.

According to the Comfort Criterion requirements, thermal comfort is achieved as long as the average temperature over the interior surface of windows and exterior doors remains within 7.6˚F (4.2K) of the operative room temperature [77, 78]. This is also referred to as Delta T.

For each building standard considered, the average Delta T values across all projects are listed in Table 04, and graphically represented in Image 17.

Local climate impacts thermal comfort significantly therefore this study evaluates a blend of different climate zones.

With regards to the results for California Title 24, it has to be noted that the U-factor requirement of T24 are fairly similar to the ones of the 2018 IECC. The better results shown in Table 04 and Image 17 for T24 are to be attributed to the California climate conditions being fairly mild, not to T24 being stringent in any

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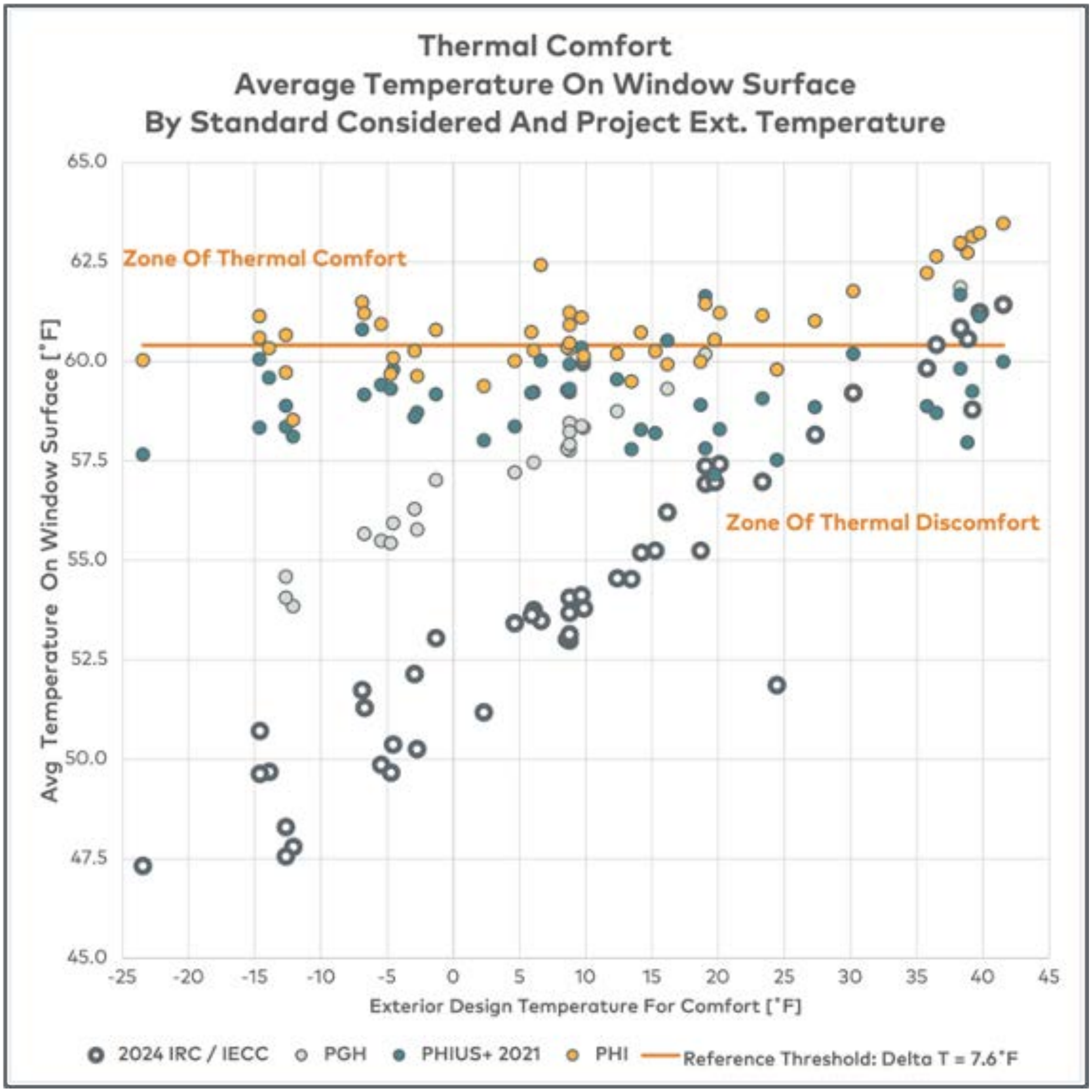

Image 16: Average temperature on window interior surface, for some of the building standards considered

way with regards to thermal comfort.

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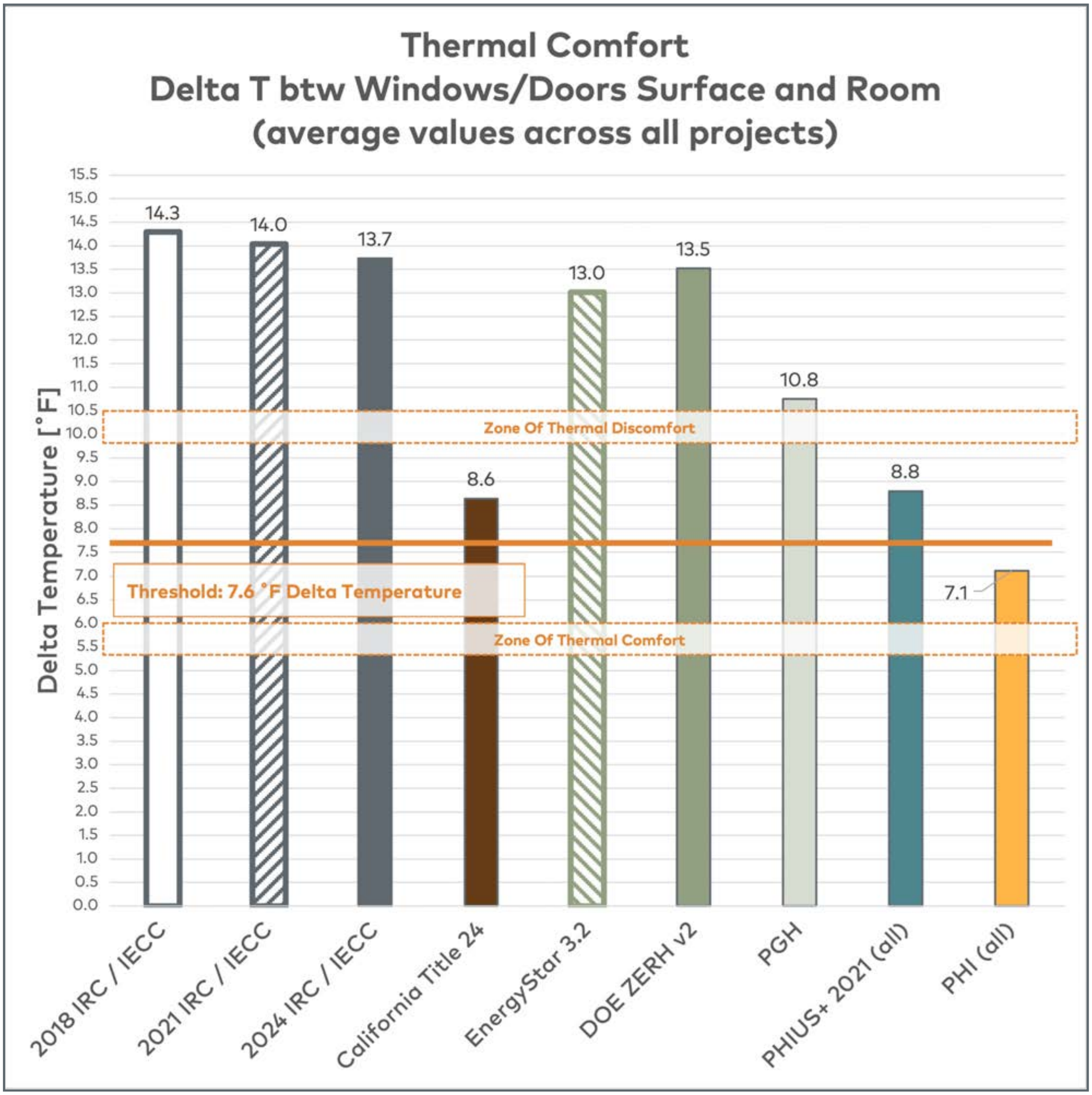

Image 17: Average Delta T values for the building standards considered, across all projects.

Air Tightness

With regards to thermal comfort, the air tightness level of a building prevents:

- cold air drafts
- air stratification within the building

The comparison between building standards in terms of maximum allowed air

Thermal Comfort - Overview

Delta temperature to prevent thermal discomfort						dT* ≤	4.2	K	7.6	°F
	Delta temperature by standard modeled Average values across projects modeled:									
	Design Temp For Comfort*	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	PHIUS+ 2021 (all)	PHI (all)
[°F]	10.8	14.3	14.0	13.7	8.6	13.0	13.5	10.8	8.8	7.1
*	Average temperature of consecutive coldest 12 hours of the year (calculated in PHPP)									

Table 04: Average Delta T values for the building standards considered.

leakage is addressed in detail later in this report, see Images 29 and 31.

Scoring: Thermal Comfort

Table 05 summarizes the Criteria covered in the previous pages for the Thermal Comfort Metric. The same table shows the points allocated to each building standard, and the totals.

Image 18 provides a visual representation of the scoring results.

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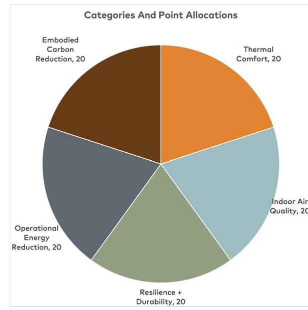
Indoor Air Quality



All building standards included in the research address indoor air quality in one way or another.

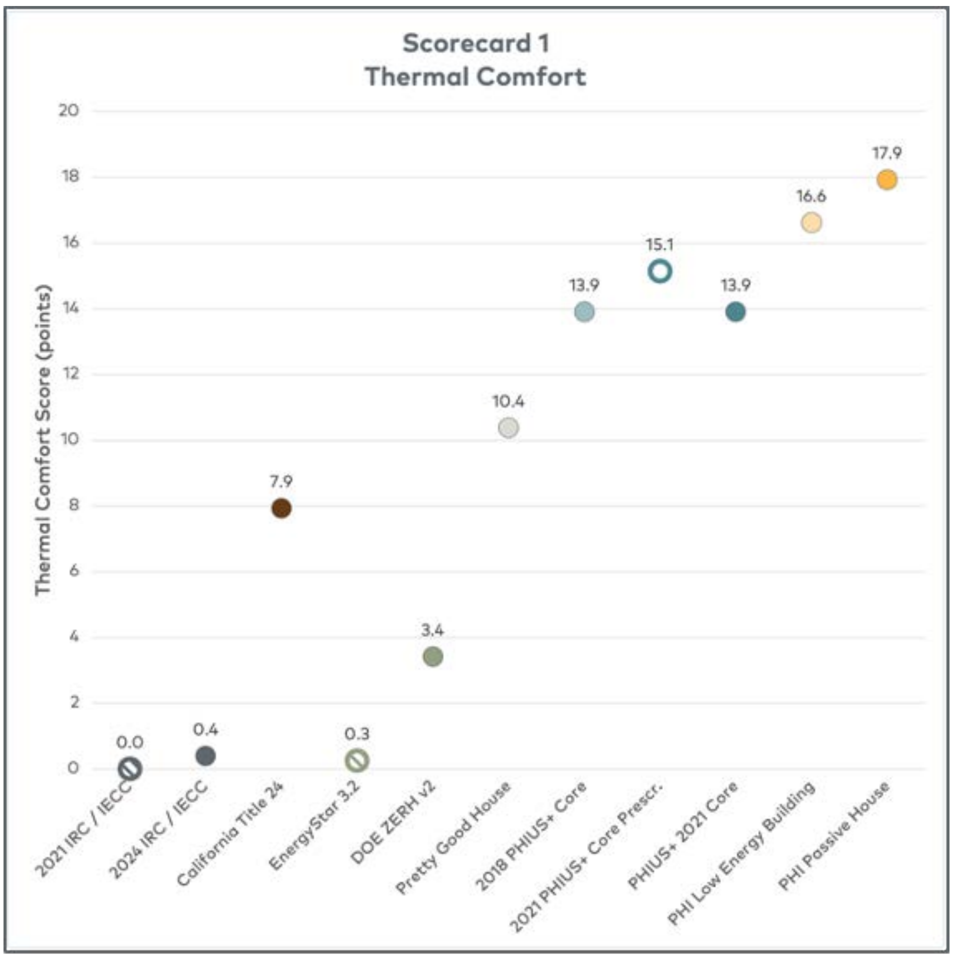


Image 18: Scoring results for each building standard for Thermal Comfort.

Scorecard 1						
Thermal Comfort						
	Delta T: Window Surface vs Room Average	Air Leakage Reduction				
	Tsi_avg	q50				
Criteria	≤ 7.6˚F	Leakage reduction comp. to 2018 IECC				
Motivation	create even thermal environment	eliminate drafts				Total
Points Available	10	10				20
2021 IRC / IECC	0.0%	0.0%				0.0
2024 IRC / IECC	0.0%	3.9%				0.4
California Title 24	79.3%	0.0%				7.9
EnergyStar 3.2	0.0%	2.5%				0.3
DOE ZERH v2	0.0%	34.2%				3.4
Pretty Good House	37.0%	66.8%				10.4
2018 PHIUS+ Core	76.1%	63.0%				13.9
2021 PHIUS+ Core Prescr.	76.1%	75.4%				15.1
PHIUS+ 2021 Core	76.1%	63.0%				13.9
PHI Low Energy Building	100.0%	66.2%				16.6
PHI Passive House	100.0%	79.2%				17.9
Baseline:	2018 IECC					
Tsi_avg	average temperature over the interior surface of windows/doors					
Allowance	5 ˚F					
q50	surface-related air leakage of the building envelope					

Table 05: Scoring results for each building standard for Thermal Comfort.

Fresh Air Supply

The requirements for fresh air supply considered for each project and building standard are listed in Appendix B.

For the IECC standards, the continuous fresh air ventilation rates contained in the International Residential Code (IRC) were assumed for all projects. This is very generous with regards to the estimation air quality inside IECC-built buildings, as continuous ventilation is typically not mandated.

Images 19 and 20 show the air flow rates in buildings using extraction only (IRC/IECC bath fan only ventilation), which is more representative of real conditions in most Code-minimum buildings.

For Pretty Good House projects, in lack of specific requirements the same ventilation rates were assumed as the IRC.

Appendix A provides the list of assumed air flow rates per project and building standard, and an evaluation of the air flow rates per occupant, and an evaluation of indoor air quality on assumed resulting CO2 concentration [28].

Image 19 shows the air flow rates per occupant for each project, and Image 20 provides an evaluation of indoor air quality [28].

Table 06 summarizes the air flow rates per building standard investigated, and provides an evaluation of indoor air quality level by estimated CO2 concentration (according to EN 13779).

The results shown in Table 06 for the International Residential Code / International Energy Conservation Code (IRC/IECC) are to be considered generous, as they are based on the the assumption of continuous fresh air ventilation. In Emu's experience, most projects built to minimum Code compliance are not provided with continuous ventilation (so they would fall in

Fresh Air Ventilation Airflow Rates By Standard

Occupancy-related Metric				
Target ****	30	m3/h*p	18	cfm/p

Volume-related Metric		
Typical (PHI)	0.3	ACH

Airflow Rate Per Occupant

Coverage Of Fresh Air Target Per Occupant
Median Values Across All Projects

IRC / IECC bath fan only vent. *	IRC / IECC contin. vent. **, ***	California Title 24	PGH	PHIUS (all)	PHI (all) ****
cfm / person					
2.1	12.4	26.1	NR	22.4	27.8

Fresh Air Ventilation - Volume-related Metric

Fresh Air Airflow Rates
Relative To Building Vented Volume
Median Values Across All Projects

IRC / IECC bath fan only vent. *	IRC / IECC contin. vent. **, ***	PGH	California Title 24	PHIUS (all)	PHI (all) ****
ACH					
0.03	0.16	NR	0.32	0.28	0.34

Coverage Of Fresh Air Need

IRC / IECC bath fan only vent. *	IRC / IECC contin. vent. **, ***	California Title 24	PGH	PHIUS (all)	PHI (all) ****
11.6%	66.7%	132.2%	NR	120.4%	141.1%

Indoor Air Quality Level

IRC / IECC bath fan only vent. *	IRC / IECC contin. vent. **, ***	California Title 24	PGH	PHIUS (all)	PHI (all) ****
low IAQ	low IAQ	high IAQ	NR	high IAQ	high IAQ

*	Common condition in buildings not provided with dedicated fresh air system.
**	Typically not mandated.
***	DOE ZERH: see IRC
****	Weighted average of the airflow rates (design + boost) per Emu's specs for the individual project, following PHI's guidelines
*****	Assuming fresh air need = 18 cfm per adult occupant
******	Per EN 13779. Does not account for air filtration, or building air tightness

Table 06: Average Fresh air rates per building standard, and evaluation of resulting indoor air quality

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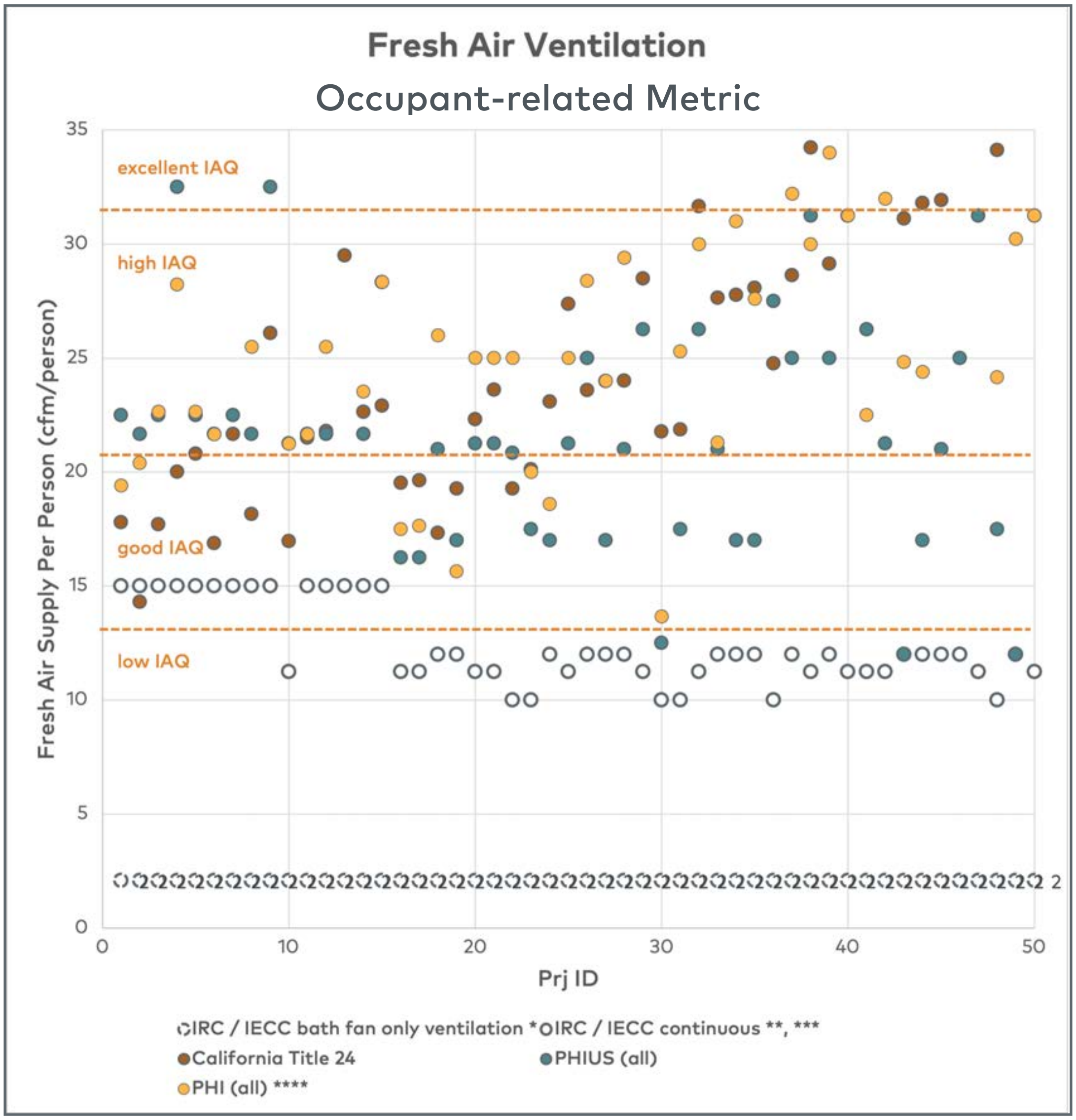

Image 19: Fresh air supply rates per person, depending on the building standard considered.

category of 'bath fan only ventilation'). Either way, the estimated indoor air quality for Code-built buildings is "Low IAQ".

Fresh Air Filtration

Filtration of fresh air significantly limits occupants exposure to pollutants carried by outside air. A typical example of airborne pollutant carried by exterior air is particulate matter (PM2.5), which is linked to cancer.

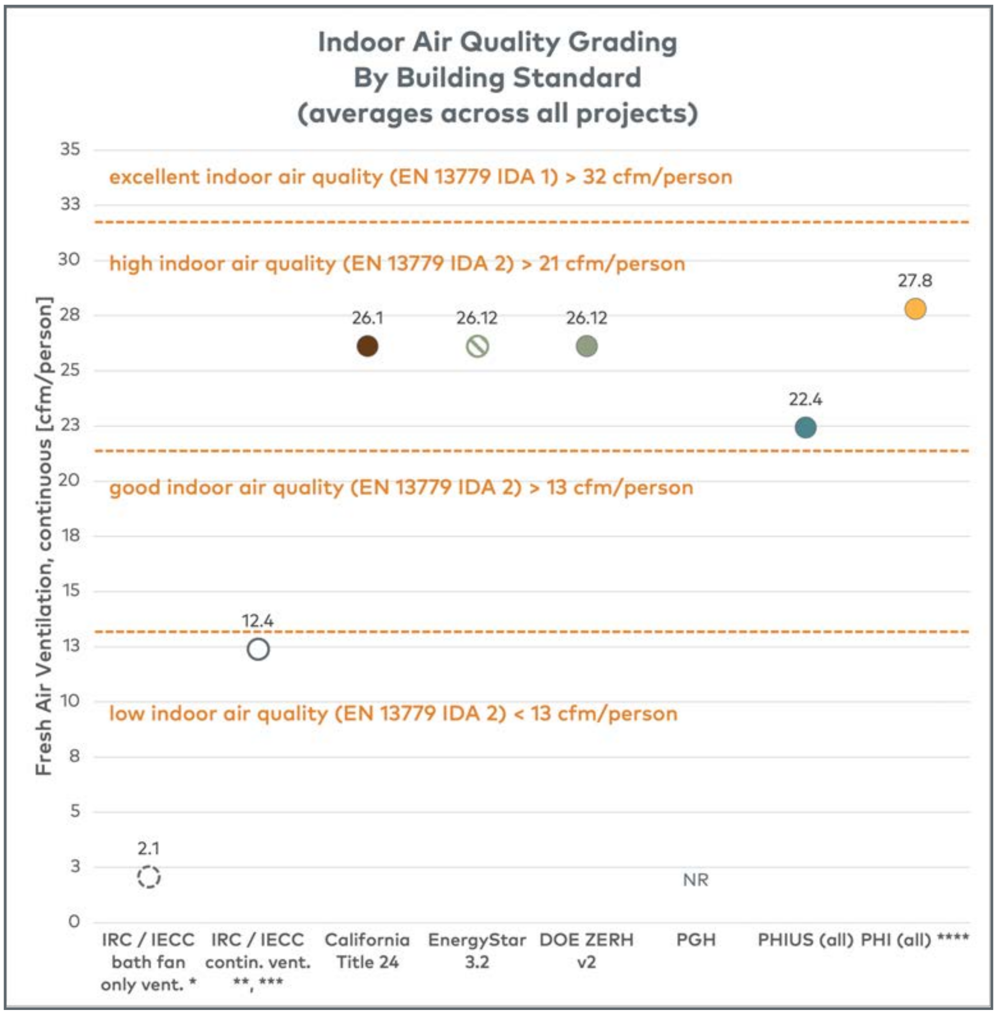

Image 20: Average fresh air rates per person across all projects, and evaluation of indoor air quality based on estimate CO2 concentration [28]

Image 21 shows daily average concentrations of PM2.5 across the US. Image 22 shows MERV13 filters, before and after being used in a Passive House ERV system.

Most of the building standards reviewed in this research prescribe a minimum filtration grade for the fresh air system installed in buildings. These requirements are summarized in Table 07, which also shows the corresponding filtration efficiency per particle size according to ASHRAE Standard 52.2 [6].

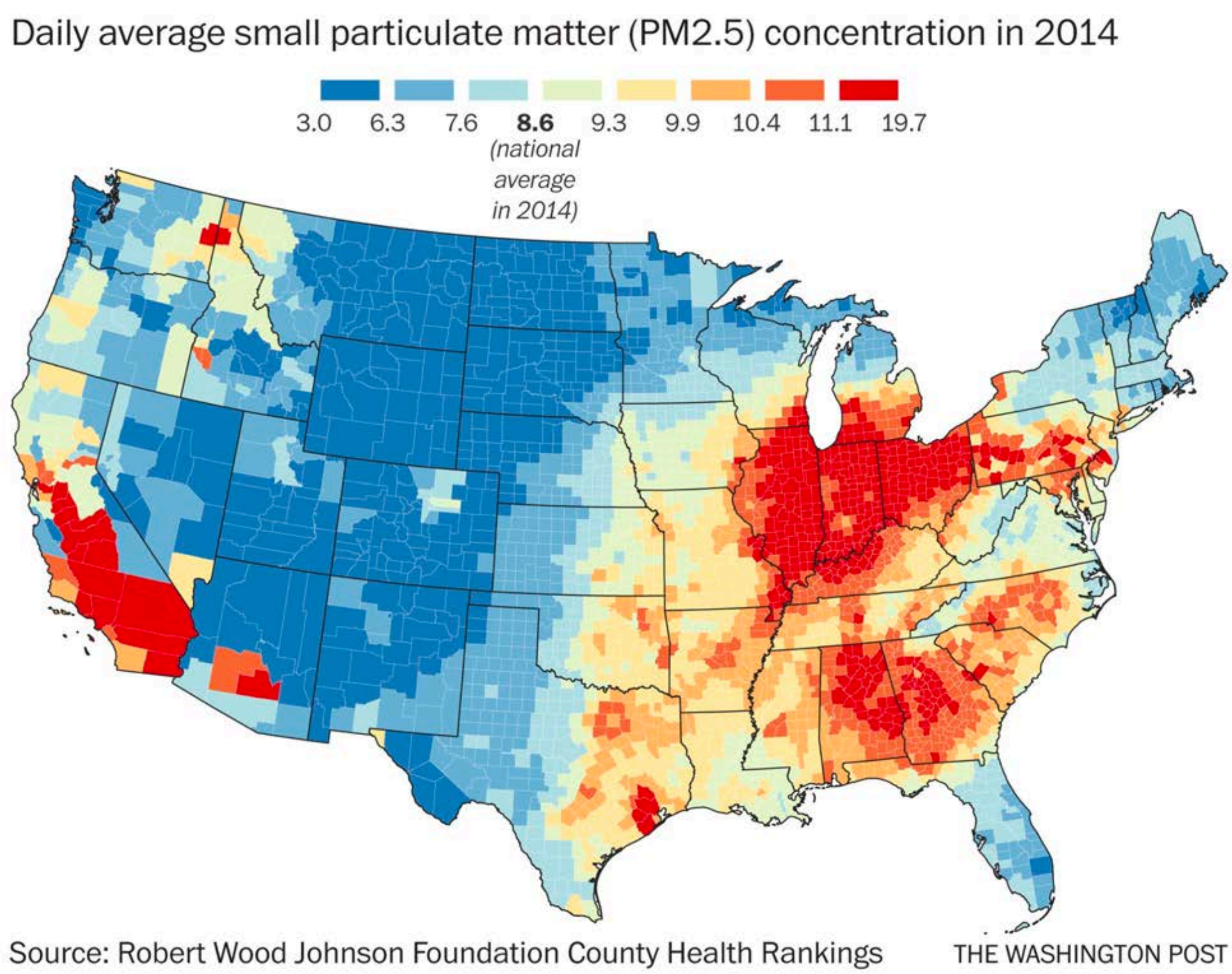

Image 21: Daily average concentration of small particulate matter (PM2.5)

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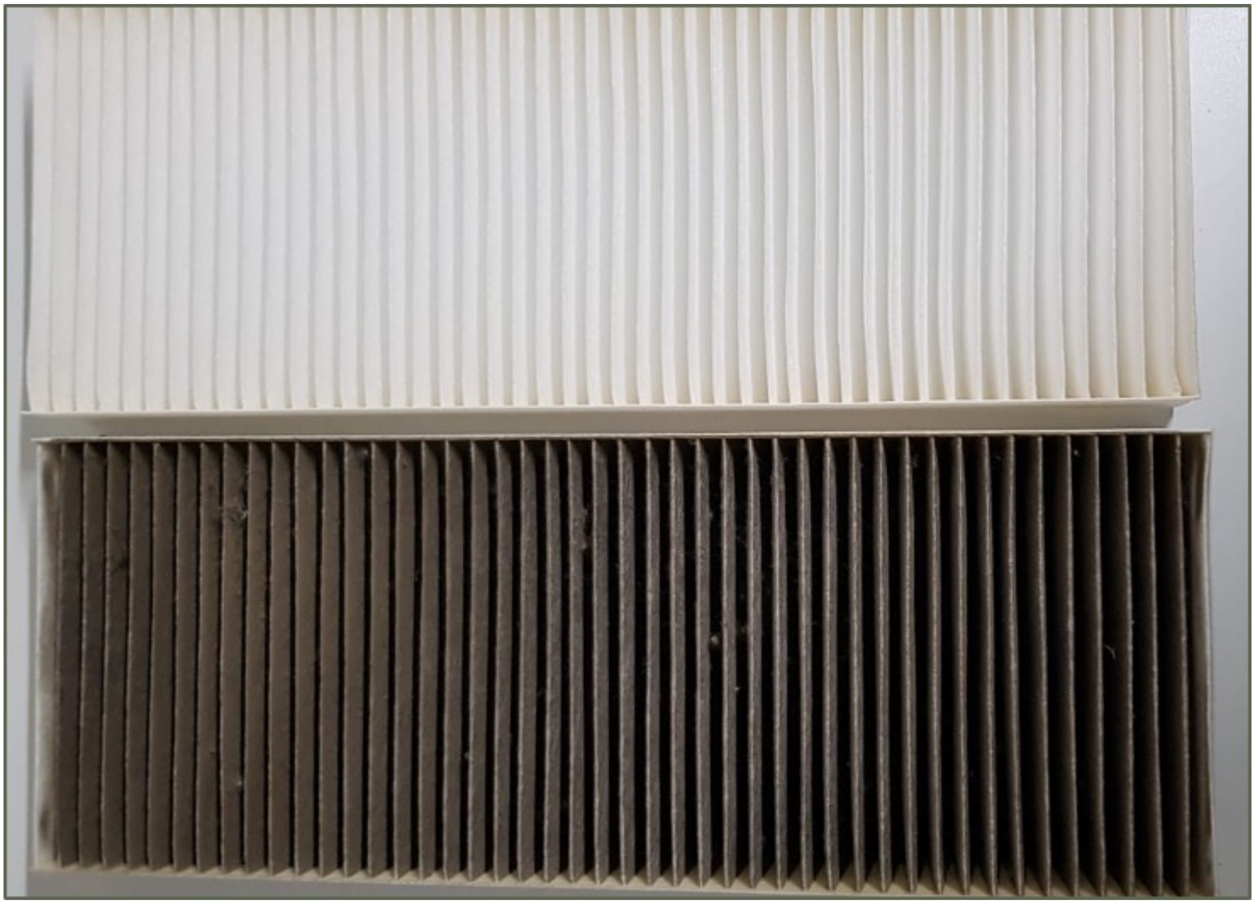

Image 22: MERV13 filters, before (above), and after (below) being used in a Passive House ERV for approximately 3 months (Emu).

From investigating the International Residential Codes (IRC) [40, 42], and the International Energy Conservation Codes (IECC) [38, 39, 41, 43], it appears that these Codes don't require any filtration for fresh air systems. This was confirmed from conversations with colleagues that handle building code updates.

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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 07: Minimum filtration grade required by each building standard included in this research. The filtration grade required by building standard for PM2.5 pollution is shown in the middle column (1.0-3.0 micron)

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EnergyStar, DOE ZERH, and Phius require a considerably lower level of filtration compared to California Title 24, and PHI standards.

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Air Tightness

Similarly to fresh air filtration, the air tightness of a building significantly limits occupants exposure to pollutants carried by outside air. This was proven by Cameron Monroe's studies on wild fire smoke exposure in Melbourne, Australia [58].

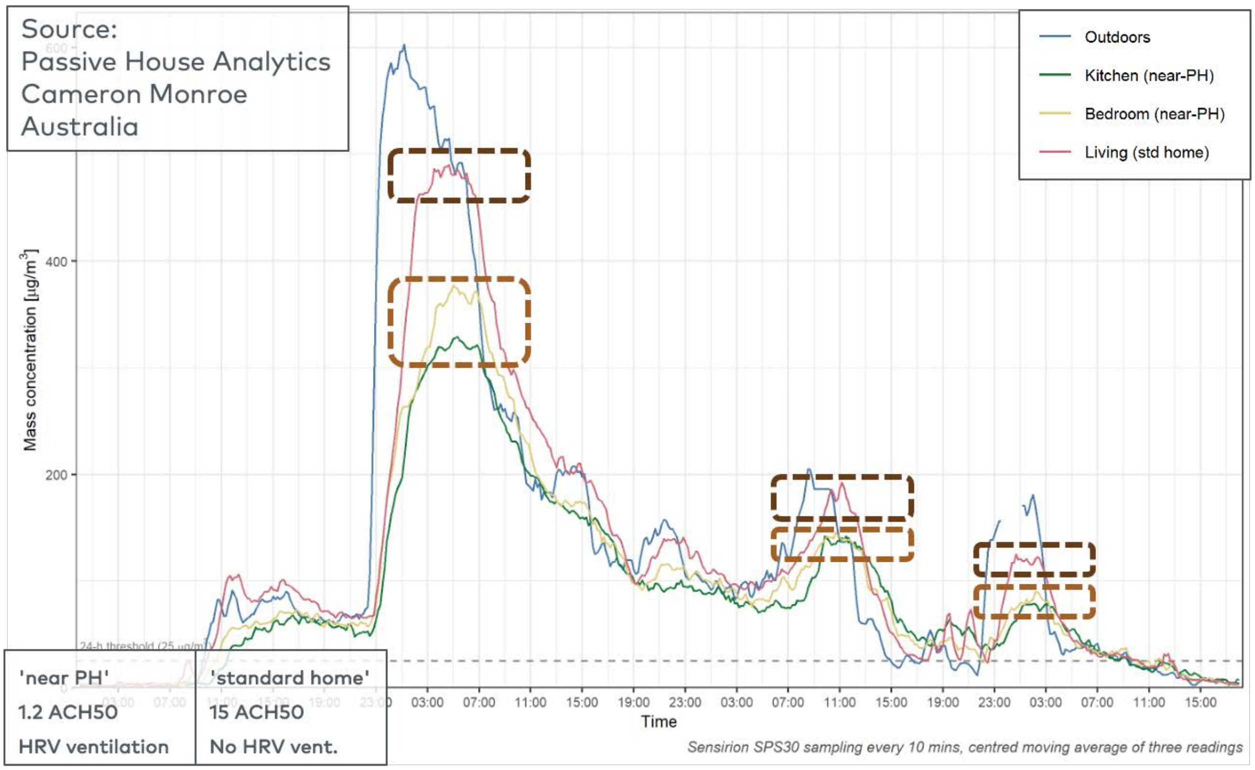

Image 23: Concentration of particulate matter (PM2.5) in an airtight building vs standard home, during the a wildfire event near Melbourne, Australia [58]

Monroe's study shows a direct relationship between the level of air tightness of a building, and the protection occupants receive from outdoor pollutants.

Once the building is airtight, the one point of entry remains the fresh air system (ERV/HRV), with the air filtration grade described at the previous paragraph.

Avoidance Of Mold and Surface Condensation

With buildings becoming more insulated and more airtight, the risk for mold and condensation forming on the interior surfaces of the building increases. This is due to the combination of lower localized temperatures (caused by thermal bridging), and higher relative humidity (caused by poor ventilation).

Image 24: Interior of a building afflicted by mold, which resulted from a partial energy retrofit (photo: Damiano Chiarini).

This phenomenon is different and independent from the interstitial condensation (dewpoint) addressed by Building Code. For reference, see ISO13788 [51].

It is worth mentioning that mold can occur in absence of condensation, so that the bare dewpoint calculation is insufficient in addressing the risk entirely.

Among the industry standards that address this issue, the following provide thorough analytical tools to prevent mold and surface condensation:

- ISO 13788 [51], via finite element modeling
- CSA A440.2 [18], via specimen testing

The following standard are deemed insufficient in addressing the risk, due to the reasons listed:

- NFRC Condensation Resistance (CR) [61]. It provides a score intended to compare products with one another. The score is the blended result of modeling/testing results, and it's not suitable to analytically evaluate the risk for mold/condensation
- NFRC Condensation Index (CI) [62]. While the modeling is very similar to ISO 13788, NFRC CI intentionally excludes from the analysis the first 1" of glass along the frame edge (where condensation is most likely to occur)
- AAMA Standard 1503 [1] The score is the blended result of modeling/testing results, and it's not suitable to analytically evaluate the risk for mold/condensation

PHI requires ISO 13788 verification of avoidance of mold and surface condensation for all components of the building thermal envelope, with mandated threshold values that are calculated on a climate- and project-specific basis (depending on occupancy, ERV/HRV airflow rates, and building air leakage).

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Phius allows for ISO 13788, as well as CSA 440.2, AAMA 1503, and NFRC metrics. For this reason, Phius was only allocated partial credit for this parameter.

No other building standard considered in this research addresses the risk for surface mold and condensation.

Other IAQ Goals

DOE Zero Energy Ready Homes program, and Phius, address other IAQ goals by requiring EPA indoorAir Plus certification.

EPA indoorAir Plus [31] addresses a range of indoor air quality-related matters, including:

- moisture control
- radon
- pests
- HVAC systems
- combustion pollutants
- material (finishes)

This research did not investigate to what degree meeting the EPA indoorAir Plus checklist improves the indoor air quality in buildings.

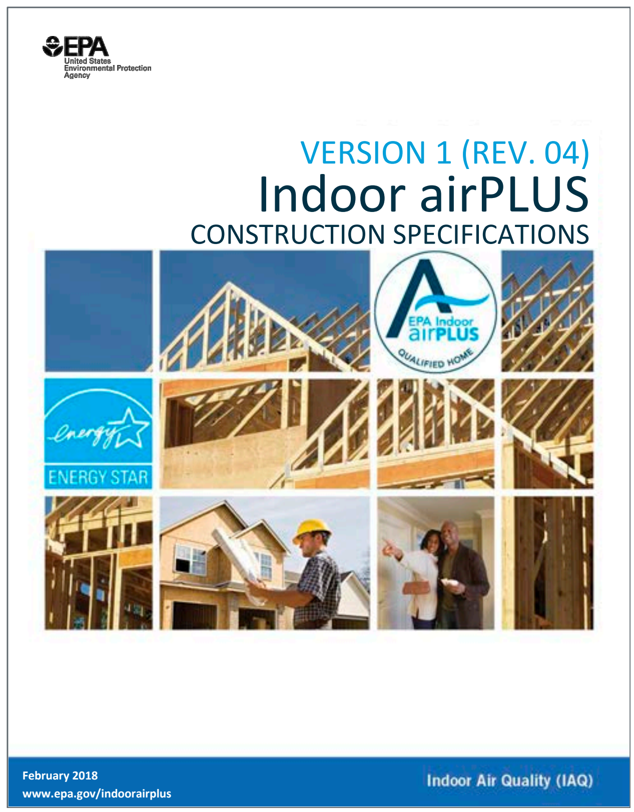

Image 25: Cover of the EPA Indoor AirPlus certification protocol.

For the purpose of the proposed scoring, points were assigned to the standards that require this certification as part of their IAQ goals.

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Scoring: Indoor Air Quality

The scoring results for indoor air quality are shown in Table 08, which is based on the motivations illustrated above.

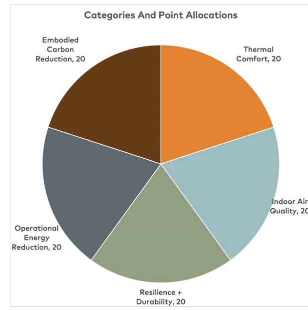

Image 26 provides a graphical representation of the results.

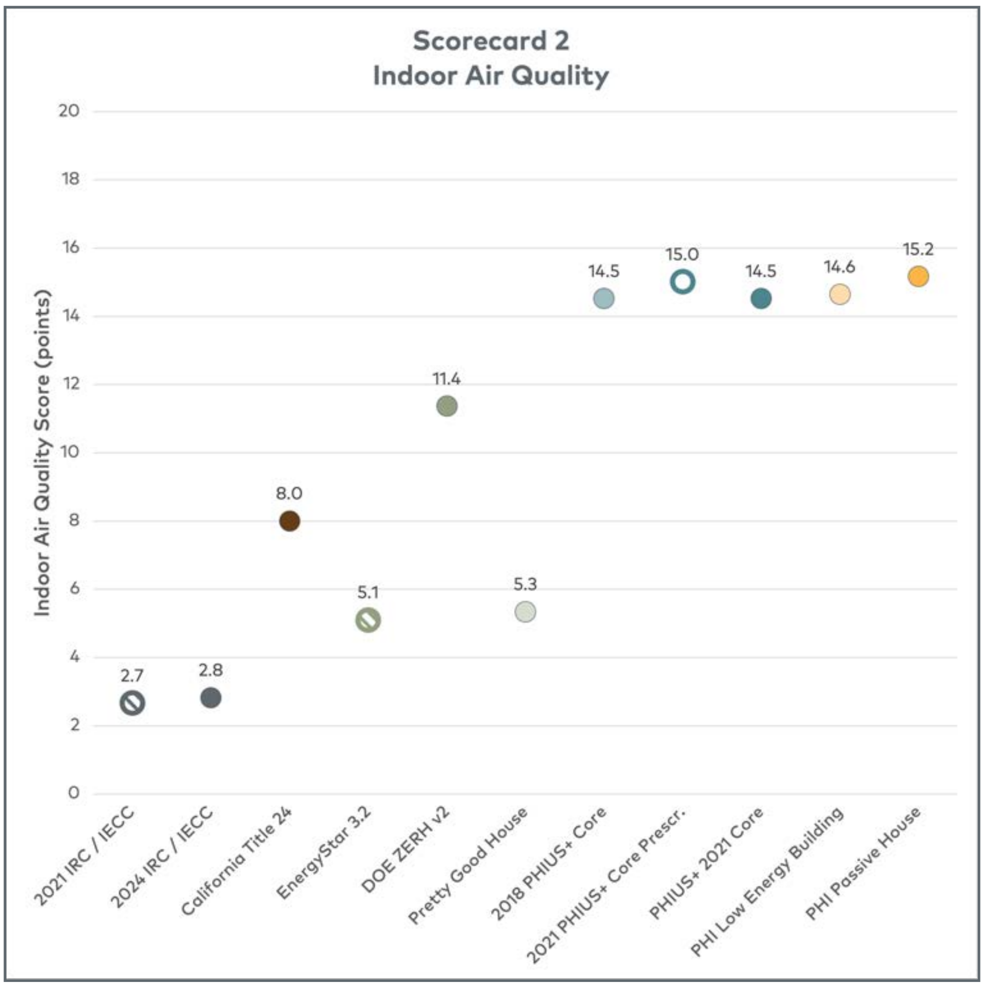

Image 26: Indoor Air Quality scoring for the different criteria covered in this section of the study.

Scorecard 2						
Indoor Air Quality						
	Coverage Of Fresh Air Need	Air Leakage Reduction	Minimum Air Filtration	Avoidance Of Mold And Surface Condensation	EPA AirPlus Required	
		q50	MERV	fRsi		
Criteria	EN13779 airflow rates per person	Leakage reduction comp. to 2018 IECC	filtration grade required by standard	avoidance via analytical method	building standard require EPA AirPlus	
Motivation	supply occupants with quality air	prevent ext. pollution from entering the building	filter exterior pollutants	protect occupants from mold	protect occupants from other airborne risks	Total
Points Available	4	4	4	4	4	20
2021 IRC / IECC	66.7%	0.0%	NR	no	no	2.7
2024 IRC / IECC	66.7%	3.9%	NR	no	no	2.8
California Title 24	100.0%	-62.4%	MERV13	no	no	8.0
EnergyStar 3.2	100.0%	2.5%	MERV6	no	no	5.1
DOE ZERH v2	100.0%	34.2%	MERV8	no	yes	11.4
Pretty Good House	66.7%	66.8%	NR	no	no	5.3
2018 PHIUS+ Core	100.0%	63.0%	MERV8	partially	yes	14.5
2021 PHIUS+ Core Prescr.	100.0%	75.4%	MERV8	partially	yes	15.0
PHIUS+ 2021 Core	100.0%	63.0%	MERV8	partially	yes	14.5
PHI Low Energy Building	100.0%	66.2%	MERV13	yes	no	14.6
PHI Passive House	100.0%	79.2%	MERV13	yes	no	15.2
Baseline:	2018 IECC					
Values < 0	It means that for that metric, the building standard performs worse than the 2018 IECC					
q50	surface-related air leakage of the building envelope					
MERV	filtration efficiency of fresh air filters					
fRsi	analysis method to prevent mold and condensation on the interior surfaces					

Table 08: IAQ scoring for the different criteria covered in this section of the study.

Durability

The durability of a building relies on whether the building is exposed to moisture driven damages throughout its lifetime. Moisture driven damages can occur from a variety of different physical phenomena within the building.

Image 27: Wood rot at the roof. The lack of air tightness allows for warm, humid air to exfiltrate to the outside, carrying moisture from inside the building into the building assembly.

Among these phenomena, the ones addressed in this research include:

- Air Leakage Reduction (i.e. building air tightness)
- Avoidance Of Interstitial Condensation (interstitial dewpoint)
- Avoidance Of Surface Mold/Condensation (surface dewpoint)

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Air Leakage Reduction

Air leaks carry moisture into building assemblies through a phenomenon called "exfiltration". This can cause significant permanent damages to the structure of the building, as shown in Image 27.

With the exception of California Title 24, all building standards considered in this Report set maximum values to the air leakage allowed in buildings.

Most building standards considered here use a volume-specific metric (ACH50) in setting their maximum air leakage limits.

Phius uses a surface-area related metric (q50) to set their air leakage maximum allowances. PHI has a q50 requirement for very large buildings, in addition to the standard ACH50 requirement (this did not apply to the buildings covered in this report).

Both volume-related and surface area-related metrics come with pros and cons:

ACH50 Pros:

- It favors more efficient design, i.e. it's easier to meet for buildings with low form factors

ACH50 Cons:

- It becomes very hard to meet for small buildings (e.g. tiny houses)
- For very large buildings, it's very easy to meet

q50 Pros:

- Easier to meet for small buildings (e.g. tiny houses)

q50 Cons:

- Indulgent towards poor design. As the allowed air leakage is proportional to the surface area of the building, high form factor buildings of any size are allowed to be more leaky

The volume-related and surface area-related target values were calculated for each building standard for each project. Appendix A lists the ACH50 and q50 values for each project.

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Images 28 and 30 show the volume- and surface area-related metrics for each project for PHI and Phius standards. The median values are shown in Image 29 and 31.

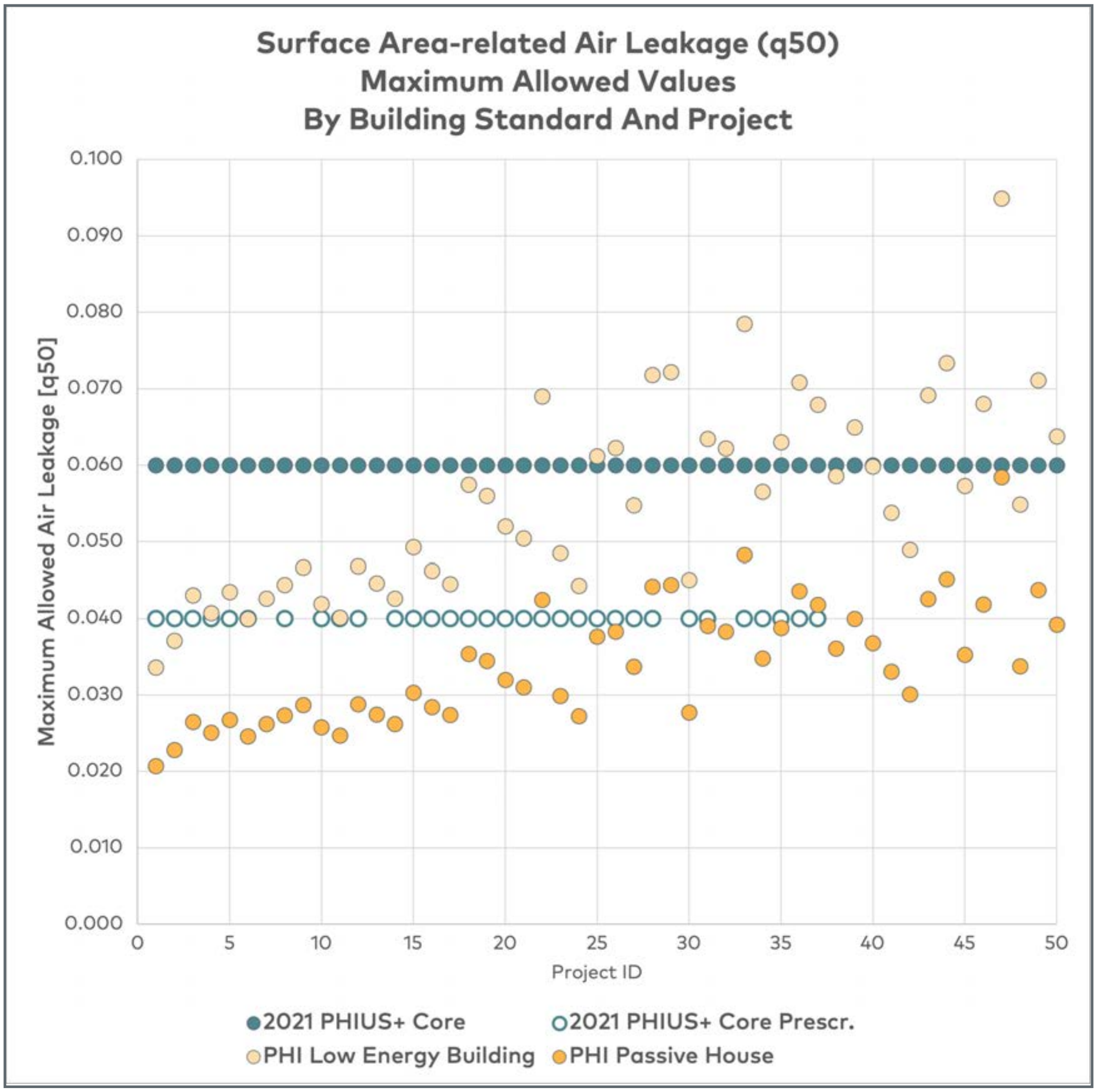

Image 28: Surface Area-related allowed air leakage for PHI and Phius standards, for each project included in this report.

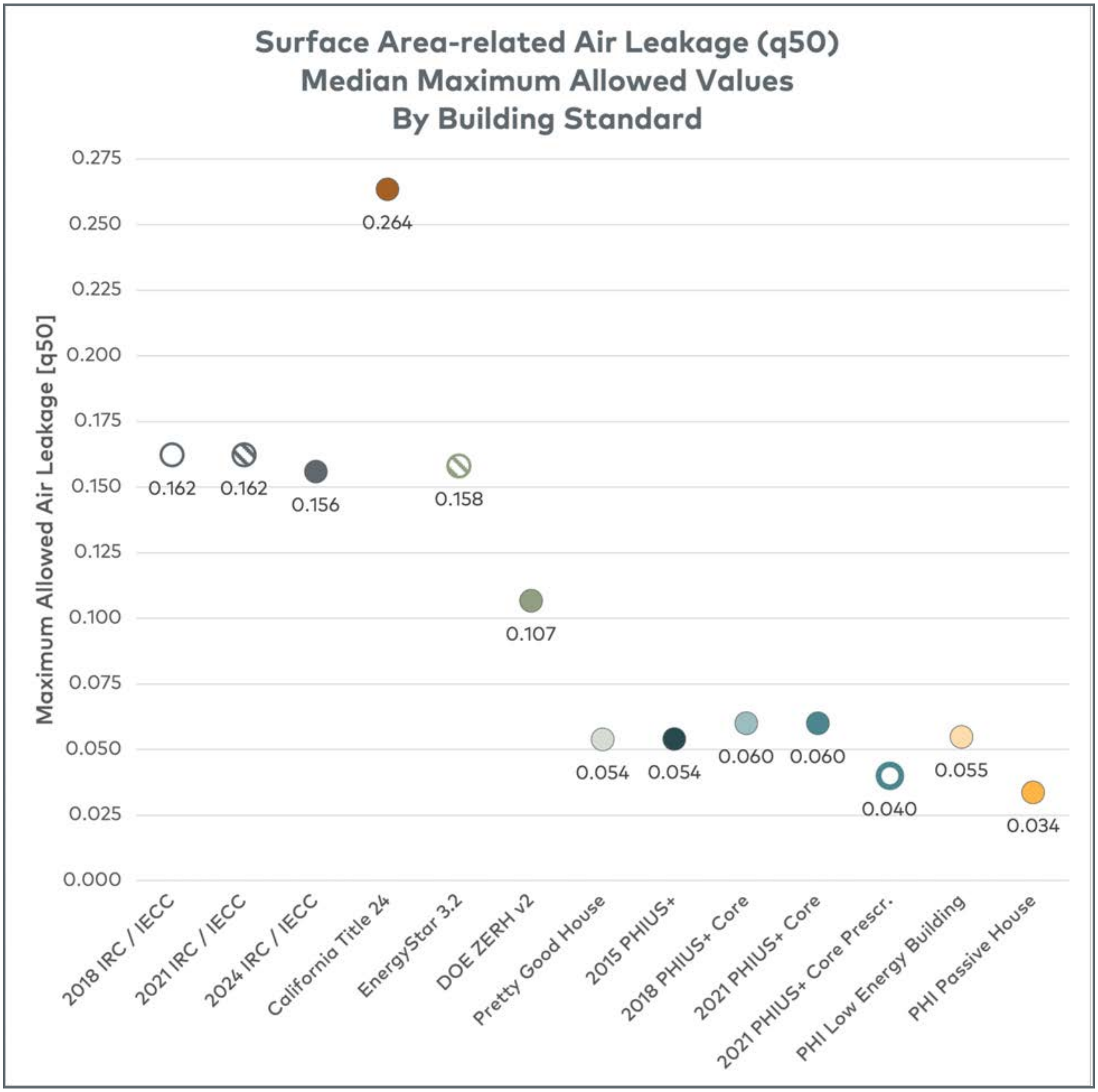

Image 29: Surface Area-related allowed air leakage for each building standard included in this report - median values across all projects.

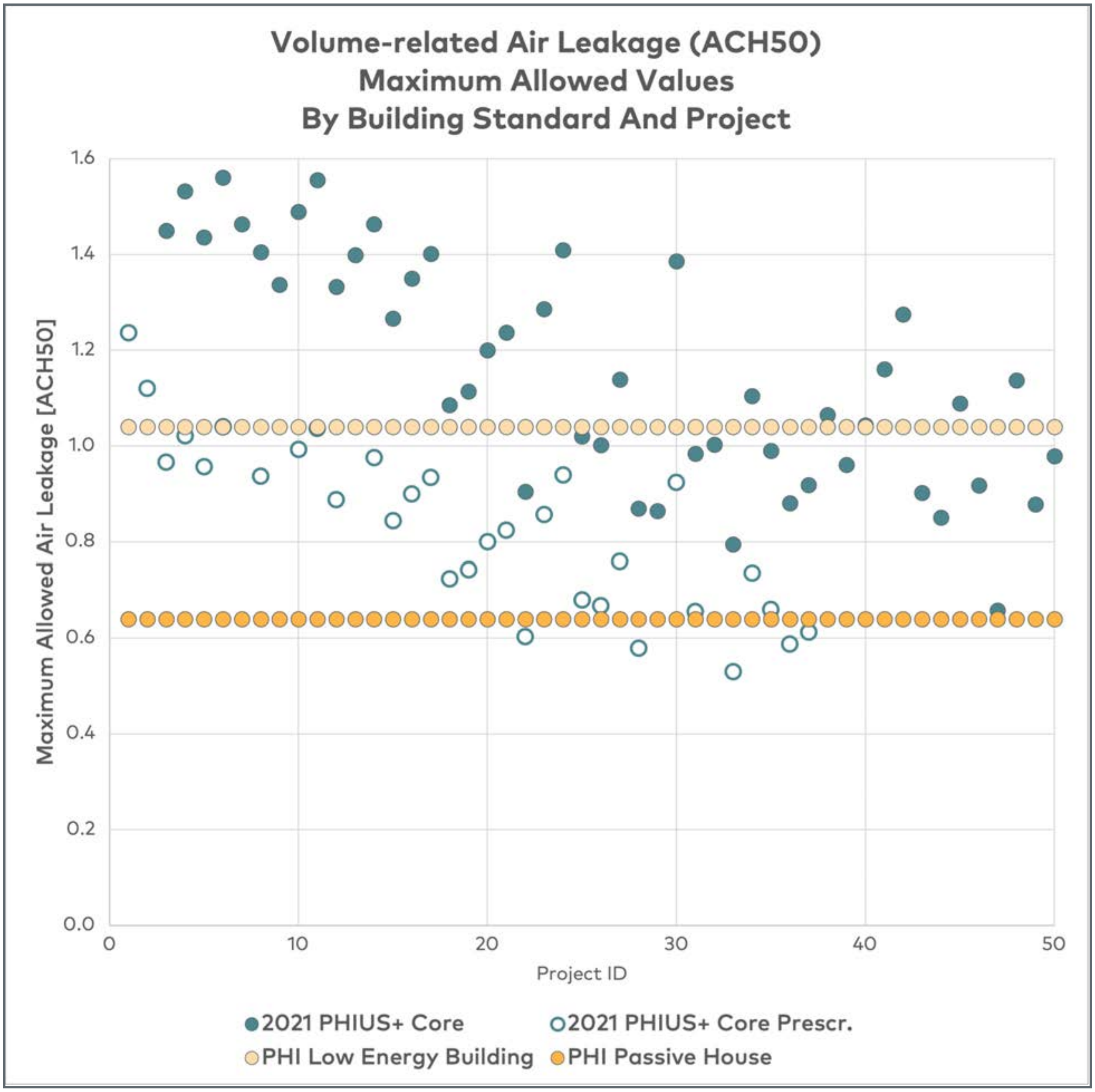

Image 30: Volume-related allowed air leakage for PHI and Phius standards, for each project included in this report.

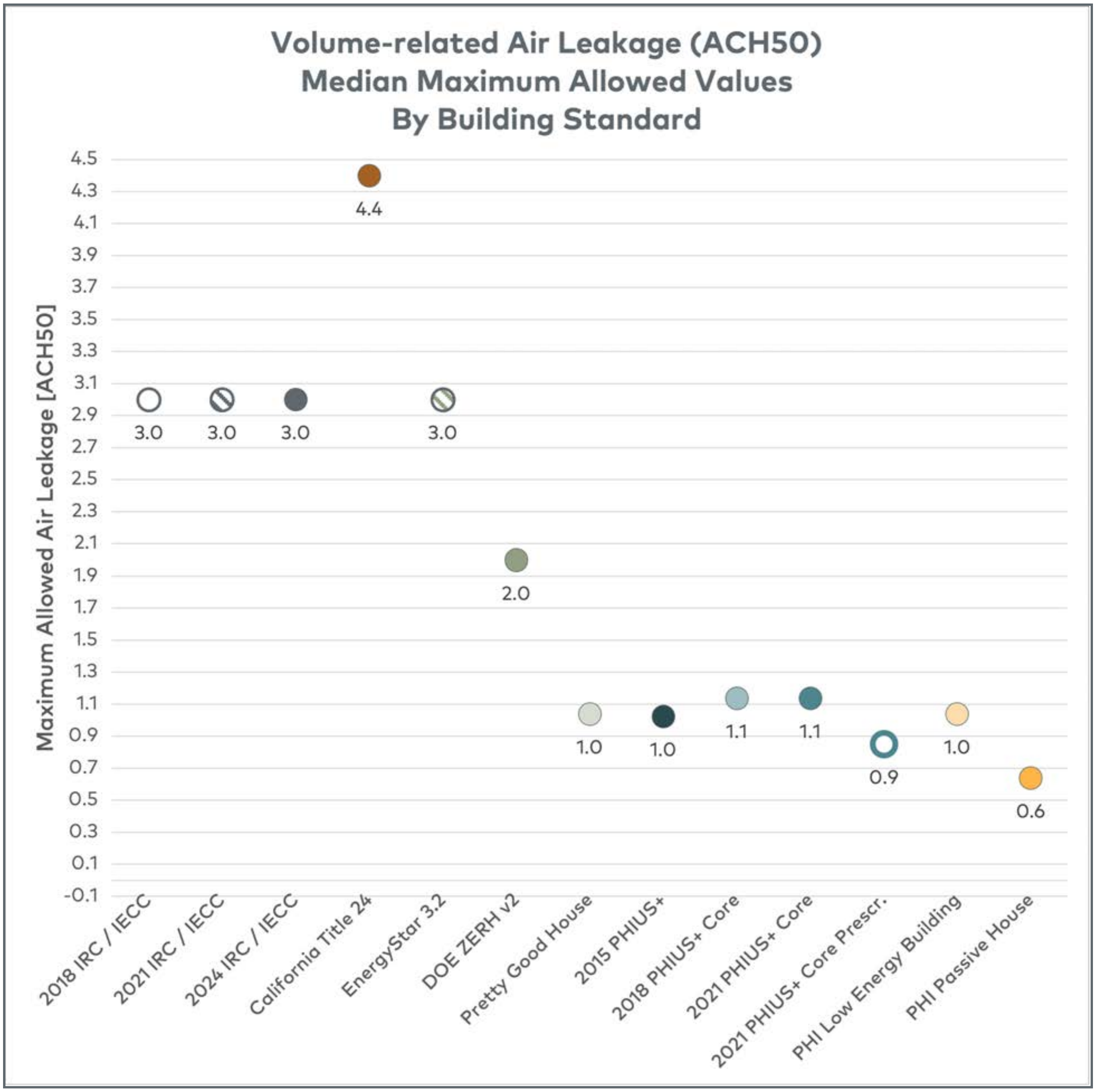

Image 31: Volume-related allowed air leakage for each building standard included in this report - median values across all projects.

For both volume- and surface area-related metrics, the median values show the following patterns:

- California Title 24 does not set maximum values for air leakage (the values shown refer to the assumption included in the modeling software
- The most stringent standard with regards to air leakage reduction is PHI Passive House.
- The second most stringent standard is the 2021 PHIUS+ Core Prescriptive standard, which is more stringent than the 2021 PHIUS+ Core performance-based standard
- Performance-based Phius standards (2018 PHIUS+ Core, and 2021 PHIUS+ Core) allow almost twice as much air leakage than PHI Passive House (0.060 cfm/ft2 as opposed to 0.034 cfm/ft2, or 1.1 ACH50 as opposed to 0.6 ACH50).

Avoidance Of Interstitial Condensation (interstitial dewpoint)

All building standards included in this report address the risk of condensation occurring within an assembly of a building.

One of the intentions of calling out this requirement here is to underline how this is a different phenomenon compared to surface mold/condensation occurring on interior surfaces of building components (see next paragraph).

Avoidance Of Surface Mold / Condensation (surface dewpoint)

This aspect has been illustrated in detail in the previous section under Indoor Air Quality.

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Resilience

For the purposes of this Report, we refer to resilience in terms of thermal resilience. Thermal resilience is the ability of a building to remain livable (in terms of interior temperatures) in case of a failure of the grid, or of the heating/cooling system.

Proof of concept of thermal resilience are provided by both the Ice Box Challenge events organized by the Passive House Network, and the Resilience Test run by Emu as part of the Passive House Boot Camps.

For the Ice Box Challenge, two mini buildings are built: one constructed to meet the local building code, and the other to meet PHI Passive House. They are filled with ice, and left to the elements for the same amount of time. Once the time is up, the remaining ice is weighted for the Code-built and Passive-built boxes. The Passive House-built box always outperforms the Code-built box, as it keeps about twice the amount of ice. This shows how Passive can keep the building "cool" even in hot weather conditions.

Emu's Resiliency Test works in a similar way as the Ice Box Challenge. During a week of Passive House Training (aka Emu's Passive Design/Build™ Boot Camp), participants assemble "Passive Pods" (or miniature houses) where they learn to insulate, air seal, install Passive House windows, etc.. At the end of the workshop, the Passive Pods are heated up together with one Pod built to the 2021 IECC building standard. Once warm, the heating is turned off, and all Pods are moved to the exterior. The winning Pod is the Pod that stays the warmest overnight with no heating. Passive Pods consistently outperform the Code Pod, by keeping the interior several degrees warmer. This shows how Passive can keep the building warm even in case of grid or system failure.

Image 32 shows the Ice Box Challenge carried out in downtown Denver, CO, during the 2023 Passive House Network conference. Image 33 show Emu's Pods undergoing the Resilience Test, with the results shown in Image 34.

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Image 32: Ice Box Challenge in Denver, CO, during the 2023 Passive House Network conference.

Image 33: Resiliency Test carried out at the end of one of Emu's Passive Design/Build Boot Camps.

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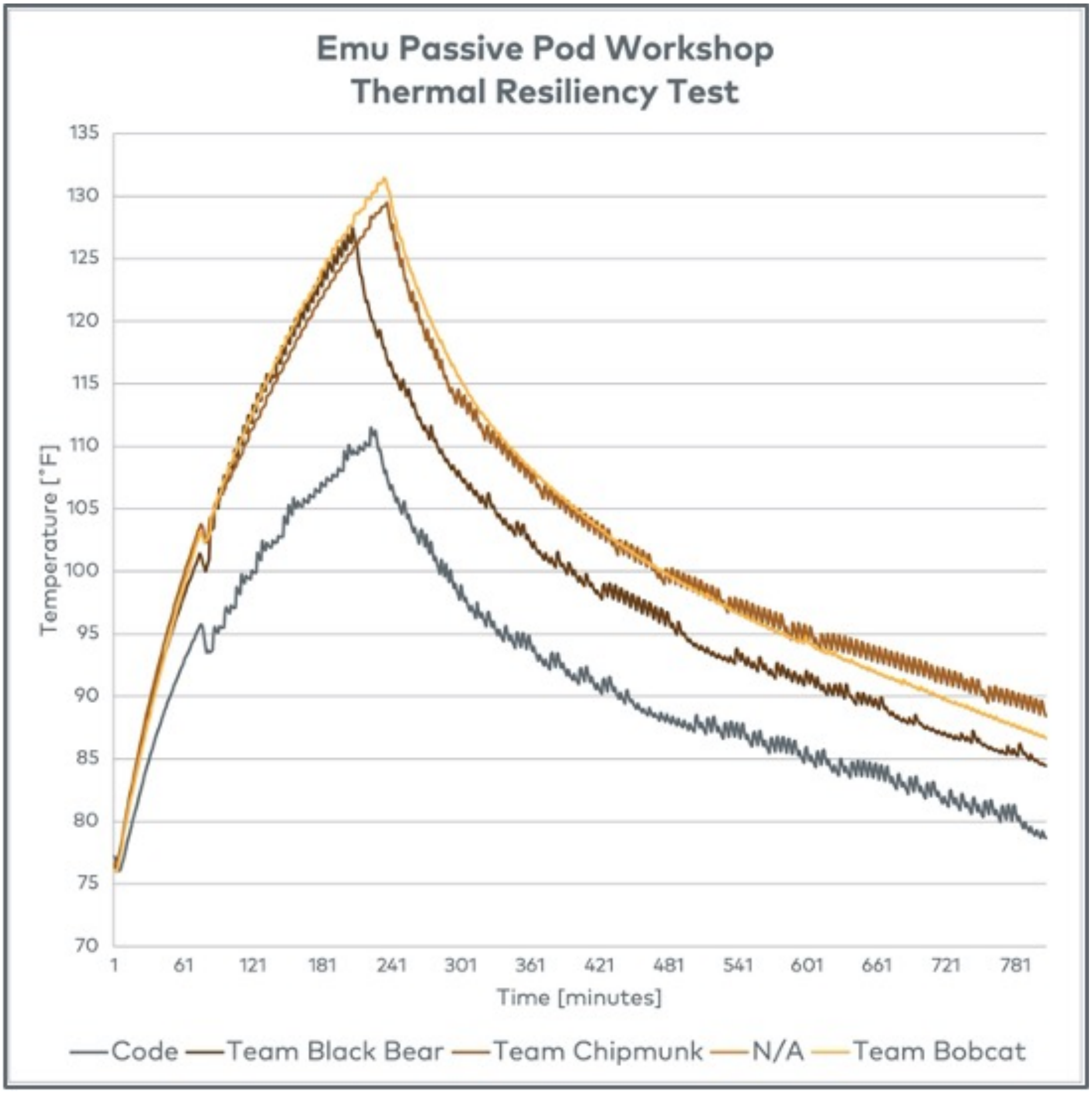

Image 34: Results of a Resilience Test at the end of one of Emu's Passive House Design/Build Boot Camps. Passive Pods consistently outperform a Code-built Pod in keeping the building warmer with no active heating provided.

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Inclusive R-value (IR-value)

The concept of the "inclusive R-value" was developed as part of this research in order to compare the ability of a building to remain thermally consistent independently from exterior changing conditions.

The inclusive R-value is defined as the peak heating load, divided by the total surface area of the building envelope, and by the delta T used in calculating the peak heating load:

$$\text{IR-value} = 1 / (HL\_p / (A\_e * dT\_p))$$

Where:

- HL_p: peak heating load for the building
- A_e: total surface area of the building thermal envelope
- dT_p: delta T used in calculating the peak heating load.

In the Inclusive R-value, we account for heat losses due to:

- building assemblies
- thermal bridging
- windows, ext. doors, etc.
- air leaks
- losses through fresh air ventilation (incl. degree of heat recovery of the ERV/HRV)
- all other heat losses that contribute to the heating load

The median IR-values for each building standard considered are shown in Image 35. Here we can see how little the thermal envelope improves form the 2021 ICC to the 2024 IECC draft. More on this later in this paper.

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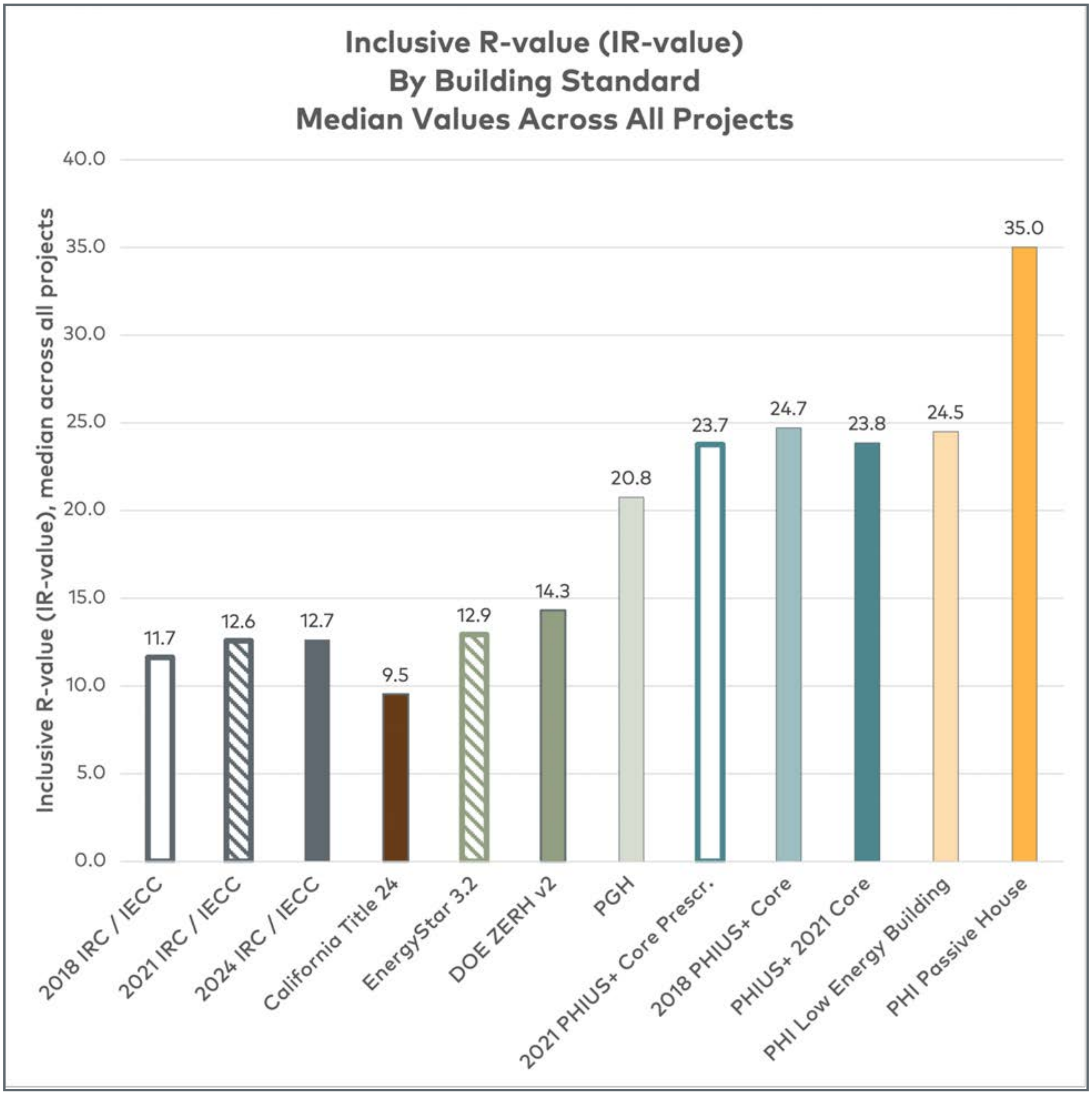

Image 35: Inclusive R-value (IR-value) by building standard, median value across all projects.

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Image 36 benchmarks the IR-values against the baseline of the 2018 IECC, whereas Image 37 benchmarks them against the baseline of PHI Passive House.

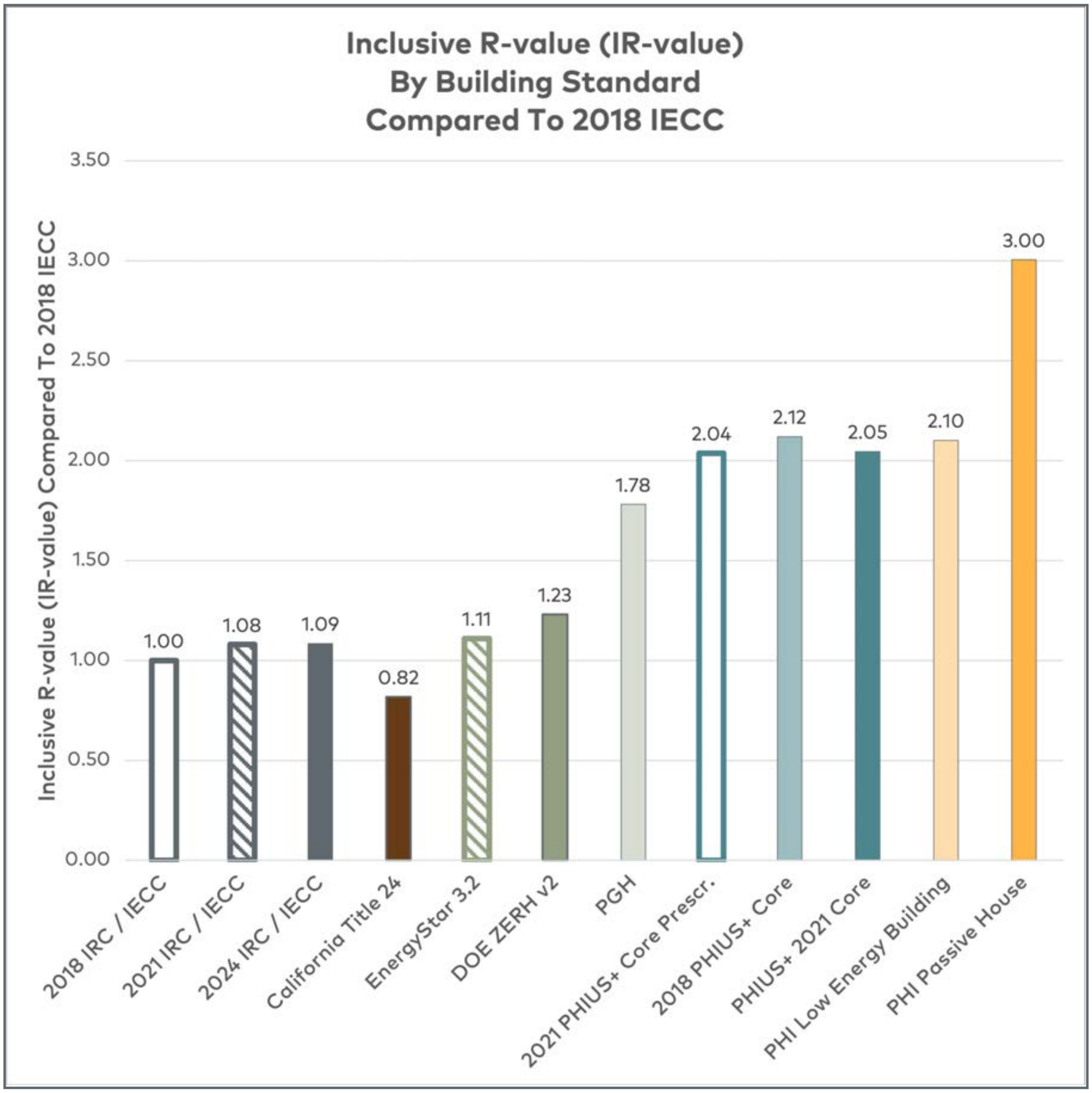

Image 36: IR-values by building standard, benchmarked against the median IR-value of the 2018 IECC standard

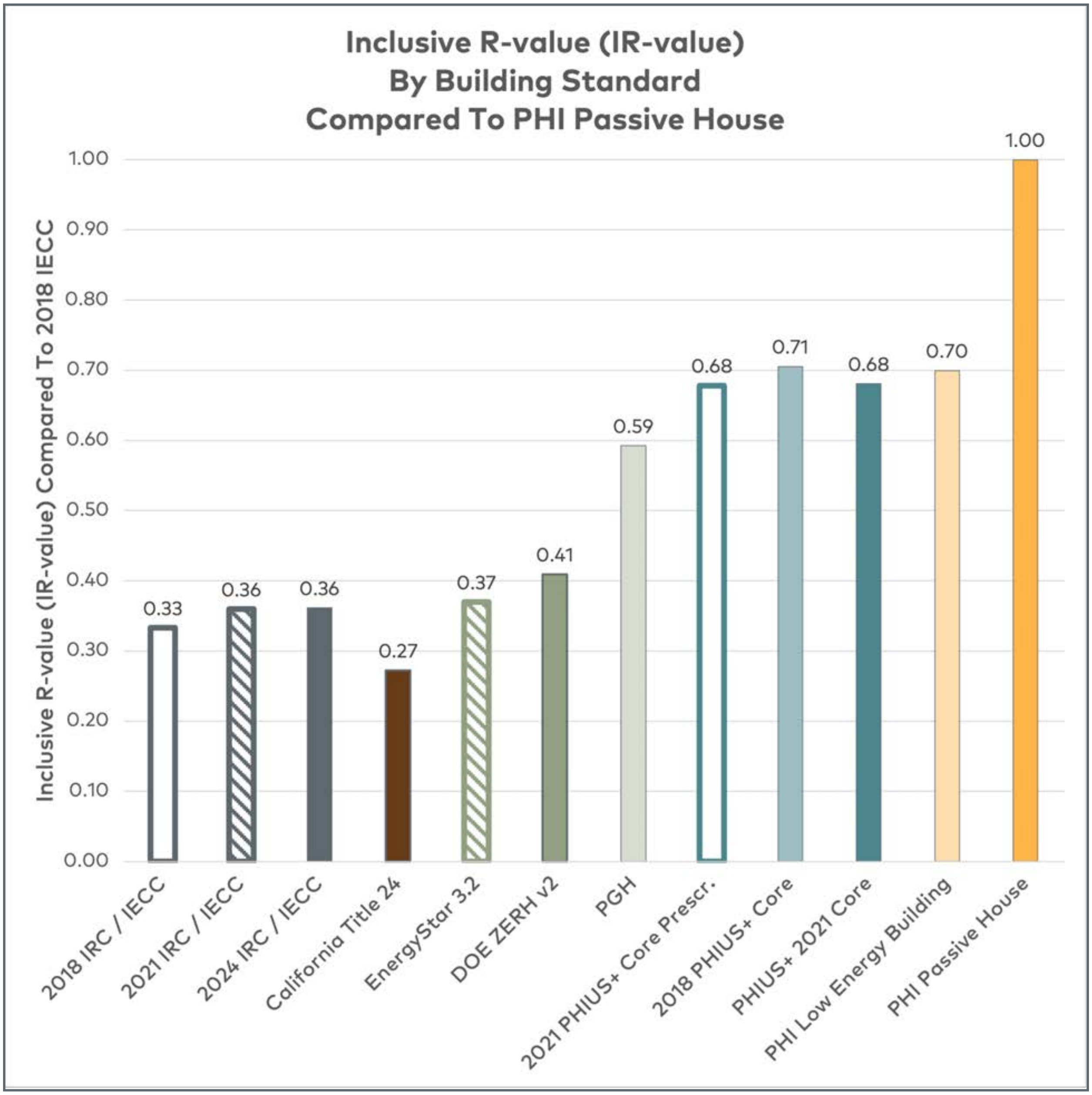

Image 37: IR-values by building standard, benchmarked against the median IR-value of the PHI Passive House standard

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In terms of thermal resilience, Images 35-37 show that:

- the 2021 IECC provides some minor improvements on the overall "thermal protection" compared to the 2018 IECC
- compared to the 2021 IECC, the current draft for the 2024 IECC update provides no significant improvements
- with the exception of PHI Passive House, the other Passive standards (2018 PHIUS+ Core, 2021 PHIUS+ Core, 2021 PHIUS+ Core Prescriptive, and PHI Low Energy Building) show similar performance in terms of inclusive R-value (IR-value)
- PHI Passive House significantly outperforms all other building standards in terms of inclusive R-value (IR-value).
- California Title 24 has the worst performance in terms of inclusive R-value, due to the low requirements it sets for the building envelope (R-values, windows, etc.), and for the much higher allowance for air leaks compared to any other standard considered.

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Scoring: Durability + Resilience

The combined scoring results for durability and resilience are shown in Table 09, which is based on the motivations illustrated above.

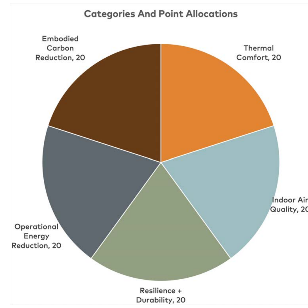

Image 38 provides a graphical representation of the results.

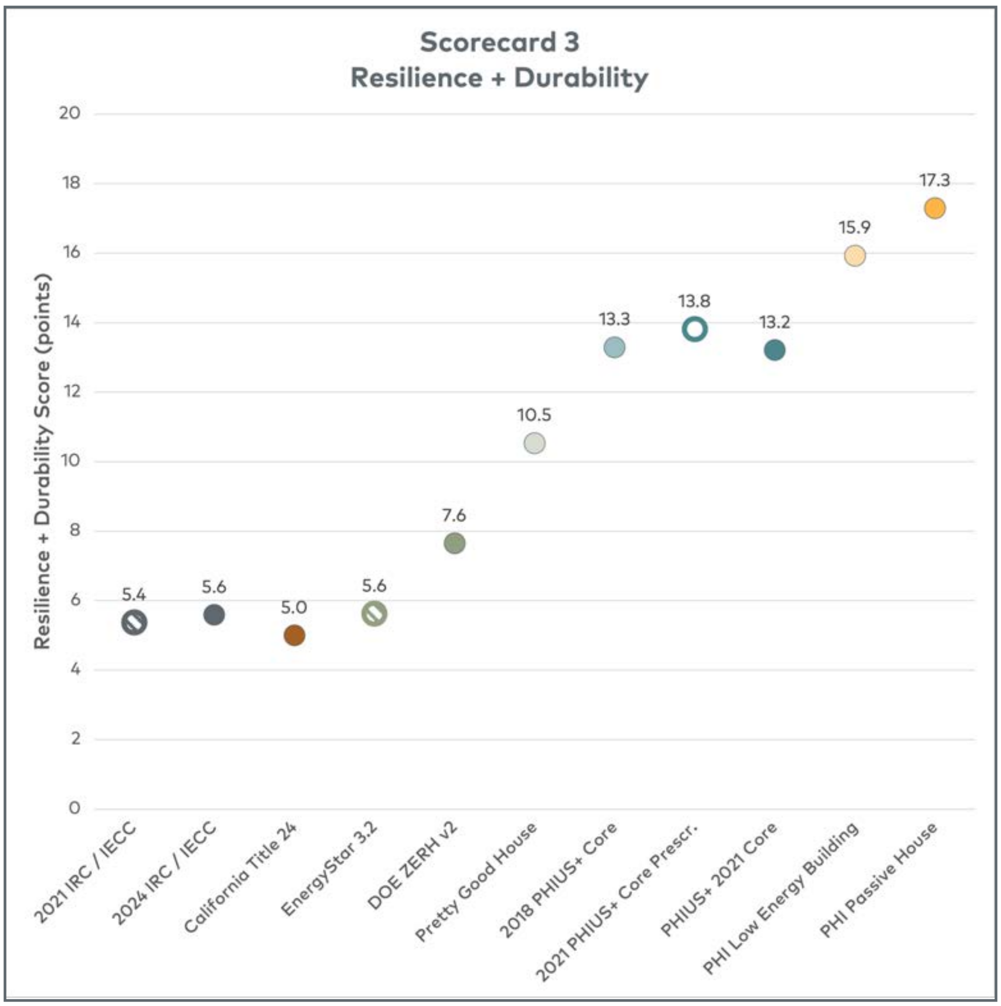

Image 38: Scoring for the resilience and durability criteria, for the different criteria covered in this section of the study.

Scorecard 3

Resilience + Durability

	Air Leakage Reduction	Avoidance Of Interstitial Condensation	Avoidance Of Mold And Surface Condensation	Thermal Resiliency		Total
	q50	int. depwoint	fRsi	IR-value		
Criteria	Leakage reduction comp. to 2018 IECC	avoidance via analytical method	avoidance via analytical method	Inclusive R-value (IR-value)		
Motivation	protects bldg from moisture damages (air exfiltration)	protects bldg from moisture damages (interst. depoint)	protects bldg from moisture damages (surface depoint)	bldg remains comfortable if HVAC or grid fail		
Points Available	5	5	5	5		20
2021 IRC / IECC	0.0%	yes	no	7.4%		5.4
2024 IRC / IECC	3.9%	yes	no	7.9%		5.6
California Title 24	-62.4%	yes	no	-22.1%		5.0
EnergyStar 3.2	2.5%	yes	no	9.9%		5.6
DOE ZERH v2	34.2%	yes	no	18.7%		7.6
Pretty Good House	66.8%	yes	no	43.8%		10.5
2018 PHIUS+ Core	63.0%	yes	partially	52.8%		13.3
2021 PHIUS+ Core Prescr.	75.4%	yes	partially	50.9%		13.8
PHIUS+ 2021 Core	63.0%	yes	partially	51.1%		13.2
PHI Low Energy Building	66.2%	yes	yes	52.4%		15.9
PHI Passive House	79.2%	yes	yes	66.7%		17.3

Baseline:	2018 IECC
Values < 0	It means that for that metric, the building standard performs worse than the 2018 IECC
q50	surface-related air leakage of the building envelope
int. dewpoint	analysis method to prevent interstitial condensation inside building assemblies
fRsi	analysis method to prevent mold and condensation on the interior surfaces
IR-value	inclusive R-value, accounts for all heat losses in the building thermal envelope

Table 09: scoring for the durability and resilience criteria, for each building standard considered

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METRICS: BUILDING PERFORMANCE

This section of the Report addresses building performance in terms of operational energy efficiency, and embodied carbon / resource efficiency.

Here we also include findings that were not part of the scope of the research, but that were deemed important in informing the conversation about building standards. These are described under the "Side Findings" section of this Report.

Additional Findings

Breakdown of Heat Losses

In developing PHPP models for so numerous projects, we had the opportunity to investigate where most of the heat losses occur.

In training Passive House professionals across the US, we have a chance to test the perception of the "general public" of the construction industry as to what should be given higher priority in order to make buildings more energy efficient.

A clear example of that is the perception that air leaks may account for 30-50% of the total heat losses of a building. We're not sure where that came from, and if that is even based on data, or if so, how old that data may be. .

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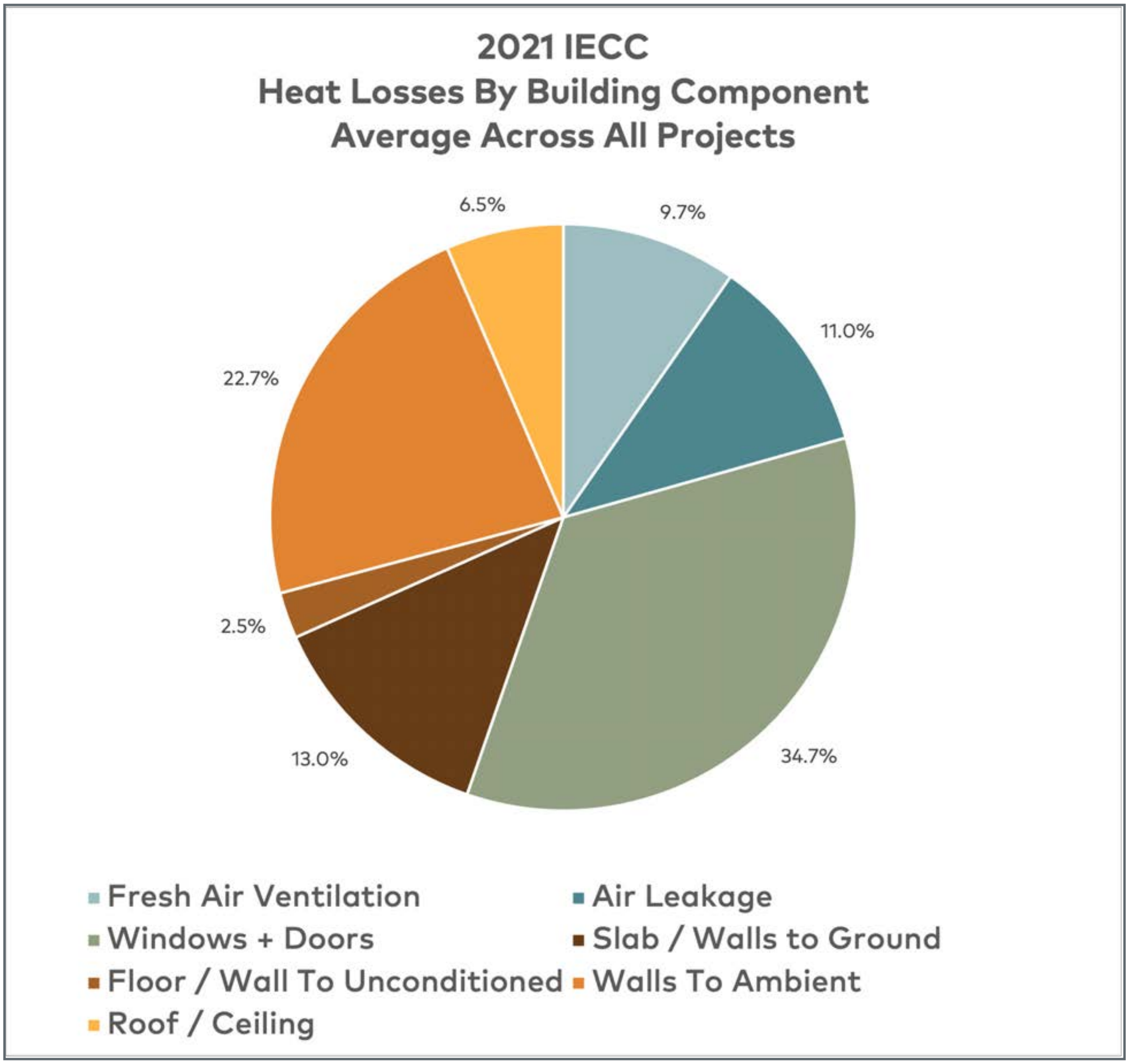

Image 39: Breakdown of average heat losses for the projects included in this report, assuming compliance with the 2021 IECC prescriptive requirements

Air sealing is crucial for building durability, indoor air quality, and thermal comfort purposes. It is also important for energy efficiency reasons, but far less than what the general public believes.

The breakdown of heat losses for the projects considered in this study is shown in Image 39, assuming the 2021 IECC prescriptive requirements being used for the building envelope.

The following components to cause the highest heat losses in Code-built buildings (from highest to lowest):

1. windows (incl. exterior doors, skylights, etc.), transmission heat losses (air leakage accounted for under "air leaks")
2. exterior walls
3. heat losses through the ground, to the outside (via e.g. slab on grade, or walls of conditioned basement)
4. air leaks (anywhere in the building, to the exterior)
5. fresh air ventilation (incl. lack of heat recovery)

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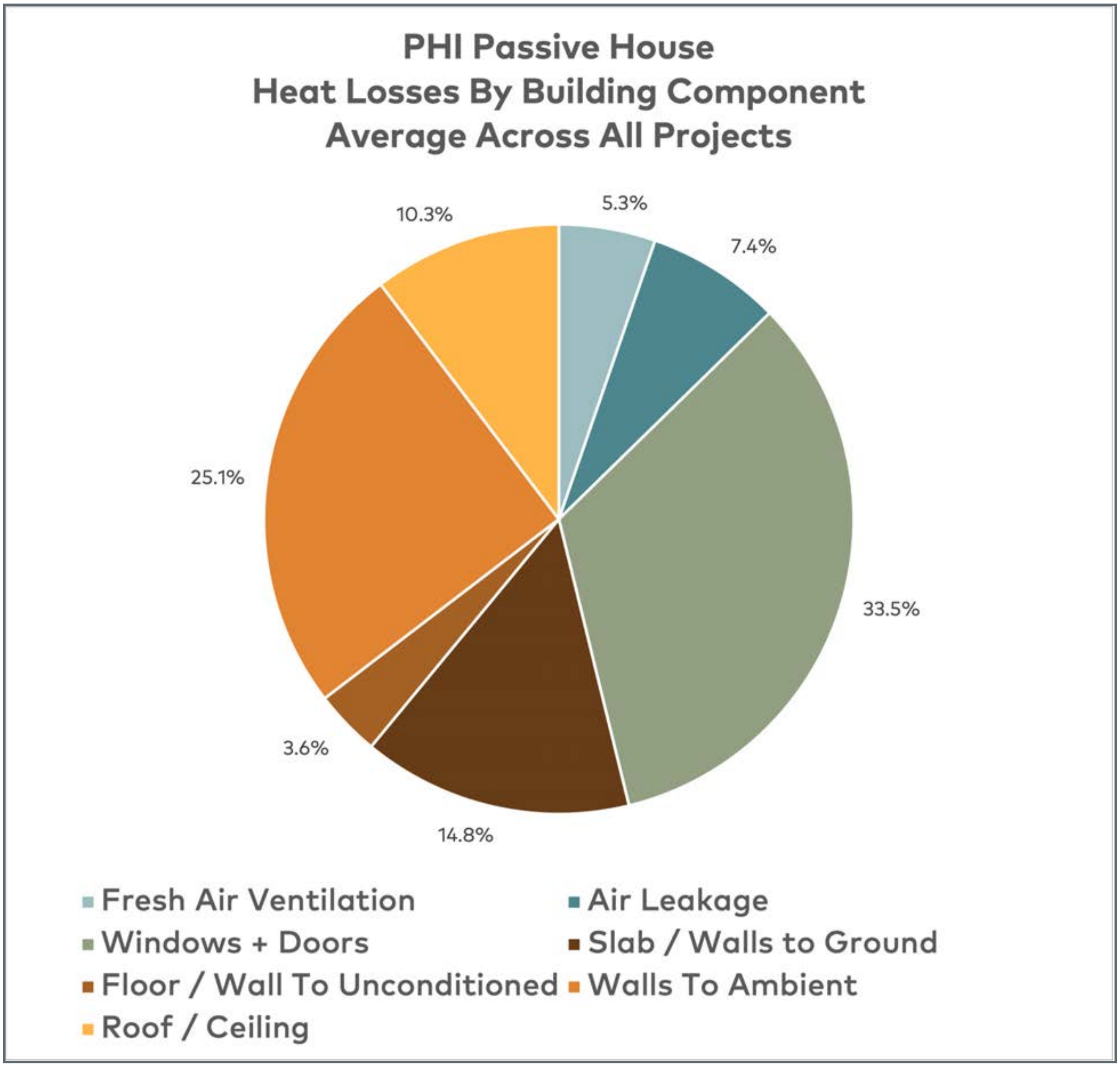

Image 40: Breakdown of average heat losses for the projects included in this report, assuming compliance with PHI Passive House requirements

Image 40 shows the breakdown of heat losses, assuming the compliance with the most performing building standard (PHI Passive House).

For Passive House-built buildings (PHI), the following components to cause the highest heat losses (from highest to lowest):

1. windows (incl. exterior doors, skylights, etc.), transmission heat losses (air leakage accounted for under "air leaks")
2. exterior walls
3. heat losses through the ground, to the outside (via e.g. slab on grade, or walls of conditioned basement)
4. Roof/ceiling
5. air leaks (anywhere in the building, to the exterior)
6. fresh air ventilation (incl. heat recovery)

Remarkably, the breakdown of typical heat losses are fairly similar between Code-minimum (2021 IECC), and Passive House (PHI). In absolute terms however, Passive House has dramatically lower heat losses, as shown in Image 41.

From looking at the heat loss breakdown, the takeaways are:

- no matter the building standard, windows, ext. doors etc. are the main source of heat losses, accounting for over 1/3 of the total
- Passive House standards set minimum performance requirements for windows/ext. doors based on comfort (see previous section). This typically results in much more stringent requirements than other building standards
- reduction of air leaks is very important for overall building quality (i.e. durability, comfort, IAQ), but often greatly overrated in terms of energy efficiency.

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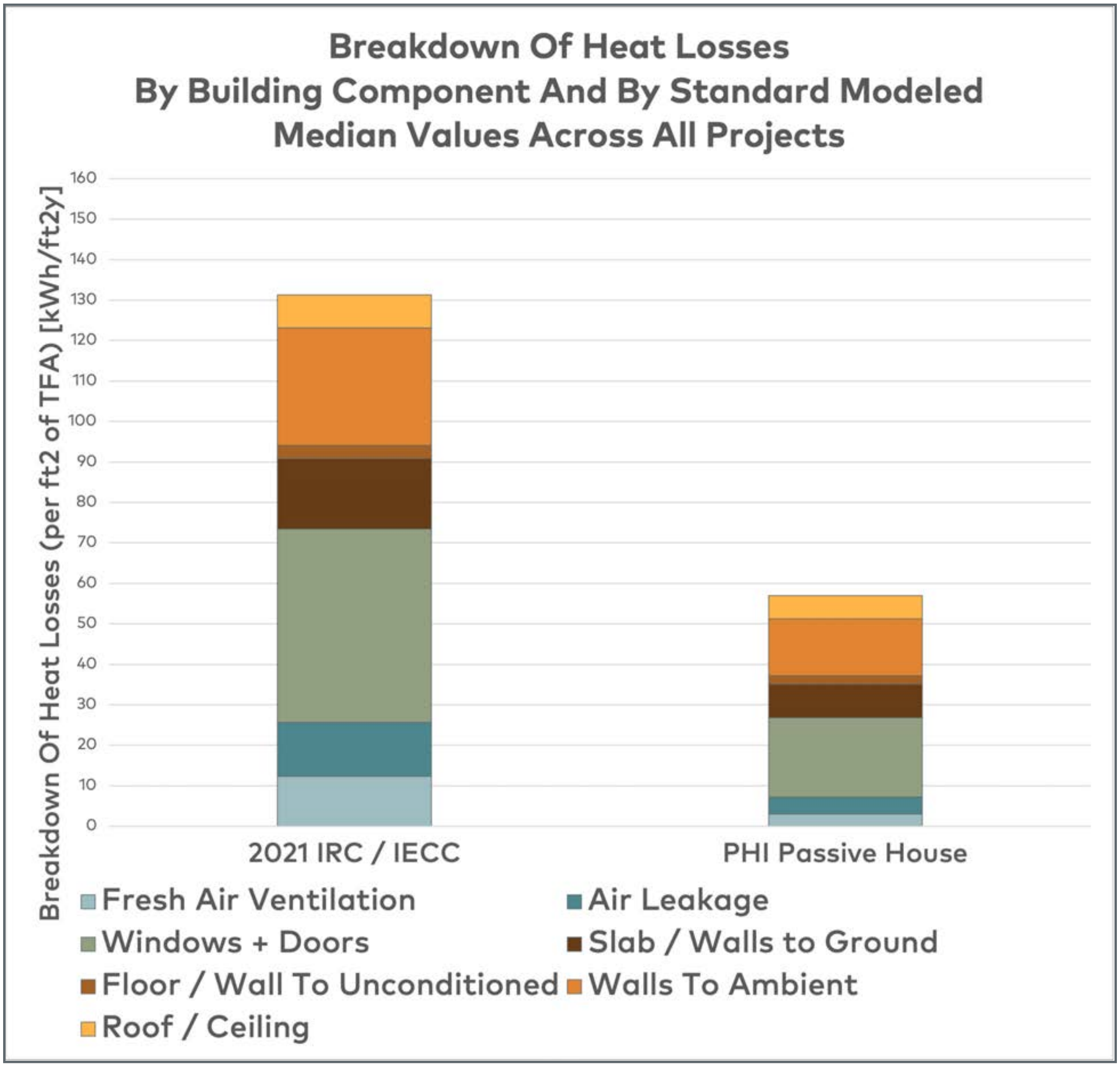

Image 41: Typical breakdown of heat losses by building components, comparing 2021 IECC-built projects vs PHI Passive House-built projects.

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Priorities: Heating vs Cooling

For buildings to be efficient, they need to perform well in both Summer and Winter. A long standing myth about Passive building standards is that they perform better in cold climates, and less well in warm and hot climates. Internationally, PHI Passive House buildings have been successfully built and operated in some of the hottest and most humid climates; including Dubai, India, Australia, and Southern China (for reference, see the international database of Passive House buildings).

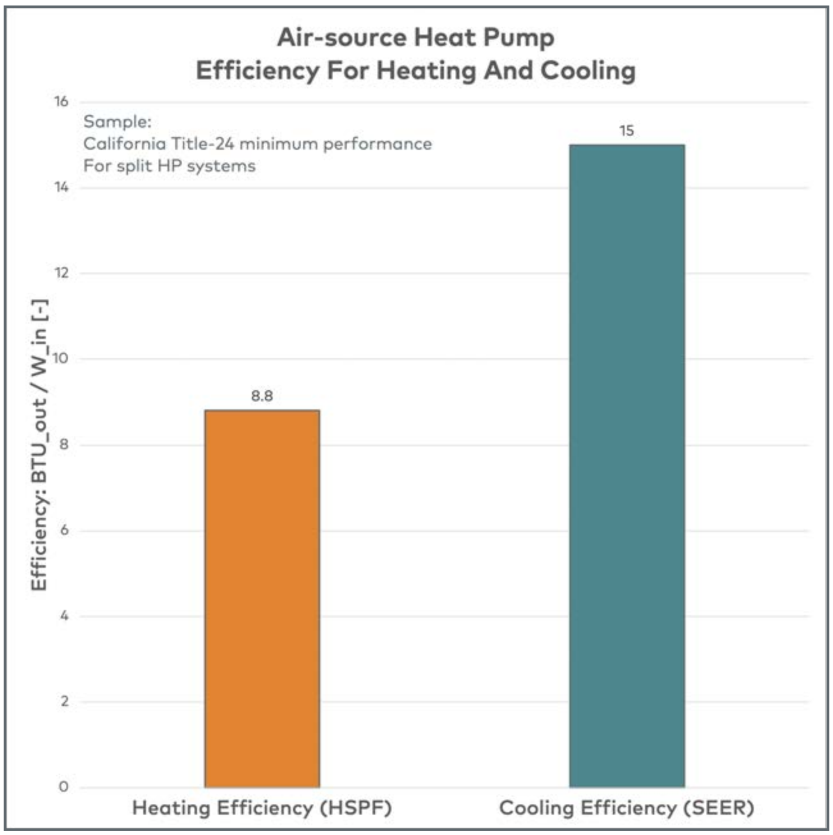

Image 42: efficiency for heating (HSPF) and for cooling (SEER) for a heat pump to comply with California Title 24. Cooling efficiency is typically around twice as high as the heating efficiency of the same heat pump.

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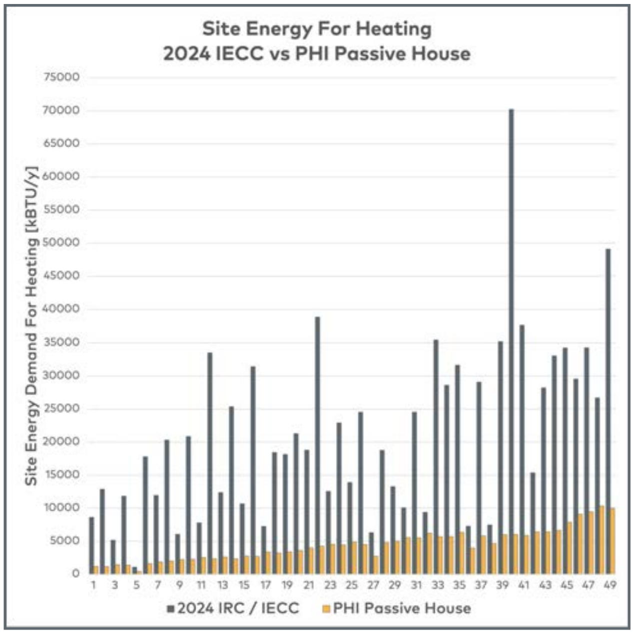

Image 43: Site energy demand for Heating, for projects complying with the 2024 IECC draft (grey), and with PHI Passive House (yellow)

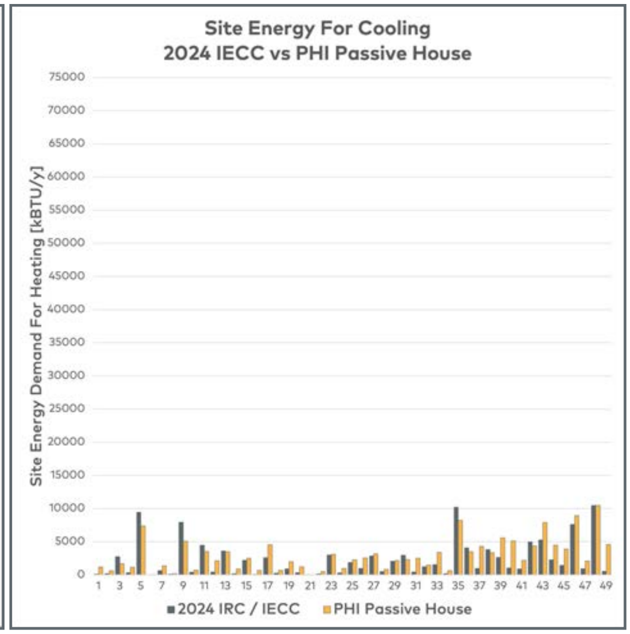

Image 44: Site energy demand for Cooling, for projects complying with the 2024 IECC draft (grey), and with PHI Passive House (yellow). Note that this graph is at the same scale as Image 43.

When working on projects located in warm and hot climates, we are often faced with a rooted disregard for the projects need for heating. Contrary to popular belief, heating causes a significant portion of a building's total energy consumption even in warm climates. In addition to that, the process of electrification via heat pumps has to thoroughly prioritize the reduction of heating via Passive building strategies, as heat pumps are greatly more efficient in generating cooling than in generating heating. The disproportion between cooling efficiency (SEER) and heating efficiency (HSPF) is illustrated in Image 42, which illustrate compliance requirements for types of heat pumps for California Title 24. Typically for the same heat pump, the efficiency for cooling can be expected to be around twice as high as its efficiency for heating.

Once the different efficiencies for heat pump heating and cooling are accounted for, it becomes more evident how heating demand reduction is a priority for warm climates. Images 43 and 44 compare the need for heating and cooling for the projects included in this report, if they are built to meet the 2024 IECC draft (grey), or PHI Passive House (yellow).

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Evolution Of Energy Code (i.e. 2024 IECC vs 2021 IECC)

The energy modeling executed for this Report also gave an opportunity to compare the current draft for the 2024 IECC prescriptive requirements to the 2021 IECC.

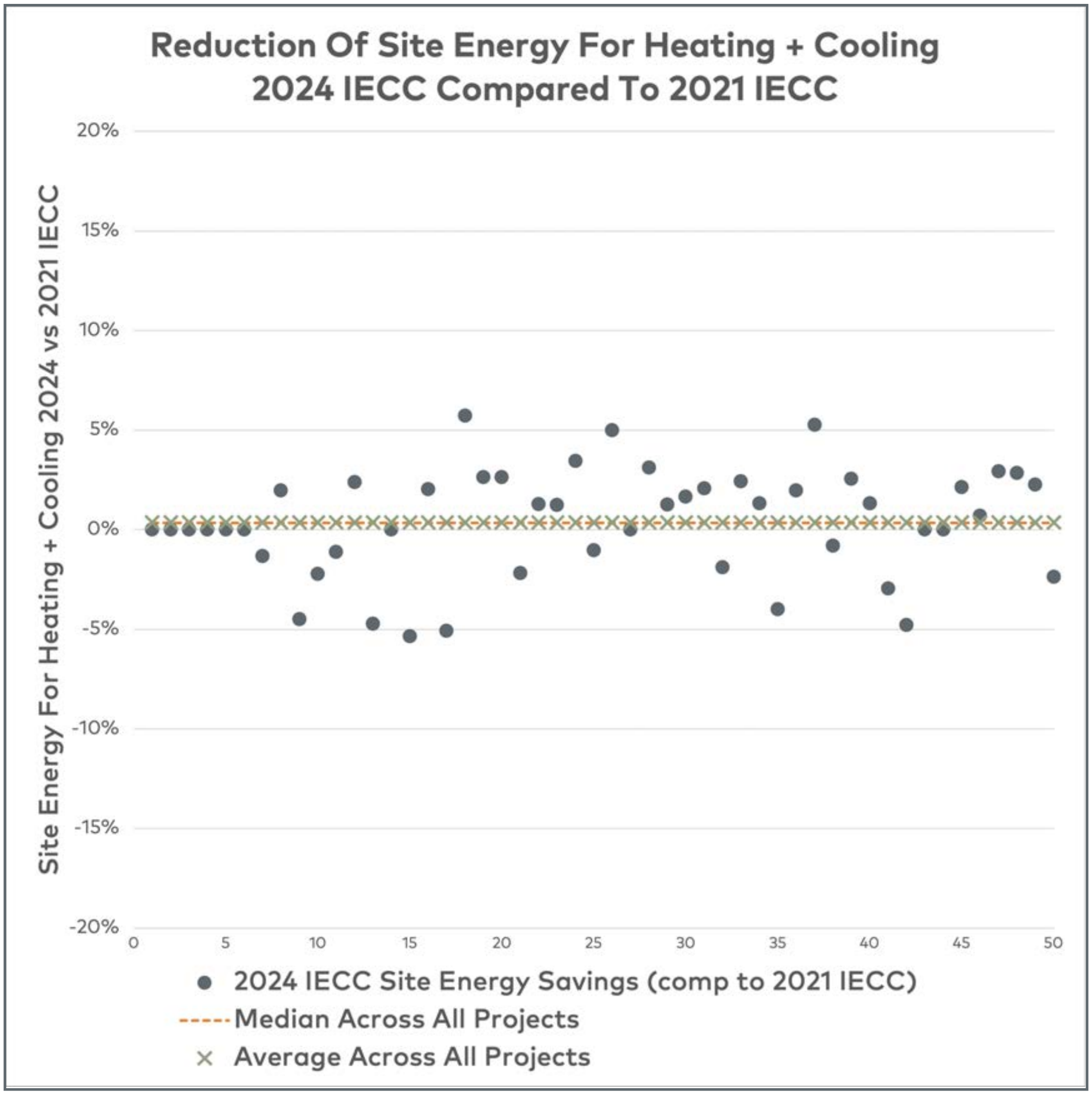

Image 45: Reduction of site energy for heating and cooling for the 2024 IECC draft, compared to the 2021 IECC

Image 45 shows the variation of the combined site energy demand for heating and cooling for the projects in this report, if they are built to meet the 2024 IECC draft, compared to meeting the 2021 IECC requirements.

The results are discouraging, as on average the 2024 IECC draft shows no significant improvements over the 2021 IECC.

Actually, on average buildings built to the 2024 IECC draft perform about 1% worse than the same buildings built to the 2021 IECC.

In other words, under the draft used for this research, the adoption of the 2024 IECC will not provide any significant improvements compared to the 2021 IECC.

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Operational Energy Efficiency

One of the goals for the building standards investigated in this Report is to improve on the energy efficiency of buildings. Specific requirements of each building standard were illustrated earlier in this Report, and Appendix A provides detail requirements for each project.

Each combination of project and applicable building standard was modeled in PHPP, according to the assumptions and conditions illustrated above.

The following sections summarize the resulting operational energy consumption levels for each building standards, and improvements over the baseline of the 2018 IECC standard.

Site Energy For Heating + Cooling

The site energy demand for heating and cooling was calculated in PHPP, on the basis of building standard-specific requirements for the building envelope, overall modeling assumptions, as well as performance requirements for heat pump heating and cooling.

The site energy for heating and cooling was calculated assuming a heat pump used to generate heating and cooling. The performance of said heat pump was simulated from the minimum performance requirements for heating and cooling (HSPF, SEER) prescribed by each building standard. These are illustrated in Table 10. For building standards that do not set minimum performance requirements for heat pumps, the "basic heat pump" listed in Table 10 was assumed.

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Heat Pump Performance Requirements				
Type	SEER	HSPF	Climate	Notes
Basic*	15	8.2	any	
California Title-24 HP	15	8.8	any	
EnergyStar	16	9.2	any	
DOE ZERH type 1	18	9.2	warm climates	
DOE ZERH type 2	16	9.2	mild climates	
DOE ZERH type 3	16	9.5	cold climates	
PHIUS+ 2021 Prescriptive type 1	18	9.6	warm climates	
PHIUS+ 2021 Prescriptive type 2	15	9.2	cold climates	COP ≥ 1.75 @ 5˚F
*	"Basic" unit used in the modeling for building standards that don't include specific requirements for heat pump, i.e. IECC, PHIUS performance-based, and PHI (all)			

Table 10: Heat pump performance requirements for the building standards investigated in this Report.

Image 46 shows the combined heating and cooling demand for individual projects included in this Report, depending on which building standard is applied to them.

Images 47, 48, and 49 respectively show the average reduction results for warm, mild, and cold climates. Image 50 shows the average results across all projects

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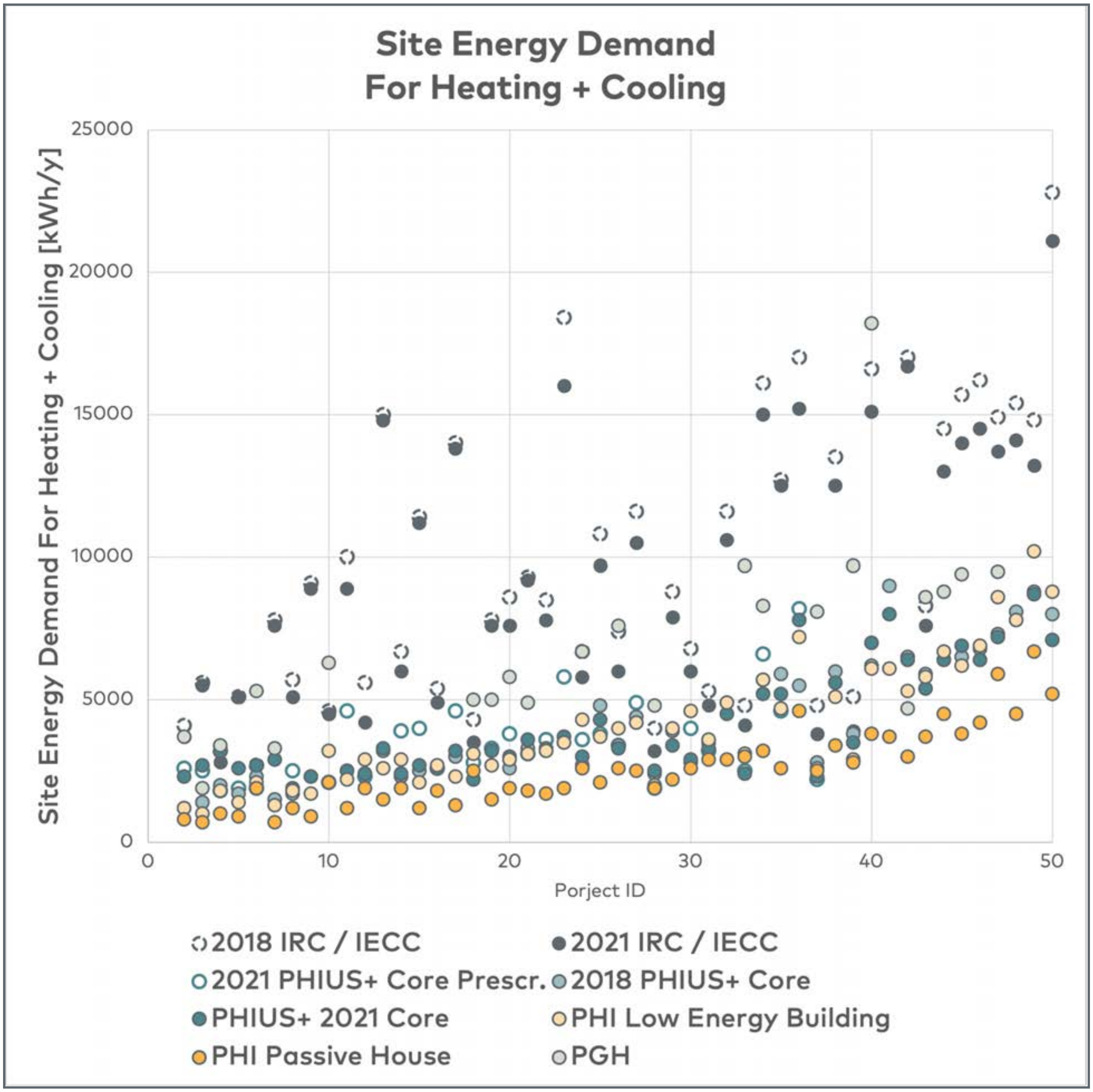

Image 46: Combined site energy demand for heating and cooling for each project, depending on which building standard is implemented

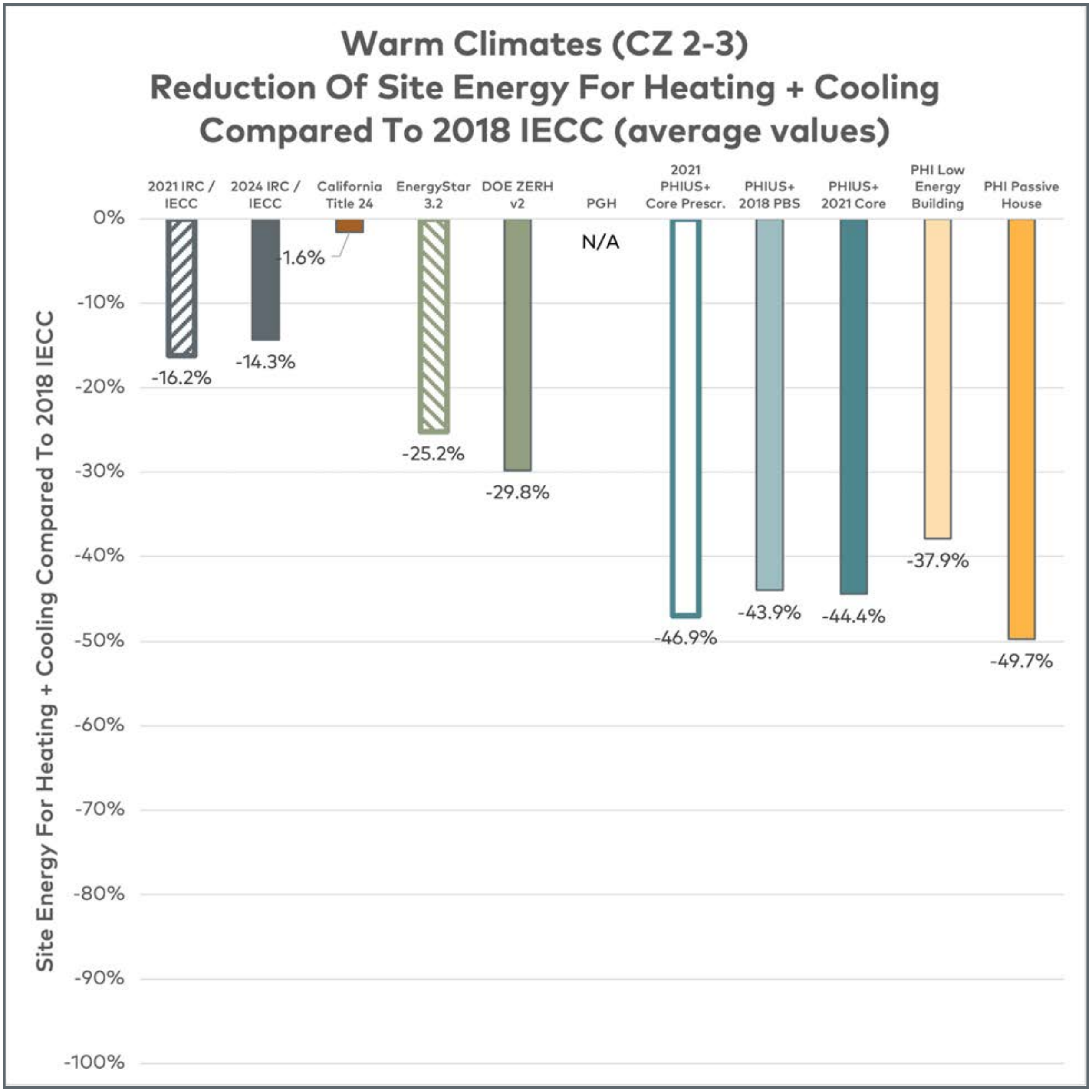

Image 47: Average reduction of combined site energy for heating and cooling for projects located in warm climates

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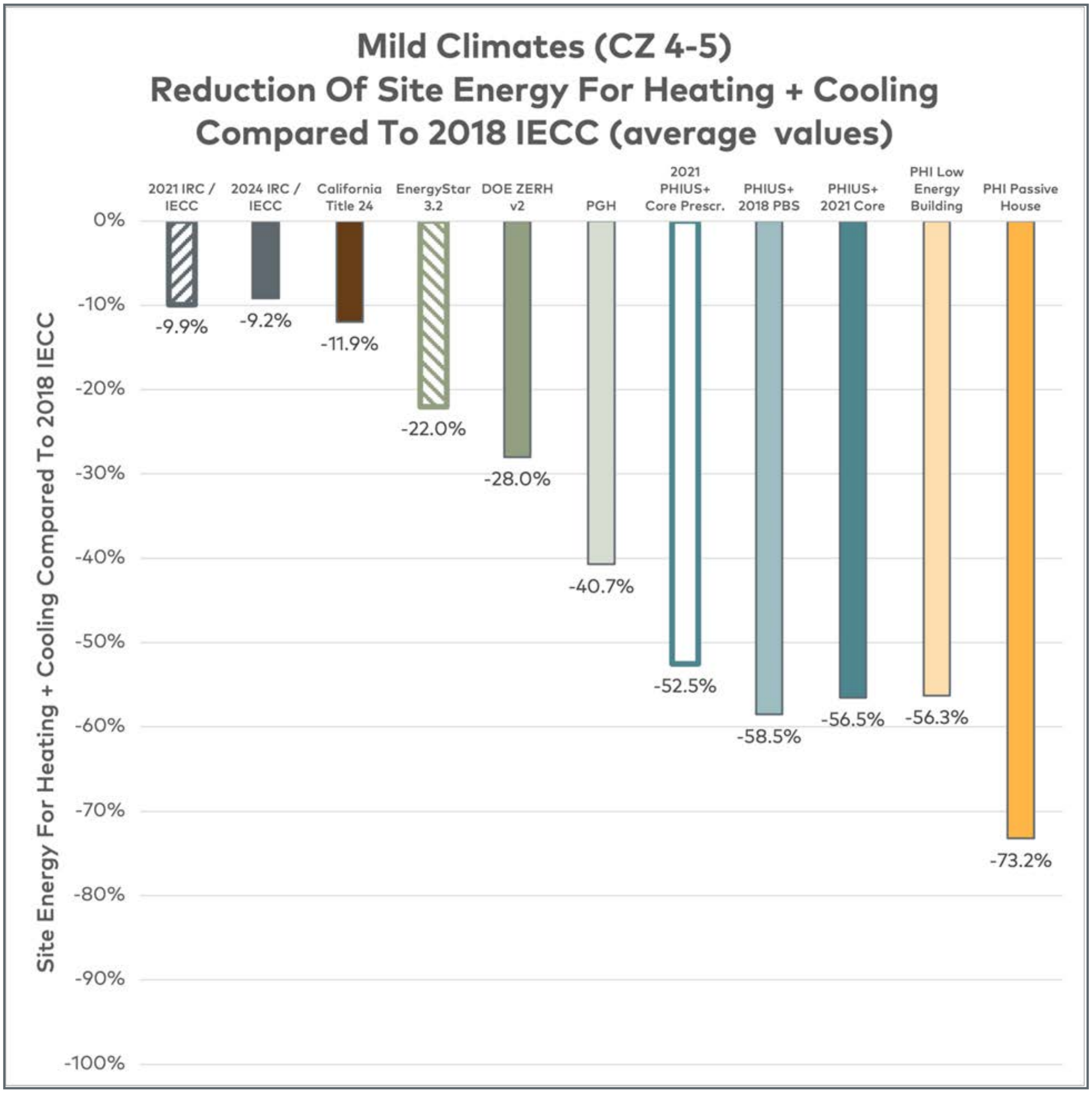

Image 48: Average reduction of combined site energy for heating and cooling for projects located in mild climates

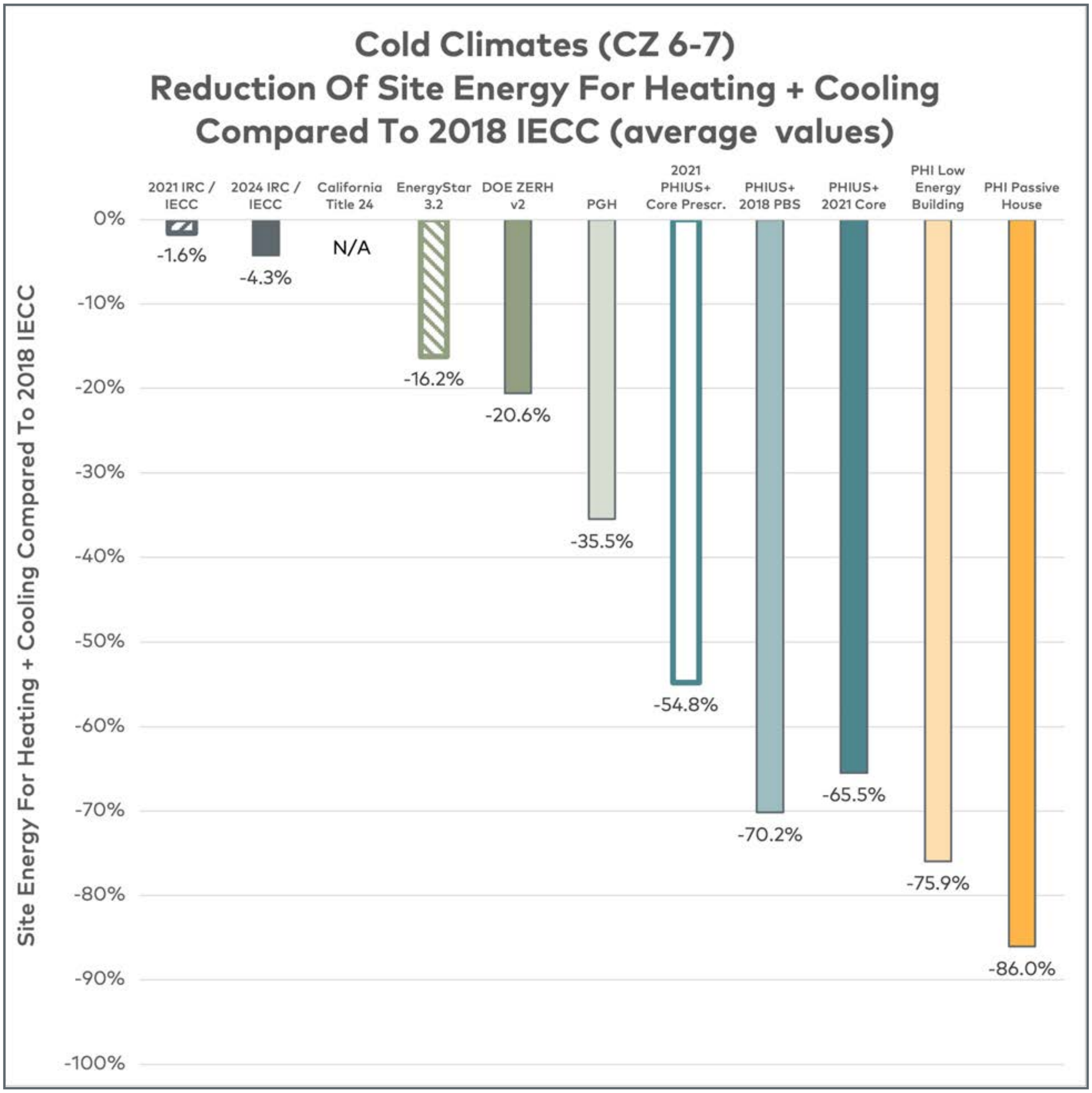

Image 49: Average reduction of combined site energy for heating and cooling for projects located in cold climates

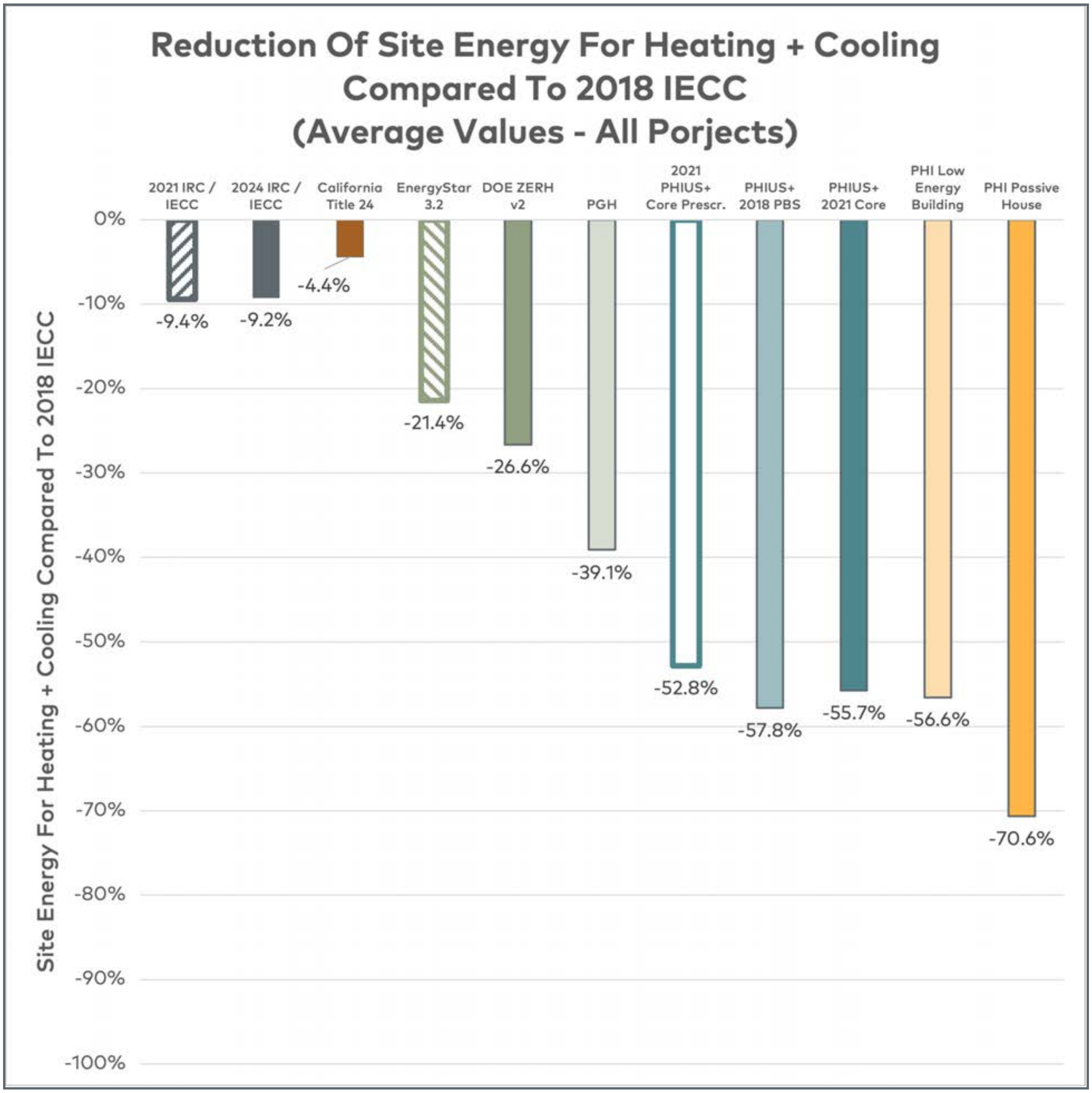

Image 50: Reduction of combined site energy for heating and cooling - average values across all projects.

Image 51 benchmarks the average combined site energy for heating and cooling for each building standard against the average 2018 IECC performance. Image 52 does the same, with the benchmark of the PHI Passive House performance.

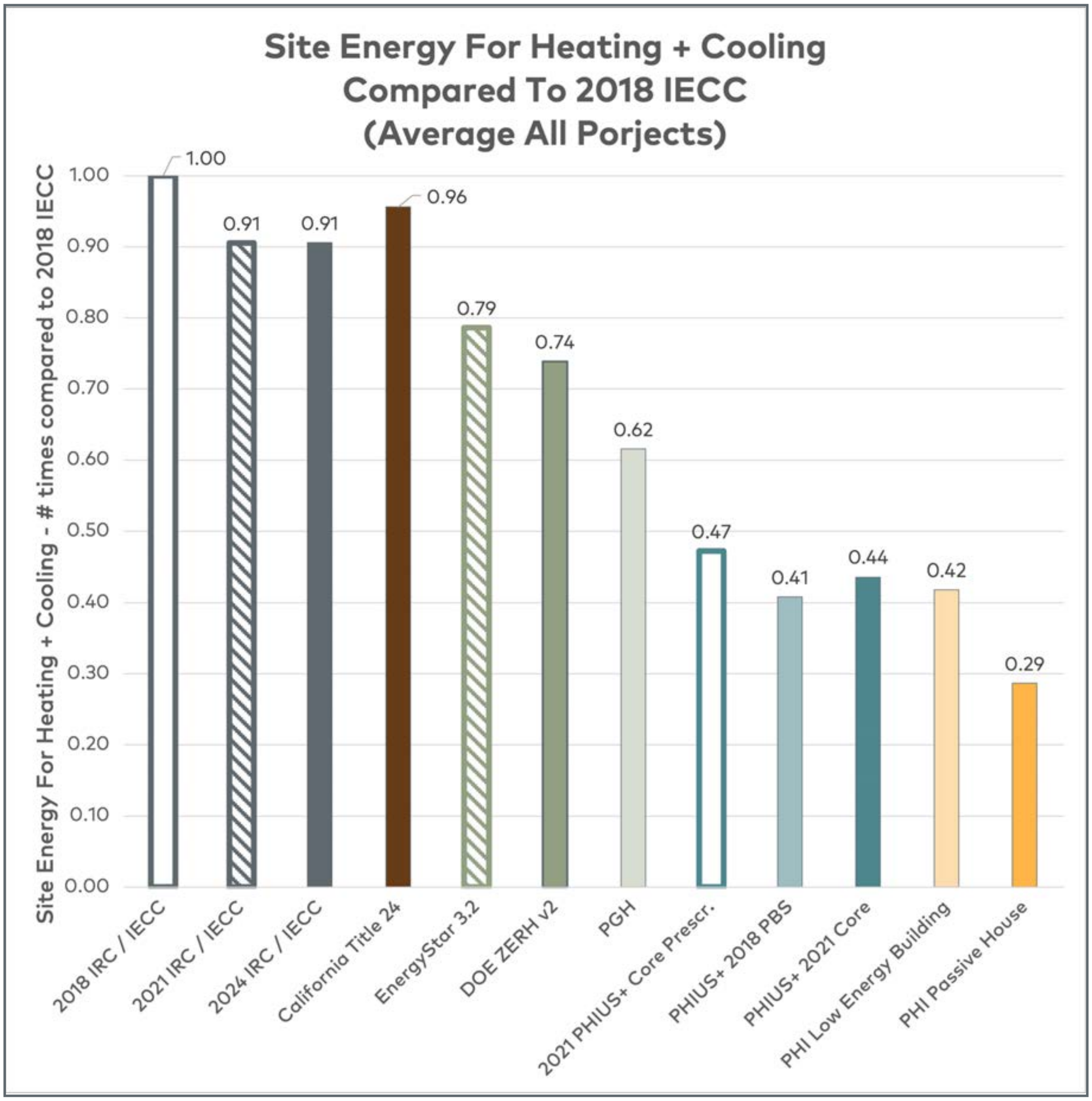

Image 51: Average combined site energy demand for heating and cooling for each building standard considered, benchmarked against the 2018 IECC performance.

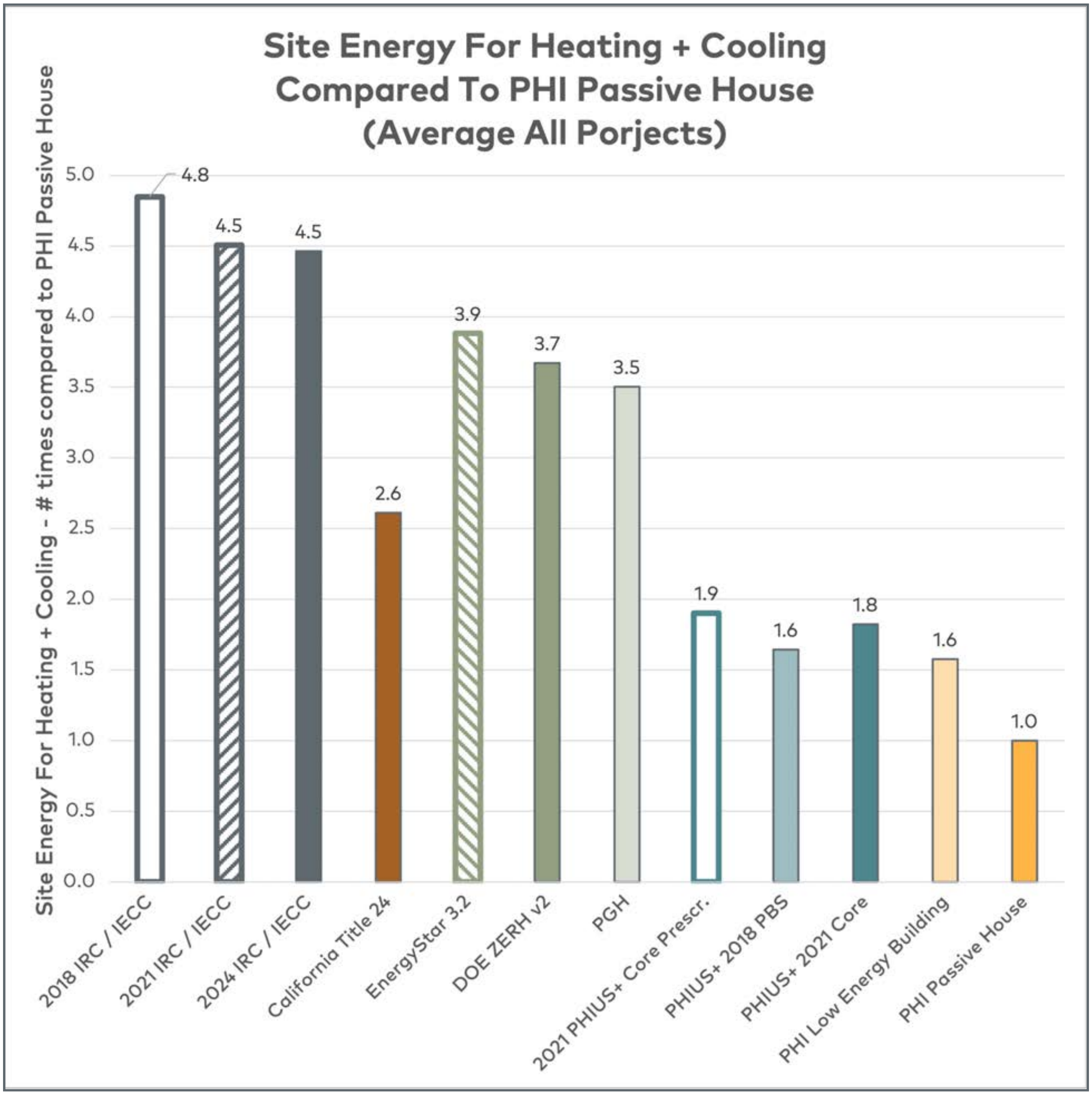

Image 52: Average combined site energy demand for heating and cooling for each building standard considered, benchmarked against the PHI Passive House performance.

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Energy Use Intensity (EUI)

The energy use intensity of each project was calculated including:

- energy for heating and cooling (from previous section)
- domestic hot water (DHW) generation
- household appliances ("other appliances")
- PV production

Appendix A shows specific details for DHW, other appliances, and renewable energy production from on-site photovoltaic systems (PVs).

Image 53 shows the median results across all projects by building standard.

With regards to the energy performance for the California Title 24 standard, it is worth noting that:

- for building envelope performance, the standard performs similarly to the IECC standards, in that the requirements of the two are very close to one another.
- the main difference between T24 and IECC is that T24 only applies to California-based projects, where the mild climate conditions cause low demand for heating and cooling.
- it is the only standard considered that mandates the installation of PV systems.
- In addressing EUIs, the apparent great performance of Title 24 is due to compensation of energy consumed via production from a PV system, instead of the standard being more strict in terms of energy conservation.

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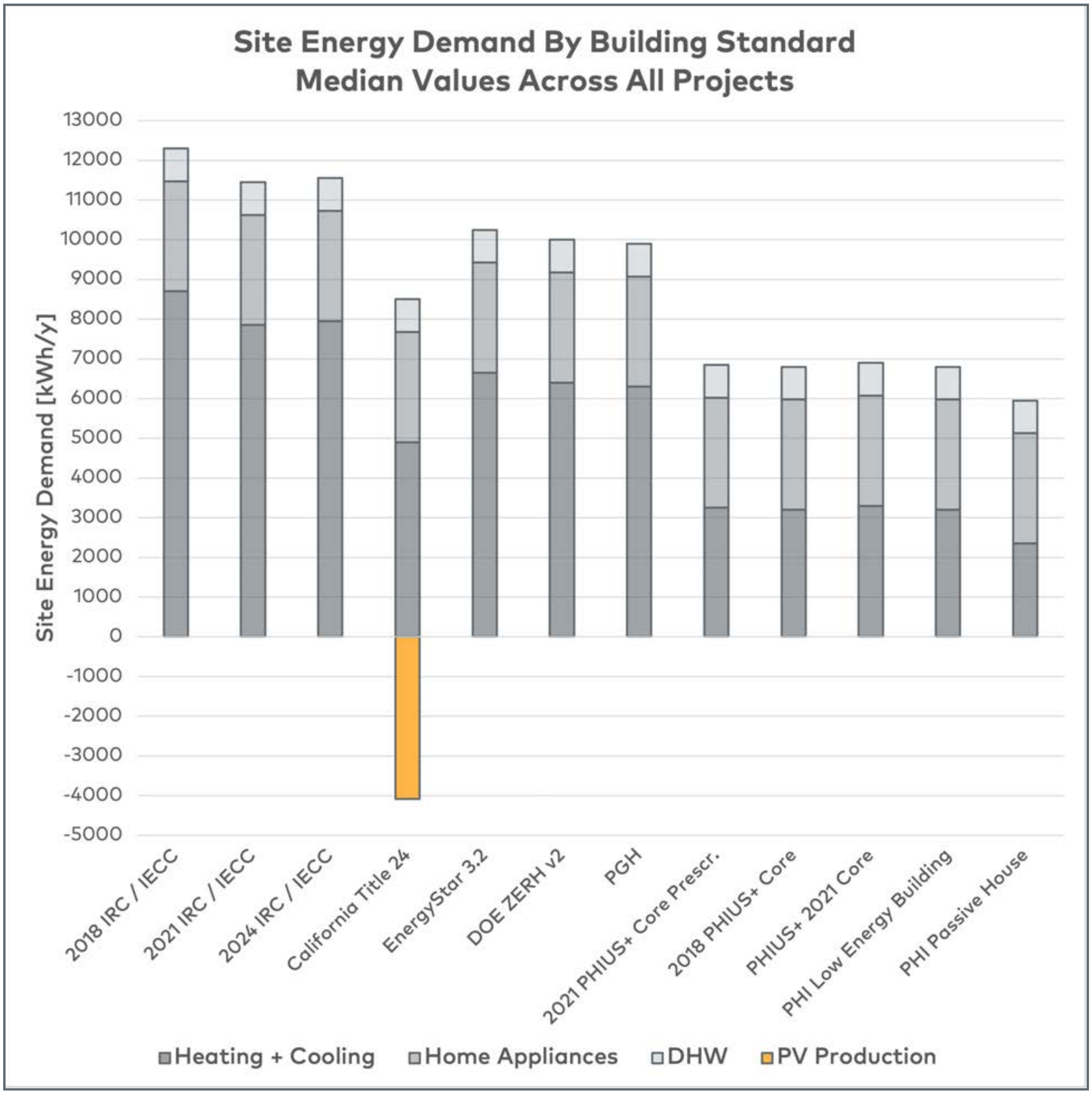

Image 53: Site energy demand by building standard, and by type of use.

The resulting EUI are shown in Image 54, which accounts for energy compensation via PV production (for California Title 24).

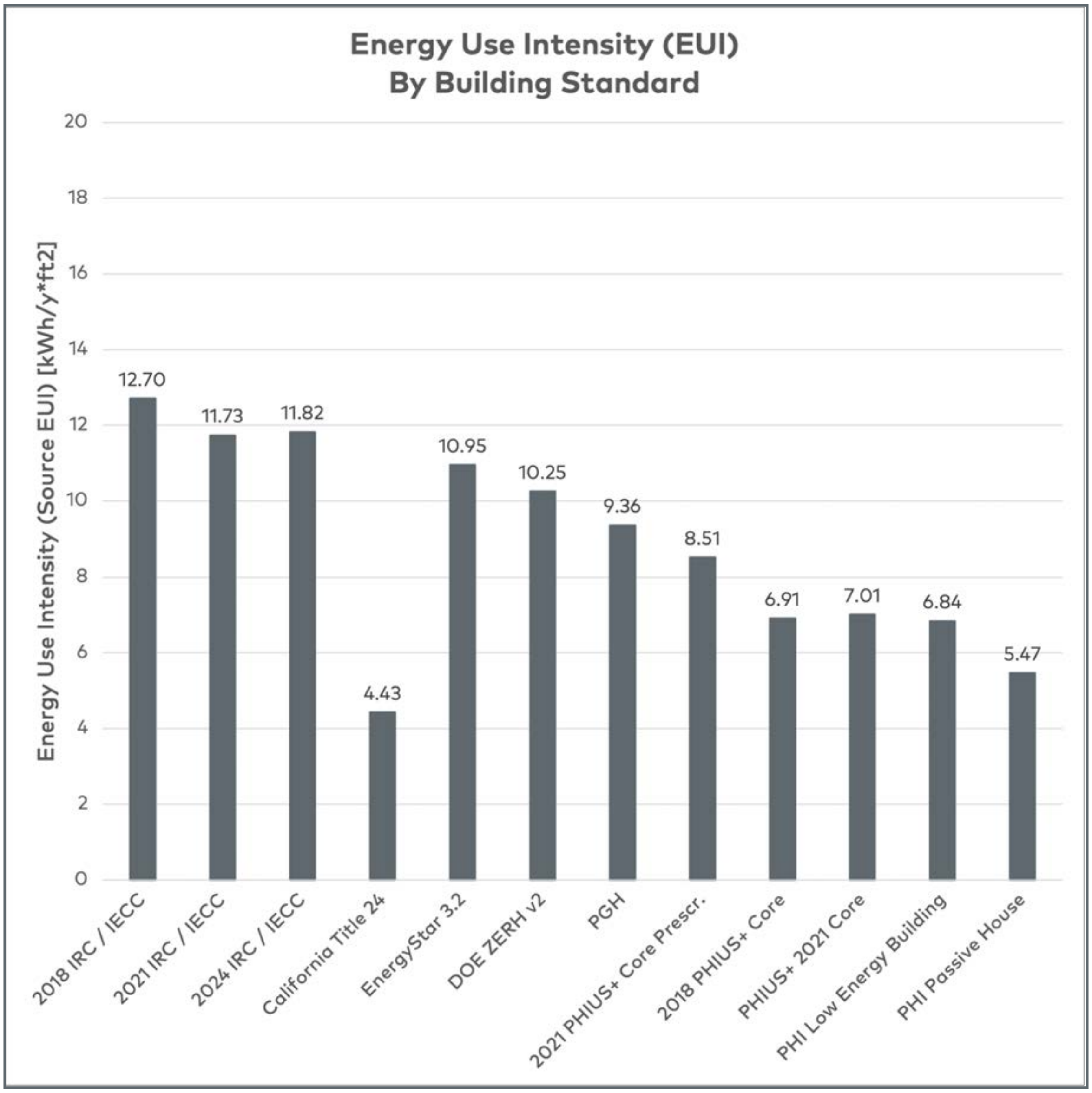

Image 54: Energy Use Intensity (EUI) by building standard. Note that California Title 24 performs well due to 1) milder climate conditions (i.e. California-only projects), and 2) the energy compensation due to the PV systems it mandates.

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Future Proofing For EV Adoption

So far, the concept of Net Zero building has been defined as a "building that produces equal to or more energy than it consumes, over a typical year" [19].

With the energy market rapidly changing due to the wider adoption of electric vehicles (EVs), the concept of Net Zero has been recently expanded to including the on-site charging of vehicles used for transportation off-site - see ASHRAE Standard 228 [14].

Based on average miles driven by Americans over a typical year [17], and an average energy efficiency of an electric car [21], a site energy demand for charging two EVs was calculated for this research.

Image 55 shows the EUIs per building standard previously listed in Image 54, with the additional EUIs caused by charging two electric vehicles at home.

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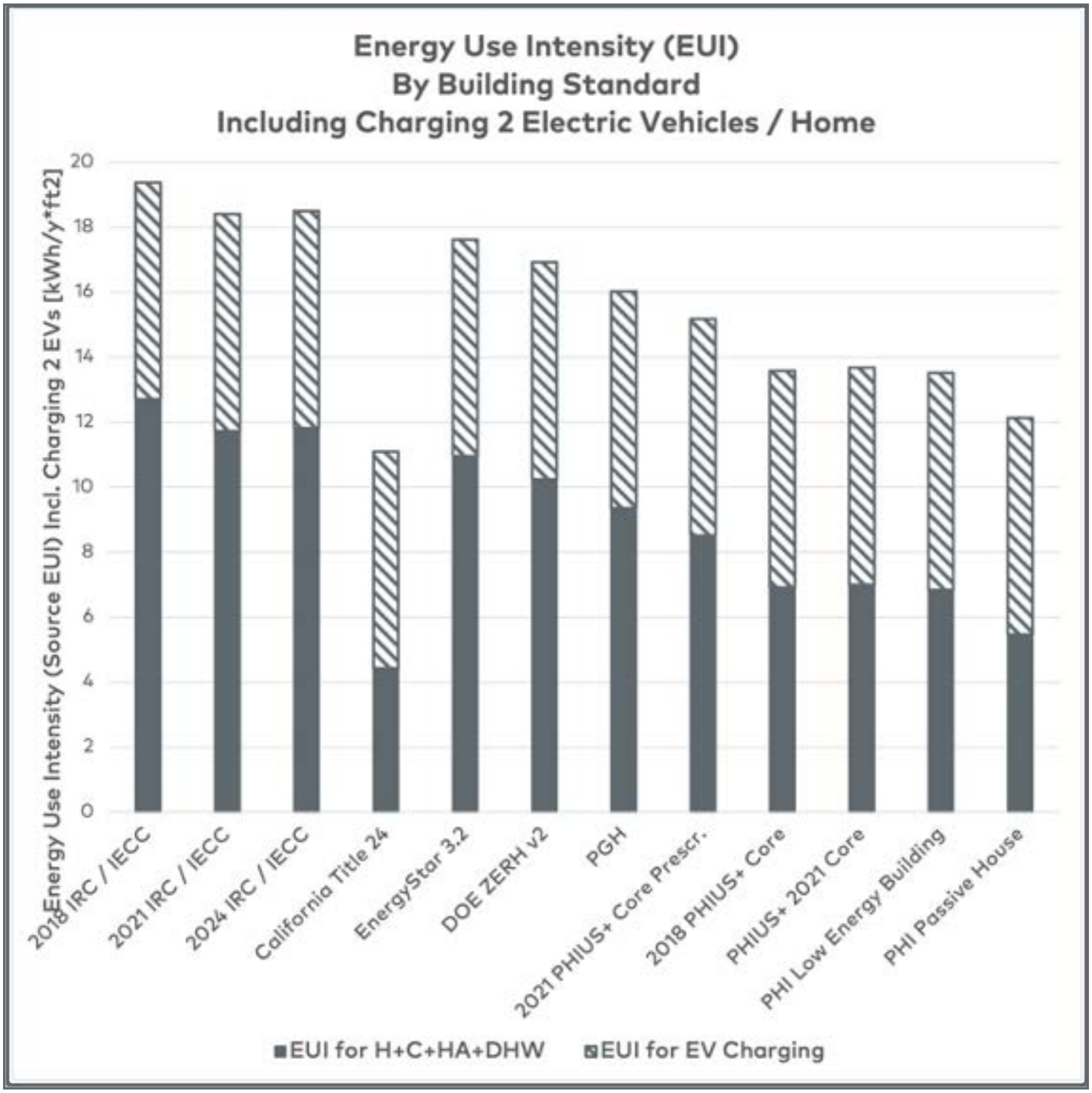

Image 55: EUIs per building standard previously listed in Image 54, with the additional EUIs caused by charging two electric vehicles at home.

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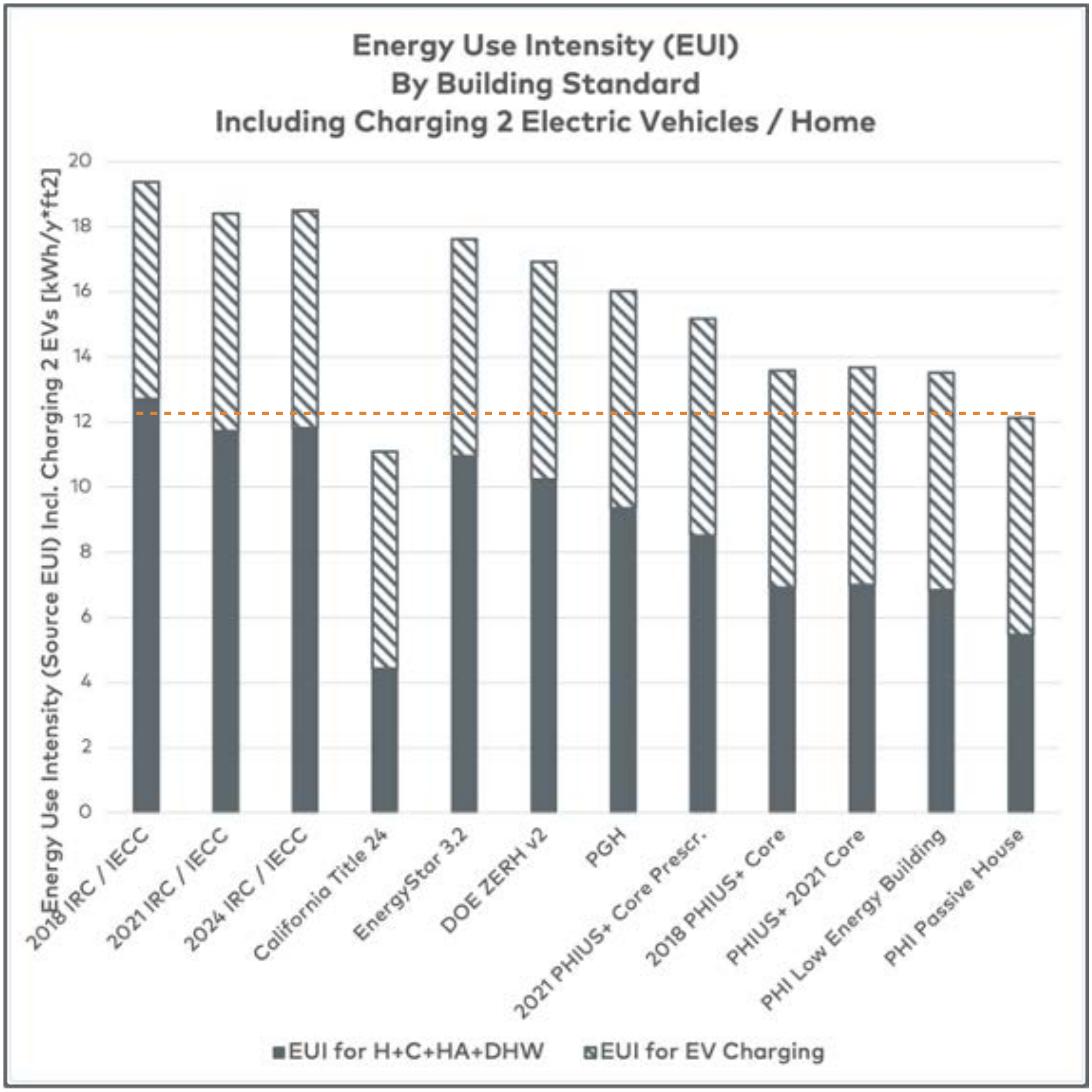

Image 55-2 (repeated): average EUIs to operate a Code-minimum built house are the same as the EUIs to operate a PHI Passive House, and to charge two electric vehicles at home

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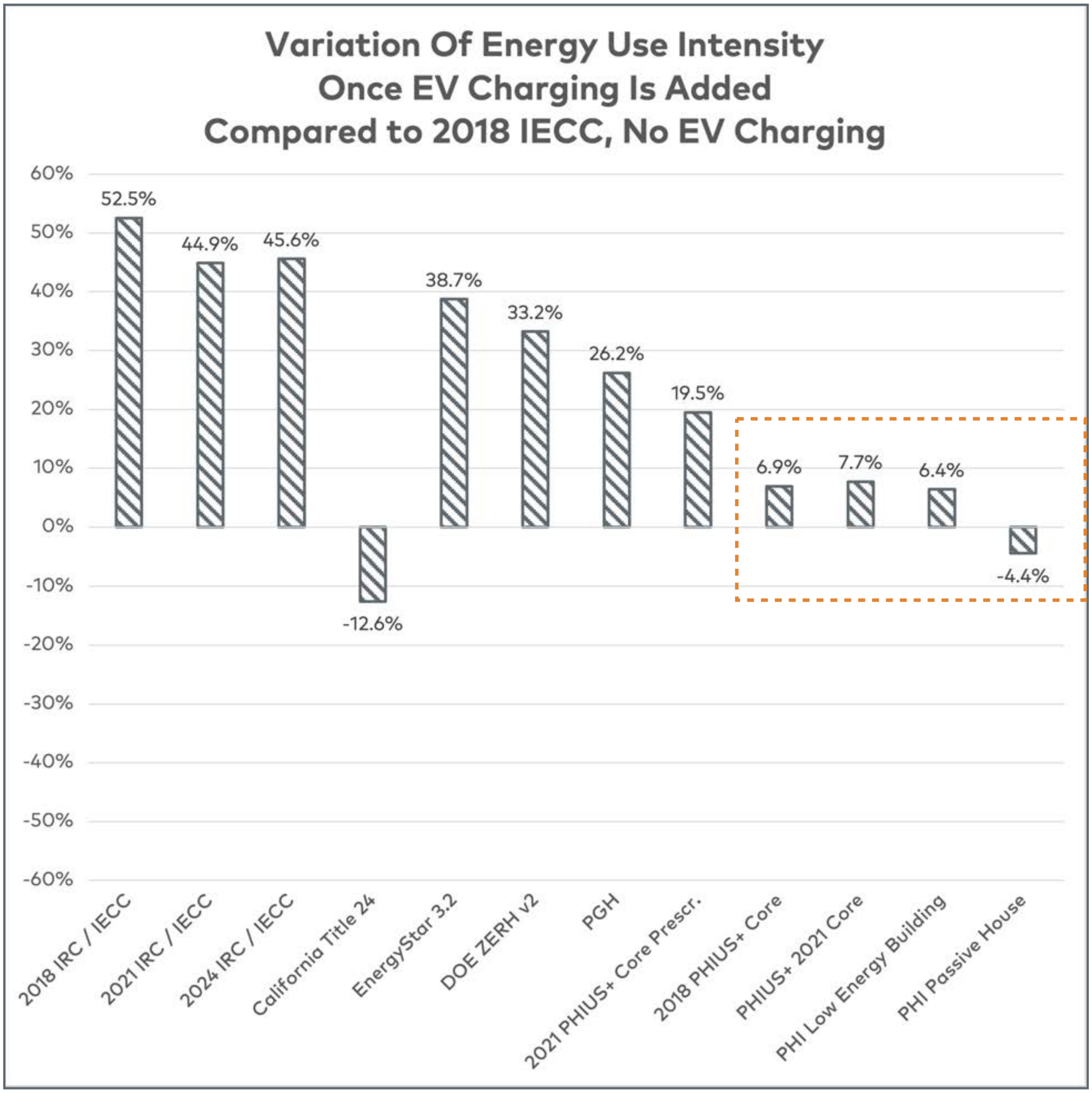

Image 56: Passive building standards allow to charge two electric vehicles at home with a minimum variation in EUI compared to a 2018 IECC-built home with no EV charging. Note that California Title 24 results account for energy compensation via on-site PV production.

Image 55-2 (repeated) shows how the EUI needed to operate a code minimum home without EV charging is about the same EUI that a Passive needs to operate, including the addition of EV charging.

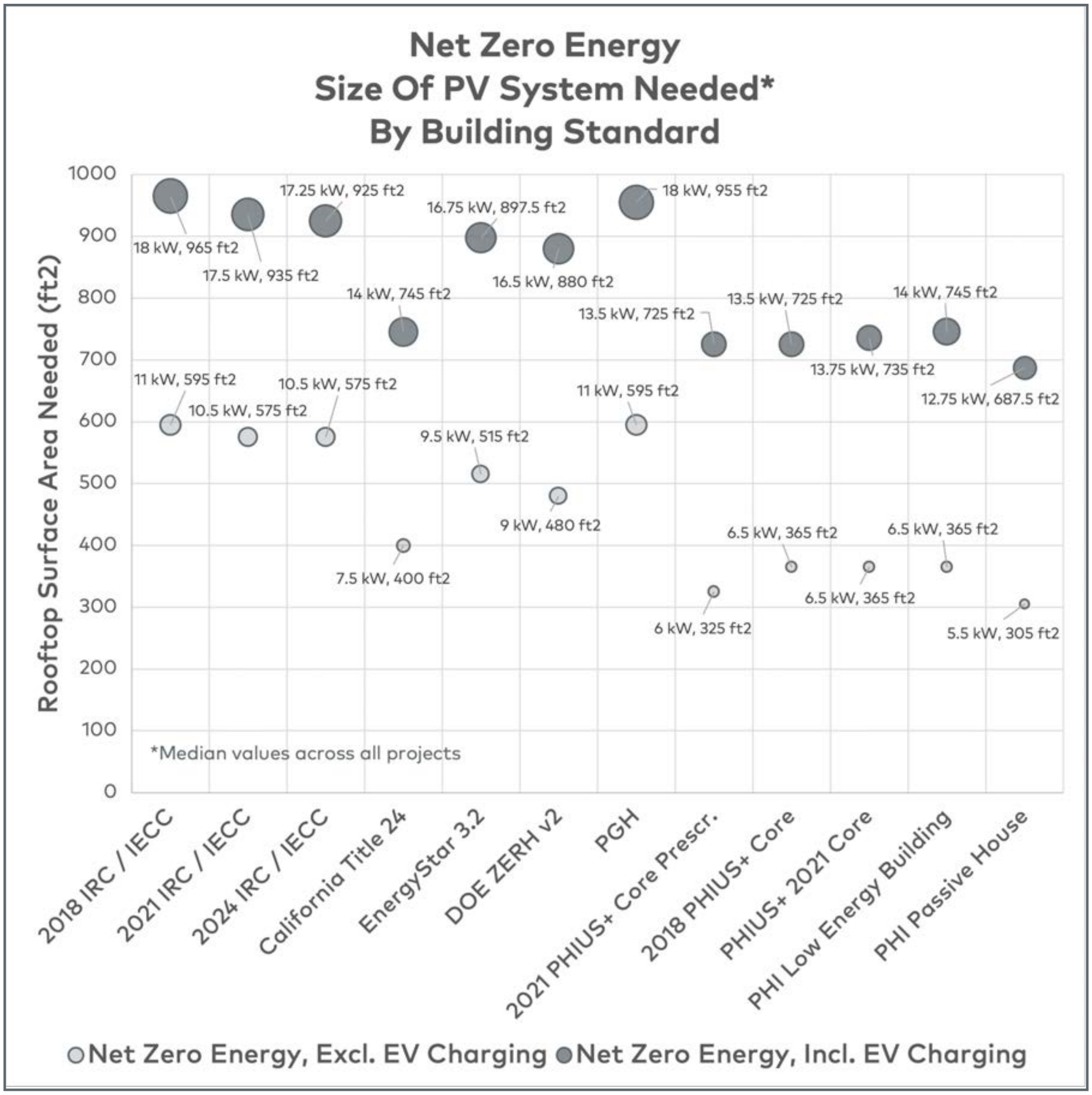

Image 57: Average Size of PV system for a project to meet Net Zero, Whether or not EV charging is included in the Net Zero balance.

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This finding is very significant for policy makers, as the wider adoption of electric vehicle is expected to cause a drastic increase in demand for electricity.

The adoption of passive building standards minimize the impact on future electric grids.

Image 56 shows the expected increase in consumption of electricity by building standard when two electric vehicles are charged at home (benchmarked against the baseline of a 2018 IECC-built home, with no EV charging).

Image 57 shows the average size of PV systems needed for projects to meet Net Zero by building standard, whether that includes the charging of electric vehicles, or not.

The ballpark size of a PV system to offset the energy consumed by an IECC-compliant home is around 950 ft2, and about 750 ft2 for a California Title 24-compliant one.

Once the new definition of Net Zero is adopted (i.e. EV charging included in the energy balance), it may simply be impossible for Code-minimum buildings to meet Net Zero with on-site PVs due to the sheer square footage needed.

Verifiable Results

In setting up any expectation of higher energy efficiency (whatever the goal), it is key to establish a design performance against which the actual performance can be measured and verified.

For this reason, building standards that establish a design performance expectation were credited with points in the scoring process. For simplicity, this was done without diving into different levels of accuracy in the modeling required by different building standards.

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Prescriptive standards were allocated zero points for this criterion, as they offer no way to even roughly estimate a level of performance for buildings implementing their requirements.

Resource Efficiency

The concept of resource efficiency is addressed in detail in the following section of the Report.

For the purposes of operational energy efficiency, performance-based building standards were allocated points, whereas prescriptive building standards were not. The motivations illustrated in the following sections describe the motivations for this choice.

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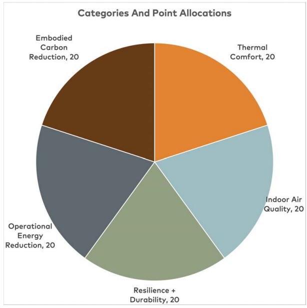
Scoring: Operational Energy



The scoring results for Operational Energy Reduction are shown in Table 11, which is based on the motivations illustrated above.

Image 58 provides a graphical representation of the results.

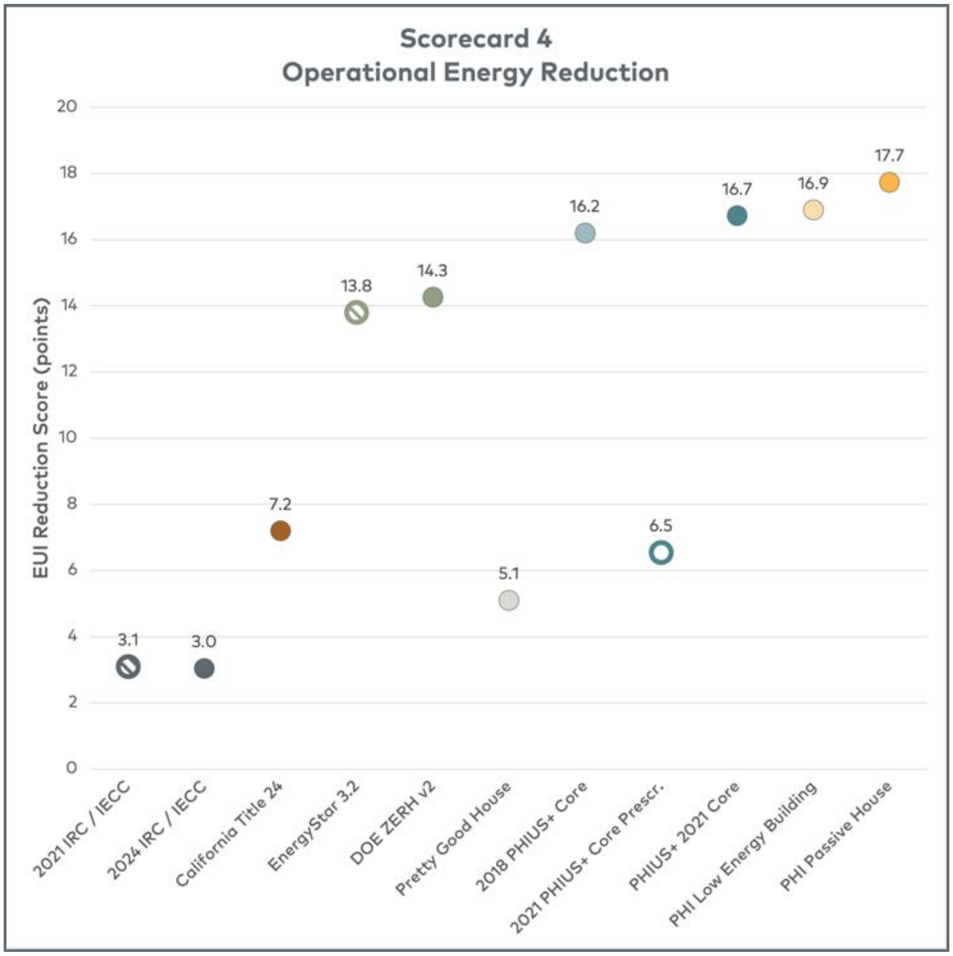


Image 58: Scoring for the the operational energy efficiency criteria, for the different criteria covered in this section of the study.

Scorecard 4						
Operational Energy Reduction						
	EUI Reduction	Verifiable Reuslts	Resource Efficiency	Future Profing For EV Adoption		
Criteria	EUI Reduction comp. to 2018 IECC	bldg perform. estimated via detailed energy analysis	bldg perform. estimated via detailed energy analysis	avoided infrastr. demand increase due to EVs		
Motivation	reduces cost and impact of operating the building	allows for measurement and verification	meet energy performance using fewer resources	prevents infrastructure demand comp. to 2018 IECC		Total
Points Available	5	5	5	5		20
2021 IRC / IECC	6.8%	no	no	44.9%		3.1
2024 IRC / IECC	6.4%	no	no	45.6%		3.0
California Title 24	43.9%	no	no	-12.6%		7.2
EnergyStar 3.2	14.7%	yes	yes	38.7%		13.8
DOE ZERH v2	18.4%	yes	yes	33.2%		14.3
Pretty Good House	28.2%	no	no	26.2%		5.1
2018 PHIUS+ Core	43.5%	yes	yes	19.5%		16.2
2021 PHIUS+ Core Prescr.	37.8%	no	no	6.9%		6.5
PHIUS+ 2021 Core	42.1%	yes	yes	7.7%		16.7
PHI Low Energy Building	44.3%	yes	yes	6.4%		16.9
PHI Passive House	54.7%	yes	yes	-4.4%		17.7
Baseline:	2018 IECC					
IECC, CA Title 24	Assumes most widely used compliance method (i.e. prescriptive path).					

Table 11: scoring for the operational energy efficiency criteria, for each building standard considered

Embodied Carbon + Resource Efficiency

One of the means to reduce the environmental impact of a building is to minimize the embodied carbon contained in the materials used to build it.

This section of the report address how the building standards investigated address embodied carbon directly, and what efficiencies they allow for in their processes.

Embodied Carbon

Among others, embodied carbon in construction materials is one of the metrics that address the environmental impact of building a building.

Through the use of tools such as BEAM [15] and PH Ribbon [90], teams can evaluate and minimize the embodied carbon of products and materials used in their projects.

Images 59 and 60: BEAM (left), and PH Ribbon (right)

However, at the time this research was conducted, none of the building standards investigated had set specific hard requirements or goals for reduction of embodied carbon.

For this reason, none of the building standards considered were allocated points for embodied carbon reduction.

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Resource Efficiency

While none of the building standards had specific requirements for reduction of embodied carbon, some building standards resulted in more "resource efficient" than others in meeting higher operational energy efficiency.

To illustrate the concept of resource efficiency, we'll compare a performance-based standard (i.e. PHI Low Energy Building) with a prescriptive standard (2021 Phius+ Core Prescriptive).

The two standards were not selected to compare PHI and Phius to one another, but rather to compare a prescriptive approach (Phius) with a performance-based one (PHI LEB).

The criteria followed in this comparison were:

- A - Prescriptive Standard (2021 PHIUS+ Core Prescriptive)
- B - Performance-based Standard (PHI Low Energy Building
- projects where A and B came within 20% of one another in terms of combined site energy for heating and cooling

Overall, 18 projects fit the criteria, and were used for this comparison. Appendix A shows details of the selected details.

Of all projects were the 2021 Phius+ Core Prescriptive standard was applicable (i.e. due to building size restrictions set by Phius), Image 61 shows the ones where the combined site energy for heating and coolings comes within +/-20% of PHI Low Energy Building.

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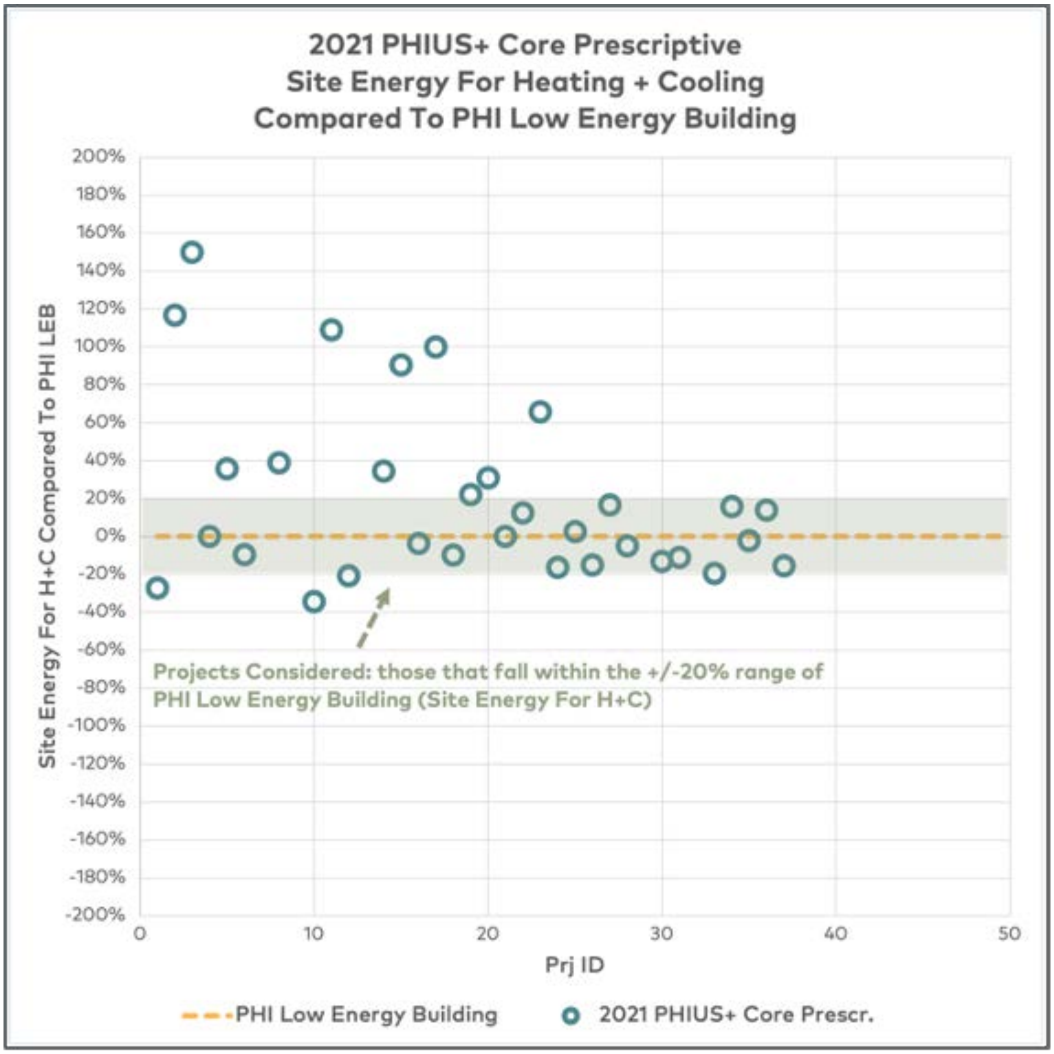

Image 61: Selection of 2021 Phius+ Core Prescriptive projects that perform within a +/-20% range (area highlighted in green) for combined site energy for heating and cooling compared to PHI Low Energy Building standard

The comparison found that on average, the performance-based standard (PHI Low Energy Building) met the target performance needing 830 less cubic feet of insulation, compared to the prescriptive standard (2021 Phius+ Core Prescriptive.

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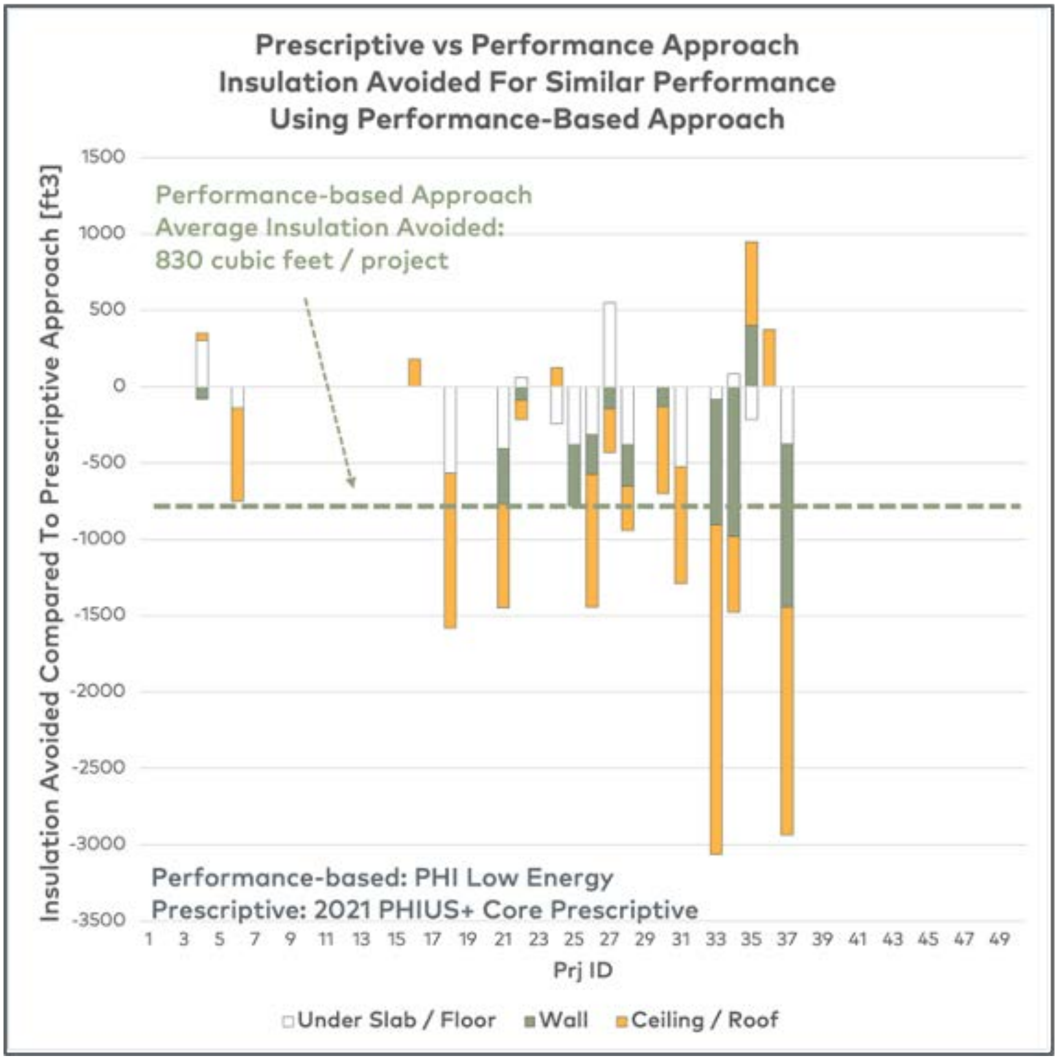

Image 62: Insulation avoided by the performance-based standard (PHI Low Energy Building) for each of the 18 projects selected for this comparison, compared to the prescriptive standard (2021 Phius+ Core Prescriptive)

For each of the 18 projects used in this comparison, Image 62 shows the differences in insulation avoided for the floors, walls, and ceiling of the performance-based standard (PHI Low Energy Building), compared to the prescriptive standard (2021 Phius+ Core Prescriptive).

The reason for such a staggering difference is that the performance-based standard sets specific performance goals for heating and cooling. The required energy analysis allows for informed tradeoffs and optimizations. This allows to tweak key aspects of a building (e.g. glass low-e coating, and resulting solar gains coefficients).

A prescriptive standard is fundamentally reactive with regards to any energy performance goals - the standard prescribes the performance of the individual pieces (e.g. wall minimum R-value), but the performance of the whole is not addressed. In other words, a prescriptive approach does not set specific goals, and teams have no a way to apply informed tradeoffs.

As the performance-based standard has the additional cost of the energy analysis, that cost was compared to the savings obtained from the avoided insulation.

For modeling fees, Appendix A lists the actual fees Emu charged the individual projects to develop the energy analysis at the schematic design stage (as part of the Project Boost).

The avoided cost of the insulation were sourced from Home Depot, and do not include the cost of labor saved.

The cost comparison for the selected project is shown in Image 63, with specific details listed in Appendix A.

On average, the performance-based approach saves over $5000/project (including the additional energy modeling fees) compared to the prescriptive approach, thanks to avoiding unnecessary insulation.

This shows that a performance-based standard that is supported and informed by an energy analysis needs less resources (i.e. construction materials, and cost) than a prescriptive standard.

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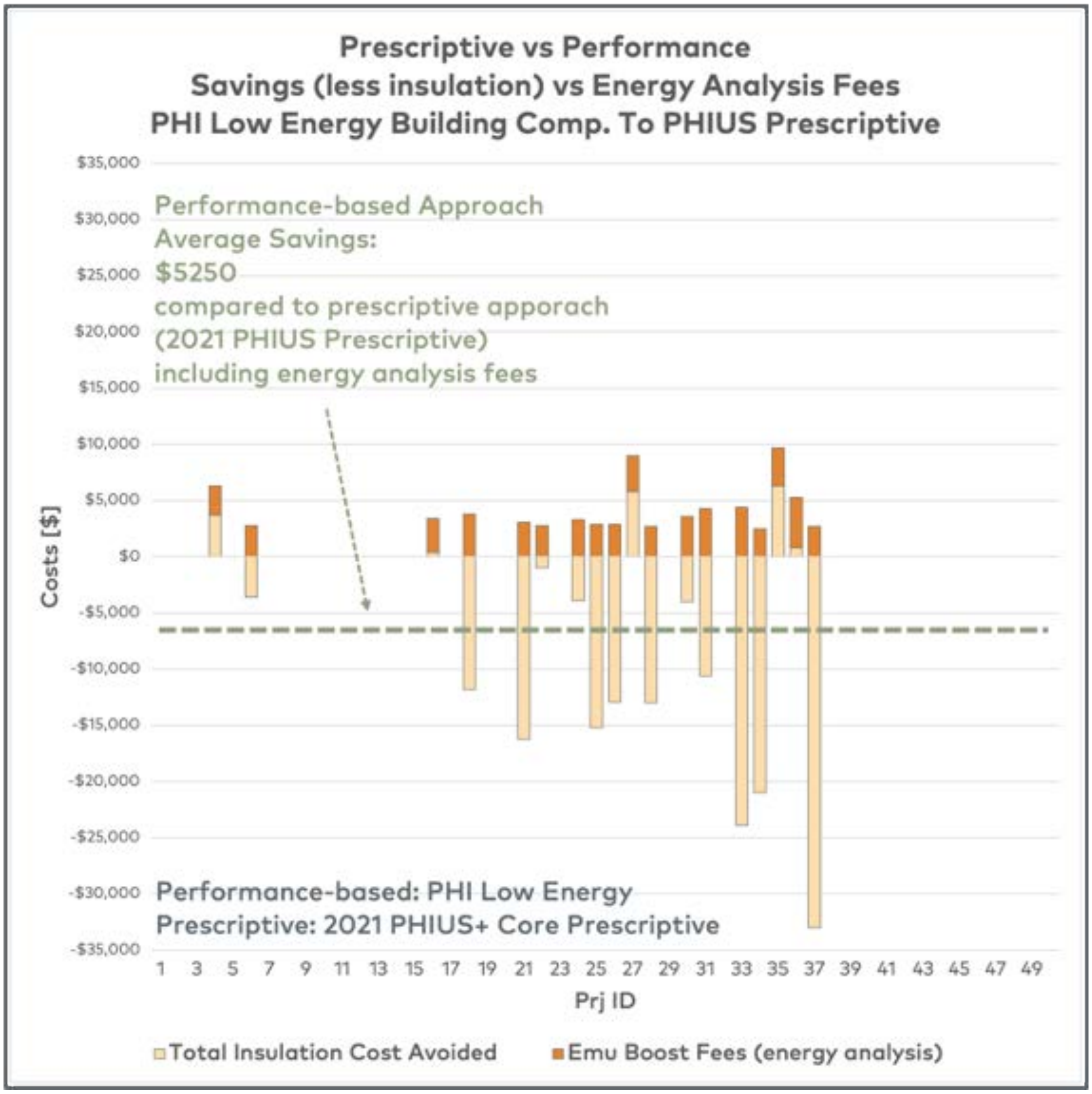

Image 63: Extra cost due to energy modeling fees, and savings due to avoided insulation. On average, the performance-based standard saved over $5000 per project compared to the prescriptive approach.

In terms of embodied carbon, it's easy to understand how saving 800+ cubic feet of insulation on a single project has a dramatic impact on reducing the environmental impact of that project, and on its economic feasibility.

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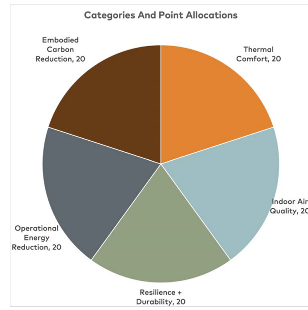
Scoring: Embodied Carbon + Resource Efficiency



The combined scoring results for Embodied Carbon and Resource Efficiency are shown in Table 12, which is based on the motivations illustrated above.

Image 64 provides a graphical representation of the results.

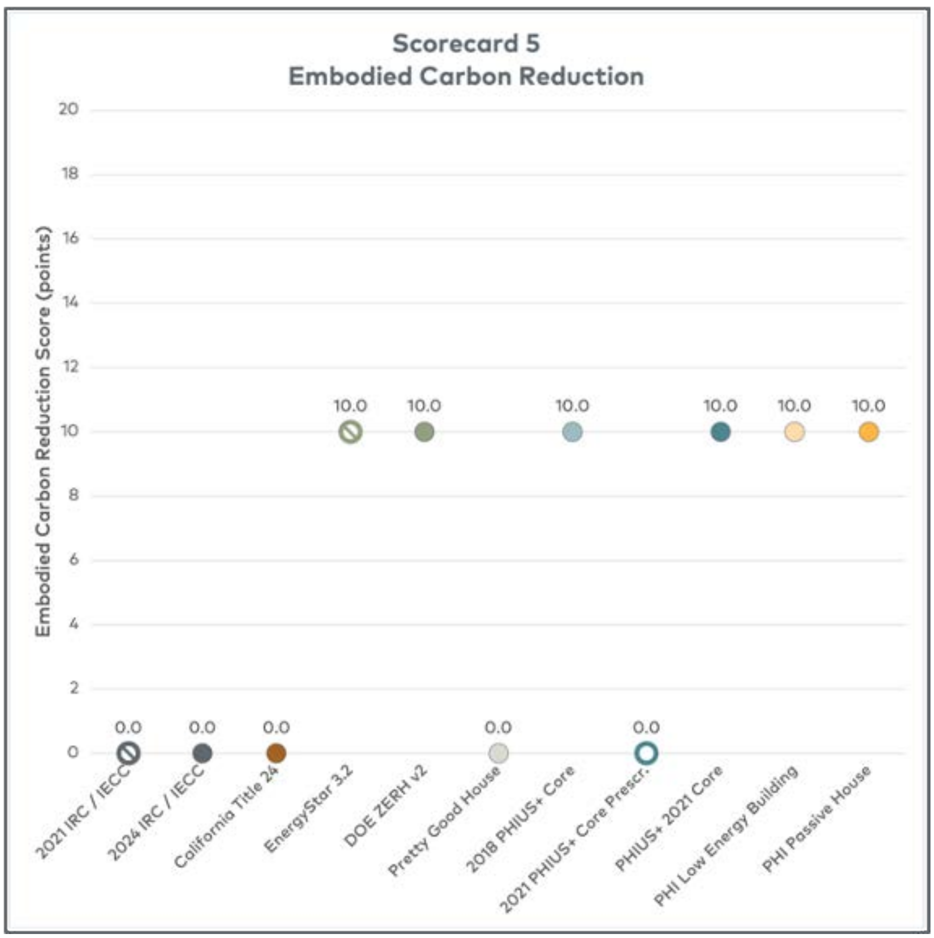


Image 64: Scoring for the the embodied carbon and resource efficiency criteria, for the different criteria covered in this section of the study.

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Scorecard 5						
Embodied Carbon Reduction						
	Embodied Carbon Reduction	Resource Efficiency				
Criteria	Emb. Carbon Reduction comp. to 2018 IECC	bldg perform. estimated via detailed energy analysis				
Motivation	reduces impact of building the building	meet energy performance using fewer resources				Total
Points Available	10	10				20
2021 IRC / IECC	NR	no				0.0
2024 IRC / IECC	NR	no				0.0
California Title 24	NR	no				0.0
EnergyStar 3.2	NR	yes				10.0
DOE ZERH v2	NR	yes				10.0
Pretty Good House	NR	no				0.0
2018 PHIUS+ Core	NR	yes				10.0
2021 PHIUS+ Core Prescr.	NR	no				0.0
PHIUS+ 2021 Core	NR	yes				10.0
PHI Low Energy Building	NR	yes				10.0
PHI Passive House	NR	yes				10.0
Baseline:	2018 IECC					
NR	No requirements					

Table 12: scoring for the embodied carbon and resource efficiency criteria, for each building standard considered

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CONCLUSIONS

The goal of this research was to investigate the ability of different building standards to improve living conditions of people that occupy them, and to reduce the environmental impact of building and operating them.

Table 13 summarizes the results for the metrics considered in this research. As this results summary consists of metrics that are very different from one another (from mold risk avoidance to thermal comfort, from operational energy efficiency to building durability), a scoring system was developed to provide a simplified comparison between building standards. The scoring results are shown in Table 14 and Images 65 and 66.

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.

For California-specific conclusions, see Appendix B.

Thermal Comfort

The choice of window and door performance impacts occupant comfort. In this regards, the following results were noted:

- there is a significant disconnect between window- and ext. door-related requirements (U-values) and thermal comfort, for most of the non-Passive building standards investigated (incl. all IECC standards, California Title 24, EnergyStar, and DOE ZERH). The disconnect does not seem to be improved upon by the 2024 IECC draft.
- PHI outperforms all other building standards in terms of thermal comfort.

Indoor Air Quality

Air quality ranks high on the priority list for most people. The results of this research showed that:

- In terms of air flow requirements per occupant, filtration grade, and air tightness of the building envelope, PHI outperforms all other building standards.
- For air filtration grade, Phius and DOE ZERH (MERV 8) rank second to PHI and California Title 24 (MERV 13)
- A key difference in delivering indoor air quality is the assumptions made for number of occupants. ASHRAE 62.2 (California Title 24, EnergyStar, DOE ZERH) assumes occupants = # bedrooms +1. Phius considers fewer occupants (occupants = # bedrooms), while PHI determines air flow needs based on a combination of occupancy, extraction, and volume.

Durability + Resilience

The Report addresses the matter of durability and resilience in terms of air leakage reduction, avoidance of interstitial condensation, avoidance of surface mold/condensation, and inclusive R-value:

- building standards other than Passive standards fail at implementing thorough mold avoidance strategy
- Phius standards partially implement a thorough mold avoidance strategy, yet also allow non-analytical methods (such as NFRC Condensation Resistance, Condensation Index, and AAMA 1503).
- PHI's Passive House standard has the most strict requirements for mold avoidance, and resilience (via the inclusive R-value evaluation).
- In terms of air leakage reduction, PHI Passive House has the most strict requirement of 0.034 cfm/ft2 (0.6 ACH60), followed by Phius Prescriptive at 0.040 cfm/ft2 (0.9 ACH50), PHI Low Energy Building and Pretty Good House at 0.054 cfm/ft2 (1.0 ACH50), followed by Phis Performance-based (2018 and 2021) at 0.060 cfm/ft2 (1.1 ACH50).

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Operational Energy Efficiency

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

- PHI Passive House outperforms all other building standards considered, followed by the 2018 Phius+ Core, then by the PHI Low Energy Building, and by the 2021 Phius+ Core.
- It takes the same amount of energy (EUI) to operate a 2018 IECC-built home, or to operate a Passive home* *and* charge two electric vehicles.

*PHI Passive House, PHI Low Energy Building, and performance-based Phius.

Embodied Carbon and Resource Efficiency

None of the building standards evaluated set specific requirements in terms of reduction of embodied carbon.

The investigation showed that when a prescriptive building standard and a performance-based one achieve a similar efficiency level for operational energy consumption, the performance-based approach does so in a much more resource-efficient way.

On average, the results show 830 cubic feet of additional insulation avoided by the performance-based approach compared to the prescriptive approach.

Even considering the extra energy analysis fees associated with the performance-based approach, the average net savings allowed by the performance-based method exceeds $5000 compared to a prescriptive building standard.

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In other words, the energy analysis typically pays for itself with the optimization it brings to a project.

Overall Conclusions

What was found in the Resource Efficiency section may be the single greatest outcome of the research.

As buildings get closer to consuming zero energy, details such as effective R-values, solar gains coefficient, actual seasonal shading, and other similar parameters have a great impact on the building's performance.

The biggest and most needed lift for the American construction industry is to abandon prescriptive energy codes altogether, and to switch to specific and verifiable whole building performance targets.

A goal that is not defined, cannot be met. Currently, American energy codes set no actual goals with regards to how buildings perform as a whole, whether in terms of energy performance, thermal comfort, indoor air quality, durability, and resilience.

Performance-based Passive building standards today provide valid alternatives to set and meet such goals, so that policymakers, professionals, and owners don't have to wait for mainstream building standards to finally get onboard.

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RESULTS SUMMARY

Building Standard	Thermal Comfort		Indoor Air Quality						Hygiene (i.e. mold avoidance)		Durability			Operational Energy Efficiency				Embodied Carbon
	Building Standard Sets Specific Goals	Average Delta Temperature Btw Window/ Door Surface And Room Temperature	Building Standard Sets Specific Goals	Coverage Of Fresh Air Need	Indoor Air Quality Grading (EN 13779)		Minimum Air Filtration	EPA AirPlus Required	Building Standard Sets Specific Goals	mold avoidance via analytical method	Building Standard Sets Specific Goals	Maximum Allowed Air Leakage		Requires Energy Analysis	Building Standard Sets Specific Goals	EUI Reduction Compared To 2018 IECC	Future Profing For EV Adoption	Building Standard Sets Specific Goals
		[°F]		[%]								Volume-related Metric	Surface-related Metric					
	1	2	3	4	cfm/person	Air Quality			5	6	7	ACH50	q50		8	[%]	9	
2018 IRC / IECC	No	14.3	Yes	67%	12	low IAQ	NR	No	No	No	Yes	3.0	0.162	No	No	N/A (baseline)	N/A (baseline)	No
2021 IRC / IECC	No	14.0	Yes	67%	12	low IAQ	NR	No	No	No	Yes	3.0	0.162	No	No	-6.8%	44.9%	No
2024 IRC / IECC	No	13.7	Yes	67%	12	low IAQ	NR	No	No	No	Yes	3.0	0.156	No	No	-6.4%	45.6%	No
California Title 24	No	8.6	Yes	132%	26	high IAQ	MERV13	No	No	No	No	4.4	0.264	No	No	-43.9%	-12.6%	No
EnergyStar 3.2	No	13.0	Yes	132%	26	high IAQ	MERV6	No	No	No	Yes	3.0	0.158	Yes	Yes	-14.7%	38.7%	No
DOE ZERH v2	No	13.5	Yes	132%	26	high IAQ	MERV8	Yes	No	No	Yes	2.0	0.107	Yes	Yes	-18.4%	33.2%	No
Pretty Good House	No	10.8	No	67%	12	low IAQ	NR	No	No	No	Yes	1.0	0.054	No	No	-28.2%	26.2%	No
2015 PHIUS+	No	N/I	Yes	N/I	22	high IAQ	MERV8	N/I	Yes	partially	Yes	1.0	0.054	Yes	Yes	N/I	N/I	No
2018 PHIUS+ Core	Yes	8.8	Yes	120%	22	high IAQ	MERV8	Yes	Yes	partially	Yes	1.1	0.060	Yes	Yes	-43.5%	19.5%	No
2021 PHIUS+ Core Prescr.	Yes	8.8	Yes	120%	22	high IAQ	MERV8	Yes	Yes	partially	Yes	0.9	0.040	No	No	-37.8%	6.9%	No
PHIUS+ 2021 Core	Yes	8.8	Yes	120%	22	high IAQ	MERV8	Yes	Yes	partially	Yes	1.1	0.060	Yes	Yes	-42.1%	7.7%	No
PHI Low Energy Building	Yes	7.1	Yes	141%	28	high IAQ	MERV13	No	Yes	Yes	Yes	1.0	0.055	Yes	Yes	-44.3%	6.4%	No
PHI Passive House	Yes	7.1	Yes	141%	28	high IAQ	MERV13	No	Yes	Yes	Yes	0.6	0.034	Yes	Yes	-54.7%	-4.4%	No

Values	Values listed are medians across all projects
NR	No requirements
N/I	Not Investigated
H+C	Heating + Cooling
1	Building standards sets specific criteria to prevent thermal discomfort as part of the compliance requirements.
2	Calculated in PHPP from building standard requirements and project conditions including window/door schedule and exterior design conditions.
3	Building standard defines minimum supply fresh air flow rates. For IECC, continuous ventilation was assumed (typically not mandated). For PGH, IRC airflow rates were assumed.
4	Assuming fresh air need = 18 cfm per adult occupant (EN 13779)
5	Building standard sets specific analytical requirements for prevention of mold development inside the building (e.g. ISO 13788)
6	Analytical methods include ISO13788 Temperature Factor and CSA 440.2 Temperature Index. Standards such as AAMA 1503-09 Condensation Resistance Factor, NFRC 500 Condensation Resistance, and NFRC 501 Condensation Index are designed for product comparison, not for actual mold/condensation risk assessment.
7	I.e. a limit to the maximum allowed building air leakage to be verified via measurement after construction, such as a volume-related maximum leakage (ACH50) or surface-related (q50).
8	Limits to energy demand used in buildings such as heating demand, cooling demand, site or source energy demand.
9	Increase in overall site energy demand once electric vehicles are adopted and charged on site. Baseline is 2018 IECC-built building, with no EV charging.

Table 13: Results summary for the metrics investigated in this research

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Overall Scoring

	Scorecard 1	Scorecard 2	Scorecard 3	Scorecard 4	Scorecard 5	
	Thermal Comfort	Indoor Air Quality	Resilience + Durability	Operational Energy Reduction	Embodied Carbon Reduction	**Overall**
	Points					
2021 IRC / IECC	0.0	2.7	5.4	3.1	0.0	**11.1**
2024 IRC / IECC	0.4	2.8	5.6	3.0	0.0	**11.8**
California Title 24	7.9	8.0	5.0	7.2	0.0	**28.1**
EnergyStar 3.2	0.3	5.1	5.6	13.8	10.0	**34.8**
DOE ZERH v2	3.4	11.4	7.6	14.3	10.0	**46.7**
Pretty Good House	10.4	5.3	10.5	5.1	0.0	**31.4**
2018 PHIUS+ Core	13.9	14.5	13.3	16.2	10.0	**67.9**
2021 PHIUS+ Core Prescr.	15.1	15.0	13.8	6.5	0.0	**50.5**
PHIUS+ 2021 Core	13.9	14.5	13.2	16.7	10.0	**68.4**
PHI Low Energy Building	16.6	14.6	15.9	16.9	10.0	**74.1**
PHI Passive House	17.9	15.2	17.3	17.7	10.0	**78.1**

Table 14: Overall scoring results by building standard, broken down by Value Items investigated.

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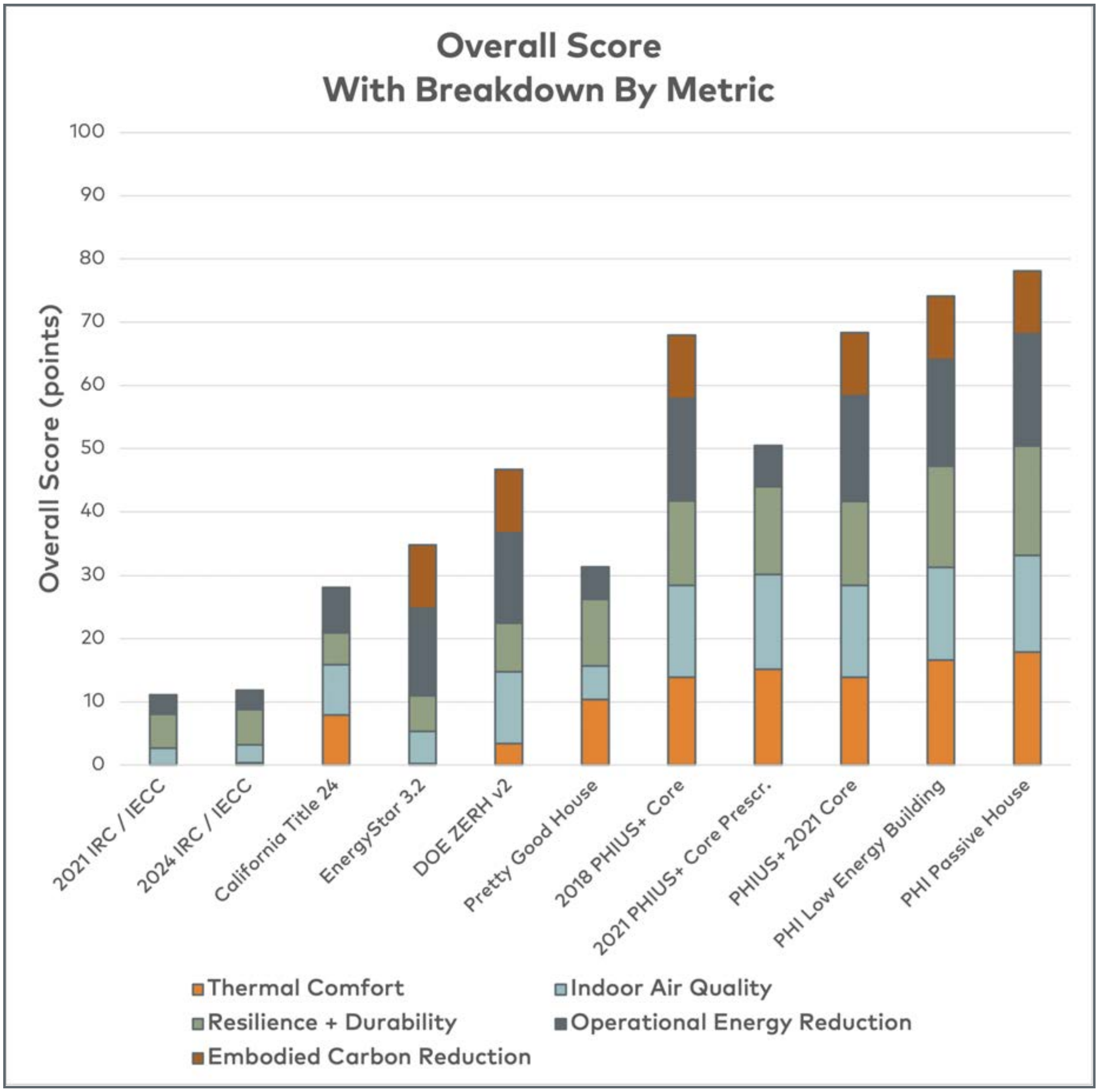

Image 65: Overall scoring results by building standard, broken down by Value Items investigated.

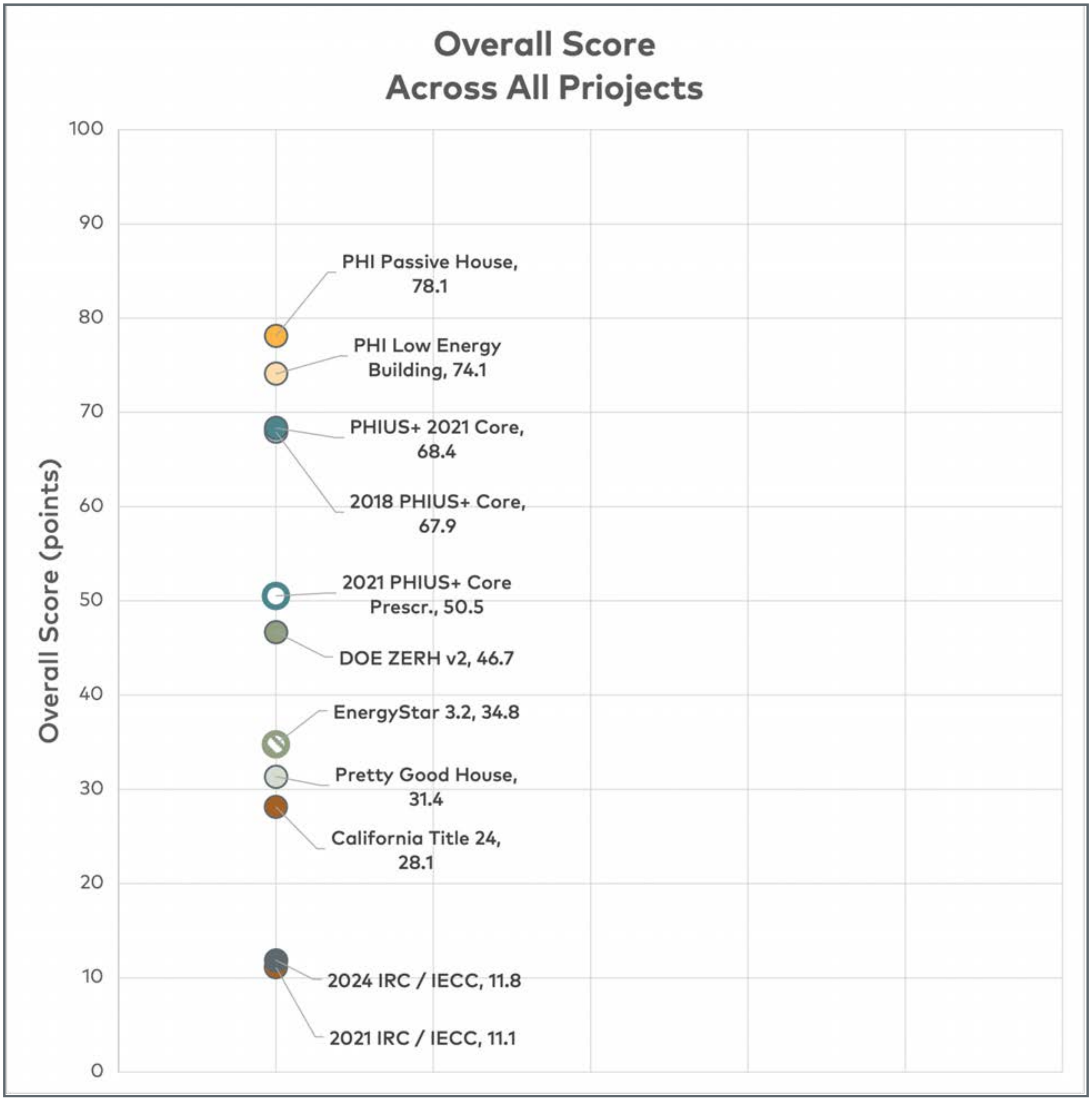

Image 66: Overall scoring results by building standard.

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REFERENCES

1. **AAMA Standard 1503:** 'Voluntary Test Method For Thermal Transmittance And Condensation Resistance Of Windows, Doors, And Glazed Wall Sections'
2. **ANSI/RESNET/ICC Standard 301-2022:** 'Standard For The Calculation And Labeling Of The Energy Performance Of Dwelling And Sleeping Units Using An Energy Rating Index'
3. **AP New:** 'Governors, Biden administration push to quadruple efficient heating, AC units by 2030'
4. **ASHRAE** - 'Filtration And Disinfection FAQs'
5. **ASHRAE** - 'Indoor Air Quality Guide'
6. **ASHRAE - Standard 52.2:** 'Method Of Testing General Ventilation Air-Cleaning Devices For Removal Efficiency By Particle Size'
7. **ASHRAE - Standard 55:** 'Thermal Environmental Conditions For Human Occupancy'
8. **ASHRAE - Standard 62.2:** 'Ventilation And Acceptable Indoor Air Quality In Residential Buildings'
9. **ASHRAE - Standard 90.1:** 'Energy Standard For Sites And Buildings Except Low-Rise Residential Buildings'
10. **ASHRAE - Standard 90.2:** 'Energy-Efficient Design Of Low-Rise Residential Buildings'
11. **ASHRAE - Standard 105:** 'Standard Methods Of Determining, Expressing, And Comparing Building Energy Performance And Greenhouse Gas Emissions'
12. **ASHRAE - Standard 140:** 'Standard Method Of Test For The Evaluation Of Building Energy Analysis Computer Programs'
13. **ASHRAE - Standard 169:** 'Climatic Data For Building Design Standards'

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14. **ASHRAE - Standard 228**: 'Standard Method Of Evaluating Zero Net Energy And Zero Net Carbon Building Performance'
15. **Builders For Climate Action**: 'BEAM Estimator'
16. **California Energy Commission**: '2022 Building Energy Efficiency Standards For Residential And Non-residential Buildings'
17. **Cardriver.com**: 'What is the average mileage per year?'
18. **CSA A440.2**: 'Fenestration Energy Performance'
19. **DOE**: 'A Common Definition Of Zero Net Buildings'
20. **DOE**: 'Achieving American Leadership In The Solar Photovoltaics Supply Chain'
21. **DOE**: 'What Is The Cost Of Charging An EV?'
22. **DOE**: 'Zero Energy Ready Homes, version 2'
23. **EIA**: 'US Electricity Consumption Increases Between 0 and 15% By 2050'
24. **EIA**: 'Heat Pumps Are A Proven Way To Provide Secure And A Sustainable Heating'
25. **ElectricityLocal** - Local Electricity Rates and Statistics
26. **Emu Passive's YouTube Channel:** https://youtube.com/playlist?list=PLoDR94ljwiBECQ-3mSqTRnUm5S1vP2iBa&si=2zLH99nTAuVJgZIi
27. **EN 673**: 'Glass In Buildings - Determination Of Thermal Transmittance (U value) - Calculation Methods'
28. **EN 13779**: 'Ventilation For Non-residential Buildings - Performance Requirements For Ventilation And Room-conditioning Systems'
29. **EN 13829**: 'Thermal Performance Of Buildings - Determination Of Air Permeability Of Buildings, Fan Pressurization Method'
30. **EnergyStar** - 'Single Family Homes National Program Requirements, v3.2'
31. **EPA**: 'Indoor airPlus'
32. **EPA**: 'eGRID Power Profiler'
33. **EPA**: 'Indoor Air Quality: What are the trends in indoor air quality and their effects on human health?'
34. **EVadoption.com**: 'EV Sales Forecast'
35. **Fraunhofer Institut** - WUFI Passive
36. **Fraunhofer Institut** - WUFI Passive ISO 13790 Validation
37. **Garland, J.** - 'WUFI Passive v3.2.0.1 Validation Using ANSI/ASHRAE Standard 140:2017'

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38. **ICC, 2015 IECC** - '2015 International Energy Conservation Code'
39. **ICC, 2018 IECC** - '2018 International Energy Conservation Code'
40. **ICC, 2018 IRC** - '2018 International Residential Code'
41. **ICC, 2021 IECC** - '2021 International Energy Conservation Code'
42. **ICC, 2021 IRC** - '2021 International Residential Code'
43. **ICC, 2024 IECC** - Draft #2 dated May 9, 2023
44. **IRS**: 'Inflation Reduction Act, Section 45L'
45. **ISO - Standard 7730**: 'Ergonomics Of The Thermal Environment: Analytical Determination And Interpretation Of Thermal Comfort Using Calculation Of The PMV And PPD Indeces And Local Thermal Comfort Criteria'
46. **ISO - Standard 6946**: 'Building Components And Building Elements - Thermal Resistance And Thermal Transmittance, Calculation Methods'
47. **ISO - Standard 9972**: 'Thermal Performance Of Buildings - Determination Of Air Permeability Of Buildings, Fan Pressurization Method'
48. **ISO - Standard 10077-2**: 'Thermal Performance Of Windows, Doors, And Shutters - Calculation Of Thermal Transmittance. Part 2: Numerical Methods For Frames'
49. **ISO - Standard 10211**: 'Thermal Bridges In Building Construction - Heat Flows And Surface Temperatures, Detailed Calculations'
50. **ISO - Standard 13370**: 'Thermal Performance Of Buildings - Heat Transfer Via The Ground, Calculation Methods'
51. **ISO - Standard 13788**: 'Hygrothermal Performance Of Building Components And Building Elements - Internal Surface Temperature To Avoid Critical Surface Humidity And Interstitial Condensation. Calculation Methods'
52. **ISO - Standard 13790**: 'Thermal Performance Of Buildings - Calculation Of Energy Use For Space Heating And Cooling'
53. **ISO - Standard 15099**: 'Thermal Performance Of Windows, Doors, And Shading Devices, Detailed Calculations'
54. **Kahneman, D.** - 'Thinking, Fast and Slow'
55. **Kolbert, D., Mottram, E., Maines, M., Briley, C.**, - 'Pretty Good House'
56. **Koolhaas, R.**: 'Exodus, or the Voluntary Prisoners Of Architecture'
57. **Marshsall ROC**: 'Marshall Fire And Straight Line Winds Disaster Recovery Assistance'
58. **Seagren J., Monroe, C.**: 'Bushfire Smoke - Passive House Performance'

59. **NAHB**: 'Latest Study Shows Average Buyer Expected To Stay In A Home 13 Years'
60. **NFRC 100-2023**: 'Procedure For Determining Fenestration Product U-factors'
61. **NFRC 500-2023**: 'Procedure For Determining Fenestration Product Condensation Resistance Values'
62. **NFRC 501-2023**: 'Procedure For Determining Fenestration Product Condensation Index Values'
63. **NREL**: 'Enhancing Resilience In Buildings Through Energy Efficiency'
64. **NREL**: pvWatts
65. **NREL**: 'US Photovoltaic System And Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis (Q1 2022)'
66. **Passive House Accelerator**: 'How Passive House Protects Against Natural Disasters'
67. **Paul, E.**: 'Prüfmethoden Für WRG Geräte'
68. **PHI** - DesignPH (Passive House energy modeling plugin for SketchUp)
69. **PHI** - 'Criteria for the Passive House, EnerPHit, and Low Energy Building Standards'
70. **PHI** - 'Der Einfluß Der Speichermasse Von Außenwände Auf Den Jahresheizwärmebedarf Von Passivhäusern'
71. **PHI** - 'Energy Efficiency Of The Passive House Standard: Expectations confirmed by measurements in practice'
72. **PHI** - 'Heat Pump Tool'
73. **PHI** - 'Passive House And The Energy Crisis'
74. **PHI** - Passive House Planning Package (PHPP)
75. **PHI** - 'Passive House In South West Europe'
76. **PHI** - 'Passivhaus Schulen'
77. **PHI - Protokollband 14**: 'Passivhaus-Fenster'
78. **PHI - Protokollband 37**: 'Optimierungsstrategien Für Fensterbauart Und Solartemperatur'
79. **PHI** - 'Validation of PHPP v9.6 Using ANSI/ASHRAE Standard 140:2017'
80. **PHI** - 'Wärmeverluste Durch Das Erdreich'
81. **Phius** - 'Phius+ 2015 Certification Guidebook'
82. **Phius** - 'Phius+ 2018 Certification Guidebook'

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83. **Phius** - 'PHIUS+ 2018 Performance Criteria Calculator'
84. **Phius** - 'PHIUS+ 2018 / 2021 Window Comfort Calculator'
85. **Phius** - 'Phius+ 2021 Certification Guidebook v3.2'
86. **Phius** - 'PHIUS+ 2021 Performance Criteria Calculator'
87. **Phius** - 'PHIUS+ 2021 Prescriptive Snapshot'
88. **Phius** - Phius+ 2021 Standard Setting Documentation v1.1
89. **Phius** - 'PHIUS+ Climate & 2021 Prescriptive Snapshot Map'
90. **PHN** - 'PH Ribbon'
91. **Pretty Good House** - 'A Guide To Creating Better Homes'
92. **UNI - Standard TS 11300-2**: 'Prestazioni Energetiche Degli Edifici - Parte 2: Determinazione Del Fabbisogno Di Energia Primaria E Dei Rendimenti Per La Climatizzazione Invernale, Per La Produzione Di Acqua Calda Sanitaria, Per La Ventilazione Meccanica E Per L'Illuminazione In Edifici Non Residenziali'
93. **US News**: 'Will the US Reach 50% EVs by 2030?'
94. **Wright, G., Klingenberg K.** - 'Climate-Specific Passive Building Standards'
95. **Wright, G., White L.** - 'Setting The Heating/Cooling Performance Criteria For The 2018 Phius+ Passive Building Standard'
96. **Xcel Energy**: 'Colorado Clean Energy Plan'
97. **Xcel Energy**: 'Marshall Fire Rebuilding Rebates'
98. **The Zebra**: 'Average length of homeownership: Americans spend less than 15 years in one home'

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APPENDIX A - DETAILED DATA TABLES

This appendix includes detailed data tables for individual metrics addressed in the Report.

In the tables, the 50 projects are always listed in the same order, with the smallest project (i.e. lowest TFA) at the top, and largest at the bottom.

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Overview Of Projects Considered

Prj ID	State	ASHRAE Climate Zone	Site Elevation [ft]	Heating Degree Hour [kKh/y]	Cooling Degree Hour [kKh/y]	# Bedrooms	Design Occupancy (ASHRAE 62.2)	Design Occupancy (PHIUS)	TFA* [ft2]	GFA** [ft2]	Gross Envelope [ft2]	Form Factor	TFA / Occupancy* [ft2]	TFA / Bedroom [ft2]	BDT Volume [ft3]
1	CA	3B	312	33	-51	1	2	1	572	698	2700	4.6	290	580	5200
2	WA	4C	279	90	-104	2	3	2	680	830	3300	4.8	230	350	7050
3	MT	6B	5289	135	-156	1	2	1	681	830	3450	5.1	350	690	8550
4	ID	5B	2231	62	-96	1	2	1	834	1018	4100	4.9	420	840	9550
5	CO	6B	7083	122	-142	1	2	1	887	1082	3800	4.3	450	890	9500
6	FL	2A	69	10	-25	2	3	2	938	1144	3700	3.9	320	470	8500
7	CO	6B	7799	157	-86	1	2	1	944	1152	4250	4.5	480	950	10450
8	CO	5B	5322	94	-136	2	3	2	1066	1301	4050	3.8	360	540	10300
9	MN	7	1152	137	-32	1	2	1	1240	1513	5200	4.2	630	1250	13950
10	TX	2A	476	28	-46	3	4	3	1264	1542	4750	3.7	320	430	11450
11	ID	5B	2598	108	-77	2	3	2	1401	1709	6500	4.6	470	710	15050
12	AL	3A	591	50	-81	2	3	2	1429	1743	6050	4.2	480	720	16250
13	WY	7	6663	148	-103	1	2	1	1466	1789	5700	3.9	740	1470	14650
14	NC	4A	1165	62	-98	2	3	2	1513	1846	7350	4.9	510	760	18100
15	CO	7	9600	162	-207	2	3	2	1541	1879	6100	4.0	520	780	17350
16	MO	4A	640	70	-11	3	4	3	1604	1957	6300	3.9	410	540	16750
17	CO	7	8599	165	-210	3	4	3	1619	1975	7300	4.5	410	540	18650
18	CA	3B	771	48	-72	4	5	4	1640	2000	9800	5.9	330	410	32350
19	ID	6B	4446	112	-23	4	5	4	1962	2394	5900	3.0	400	500	19000
20	NM	5B	7001	92	-138	3	4	3	1977	2412	8200	4.1	500	660	24550
21	CO	6B	7165	113	-158	3	4	3	2149	2622	6500	3.0	540	720	18800
22	CO	5B	5351	95	-2	5	6	5	2354	2871	7000	3.0	400	480	27800
23	CA	4B	6240	142	-186	5	6	5	2525	3080	8150	3.2	430	510	22800
24	CA	4B	3901	64	-103	4	5	4	2598	3170	9200	3.5	520	650	23400
25	ME	5A	85	64	-103	3	4	3	2650	3233	7800	2.9	670	890	27450
26	CA	3C	732	60	-107	4	5	4	2681	3271	8000	3.0	540	680	28750
27	NY	5A	600	94	-136	4	5	4	2747	3351	10150	3.7	550	690	32000
28	CA	3B	719	36	-80	4	5	4	2751	3356	9250	3.4	560	690	38350
29	CO	5B	5308	94	-47	3	4	3	2798	3413	6950	2.5	700	940	28850
30	CA	4B	669	55	-96	5	6	5	2855	3483	10600	3.7	480	580	27500
31	CA	3C	59	36	-76	5	6	5	2875	3508	9050	3.1	480	580	32950
32	WA	4C	66	87	-101	3	4	3	3221	3930	9700	3.0	810	1080	34750
33	CA	3C	3	46	-95	4	5	4	3357	4095	8050	2.4	680	840	36450
34	CO	5B	5322	94	-136	4	5	4	3379	4122	11750	3.5	680	850	38250
35	MT	6B	4652	119	-39	4	5	4	3428	4183	9550	2.8	690	860	34750
36	NC	3A	627	53	-85	5	6	5	3452	4211	18800	5.4	580	700	76700
37	CA	3B	1601	39	-82	4	5	4	3521	4296	9350	2.7	710	890	36650
38	ID	5B	2165	101	-90	3	4	3	3565	4349	9550	2.7	900	1190	32200
39	CA	3B	1601	39	-82	4	5	4	3606	4399	9600	2.7	730	910	35950
40	CO	5B	5003	91	-133	3	4	3	3668	4474	11400	3.1	920	1230	39350
41	ID	6B	6109	142	-192	3	4	3	3715	4533	14400	3.9	930	1240	44550
42	MN	7	906	121	-25	3	4	3	3716	4534	11900	3.2	930	1240	33550
43	KS	5A	3100	69	-108	4	5	4	3937	4803	10300	2.6	790	990	41050
44	KS	5A	1247	85	-123	4	5	4	4050	4941	12250	3.0	820	1020	51800
45	CO	5B	5003	91	-133	4	5	4	4070	4965	13650	3.3	820	1020	45100
46	CO	5B	5322	93	-135	4	5	4	4694	5727	12800	2.7	940	1180	50150
47	KS	4A	1421	71	-8	3	4	3	5150	6283	14750	2.9	1290	1720	80650
48	CO	5B	5030	93	-95	5	6	5	5323	6494	15200	2.9	890	1070	48100
49	VA	4A	689	56	-89	4	5	4	5765	7033	18250	3.2	1160	1450	74850
50	WA	4C	3	93	-33	3	4	3	5872	7164	17300	2.9	1470	1960	63600
*	Treated Floor Area, calculated per PHI guidelines														
**	Gross Floor Area, excludes garages (assumed unconditioned), uncond. crawl spaces and attics.														

Table A.01: Details of the projects included in the report

320 E Vine Dr, Suite 218
Fort Collins, CO, USA 80524
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Applicability Of Building Standards To Projects

Prj ID	ASHRAE Climate Zone	State	TFA	Applicability Criteria			Building Standard Applicable											
				California Title 24	2021 PHIUS+ Core Prescr.	Pretty Good House	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
			ft2	Project Location: California?	Project Meets Requir.mnt TFA < 900 ft2 * Br	Climate Zone 5 or 6?												
1	3B	CA	572	Yes	Yes		x	x	x	x	x	x		x	x	x	x	x
2	4C	WA	340		Yes		x	x	x		x	x		x	x	x	x	x
3	6B	MT	681		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
4	5B	ID	834		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
5	6B	CO	887		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
6	2A	FL	469		Yes		x	x	x		x	x		x	x	x	x	x
7	6B	CO	944			Yes	x	x	x		x	x	x		x	x	x	x
8	5B	CO	533		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
9	7	MN	1240				x	x	x		x	x			x	x	x	x
10	2A	TX	421		Yes		x	x	x		x	x		x	x	x	x	x
11	5B	ID	700		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
12	3A	AL	714		Yes		x	x	x		x	x		x	x	x	x	x
13	7	WY	1466				x	x	x		x	x			x	x	x	x
14	4A	NC	757		Yes		x	x	x		x	x		x	x	x	x	x
15	7	CO	770		Yes		x	x	x		x	x		x	x	x	x	x
16	4A	MO	535		Yes		x	x	x		x	x		x	x	x	x	x
17	7	CO	540		Yes		x	x	x		x	x		x	x	x	x	x
18	3B	CA	410	Yes	Yes		x	x	x	x	x	x		x	x	x	x	x
19	6B	ID	491		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
20	5B	NM	659		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
21	6B	CO	716		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
22	5B	CO	471		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
23	4B	CA	505	Yes	Yes		x	x	x	x	x	x		x	x	x	x	x
24	4B	CA	650	Yes	Yes		x	x	x	x	x	x		x	x	x	x	x
25	5A	ME	883		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
26	3C	CA	670	Yes	Yes		x	x	x	x	x	x		x	x	x	x	x
27	5A	NY	687		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
28	3B	CA	688	Yes	Yes		x	x	x	x	x	x		x	x	x	x	x
29	5B	CO	933			Yes	x	x	x		x	x	x		x	x	x	x
30	4B	CA	571	Yes	Yes		x	x	x	x	x	x		x	x	x	x	x
31	3C	CA	575	Yes	Yes		x	x	x	x	x	x		x	x	x	x	x
32	4C	WA	1074				x	x	x		x	x			x	x	x	x
33	3C	CA	839	Yes	Yes		x	x	x	x	x	x		x	x	x	x	x
34	5B	CO	845		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
35	6B	MT	857		Yes	Yes	x	x	x		x	x	x	x	x	x	x	x
36	3A	NC	690		Yes		x	x	x		x	x		x	x	x	x	x
37	3B	CA	880	Yes	Yes		x	x	x	x	x	x		x	x	x	x	x
38	5B	ID	1188			Yes	x	x	x		x	x	x		x	x	x	x
39	3B	CA	901	Yes			x	x	x	x	x	x			x	x	x	x
40	5B	CO	1223			Yes	x	x	x		x	x	x		x	x	x	x
41	6B	ID	1238			Yes	x	x	x		x	x	x		x	x	x	x
42	7	MN	1239				x	x	x		x	x			x	x	x	x
43	5A	KS	984			Yes	x	x	x		x	x	x		x	x	x	x
44	5A	KS	1013			Yes	x	x	x		x	x	x		x	x	x	x
45	5B	CO	1018			Yes	x	x	x		x	x	x		x	x	x	x
46	5B	CO	1173			Yes	x	x	x		x	x	x		x	x	x	x
47	4A	KS	1717				x	x	x		x	x			x	x	x	x
48	5B	CO	1065			Yes	x	x	x		x	x	x		x	x	x	x
49	4A	VA	1441				x	x	x		x	x			x	x	x	x
50	4C	WA	1957				x	x	x		x	x			x	x	x	x
"x"	Building standard is applicable to the project																	

Table A.02: Applicability of building standards to individual projects included in the research.

2018 IECC Prescriptive Requirements

Prj ID	ASHRAE Climate Zone	Min R-value					Fenestration	Max Air Leakage	Ventilation *
		Wall Above Grade	Roof/ Ceiling	Slab	BSMT Wall	Floor on Uncond.	Max U-value**		
		[h*ft2*°F/BTU]					[BTU / h*ft2*°F]	ACH50	cfm
1	3B	20	38	0	13	19	0.32	3.0	30
2	4C	20	49	10	19	30	0.30	3.0	45
3	6B	20+5	49	10	19	30	0.30	3.0	30
4	5B	20	49	10	19	30	0.30	3.0	30
5	6B	20+5	49	10	19	30	0.30	3.0	30
6	2A	13	38	0	0	13	0.40	5.0	45
7	6B	20+5	49	10	19	30	0.30	3.0	30
8	5B	20	49	10	19	30	0.30	3.0	45
9	7	20+5	49	10	19	38	0.30	3.0	30
10	2A	13	38	0	0	13	0.40	5.0	45
11	5B	20	49	10	19	30	0.30	3.0	45
12	3A	20	38	0	13	19	0.32	3.0	45
13	7	20+5	49	10	19	38	0.30	3.0	30
14	4A	20	49	10	13	19	0.32	3.0	45
15	7	20+5	49	10	19	38	0.30	3.0	45
16	4A	20	49	10	13	19	0.32	3.0	45
17	7	20+5	49	10	19	38	0.30	3.0	45
18	3B	20	38	0	13	19	0.32	3.0	60
19	6B	20+5	49	10	19	30	0.30	3.0	60
20	5B	20	49	10	19	30	0.30	3.0	45
21	6B	20+5	49	10	19	30	0.30	3.0	45
22	5B	20	49	10	19	30	0.30	3.0	60
23	4B	20	49	10	13	19	0.32	3.0	60
24	4B	20	49	10	13	19	0.32	3.0	60
25	5A	20	49	10	19	30	0.30	3.0	45
26	3C	20	38	0	13	19	0.32	3.0	60
27	5A	20	49	10	19	30	0.30	3.0	60
28	3B	20	38	0	13	19	0.32	3.0	60
29	5B	20	49	10	19	30	0.30	3.0	45
30	4B	20	49	10	13	19	0.32	3.0	60
31	3C	20	38	0	13	19	0.32	3.0	60
32	4C	20	49	10	19	30	0.30	3.0	45
33	3C	20	38	0	13	19	0.32	3.0	60
34	5B	20	49	10	19	30	0.30	3.0	60
35	6B	20+5	49	10	19	30	0.30	3.0	60
36	3A	20	38	0	13	19	0.32	3.0	60
37	3B	20	38	0	13	19	0.32	3.0	60
38	5B	20	49	10	19	30	0.30	3.0	45
39	3B	20	38	0	13	19	0.32	3.0	60
40	5B	20	49	10	19	30	0.30	3.0	45
41	6B	20+5	49	10	19	30	0.30	3.0	45
42	7	20+5	49	10	19	38	0.30	3.0	45
43	5A	20	49	10	19	30	0.30	3.0	60
44	5A	20	49	10	19	30	0.30	3.0	60
45	5B	20	49	10	19	30	0.30	3.0	60
46	5B	20	49	10	19	30	0.30	3.0	60
47	4A	20	49	10	13	19	0.32	3.0	45
48	5B	20	49	10	19	30	0.30	3.0	60
49	4A	20	49	10	13	19	0.32	3.0	45
50	4C	20	49	10	19	30	0.30	3.0	45
*	Assuming continuous ventilation per IRC requirements								
**	Incl. exceptions due to site elevation, as applicable								

Table A.03: 2018 IECC prescriptive requirements for each individual project in this study.

2021 IECC Prescriptive Requirements

Prj ID	ASHRAE Climate Zone	Min R-value					Fenestration	Max Air Leakage	Ventilation *
		Wall Above Grade	Roof/ Ceiling	Slab	BSMT Wall	Floor on Uncond.	Max U-value**		
		[h*ft2*°F/BTU]					[BTU / h*ft2*°F]	ACH50	cfm
1	3B	20	49	10	13	19	0.30	3.0	30
2	4C	20+5	60	10	19	30	0.30	3.0	45
3	6B	20+5	60	10	19	30	0.30	3.0	30
4	5B	20+5	60	10	19	30	0.30	3.0	30
5	6B	20+5	60	10	19	30	0.30	3.0	30
6	2A	13	49	0	0	13	0.40	5.0	45
7	6B	20+5	60	10	19	30	0.30	3.0	30
8	5B	20+5	60	10	19	30	0.30	3.0	45
9	7	20+5	60	10	19	38	0.30	3.0	30
10	2A	13	49	0	0	13	0.40	5.0	45
11	5B	20+5	60	10	19	30	0.30	3.0	45
12	3A	20	49	10	13	19	0.30	3.0	45
13	7	20+5	60	10	19	38	0.30	3.0	30
14	4A	20+5	60	10	13	19	0.30	3.0	45
15	7	20+5	60	10	19	38	0.30	3.0	45
16	4A	20+5	60	10	13	19	0.30	3.0	45
17	7	20+5	60	10	19	38	0.30	3.0	45
18	3B	20	49	10	13	19	0.30	3.0	60
19	6B	20+5	60	10	19	30	0.30	3.0	60
20	5B	20+5	60	10	19	30	0.30	3.0	45
21	6B	20+5	60	10	19	30	0.30	3.0	45
22	5B	20+5	60	10	19	30	0.30	3.0	60
23	4B	20+5	60	10	13	19	0.30	3.0	60
24	4B	20+5	60	10	13	19	0.30	3.0	60
25	5A	20+5	60	10	19	30	0.30	3.0	45
26	3C	20	49	10	13	19	0.30	3.0	60
27	5A	20+5	60	10	19	30	0.30	3.0	60
28	3B	20	49	10	13	19	0.30	3.0	60
29	5B	20+5	60	10	19	30	0.30	3.0	45
30	4B	20+5	60	10	13	19	0.30	3.0	60
31	3C	20	49	10	13	19	0.30	3.0	60
32	4C	20+5	60	10	19	30	0.30	3.0	45
33	3C	20	49	10	13	19	0.30	3.0	60
34	5B	20+5	60	10	19	30	0.30	3.0	60
35	6B	20+5	60	10	19	30	0.30	3.0	60
36	3A	20	49	10	13	19	0.30	3.0	60
37	3B	20	49	10	13	19	0.30	3.0	60
38	5B	20+5	60	10	19	30	0.30	3.0	45
39	3B	20	49	10	13	19	0.30	3.0	60
40	5B	20+5	60	10	19	30	0.30	3.0	45
41	6B	20+5	60	10	19	30	0.30	3.0	45
42	7	20+5	60	10	19	38	0.30	3.0	45
43	5A	20+5	60	10	19	30	0.30	3.0	60
44	5A	20+5	60	10	19	30	0.30	3.0	60
45	5B	20+5	60	10	19	30	0.30	3.0	60
46	5B	20+5	60	10	19	30	0.30	3.0	60
47	4A	20+5	60	10	13	19	0.30	3.0	45
48	5B	20+5	60	10	19	30	0.30	3.0	60
49	4A	20+5	60	10	13	19	0.30	3.0	45
50	4C	20+5	60	10	19	30	0.30	3.0	45
*	Assuming continuous ventilation per IRC requirements								
**	Incl. exceptions due to site elevation, as applicable								

Table A.04: 2021 IECC prescriptive requirements for each individual project in this study.

2024 IECC Prescriptive Requirements**

Prj ID	ASHRAE Climate Zone	Min R-value: Wall Above Grade	Roof/ Ceiling	Slab	BSMT Wall	Floor on Uncond.	Fenestration: Max U-value**	Max Air Leakage	Ventilation *
		[h*ft2*°F/BTU]					[BTU / h*ft2*°F]	ACH50	cfm
1	3B	20	38	10	13	19	0.30	3.0	30
2	4C	20+5	49	10	19	30	0.28	3.0	45
3	6B	20+5	49	10	19	30	0.30	2.5	30
4	5B	20+5	49	10	19	30	0.28	3.0	30
5	6B	20+5	49	10	19	30	0.30	2.5	30
6	2A	13	38	0	0	13	0.40	4.0	45
7	6B	20+5	49	10	19	30	0.30	2.5	30
8	5B	20+5	49	10	19	30	0.30	3.0	45
9	7	20+5	49	10	19	30	0.28	2.5	30
10	2A	13	38	0	0	13	0.40	4.0	45
11	5B	20+5	49	10	19	30	0.28	3.0	45
12	3A	20	38	10	13	19	0.30	3.0	45
13	7	20+5	49	10	19	30	0.28	2.5	30
14	4A	20+5	49	10	13	19	0.30	3.0	45
15	7	20+5	49	10	19	30	0.28	2.5	45
16	4A	20+5	49	10	13	19	0.30	3.0	45
17	7	20+5	49	10	19	30	0.28	2.5	45
18	3B	20	38	10	13	19	0.30	3.0	60
19	6B	20+5	49	10	19	30	0.30	2.5	60
20	5B	20+5	49	10	19	30	0.30	3.0	45
21	6B	20+5	49	10	19	30	0.30	2.5	45
22	5B	20+5	49	10	19	30	0.30	3.0	60
23	4B	20+5	49	10	13	19	0.30	3.0	60
24	4B	20+5	49	10	13	19	0.30	3.0	60
25	5A	20+5	49	10	19	30	0.28	3.0	45
26	3C	20	38	10	13	19	0.30	3.0	60
27	5A	20+5	49	10	19	30	0.28	3.0	60
28	3B	20	38	10	13	19	0.30	3.0	60
29	5B	20+5	49	10	19	30	0.30	3.0	45
30	4B	20+5	49	10	13	19	0.30	3.0	60
31	3C	20	38	10	13	19	0.30	3.0	60
32	4C	20+5	49	10	19	30	0.28	3.0	45
33	3C	20	38	10	13	19	0.30	3.0	60
34	5B	20+5	49	10	19	30	0.30	3.0	60
35	6B	20+5	49	10	19	30	0.30	2.5	60
36	3A	20	38	10	13	19	0.30	3.0	60
37	3B	20	38	10	13	19	0.30	3.0	60
38	5B	20+5	49	10	19	30	0.28	3.0	45
39	3B	20	38	10	13	19	0.30	3.0	60
40	5B	20+5	49	10	19	30	0.30	3.0	45
41	6B	20+5	49	10	19	30	0.30	2.5	45
42	7	20+5	49	10	19	30	0.28	2.5	45
43	5A	20+5	49	10	19	30	0.28	3.0	60
44	5A	20+5	49	10	19	30	0.28	3.0	60
45	5B	20+5	49	10	19	30	0.30	3.0	60
46	5B	20+5	49	10	19	30	0.30	3.0	60
47	4A	20+5	49	10	13	19	0.30	3.0	45
48	5B	20+5	49	10	19	30	0.30	3.0	60
49	4A	20+5	49	10	13	19	0.30	3.0	45
50	4C	20+5	49	10	19	30	0.28	3.0	45
*	Assuming continuous ventilation per IRC requirements								
**	Incl. exceptions due to site elevation, as applicable								
***	Modeled per Draft #2 dated May 9, 2023								

Table A.05: Prescriptive requirements from the draft of the 2024 IECC code, for each individual project in this study.

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

California Title 24 Prescriptive Requirements

Prj ID	CA Climate Zone	Roof / Ceiling	Wall Above Grade (framed)	BSMT Wall	Floor Over Uncond.	Slab on Grade	Fenestration		Max Air Leakage	Ventilation		Heat Pump Heating/ Cooling		PV System
							Max U-factor	Max SHGC		Min Airflow Rates	Min Heat Recovery			
		Min R-value	Max U-value	Max U-value	Min R-value	Min R-value			ACH50	cfm	%	HSPF	SEER	kW_dc
1	8	38	0.048	0.200	19	0	0.30	0.23	4.4	36	NR	min	min	0.0
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18	9	38	0.048	0.200	19	0	0.30	0.23	4.4	87	NR	min	min	2.4
19														
20														
21														
22														
23	16	38	0.048	0.200	19	8	0.30	NR	4.4	121	NR	min	min	2.7
24	14	38	0.048	0.200	19	8	0.30	0.23	4.4	115	NR	min	min	3.2
25														
26	2	38	0.048	0.200	19	8	0.30	0.23	4.4	118	NR	min	min	2.9
27														
28	10	38	0.048	0.200	19	0	0.30	0.23	4.4	120	NR	min	min	3.1
29														
30	12	38	0.048	0.200	19	4	0.30	0.23	4.4	131	NR	min	min	3.2
31	4	38	0.048	0.200	19	0	0.30	0.23	4.4	131	NR	min	min	2.9
32														
33	3	30	0.048	0.200	19	0	0.30	NR	4.4	138	NR	min	min	3.2
34														
35														
36														
37	10	38	0.048	0.200	19	0	0.30	0.23	4.4	143	NR	min	min	3.6
38														
39	10	38	0.048	0.200	19	0	0.30	0.23	4.4	146	NR	min	min	3.7
40														
41														
42														
43														
44														
45														
46														
47														
48														
49														
50														

Table A.06: California Title 24 prescriptive requirements for each individual project in this study located in California.

EnergyStar SFH National Program Requirements, v3.2****												
Prj ID	ASHRAE Climate Zone	Min R-value					Fenestration	Max Air Leakage	Ventilation*		Air-Source HP	
		Wall Above Grade	Roof/ Ceiling	Slab	BSMT Wall	Floor on Uncond.	Max U-value**		Airflow Rate	Sensible Heat Recovery (min)***		
		[h*ft2*°F/BTU]					[BTU / h*ft2*°F]	ACH50	cfm	%	HSPF	SEER
1	3B	20	49	10	13	19	0.30	3	30	NR	9.2	16
2	4C	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
3	6B	20+5	60	10	19	30	0.27	3	30	NR	9.2	16
4	5B	20+5	60	10	19	30	0.27	3	30	NR	9.2	16
5	6B	20+5	60	10	19	30	0.27	3	30	NR	9.2	16
6	2A	13	49	0	0	13	0.40	3	45	NR	9.2	16
7	6B	20+5	60	10	19	30	0.27	3	30	NR	9.2	16
8	5B	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
9	7	20+5	60	10	19	38	0.27	3	30	NR	9.2	16
10	2A	13	49	0	0	13	0.40	3	45	NR	9.2	16
11	5B	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
12	3A	20	49	10	13	19	0.30	3	45	NR	9.2	16
13	7	20+5	60	10	19	38	0.27	3	30	NR	9.2	16
14	4A	20+5	60	10	13	19	0.30	3	45	NR	9.2	16
15	7	20+5	60	10	19	38	0.27	3	45	NR	9.2	16
16	4A	20+5	60	10	13	19	0.30	3	45	NR	9.2	16
17	7	20+5	60	10	19	38	0.27	3	45	NR	9.2	16
18	3B	20	49	10	13	19	0.30	3	60	NR	9.2	16
19	6B	20+5	60	10	19	30	0.27	3	60	NR	9.2	16
20	5B	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
21	6B	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
22	5B	20+5	60	10	19	30	0.27	3	60	NR	9.2	16
23	4B	20+5	60	10	13	19	0.30	3	60	NR	9.2	16
24	4B	20+5	60	10	13	19	0.30	3	60	NR	9.2	16
25	5A	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
26	3C	20	49	10	13	19	0.30	3	60	NR	9.2	16
27	5A	20+5	60	10	19	30	0.27	3	60	NR	9.2	16
28	3B	20	49	10	13	19	0.30	3	60	NR	9.2	16
29	5B	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
30	4B	20+5	60	10	13	19	0.30	3	60	NR	9.2	16
31	3C	20	49	10	13	19	0.30	3	60	NR	9.2	16
32	4C	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
33	3C	20	49	10	13	19	0.30	3	60	NR	9.2	16
34	5B	20+5	60	10	19	30	0.27	3	60	NR	9.2	16
35	6B	20+5	60	10	19	30	0.27	3	60	NR	9.2	16
36	3A	20	49	10	13	19	0.30	3	60	NR	9.2	16
37	3B	20	49	10	13	19	0.30	3	60	NR	9.2	16
38	5B	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
39	3B	20	49	10	13	19	0.30	3	60	NR	9.2	16
40	5B	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
41	6B	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
42	7	20+5	60	10	19	38	0.27	3	45	NR	9.2	16
43	5A	20+5	60	10	19	30	0.27	3	60	NR	9.2	16
44	5A	20+5	60	10	19	30	0.27	3	60	NR	9.2	16
45	5B	20+5	60	10	19	30	0.27	3	60	NR	9.2	16
46	5B	20+5	60	10	19	30	0.27	3	60	NR	9.2	16
47	4A	20+5	60	10	13	19	0.30	3	45	NR	9.2	16
48	5B	20+5	60	10	19	30	0.27	3	60	NR	9.2	16
49	4A	20+5	60	10	13	19	0.30	3	45	NR	9.2	16
50	4C	20+5	60	10	19	30	0.27	3	45	NR	9.2	16
*	Assuming continuous ventilation per IRC requirements											
**	Incl. exceptions due to site elevation, as applicable											
***	Reduction of label heat recovery rate applied per PHI guidelines, as applicable											
****	National requirements applied to all projects, regardless of the location state, and adoption stage.											

Table A.07: EnergyStart v3.2 component performance modeled for each individual project in this study.

DOE Zero Energy Ready Home Requirements v2

Prj ID	ASHRAE Climate Zone	Min R-value					Fenestration	Max Air Leakage	Ventilation*		Air-Source HP	
		Wall Above Grade	Roof/ Ceiling	Slab	BSMT Wall	Floor on Uncond.	Max U-value**		Airflow Rate	Sensible Heat Recovery (min)***		
		[h*ft2*°F/BTU]					[BTU / h*ft2*°F]	ACH50	cfm	%	HSPF	SEER
1	3B	20	49	10	13	19	0.30	2.25	30	NR	9.2	16
2	4C	20+5	60	10	19	30	0.27	2	45	65%	9.5	16
3	6B	20+5	60	10	19	30	0.30	2	30	65%	9.5	16
4	5B	20+5	60	10	19	30	0.27	2	30	65%	9.5	16
5	6B	20+5	60	10	19	30	0.30	2	30	65%	9.5	16
6	2A	13	49	0	0	13	0.40	2.75	45	NR	9.2	18
7	6B	20+5	60	10	19	30	0.30	2	30	65%	9.5	16
8	5B	20+5	60	10	19	30	0.30	2	45	65%	9.5	16
9	7	20+5	60	10	19	38	0.25	2	30	65%	9.5	16
10	2A	13	49	0	0	13	0.40	2.75	45	NR	9.2	18
11	5B	20+5	60	10	19	30	0.27	2	45	65%	9.5	16
12	3A	20	49	10	13	19	0.30	2.25	45	NR	9.2	16
13	7	20+5	60	10	19	38	0.30	2	30	65%	9.5	16
14	4A	20+5	60	10	13	19	0.30	2.25	45	NR	9.2	16
15	7	20+5	60	10	19	38	0.32	2	45	65%	9.5	16
16	4A	20+5	60	10	13	19	0.30	2.25	45	NR	9.2	16
17	7	20+5	60	10	19	38	0.32	2	45	65%	9.5	16
18	3B	20	49	10	13	19	0.30	2.25	60	NR	9.2	16
19	6B	20+5	60	10	19	30	0.25	2	60	65%	9.5	16
20	5B	20+5	60	10	19	30	0.30	2	45	65%	9.5	16
21	6B	20+5	60	10	19	30	0.30	2	45	65%	9.5	16
22	5B	20+5	60	10	19	30	0.30	2	60	65%	9.5	16
23	4B	20+5	60	10	13	19	0.30	2.25	60	NR	9.2	16
24	4B	20+5	60	10	13	19	0.30	2.25	60	NR	9.2	16
25	5A	20+5	60	10	19	30	0.27	2	45	65%	9.5	16
26	3C	20	49	10	13	19	0.30	2.25	60	NR	9.2	16
27	5A	20+5	60	10	19	30	0.27	2	60	65%	9.5	16
28	3B	20	49	10	13	19	0.30	2.25	60	NR	9.2	16
29	5B	20+5	60	10	19	30	0.30	2	45	65%	9.5	16
30	4B	20+5	60	10	13	19	0.30	2.25	60	NR	9.2	16
31	3C	20	49	10	13	19	0.30	2.25	60	NR	9.2	16
32	4C	20+5	60	10	19	30	0.27	2	45	65%	9.5	16
33	3C	20	49	10	13	19	0.30	2.25	60	NR	9.2	16
34	5B	20+5	60	10	19	30	0.30	2	60	65%	9.5	16
35	6B	20+5	60	10	19	30	0.25	2	60	65%	9.5	16
36	3A	20	49	10	13	19	0.30	2.25	60	NR	9.2	16
37	3B	20	49	10	13	19	0.30	2.25	60	NR	9.2	16
38	5B	20+5	60	10	19	30	0.27	2	45	65%	9.5	16
39	3B	20	49	10	13	19	0.30	2.25	60	NR	9.2	16
40	5B	20+5	60	10	19	30	0.30	2	45	65%	9.5	16
41	6B	20+5	60	10	19	30	0.30	2	45	65%	9.5	16
42	7	20+5	60	10	19	38	0.25	2	45	65%	9.5	16
43	5A	20+5	60	10	19	30	0.27	2	60	65%	9.5	16
44	5A	20+5	60	10	19	30	0.27	2	60	65%	9.5	16
45	5B	20+5	60	10	19	30	0.30	2	60	65%	9.5	16
46	5B	20+5	60	10	19	30	0.30	2	60	65%	9.5	16
47	4A	20+5	60	10	13	19	0.30	2.25	45	NR	9.2	16
48	5B	20+5	60	10	19	30	0.30	2	60	65%	9.5	16
49	4A	20+5	60	10	13	19	0.30	2.25	45	NR	9.2	16
50	4C	20+5	60	10	19	30	0.27	2	45	65%	9.5	16

* Assuming continuous ventilation per IRC requirements

** Incl. exceptions due to site elevation, as applicable

*** Reduction of label heat recovery rate applied per PHI guidelines, as applicable

**** National requirements applied to all projects, regardless of the location state, and adoption stage.

Table A.08: DOE Zero Energy Ready Home v2 component performance modeled for each individual project in this study.

Pretty Good House - Indicative Requirements

Prj ID	ASHRAE Climate Zone	Applicable Climate Zone?	R-value					Fenestration	Max Air Leakage	Ventilation*		Heat Pump Heating/Cooling**	
			Wall Above Grade	Roof/ Ceiling	Slab	BSMT Wall	Floor on Uncond.	Max U-value		Airflow Rate	Sensible Heat Recovery (min)***		
			h*ft2*°F/BTU					[BTU / h*ft2*°F]	ACH50	cfm	%	HSPF	SEER
1	3B	No											
2	4C	No											
3	6B	Yes	40	60	10	20	30	0.20	1	30	50%	8.2	15
4	5B	Yes	40	60	10	20	30	0.20	1	30	50%	8.2	15
5	6B	Yes	40	60	10	20	30	0.20	1	30	50%	8.2	15
6	2A	No											
7	6B	Yes	40	60	10	20	30	0.20	1	30	50%	8.2	15
8	5B	Yes	40	60	10	20	30	0.20	1	45	50%	8.2	15
9	7	No											
10	2A	No											
11	5B	Yes	40	60	10	20	30	0.20	1	45	50%	8.2	15
12	3A	No											
13	7	No											
14	4A	No											
15	7	No											
16	4A	No											
17	7	No											
18	3B	No											
19	6B	Yes	40	60	10	20	30	0.20	1	60	50%	8.2	15
20	5B	Yes	40	60	10	20	30	0.20	1	45	50%	8.2	15
21	6B	Yes	40	60	10	20	30	0.20	1	45	50%	8.2	15
22	5B	Yes	40	60	10	20	30	0.20	1	60	50%	8.2	15
23	4B	No											
24	4B	No											
25	5A	Yes	40	60	10	20	30	0.20	1	45	50%	8.2	15
26	3C	No											
27	5A	Yes	40	60	10	20	30	0.20	1	60	50%	8.2	15
28	3B	No											
29	5B	Yes	40	60	10	20	30	0.20	1	45	50%	8.2	15
30	4B	No											
31	3C	No											
33	4C	No											
34	3C	No											
35	5B	Yes	40	60	10	20	30	0.20	1	60	50%	8.2	15
36	6B	Yes	40	60	10	20	30	0.20	1	60	50%	8.2	15
37	3A	No											
38	3B	No											
38	5B	Yes	40	60	10	20	30	0.20	1	45	50%	8.2	15
39	3B	No											
40	5B	Yes	40	60	10	20	30	0.20	1	45	50%	8.2	15
41	6B	Yes	40	60	10	20	30	0.20	1	45	50%	8.2	15
42	7	No											
43	5A	Yes	40	60	10	20	30	0.20	1	60	50%	8.2	15
44	5A	Yes	40	60	10	20	30	0.20	1	60	50%	8.2	15
45	5B	Yes	40	60	10	20	30	0.20	1	60	50%	8.2	15
46	5B	Yes	40	60	10	20	30	0.20	1	60	50%	8.2	15
47	4A	No											
48	5B	Yes	40	60	10	20	30	0.20	1	60	50%	8.2	15
49	4A	No											
50	4C	No											

PGH does not provide a specific framework of requirements, wether prescriptive or preformance-based. The values listed above where compiled for the purpose of this study, in order to establish a "Pretty Good House standard" to compare to the other building standards included in the study. At the time this study was conducted, the PGH website listed recommended values (R-values, window U-value, ACH50) only for Climate Zone 5 and 6, which are indicated above as 'applicable' climate zones.

*	Unspecified by PGH, IRC/IECC minimum compliance values applied
**	Unspecified by PGH, "basic" HP assumed
***	Unspecified by PHG, deduced by PGH book

Table A.09: Pretty Good House component performance modeled for projects located in climate zone 5 and 6.

PHIUS+ Core Prescriptive - Requirements

Prj ID	Project Meets Requir.mnt TFA < 900 ft2 * Br	ASHRAE Climate Zone	Reference Location	Fenestration		E/HRV		Min R-values					Continuous Ventilation*	Extract Requirements	Supply Requirement	Air-source Heat Pump			Max Air Leakage
				Max U-value	Max SHGC	Min SRE	Min TRE	Wall	Roof	Slab	Floor on Uncond.	Wall Below Grade							
				[BTU / h*ft2*°F]	[-]	[%]		[h*ft2*°F/BTU]					cfm			type	HSPF	SEER	q50
1	Yes	3B	Fullerton, CA	0.39	0.25	NR	NR	24	53	10	15	10	45	45	15	1	9.6	18	0.04
2	Yes	4C	Seattle, WA	0.25	NR	0.69	NR	31	61	16	21	16	65	65	30	1	9.6	18	0.04
3	Yes	6B	Bozeman, MT	0.13	NR	0.83	NR	43	74	24	29	24	45	45	15	2	9.2	15	0.04
4	Yes	5B	Coer D'Alene, ID	0.17	NR	0.80	NR	39	69	21	26	21	65	65	15	2	9.2	15	0.04
5	Yes	6B	Alamosa, CO	0.13	NR	0.84	NR	44	76	26	31	26	45	45	15	2	9.2	15	0.04
6	Yes	2A	Orlando, FL	0.38	0.25	NR	0.60	22	51	8	13	8	65	65	30	1	9.6	18	0.04
7	No																		
8	Yes	5B	Denver, CO	0.16	NR	0.78	NR	37	68	19	25	19	65	65	30	2	9.2	15	0.04
9	No																		
10	Yes	2A	Austin, TX	0.26	0.25	0.60	0.60	25	55	11	16	11	85	85	45	1	9.6	18	0.04
11	Yes	5B	Coer D'Alene, ID	0.17	NR	0.80	NR	39	69	21	26	21	65	65	30	2	9.2	15	0.04
12	Yes	3A	Huntsville, AL	0.22	0.25	0.69	0.60	29	59	13	18	13	65	65	30	1	9.6	18	0.04
13	No																		
14	Yes	4A	Hickory, NC	0.22	0.25	0.71	0.60	30	60	14	19	14	65	65	30	1	9.6	18	0.04
15	Yes	7	Gunnison, CO	0.12	NR	0.86	NR	47	79	29	34	29	85	85	30	2	9.2	15	0.04
16	Yes	4A	St Louis, MO	0.18	0.4	0.78	0.50	32	63	16	21	16	65	65	45	2	9.2	15	0.04
17	Yes	7	Leadville, CO	0.14	NR	0.84	NR	51	82	34	39	34	65	65	45	2	9.2	15	0.04
18	Yes	3B	Los Angeles, CA	0.36	0.25	NR	NR	25	54	11	16	11	105	105	60	1	9.6	18	0.04
19	Yes	6B	Idaho Falls, ID	0.14	NR	0.83	NR	41	72	23	28	23	85	85	60	2	9.2	15	0.04
20	Yes	5B	Santa Fe, NM	0.18	0.4	0.78	NR	36	66	18	23	18	85	85	45	2	9.2	15	0.04
21	Yes	6B	Alamosa, CO	0.13	NR	0.84	NR	44	76	26	31	26	85	85	45	2	9.2	15	0.04
22	Yes	5B	Denver, CO	0.16	NR	0.78	NR	37	68	19	25	19	125	125	75	2	9.2	15	0.04
23	Yes	4B	Truckee, CA	0.16	0.4	0.80	NR	46	77	27	32	27	105	105	75	1	9.6	18	0.04
24	Yes	4B	Palmdale, CA	0.24	0.25	0.69	0.66	30	60	14	19	14	85	85	60	1	9.6	18	0.04
25	Yes	5A	Bangor, ME	0.14	NR	0.83	NR	45	76	25	31	25	85	85	45	2	9.2	15	0.04
26	Yes	3C	Santa Rosa, CA	0.27	0.3	0.62	NR	30	60	14	19	14	125	125	60	1	9.6	18	0.04
27	Yes	5A	Albany, NY	0.16	NR	0.82	NR	43	75	23	28	23	85	85	60	2	9.2	15	0.04
28	Yes	3B	Camp Pendleton, CA	0.3	0.25	0.66	NR	26	56	11	16	11	105	105	60	1	9.6	18	0.04
29	No																		
30	Yes	4B	Sacramento, CA	0.28	0.25	0.62	NR	28	58	13	18	13	75	65	75	1	9.6	18	0.04
31	Yes	3C	Mountain View, CA	0.33	0.3	0.60	NR	27	56	12	17	12	105	105	75	1	9.6	18	0.04
33	No																		
34	Yes	3C	Fort Collins, CO	0.16	NR	0.79	NR	38	69	20	25	20	85	85	60	1	9.6	18	0.04
35	Yes	5B	Bozeman, MT	0.13	NR	0.83	NR	43	74	24	29	24	85	85	60	2	9.2	15	0.04
36	Yes	6B	Charlotte, NC	0.23	0.25	0.69	0.60	29	59	13	18	13	165	165	75	2	9.2	15	0.04
37	Yes	3A	Riverside, CA	0.26	0.25	NR	NR	25	54	11	16	11	125	125	60	1	9.6	18	0.04
38	Yes	3B	Coer D'Alene, ID	0.17	NR	0.80	NR	39	69	21	26	21	125	125	45	1	9.6	18	0.04
38	No																		
39	No																		
40	No																		
41	No																		
42	No																		
43	No																		
44	No																		
45	No																		
46	No																		
47	No																		
48	No																		
49	No																		
50	No																		
*	Higher rate between calculated Extract and Supply																		

Table A.10: 2021 PHIUS+ Core Prescriptive prescriptive requirements for each applicable project in this study.

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Maximum Allowed Heating Demand (net)

Prj ID	ASHRAE Climate Zone	TFA	Form Factor	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2018 PHIUS+ Core	2021 PHIUS+ Core	2021 PHIUS+ Core Prescr.	PHI Low Energy Building	PHI Passive House
		ft2	ft2/ft2	kBTU/ft2y											
1	3B	572	4.6	No Requirements	No Requirements	No Requirements	No Requirements	No Requirements	No Requirements	No Requirements	2.44	2.31	No Requirements	9.50	4.75
2	4C	680	4.8								9.79	21.69		9.50	4.75
3	6B	681	5.1								12.40	29.90		9.50	4.75
4	5B	834	4.9								11.65	25.08		9.50	4.75
5	6B	887	4.3								10.20	21.50		9.50	4.75
6	2A	938	3.9								2.20	5.10		9.50	4.75
7	6B	944	4.5								10.20	21.70		9.50	4.75
8	5B	1066	3.8								9.20	10.40		9.50	4.75
9	7	1240	4.2								13.70	13.70		9.50	4.75
10	2A	1264	3.7								4.00	4.00		9.50	4.75
11	5B	1401	4.6								11.70	11.80		9.50	4.75
12	3A	1429	4.2								6.10	6.20		9.50	4.75
13	7	1466	3.9								13.20	13.70		9.50	4.75
14	4A	1513	4.9								6.75	6.90		9.50	4.75
15	7	1541	4.0								11.20	12.40		9.50	4.75
16	4A	1604	3.9								8.60	8.70		9.50	4.75
17	7	1619	4.5								12.80	13.40		9.50	4.75
18	3B	1640	5.9								2.72	2.69		9.50	4.75
19	6B	1962	3.0								11.27	11.50		9.50	4.75
20	5B	1977	4.1								7.30	8.50		9.50	4.75
21	6B	2149	3.0								10.20	11.10		9.50	4.75
22	5B	2354	3.0								9.20	9.50		9.50	4.75
23	4B	2525	3.2								9.70	10.30		9.50	4.75
24	4B	2598	3.5								4.00	4.70		9.50	4.75
25	5A	2650	2.9								12.40	11.10		9.50	4.75
26	3C	2681	3.0								5.30	5.00		9.50	4.75
27	5A	2747	3.7								10.00	9.60		9.50	4.75
28	3B	2751	3.4								3.40	3.50		9.50	4.75
29	5B	2798	2.5								9.20	7.80		9.50	4.75
30	4B	2855	3.7								4.30	4.50		9.50	4.75
31	3C	2875	3.1								4.69	4.18		9.50	4.75
32	4C	3221	3.0								9.50	8.50		9.50	4.75
33	3C	3357	2.4								4.81	3.20		9.50	4.75
34	5B	3379	3.5								9.40	8.70		9.50	4.75
35	6B	3428	2.8								12.40	11.20		9.50	4.75
36	3A	3452	5.4								6.00	12.50		9.50	4.75
37	3B	3521	2.7								2.80	1.90		9.50	4.75
38	5B	3565	2.7								11.70	9.90		9.50	4.75
39	3B	3606	2.7								2.80	1.90		9.50	4.75
40	5B	3668	3.1								9.40	10.00		9.50	4.75
41	6B	3715	3.9								13.20	13.50		9.50	4.75
42	7	3716	3.2								11.90	11.70		9.50	4.75
43	5A	3937	2.6								8.68	7.70		9.50	4.75
44	5A	4050	3.0								8.90	8.70		9.50	4.75
45	5B	4070	3.3								9.40	10.00		9.50	4.75
46	5B	4694	2.7								9.20	8.60		9.50	4.75
47	4A	5150	2.9								7.60	7.20		9.50	4.75
48	5B	5323	2.9								9.40	9.10		9.50	4.75
49	4A	5765	3.2								8.01	7.89		9.50	4.75
50	4C	5872	2.9								9.50	8.30		9.50	4.75

Table A.11: Maximum allowed heating demand values for each project for PHI and Phius performance-based standards.

Maximum Allowed Cooling Demand (net)																
Prj ID	ASHRAE Climate Zone	TFA	Form Factor	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2018 PHIUS+ Core	2021 PHIUS+ Core	2021 PHIUS+ Core Prescr.	PHI Low Energy Building	PHI Passive House
		ft2	ft2/ft2	kBTU/ft2y											
1	3B	572	4.6	No Requirements	No Requirements	No Requirements	No Requirements	No Requirements	No Requirements	No Requirements	19.57	12.57	No Requirements	10.13	5.38
2	4C	680	4.8								9.91	16.59		9.50	4.75
3	6B	681	5.1								10.10	16.80		9.50	4.75
4	5B	834	4.9								9.47	17.89		9.50	4.75
5	6B	887	4.3								13.40	13.20		9.50	4.75
6	2A	938	3.9								29.90	33.30		17.42	8.55
7	6B	944	4.5								13.40	16.20		9.50	4.75
8	5B	1066	3.8								12.40	7.20		9.50	4.75
9	7	1240	4.2								9.30	5.60		9.50	4.75
10	2A	1264	3.7								27.30	20.00		14.57	7.28
11	5B	1401	4.6								9.50	6.10		9.50	4.75
12	3A	1429	4.2								18.10	12.60		11.40	6.65
13	7	1466	3.9								10.20	4.90		9.50	4.75
14	4A	1513	4.9								16.44	10.70		11.08	6.33
15	7	1541	4.0								12.50	5.60		9.50	4.75
16	4A	1604	3.9								15.40	10.10		10.45	5.70
17	7	1619	4.5								10.40	5.30		9.50	4.75
18	3B	1640	5.9								18.46	11.27		9.50	4.75
19	6B	1962	3.0								11.31	5.99		9.50	4.75
20	5B	1977	4.1								16.50	7.30		9.50	4.75
21	6B	2149	3.0								13.40	5.60		9.50	4.75
22	5B	2354	3.0								12.30	6.70		9.50	4.75
23	4B	2525	3.2								11.80	6.00		9.50	4.75
24	4B	2598	3.5								21.80	10.30		9.50	4.75
25	5A	2650	2.9								9.60	5.70		9.50	4.75
26	3C	2681	3.0								13.70	7.60		9.50	4.75
27	5A	2747	3.7								11.30	7.50		9.50	4.75
28	3B	2751	3.4								17.20	9.80		9.82	5.07
29	5B	2798	2.5								12.50	4.80		9.50	4.75
30	4B	2855	3.7								16.40	10.10		9.50	4.75
31	3C	2875	3.1								12.64	9.50		9.50	4.75
32	4C	3221	3.0								8.60	6.30		9.50	4.75
33	3C	3357	2.4								13.87	5.19		9.50	4.75
34	5B	3379	3.5								12.90	6.60		9.50	4.75
35	6B	3428	2.8								10.10	4.60		9.50	4.75
36	3A	3452	5.4								18.50	5.90		10.45	5.70
37	3B	3521	2.7								19.50	10.20		9.80	5.07
38	5B	3565	2.7								9.80	4.50		9.50	4.75
39	3B	3606	2.7								19.50	10.30		9.80	5.07
40	5B	3668	3.1								13.00	6.90		9.50	4.75
41	6B	3715	3.9								10.30	5.00		9.50	4.75
42	7	3716	3.2								11.30	7.30		9.50	4.75
43	5A	3937	2.6								14.19	5.80		9.50	4.75
44	5A	4050	3.0								16.20	9.20		10.13	5.38
45	5B	4070	3.3								13.00	6.90		9.50	4.75
46	5B	4694	2.7								12.60	5.50		9.50	4.75
47	4A	5150	2.9								17.40	9.50		10.13	5.38
48	5B	5323	2.9								13.00	5.90		9.50	4.75
49	4A	5765	3.2								13.11	8.80		9.50	4.75
50	4C	5872	2.9								8.70	6.00		9.50	4.75

Table A.12: Maximum allowed cooling demand values for each project for PHI and Phius performance-based standards.

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Fenestration Requirements By Building Standard

Prj ID	ASHRAE Climate Zone	Max Fenestration Maw U-value, uninstalled (Uw)									Fenestration Maximum Allowed Installed U-value* (Uw_inst)								
		2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	PHIUS+ 2021 (all)	PHI (all)**	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	PHIUS+ 2021 (all)	PHI (all)**
		[BTU/ft2y]									[BTU/ft2y]								
1	3B	0.32	0.30	0.30	0.30	0.30	0.30	N/A	0.39	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.24
2	4C	0.30	0.30	0.28		0.27	0.27	N/A	0.25	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.16
3	6B	0.30	0.30	0.30		0.27	0.30	0.20	0.13	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.00
4	5B	0.30	0.30	0.28		0.27	0.27	0.20	0.17	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.18
5	6B	0.30	0.30	0.30		0.27	0.30	0.20	0.13	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.15
6	2A	0.40	0.40	0.40		0.40	0.40	N/A	0.38	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.23
7	6B	0.30	0.30	0.30		0.27	0.30	0.20	0.13	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.13
8	5B	0.30	0.30	0.30		0.27	0.30	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.18
9	7	0.30	0.30	0.28		0.27	0.25	N/A	0.12	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.13
10	2A	0.40	0.40	0.40		0.40	0.40	N/A	0.26	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.26
11	5B	0.30	0.30	0.28		0.27	0.27	0.20	0.17	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.17
12	3A	0.32	0.30	0.30		0.30	0.30	N/A	0.22	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.22
13	7	0.30	0.30	0.28		0.27	0.30	N/A	0.13	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.11
14	4A	0.32	0.30	0.30		0.30	0.30	N/A	0.22	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.21
15	7	0.30	0.30	0.28		0.27	0.32	N/A	0.12	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.12
16	4A	0.32	0.30	0.30		0.30	0.30	N/A	0.18	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.18
17	7	0.30	0.30	0.28		0.27	0.32	N/A	0.14	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.12
18	3B	0.32	0.30	0.30	0.30	0.30	0.30	N/A	0.36	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.23
19	6B	0.30	0.30	0.30		0.27	0.25	0.20	0.14	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.16
20	5B	0.30	0.30	0.30		0.27	0.30	0.20	0.18	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.19
21	6B	0.30	0.30	0.30		0.27	0.30	0.20	0.13	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.15
22	5B	0.30	0.30	0.30		0.27	0.30	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.17
23	4B	0.32	0.30	0.30	0.30	0.30	0.30	N/A	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.12
24	4B	0.32	0.30	0.30	0.30	0.30	0.30	N/A	0.24	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.21
25	5A	0.30	0.30	0.28		0.27	0.27	0.20	0.14	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.12
26	3C	0.32	0.30	0.30	0.30	0.30	0.30	N/A	0.27	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.22
27	5A	0.30	0.30	0.28		0.27	0.27	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.17
28	3B	0.32	0.30	0.30	0.30	0.30	0.30	N/A	0.30	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.23
29	5B	0.30	0.30	0.30		0.27	0.30	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.17
30	4B	0.32	0.30	0.30	0.30	0.30	0.30	N/A	0.28	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.23
31	3C	0.30	0.30	0.28	0.30	0.30	0.30	N/A	0.26	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.24
32	4C	0.30	0.30	0.28		0.27	0.27	N/A	0.26	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.21
33	3C	0.32	0.30	0.30	0.30	0.30	0.30	N/A	0.37	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.23
34	5B	0.30	0.30	0.30		0.27	0.30	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.15
35	6B	0.30	0.30	0.30		0.27	0.25	0.20	0.13	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.14
36	3A	0.32	0.30	0.30		0.30	0.30	N/A	0.23	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.20
37	3B	0.32	0.30	0.30	0.30	0.30	0.30	N/A	0.26	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.23
38	5B	0.30	0.30	0.28		0.27	0.27	0.20	0.17	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.14
39	3B	0.32	0.30	0.30	0.30	0.30	0.30	N/A	0.34	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.23
40	5B	0.30	0.30	0.30		0.27	0.30	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.18
41	6B	0.30	0.30	0.30		0.27	0.30	0.20	0.13	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.12
42	7	0.30	0.30	0.28		0.27	0.25	N/A	0.13	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.12
43	5A	0.30	0.30	0.28		0.27	0.27	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.21
44	5A	0.30	0.30	0.28		0.27	0.27	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.15
45	5B	0.30	0.30	0.30		0.27	0.30	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.18
46	5B	0.30	0.30	0.30		0.27	0.30	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.16
47	4A	0.32	0.30	0.30		0.30	0.30	N/A	0.18	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.16
48	5B	0.30	0.30	0.30		0.27	0.30	0.20	0.16	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.16
49	4A	0.30	0.30	0.30		0.30	0.30	N/A	0.18	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.18
50	4C	0.30	0.30	0.28		0.27	0.27	N/A	0.26	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.19
*	Inclusive of the intallation thermal bridges.																		

Table A.13: Uninstalled and installed U-factors (Uw, Uw_inst) required by building standard for each project.

Results: Thermal Comfort

Prj ID	ASHRAE Climate Zone	Design Temp For Comfort*	Delta Temperature (dT): Window Surface vs Room Average***								
			2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	PHIUS+ 2021 (all)	PHI (all)**
		[°F]	[°F]								
1	3B	38.8	8.0	7.4	7.4	7.4	7.4	7.4		10.0	5.3
2	4C	-12.1	20.2	20.2	20.2		17.5	17.5	14.2	9.9	9.5
3	6B	19.0	11.9	11.9	11.1		11.1	12.5		10.2	
4	5B	19.0	11.3	11.3	10.6		10.3	10.3	7.8	6.4	6.6
5	6B	-4.5	17.6	17.6	17.6		15.8	17.6	12.1	8.2	7.9
6	2A	39.2	9.2	9.2	9.2		9.2	9.2		8.8	4.9
7	6B	-5.4	18.1	18.1	18.1		16.3	18.1	12.5	8.6	7.1
8	5B	8.8	15.0	15.0	15.0		13.3	15.0	10.2	8.8	7.7
9	7	-13.9	19.6	19.6	18.3		17.8	16.6		8.4	7.7
10	2A	24.4	16.1	16.1	16.1		16.1	16.1		10.5	8.2
11	5B	4.6	15.7	15.7	14.6		14.0	14.0	10.8	9.6	8.0
12	3A	18.7	13.7	12.8	12.8		12.8	12.8		9.1	8.0
13	7	-14.6	18.2	18.2	17.3		16.9	18.2		7.9	6.9
14	4A	13.5	14.5	13.5	13.5		13.5	13.5		10.2	8.5
15	7	-6.9	17.3	17.3	16.3		15.8	18.3		7.2	6.5
16	4A	2.3	18.1	16.8	16.8		16.8	16.8		10.0	8.6
17	7	-14.6	19.7	19.7	18.4		17.7	20.9		9.7	7.4
18	3B	41.5	7.1	6.6	6.6	6.6	6.6	6.6		8.0	4.5
19	6B	-2.7	17.7	17.7	17.7		15.9	14.6	12.2	9.3	8.4
20	5B	12.4	13.4	13.4	13.4		12.1	13.4	9.3	8.5	7.8
21	6B	-4.7	18.3	18.3	18.3		16.4	18.3	12.6	8.7	8.3
22	5B	8.6	15.0	15.0	15.0		13.2	15.0	10.2	8.7	7.6
23	4B	6.6	15.4	14.5	14.5	14.5	14.5	14.5		8.0	5.6
24	4B	23.4	11.8	11.0	11.0	11.0	11.0	11.0		8.9	6.8
25	5A	-6.7	17.9	17.9	16.7		16.1	16.1	12.3	8.8	6.8
26	3C	30.2	9.3	8.8	8.8	8.8	8.8	8.8		7.8	6.2
27	5A	6.1	15.3	15.3	14.2		13.8	13.8	10.5	8.8	7.7
28	3B	39.7	7.2	6.8	6.8	6.8	6.8	6.8		6.9	4.8
29	5B	8.8	14.9	14.9	14.9		13.2	14.9	10.1	8.7	7.5
30	4B	27.3	10.5	9.8	9.8	9.8	9.8	9.8		9.1	7.0
31	3C	35.8	8.8	8.2	8.2	8.2	8.2	8.2		9.1	5.8
32	4C	19.8	11.9	11.9	11.0		10.7	10.7		10.8	7.5
33	3C	36.5	8.1	7.6	7.6	7.6	7.6	7.6		9.3	5.4
34	5B	8.8	13.9	13.9	13.9		12.6	13.9	9.5	7.6	6.8
35	6B	-12.6	20.4	20.4	20.4		18.1	16.6	13.9	9.6	8.3
36	3A	15.3	13.6	12.8	12.8		12.8	12.8		9.8	7.7
37	3B	38.3	7.7	7.2	7.2	7.2	7.2	7.2	6.1	6.3	5.1
38	5B	-1.3	15.9	15.9	15.0		14.5	14.5	11.0	8.8	7.2
39	3B	38.3	7.7	7.1	7.1	7.1	7.1	7.1		8.2	5.0
40	5B	9.9	14.2	14.2	14.2		12.7	14.2	9.7	8.1	7.9
41	6B	-12.6	19.7	19.7	19.7		17.6	19.7	13.4	9.1	7.3
42	7	-23.4	22.2	22.2	20.7		20.0	18.5		10.3	8.0
43	5A	16.2	12.7	12.7	11.8		11.4	11.4	8.7	7.5	8.1
44	5A	-2.9	17.0	17.0	15.9		15.4	15.4	11.7	9.4	7.7
45	5B	9.9	14.2	14.2	14.2		12.7	14.2	9.7	8.0	7.9
46	5B	8.8	14.3	14.3	14.3		12.9	14.3	9.8	8.1	7.1
47	4A	5.9	15.3	14.4	14.4		13.5	14.4		8.8	7.3
48	5B	9.7	13.9	13.9	13.9		12.7	13.9	9.6	7.7	6.9
49	4A	14.2	13.6	12.8	12.8		12.8	12.8		9.7	7.3
50	4C	20.1	11.3	11.3	10.6		10.2	10.2		9.7	6.8

* Average temperature of consecutive coldest 12 hours of the year (calculated in PHPP)

** Derived from PHPP v9.6. Modeling in PHPP v10 may vary due to upgraded window form factor algorithm

*** Assumptions:

Room Temperature	20	°C	68	°F
Window/door installation Psi value (all):	0.040	W/mK		

Table A.14: Design temperature for thermal comfort analysis, and calculated average temperature on the interior surface of windows and ext. doors for each project and building standard.

Fresh Air Ventilation Airflow Rates By Standard

Prj ID	Treated Floor Area (TFA)	Vented Volume [ft3]	Design Occupancy (ASHRAE 62.2)	Design Occupancy (PHIUS)	IRC / IECC	IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PHIUS (all)	PHI (all) ****
					bath fan only vent. *	contin. vent. **, ***					
	ft2						cfm				
1	572	4691	2	1	4	30	36	36	36	45	39
2	680	5580	3	2	6	45	43	43	43	65	61
3	681	5584	2	1	4	30	35	35	35	45	45
4	834	6843	2	1	4	30	40	40	40	65	56
5	887	7279	2	1	4	30	42	42	42	45	45
6	938	7691	3	2	6	45	51	51	51	65	65
7	944	7746	2	1	4	30	43	43	43	45	71
8	1066	8745	3	2	6	45	54	54	54	65	76
9	1240	10175	2	1	4	30	52	52	52	65	76
10	1264	10366	4	3	8	45	68	68	68	85	85
11	1401	11493	3	2	6	45	65	65	65	65	65
12	1429	11720	3	2	6	45	65	65	65	65	76
13	1466	12031	2	1	4	30	59	59	59	85	85
14	1513	12415	3	2	6	45	68	68	68	65	71
15	1541	12638	3	2	6	45	69	69	69	85	85
16	1604	13157	4	3	8	45	78	78	78	65	70
17	1619	13284	4	3	8	45	79	79	79	65	71
18	1640	13452	5	4	10	60	87	87	87	105	130
19	1962	16100	5	4	10	60	96	96	96	85	78
20	1977	16217	4	3	8	45	89	89	89	85	100
21	2149	17629	4	3	8	45	94	94	94	85	100
22	2354	19308	6	5	13	60	116	116	116	125	150
23	2525	20712	6	5	13	60	121	121	121	105	120
24	2598	21314	5	4	10	60	115	115	115	85	93
25	2650	21738	4	3	8	45	109	109	109	85	100
26	2681	21995	5	4	10	60	118	118	118	125	142
27	2747	22537	5	4	10	60	120	120	120	85	120
28	2751	22569	5	4	10	60	120	120	120	105	147
29	2798	22954	4	3	8	45	114	114	114	105	174
30	2855	23424	6	5	13	60	131	131	131	75	82
31	2875	23587	6	5	13	60	131	131	131	105	152
32	3221	26425	4	3	8	45	127	127	127	105	120
33	3357	27540	5	4	10	60	138	138	138	105	106
34	3379	27718	5	4	10	60	139	139	139	85	155
35	3428	28126	5	4	10	60	140	140	140	85	138
36	3452	28319	6	5	13	60	149	149	149	165	267
37	3521	28890	5	4	10	60	143	143	143	125	161
38	3565	29244	4	3	8	45	137	137	137	125	120
39	3606	29581	5	4	10	60	146	146	146	125	170
40	3668	30089	4	3	8	45	140	140	140	125	125
41	3715	30481	4	3	8	45	141	141	141	105	90
42	3716	30487	4	3	8	45	141	141	141	85	128
43	3937	32299	5	4	10	60	156	156	156	60	124
44	4050	33228	5	4	10	60	159	159	159	85	122
45	4070	33391	5	4	10	60	160	160	160	105	190
46	4694	38509	5	4	10	60	178	178	178	125	186
47	5150	42252	4	3	8	45	185	185	185	125	270
48	5323	43672	6	5	13	60	205	205	205	105	145
49	5765	47297	5	4	10	60	210	210	210	60	151
50	5872	48172	4	3	8	45	206	206	206	125	125

*	Common condition in buildings not provided with dedicated fresh air system.
**	Typically not mandated.
***	EnergyStar, DOE ZERH: ASHRAE 62.2-2010
****	Weighted average of the airflow rates (design + boost) per Emu's specs for the individual project, following PHI's guidelines

Table A.15: Assumed fresh air rates per project and building standard considered.

Fresh Air Ventilation - Occupancy-related Metric

Airflow Rate Per Occupant (cfm / person)

Prj ID	Design Occupancy (ASHRAE 62.2)	IRC / IECC bath fan only vent. *	IRC / IECC contin. vent. **, ***	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	PHIUS (all)	PHI (all) ****
1	2	2	15	18	18	18	No Requirements	23	19
2	3	2	15	14	14	14		22	20
3	2	2	15	18	18	18		23	23
4	2	2	15	20	20	20		33	28
5	2	2	15	21	21	21		23	23
6	3	2	15	17	17	17		22	22
7	2	2	15	22	22	22		23	35
8	3	2	15	18	18	18		22	25
9	2	2	15	26	26	26		33	38
10	4	2	11	17	17	17		21	21
11	3	2	15	22	22	22		22	22
12	3	2	15	22	22	22		22	25
13	2	2	15	29	29	29		43	43
14	3	2	15	23	23	23		22	24
15	3	2	15	23	23	23		28	28
16	4	2	11	20	20	20		16	18
17	4	2	11	20	20	20		16	18
18	5	2	12	17	17	17		21	26
19	5	2	12	19	19	19		17	16
20	4	2	11	22	22	22		21	25
21	4	2	11	24	24	24		21	25
22	6	2	10	19	19	19		21	25
23	6	2	10	20	20	20		18	20
24	5	2	12	23	23	23		17	19
25	4	2	11	27	27	27		21	25
26	5	2	12	24	24	24		25	28
27	5	2	12	24	24	24		17	24
28	5	2	12	24	24	24		21	29
29	4	2	11	28	28	28		26	44
30	6	2	10	22	22	22		13	14
31	6	2	10	22	22	22		18	25
32	4	2	11	32	32	32		26	30
33	5	2	12	28	28	28		21	21
34	5	2	12	28	28	28		17	31
35	5	2	12	28	28	28		17	28
36	6	2	10	25	25	25		28	45
37	5	2	12	29	29	29		25	32
38	4	2	11	34	34	34		31	30
39	5	2	12	29	29	29		25	34
40	4	2	11	35	35	35		31	31
41	4	2	11	35	35	35		26	23
42	4	2	11	35	35	35		21	32
43	5	2	12	31	31	31		12	25
44	5	2	12	32	32	32		17	24
45	5	2	12	32	32	32		21	38
46	5	2	12	36	36	36		25	37
47	4	2	11	46	46	46		31	68
48	6	2	10	34	34	34		18	24
49	5	2	12	42	42	42		12	30
50	4	2	11	52	52	52		31	31

Coverage Of Fresh Air Need (*****)

Prj ID	IRC / IECC bath fan only vent. *	IRC / IECC contin. vent. **, ***	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	PHIUS (all)	PHI (all) ****
1	11.6%	83.3%	98.8%	98.8%	98.8%	No Requirements	125.0%	107.8%
2	11.6%	83.3%	79.5%	79.5%	79.5%		120.4%	113.3%
3	11.6%	83.3%	98.4%	98.4%	98.4%		125.0%	125.8%
4	11.6%	83.3%	111.2%	111.2%	111.2%		180.6%	156.9%
5	11.6%	83.3%	115.6%	115.6%	115.6%		125.0%	125.8%
6	11.6%	83.3%	93.8%	93.8%	93.8%		120.4%	120.4%
7	11.6%	83.3%	120.3%	120.3%	120.3%		125.0%	196.1%
8	11.6%	83.3%	100.9%	100.9%	100.9%		120.4%	141.6%
9	11.6%	83.3%	145.0%	145.0%	145.0%		180.6%	212.4%
10	11.6%	62.5%	94.3%	94.3%	94.3%		118.1%	118.1%
11	11.6%	83.3%	119.5%	119.5%	119.5%		120.4%	120.4%
12	11.6%	83.3%	121.0%	121.0%	121.0%		120.4%	141.6%
13	11.6%	83.3%	163.9%	163.9%	163.9%		236.1%	236.1%
14	11.6%	83.3%	125.7%	125.7%	125.7%		120.4%	130.7%
15	11.6%	83.3%	127.3%	127.3%	127.3%		157.4%	157.4%
16	11.6%	62.5%	108.5%	108.5%	108.5%		90.3%	97.2%
17	11.6%	62.5%	109.1%	109.1%	109.1%		90.3%	98.0%
18	11.6%	66.7%	96.3%	96.3%	96.3%		116.7%	144.4%
19	11.6%	66.7%	107.1%	107.1%	107.1%		94.4%	86.9%
20	11.6%	62.5%	124.0%	124.0%	124.0%		118.1%	138.9%
21	11.6%	62.5%	131.2%	131.2%	131.2%		118.1%	138.9%
22	11.6%	55.6%	107.0%	107.0%	107.0%		115.7%	138.9%
23	11.6%	55.6%	111.8%	111.8%	111.8%		97.2%	111.1%
24	11.6%	66.7%	128.3%	128.3%	128.3%		94.4%	103.3%
25	11.6%	62.5%	152.1%	152.1%	152.1%		118.1%	138.9%
26	11.6%	66.7%	131.0%	131.0%	131.0%		138.9%	157.8%
27	11.6%	66.7%	133.2%	133.2%	133.2%		94.4%	133.3%
28	11.6%	66.7%	133.4%	133.4%	133.4%		116.7%	163.3%
29	11.6%	62.5%	158.2%	158.2%	158.2%		145.8%	241.7%
30	11.6%	55.6%	121.0%	121.0%	121.0%		69.4%	75.9%
31	11.6%	55.6%	121.5%	121.5%	121.5%		97.2%	140.5%
32	11.6%	62.5%	175.9%	175.9%	175.9%		145.8%	166.7%
33	11.6%	66.7%	153.6%	153.6%	153.6%		116.7%	118.3%
34	11.6%	66.7%	154.3%	154.3%	154.3%		94.4%	172.2%
35	11.6%	66.7%	155.9%	155.9%	155.9%		94.4%	153.3%
36	11.6%	55.6%	137.6%	137.6%	137.6%		152.8%	247.2%
37	11.6%	66.7%	159.0%	159.0%	159.0%		138.9%	178.9%
38	11.6%	62.5%	190.2%	190.2%	190.2%		173.6%	166.7%
39	11.6%	66.7%	161.9%	161.9%	161.9%		138.9%	188.9%
40	11.6%	62.5%	194.5%	194.5%	194.5%		173.6%	173.6%
41	11.6%	62.5%	196.5%	196.5%	196.5%		145.8%	125.0%
42	11.6%	62.5%	196.5%	196.5%	196.5%		118.1%	177.8%
43	11.6%	66.7%	172.9%	172.9%	172.9%		66.7%	137.9%
44	11.6%	66.7%	176.7%	176.7%	176.7%		94.4%	135.6%
45	11.6%	66.7%	177.3%	177.3%	177.3%		116.7%	211.1%
46	11.6%	66.7%	198.1%	198.1%	198.1%		138.9%	206.7%
47	11.6%	62.5%	256.3%	256.3%	256.3%		173.6%	375.0%
48	11.6%	55.6%	189.5%	189.5%	189.5%		97.2%	134.3%
49	11.6%	66.7%	233.8%	233.8%	233.8%		66.7%	168.0%
50	11.6%	62.5%	286.3%	286.3%	286.3%		173.6%	173.6%

Indoor Air Quality Level (******)

Prj ID	IRC / IECC bath fan only vent. *	IRC / IECC contin. vent. **, ***	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	PHIUS (all)	PHI (all) ****
1	low IAQ	good IAQ	good IAQ	good IAQ	good IAQ	N/A	high IAQ	good IAQ
2	low IAQ	good IAQ	good IAQ	good IAQ	good IAQ		high IAQ	good IAQ
3	low IAQ	good IAQ	good IAQ	good IAQ	good IAQ		high IAQ	high IAQ
4	low IAQ	good IAQ	good IAQ	good IAQ	good IAQ		excellent IAQ	high IAQ
5	low IAQ	good IAQ	good IAQ	good IAQ	good IAQ		high IAQ	high IAQ
6	low IAQ	good IAQ	good IAQ	good IAQ	good IAQ		high IAQ	high IAQ
7	low IAQ	good IAQ	high IAQ	high IAQ	high IAQ		high IAQ	excellent IAQ
8	low IAQ	good IAQ	good IAQ	good IAQ	good IAQ		high IAQ	high IAQ
9	low IAQ	good IAQ	high IAQ	high IAQ	high IAQ		excellent IAQ	excellent IAQ
10	low IAQ	low IAQ	good IAQ	good IAQ	good IAQ		high IAQ	high IAQ
11	low IAQ	good IAQ	high IAQ	high IAQ	high IAQ		high IAQ	high IAQ
12	low IAQ	good IAQ	high IAQ	high IAQ	high IAQ		high IAQ	high IAQ
13	low IAQ	good IAQ	high IAQ	high IAQ	high IAQ		excellent IAQ	excellent IAQ
14	low IAQ	good IAQ	high IAQ	high IAQ	high IAQ		high IAQ	high IAQ
15	low IAQ	good IAQ	high IAQ	high IAQ	high IAQ		high IAQ	high IAQ
16	low IAQ	low IAQ	good IAQ	good IAQ	good IAQ		good IAQ	good IAQ
17	low IAQ	low IAQ	good IAQ	good IAQ	good IAQ		good IAQ	good IAQ
18	low IAQ	low IAQ	good IAQ	good IAQ	good IAQ		good IAQ	high IAQ
19	low IAQ	low IAQ	good IAQ	good IAQ	good IAQ		good IAQ	good IAQ
20	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		high IAQ	high IAQ
21	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		high IAQ	high IAQ
22	low IAQ	low IAQ	good IAQ	good IAQ	good IAQ		good IAQ	high IAQ
23	low IAQ	low IAQ	good IAQ	good IAQ	good IAQ		good IAQ	good IAQ
24	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		good IAQ	good IAQ
25	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		high IAQ	high IAQ
26	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		high IAQ	high IAQ
27	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		good IAQ	high IAQ
28	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		good IAQ	high IAQ
29	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		high IAQ	excellent IAQ
30	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		low IAQ	good IAQ
31	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		good IAQ	high IAQ
32	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		high IAQ	high IAQ
33	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		good IAQ	high IAQ
34	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		good IAQ	high IAQ
35	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		good IAQ	high IAQ
36	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		high IAQ	excellent IAQ
37	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		high IAQ	excellent IAQ
38	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		high IAQ	high IAQ
39	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		high IAQ	excellent IAQ
40	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		high IAQ	high IAQ
41	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		high IAQ	high IAQ
42	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		high IAQ	excellent IAQ
43	low IAQ	low IAQ	high IAQ	high IAQ	high IAQ		low IAQ	high IAQ
44	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		good IAQ	high IAQ
45	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		good IAQ	excellent IAQ
46	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		high IAQ	high IAQ
47	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		high IAQ	excellent IAQ
48	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		good IAQ	high IAQ
49	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		low IAQ	high IAQ
50	low IAQ	low IAQ	excellent IAQ	excellent IAQ	excellent IAQ		high IAQ	high IAQ

*	Common condition in buildings not provided with dedicated fresh air system.
**	Typically not mandated.
***	EnergyStar, DOE ZERH: ASHRAE 62.2-2010
****	Weighted average of the airflow rates (design + boost) per Emu's specs for the individual project, following PHI's guidelines
*****	Assuming fresh air need = 18 cfm per adult occupant
******	Per EN 13779. Does not account for air filtration, or building air tightness

Table A.16: Air flow rates per occupant, and evaluation or indoor air quality based on the estimated CO2 concentration.

Building Envelope Efficiency

Prj ID	ASHRAE Climate Zone	Heating Demand (net)												Cooling Demand (net)											
		2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE NZER	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE NZER	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
		kWh/ft2*y												kWh/ft2*y											
1	3B	4.26	2.44	2.52	4.35	2.44	2.32		2.54	1.15	1.09	3.20	2.16	2.07	2.08	2.19	1.98	2.08	2.11		1.99	2.44	2.46	1.91	1.73
2	4C	14.40	12.99	12.69		12.28	11.85		10.28	3.39	7.45	3.30	1.77	0.15	0.13	0.14		0.13	0.13		0.12	1.13	1.04	1.24	1.75
3	6B	19.36	19.15	18.92		18.19	18.93	12.83	9.54	4.56	8.98	3.09	1.71	0.27	0.27	0.27		0.27	0.27	0.24	0.22	0.62	0.62	0.51	0.92
4	5B	7.23	6.15	6.21		5.96	5.75	3.87	3.82	3.92	7.08	3.30	1.73	3.49	3.22	3.29		3.20	3.22	2.91	2.99	3.00	3.77	3.30	2.04
5	6B	13.60	13.46	13.36		12.73	13.04	8.98	5.34	3.83	6.43	3.08	1.55	0.37	0.36	0.38		0.36	0.37	0.37	0.46	1.02	0.90	1.02	1.29
6	2A	1.21	1.18	1.15		1.06	1.05		0.46	0.62	0.95	0.62	0.48	10.41	10.24	10.09		9.65	9.60		9.31	9.45	10.50	8.57	7.89
7	6B	19.73	19.30	18.83		18.63	18.89	13.34		3.77	7.15	3.17	1.71	0.04	0.03	0.03		0.03	0.03	0.02		0.05	0.06	0.05	0.06
8	5B	12.50	10.97	11.19		10.33	10.58	7.07	5.94	2.97	3.46	3.28	1.78	0.64	0.59	0.60		0.59	0.59	0.56	0.54	1.21	1.22	1.21	1.29
9	7	17.49	17.17	16.38		16.39	14.97			4.35	4.35	3.15	1.63	0.09	0.08	0.10		0.08	0.08			0.14	0.14	0.13	0.14
10	2A	5.00	4.93	4.80		4.54	4.51		1.98	1.43	1.43	3.11	1.77	6.53	6.49	6.28		5.99	5.99		4.89	4.67	4.67	5.37	4.01
11	5B	16.84	14.96	14.90		14.20	13.81	10.56	8.62	3.82	3.82	3.20	1.63	0.31	0.25	0.28		0.25	0.25	0.22	0.24	0.67	0.67	0.80	0.51
12	3A	7.48	5.30	5.45		5.30	5.01		2.92	2.13	2.13	3.34	1.80	3.42	3.05	3.12		3.05	2.96		2.77	3.43	3.43	2.60	2.47
13	7	24.33	24.07	22.84		22.69	23.16			4.28	4.41	3.14	1.61	0.29	0.28	0.29		0.28	0.28			1.54	1.54	1.77	1.46
14	4A	9.23	8.18	8.18		8.18	7.61		5.88	2.31	2.38	3.26	1.75	2.52	2.40	2.40		2.40	2.30		2.31	2.41	2.43	2.40	2.32
15	7	17.69	17.44	16.47		16.59	16.88		6.97	3.68	4.04	3.13	1.53	0.02	0.05	0.12		0.12	0.12		0.04	0.22	0.23	0.20	0.59
16	4A	7.28	6.47	6.66		6.47	6.06		3.43	2.94	2.94	3.22	1.74	1.43	1.33	1.38		1.33	1.29		1.31	1.50	1.68	1.26	1.57
17	7	20.72	20.39	19.41		19.46	20.19		7.58	4.23	4.57	3.19	1.66	0.06	0.06	0.06		0.06	0.06		0.05	0.32	0.32	0.31	0.43
18	3B	5.75	4.26	4.41	5.89	4.26	4.00		3.95	1.26	1.22	4.03	2.07	0.81	1.53	1.58	0.45	1.53	1.57		1.47	3.48	3.48	0.70	2.77
19	6B	9.39	9.21	9.39		8.94	8.22	5.96	4.35	3.65	3.73	3.13	1.64	0.13	0.12	0.13		0.12	0.12	0.11	0.14	0.28	0.27	0.25	0.34
20	5B	10.10	8.94	9.18		8.62	8.39	5.83	4.77	2.54	2.96	2.96	1.71	0.49	0.43	0.46		0.43	0.43	0.41	0.47	1.07	1.09	0.94	1.01
21	6B	10.28	10.12	9.91		9.52	9.47	6.36	3.75	3.41	3.65	3.21	1.67	0.15	0.15	0.16		0.15	0.15	0.14	0.17	0.48	0.49	0.46	0.58
22	5B	8.63	7.86	7.99		7.45	7.40	4.93	4.08	3.16	3.27	3.23	1.71	0.02	0.02	0.02		0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.01
23	4B	17.43	15.18	15.37	17.88	15.18	14.48		6.37	3.19	3.43	3.23	1.68	0.07	0.05	0.06	0.07	0.05	0.05		0.03	0.16	0.16	0.16	0.20
24	4B	5.48	4.71	4.83	3.11	4.71	4.40		3.22	1.45	1.66	3.31	1.75	1.23	1.11	1.15	1.23	1.11	1.10		1.11	1.89	1.92	1.14	1.19
25	5A	9.67	8.74	8.64		8.47	7.68	5.93	3.77	4.11	3.71	3.19	1.68	0.12	0.11	0.11		0.11	0.13	0.13	0.15	0.30	0.34	0.29	0.37
26	3C	6.39	5.02	5.18	5.70	5.02	4.67		3.15	1.91	1.80	3.12	1.82	0.30	0.65	0.71	0.64	0.65	0.67		0.64	2.06	2.09	0.72	0.86
27	5A	9.93	8.95	8.93		8.71	8.10	6.47	4.48	3.36	3.19	3.22	1.64	0.40	0.34	0.35		0.34	0.34	0.32	0.38	0.80	0.83	0.75	0.93
28	3B	3.08	2.20	2.30	3.31	2.20	1.96		1.37	1.56	1.61	1.11	1.00	0.74	0.99	1.04	0.62	0.99	1.05		1.02	0.92	0.94	1.12	1.15
29	5B	7.39	6.68	6.70		6.31	6.04	4.02		3.13	2.70	3.28	1.72	0.20	0.18	0.18		0.17	0.17	0.14		0.27	0.28	0.28	0.30
30	4B	5.28	4.59	4.66	6.29	4.59	4.29		3.46	1.58	1.65	3.38	1.76	0.79	0.69	0.72	0.74	0.69	0.69		0.74	1.28	1.32	0.76	0.76
31	3C	3.98	3.45	3.50	4.65	3.45	3.11		2.56	1.88	1.68	2.66	1.93	0.82	0.99	1.03	0.59	0.99	1.00		0.96	1.82	1.88	0.59	0.80
32	4C	8.56	7.80	7.62		7.34	6.72			3.26	2.99	3.29	1.72	0.13	0.12	0.13		0.12	0.13			0.59	0.60	0.58	0.78
33	3C	3.24	2.72	2.80	3.74	2.72	2.45		1.92	1.82	1.32	1.97	1.85	0.33	0.33	0.37	0.32	0.33	0.35		0.32	0.69	0.72	0.43	0.45
34	5B	11.14	10.39	10.49		9.82	9.73	6.65	4.91	3.23	2.93	3.36	1.69	0.47	0.45	0.46		0.45	0.45	0.41	0.47	1.39	1.39	1.21	1.00
35	6B	8.83	8.70	8.35		8.35	7.33	5.74	3.56	4.05	3.59	3.20	1.66	0.06	0.06	0.06		0.06	0.06	0.05	0.07	0.07	0.10	0.15	0.20
36	3A	10.06	9.00	9.16		9.00	8.32		5.36	2.20	4.27	3.41	1.84	3.16	2.88	2.96		2.88	2.73		2.37	2.91	2.11	2.82	2.39
37	3B	2.76	2.00	2.07	2.93	2.00	1.80		1.09	1.26	0.92	1.20	1.12	0.92	1.08	1.16	0.85	1.10	1.13		1.15	1.16	1.16	0.99	0.99
38	5B	8.90	8.26	8.16		7.92	7.23	5.30		3.82	3.21	3.09	1.63	0.28	0.26	0.27		0.27	0.27	0.29		0.34	0.93	0.53	1.21
39	3B	2.93	2.01	2.07	3.06	2.01	1.82			1.25	0.86	1.38	1.29	0.83	1.02	1.06	0.70	1.02	1.06			2.29	2.61	0.91	0.93
40	5B	10.44	9.50	9.60		8.98	8.81	5.96		3.23	3.41	3.22	1.64	0.74	0.71	0.72		0.71	0.71	0.68		1.43	2.08	1.39	1.52
41	6B	19.74	19.48	18.90		17.97	18.31	11.60		4.34	4.43	3.13	1.63	0.28	0.28	0.28		0.28	0.28	0.29		2.62	1.28	1.49	1.38
42	7	10.83	10.66	10.11		10.20	9.07			3.87	3.77	3.15	1.58	0.25	0.24	0.24		0.23	0.23			0.58	0.59	0.48	0.59
43	5A	4.34	3.91	3.90		3.73	3.30	2.19		2.93	2.64	2.84	1.64	1.30	1.25	1.26		1.25	1.23	1.16		1.22	1.19	1.25	1.11
44	5A	7.83	7.02	6.96		6.74	6.05	4.43		2.93	2.87	3.14	1.59	1.34	1.27	1.30		1.27	1.25	1.21		1.58	1.61	1.46	1.95
45	5B	8.89	7.92	8.12		7.50	7.30	4.91		3.21	3.42	3.25	1.64	0.59	0.54	0.56		0.54	0.54	0.50		1.11	1.11	0.69	1.10
46	5B	8.09	7.22	7.30		6.94	6.55	4.62		3.05	2.85	3.13	1.67	0.32	0.31	0.31		0.31	0.31	0.30		0.75	0.75	0.67	0.83
47	4A	6.12	5.59	5.73		5.59	4.98			2.60	2.52	3.14	1.77	1.51	1.45	1.48		1.45	1.36			1.47	1.51	1.53	1.74
48	5B	6.84	6.26	6.44		6.01	5.64	4.21		3.43	3.28	3.29	1.78	0.20	0.17	0.18		0.17	0.17	0.14		0.33	0.36	0.35	0.39
49	4A	5.11	4.53	4.63		4.53	4.14			2.78	2.74	3.31	1.79	1.89	1.75	1.81		1.76	1.68			1.58	1.58	1.67	1.82
50	4C	9.27	8.56	8.36		8.10	7.17			2.94	2.56	3.27	1.70	0.09	0.09	0.09		0.09	0.09			0.59	0.63	0.54	0.78

HD and CD are calculated using 70˚F interior temperature for heating and 74˚F for cooling.

Table A.17: Heating and cooling demand (net) for each project, depending on the building standard adopted.

Heating / Cooling System Efficiency

Prj ID	ASHRAE Climate Zone	Heating Efficiency (HSPF)												Cooling Efficiency (SEER)											
		2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE NZER	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE NZER	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
		*	*	*				*		*	*	*	*	*	*	*				*		*	*	*	*
		kBTU/kWh												kBTU/kWh											
1	3B	8.2	8.2	8.2	8.8	9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15	15	16	16		18	15	15	15	15
2	4C	8.2	8.2	8.2		9.2	9.5		9.6	8.2	8.2	8.2	8.2	15	15	15		16	16		18	15	15	15	15
3	6B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
4	5B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
5	6B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
6	2A	8.2	8.2	8.2		9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15		16	18		18	15	15	15	15
7	6B	8.2	8.2	8.2		9.2	9.5	8.2		8.2	8.2	8.2	8.2	15	15	15		16	16	15		15	15	15	15
8	5B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
9	7	8.2	8.2	8.2		9.2	9.5			8.2	8.2	8.2	8.2	15	15	15		16	16			15	15	15	15
10	2A	8.2	8.2	8.2		9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15		16	18		18	15	15	15	15
11	5B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
12	3A	8.2	8.2	8.2		9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15		16	16		18	15	15	15	15
13	7	8.2	8.2	8.2		9.2	9.5			8.2	8.2	8.2	8.2	15	15	15		16	16			15	15	15	15
14	4A	8.2	8.2	8.2		9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15		16	16		18	15	15	15	15
15	7	8.2	8.2	8.2		9.2	9.5		9.2	8.2	8.2	8.2	8.2	15	15	15		16	16		15	15	15	15	15
16	4A	8.2	8.2	8.2		9.2	9.2		9.2	8.2	8.2	8.2	8.2	15	15	15		16	16		15	15	15	15	15
17	7	8.2	8.2	8.2		9.2	9.5		9.2	8.2	8.2	8.2	8.2	15	15	15		16	16		15	15	15	15	15
18	3B	8.2	8.2	8.2	8.8	9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15	15	16	16		18	15	15	15	15
19	6B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
20	5B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
21	6B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
22	5B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
23	4B	8.2	8.2	8.2	8.8	9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15	15	16	16		18	15	15	15	15
24	4B	8.2	8.2	8.2	8.8	9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15	15	16	16		18	15	15	15	15
25	5A	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
26	3C	8.2	8.2	8.2	8.8	9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15	15	16	16		18	15	15	15	15
27	5A	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
28	3B	8.2	8.2	8.2	8.8	9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15	15	16	16		18	15	15	15	15
29	5B	8.2	8.2	8.2		9.2	9.5	8.2		8.2	8.2	8.2	8.2	15	15	15		16	16	15		15	15	15	15
30	4B	8.2	8.2	8.2	8.8	9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15	15	16	16		18	15	15	15	15
31	3C	8.2	8.2	8.2	8.8	9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15	15	16	16		18	15	15	15	15
32	4C	8.2	8.2	8.2		9.2	9.5			8.2	8.2	8.2	8.2	15	15	15		16	16			15	15	15	15
33	3C	8.2	8.2	8.2	8.8	9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15	15	16	16		18	15	15	15	15
34	5B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
35	6B	8.2	8.2	8.2		9.2	9.5	8.2	9.2	8.2	8.2	8.2	8.2	15	15	15		16	16	15	15	15	15	15	15
36	3A	8.2	8.2	8.2		9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15		16	16		18	15	15	15	15
37	3B	8.2	8.2	8.2	8.8	9.2	9.2		9.6	8.2	8.2	8.2	8.2	15	15	15	15	16	16		18	15	15	15	15
38	5B	8.2	8.2	8.2		9.2	9.5	8.2		8.2	8.2	8.2	8.2	15	15	15		16	16	15		15	15	15	15
39	3B	8.2	8.2	8.2	8.8	9.2	9.2			8.2	8.2	8.2	8.2	15	15	15	15	16	16			15	15	15	15
40	5B	8.2	8.2	8.2		9.2	9.5	8.2		8.2	8.2	8.2	8.2	15	15	15		16	16	15		15	15	15	15
41	6B	8.2	8.2	8.2		9.2	9.5	8.2		8.2	8.2	8.2	8.2	15	15	15		16	16	15		15	15	15	15
42	7	8.2	8.2	8.2		9.2	9.5			8.2	8.2	8.2	8.2	15	15	15		16	16			15	15	15	15
43	5A	8.2	8.2	8.2		9.2	9.5	8.2		8.2	8.2	8.2	8.2	15	15	15		16	16	15		15	15	15	15
44	5A	8.2	8.2	8.2		9.2	9.5	8.2		8.2	8.2	8.2	8.2	15	15	15		16	16	15		15	15	15	15
45	5B	8.2	8.2	8.2		9.2	9.5	8.2		8.2	8.2	8.2	8.2	15	15	15		16	16	15		15	15	15	15
46	5B	8.2	8.2	8.2		9.2	9.5	8.2		8.2	8.2	8.2	8.2	15	15	15		16	16	15		15	15	15	15
47	4A	8.2	8.2	8.2		9.2	9.2			8.2	8.2	8.2	8.2	15	15	15		16	16			15	15	15	15
48	5B	8.2	8.2	8.2		9.2	9.5	8.2		8.2	8.2	8.2	8.2	15	15	15		16	16	15		15	15	15	15
49	4A	8.2	8.2	8.2		9.2	9.2			8.2	8.2	8.2	8.2	15	15	15		16	16			15	15	15	15
50	4C	8.2	8.2	8.2		9.2	9.5			8.2	8.2	8.2	8.2	15	15	15		16	16			15	15	15	15

All projects were assumed to have active heating and cooling, provided by the same system.

HSPF, SEER: Label performance. Actual performance in project-specific conditions was not calculated

* For standards not mandating specific performance for HP heating/cooling, a "basic" heat pump was assumed for the modeling.

Table A.18: Seasonal performance (HSPF, SEER) for the heat pump considered for each project, depending on the building standard adopted.

emu REPORT

Heating + Cooling Demand, Final Energy (Site Energy)													
Prj ID	ASHRAE Climate Zone	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
		kWh/y											
1	3B	1300	900	900	1300	800	800		800	600	600	1100	800
2	4C	4100	3700	3700		3200	3000		2600	1200	2300	1200	800
3	6B	5600	5500	5500		4700	4700	3700	2500	1400	2700	1000	700
4	5B	3200	2800	2800		2500	2300	1900	1800	2000	3200	1800	1000
5	6B	5100	5100	5100		4300	4300	3400	1900	1700	2600	1400	900
6	2A	2700	2700	2700		2300	2100		1900	2300	2700	2100	1900
7	6B	7800	7600	7500		6600	6500	5300		1500	2900	1300	700
8	5B	5700	5100	5200		4300	4200	3300	2500	1700	1900	1800	1200
9	7	9100	8900	8500		7600	6700			2300	2300	1700	900
10	2A	4600	4500	4400		3800	3600		2100	2100	2100	3200	2100
11	5B	10000	8900	8800		7500	7100	6300	4600	2500	2500	2200	1200
12	3A	5600	4200	4300		3800	3600		2300	2400	2400	2900	1900
13	7	15000	14800	14100		12500	12300			3200	3300	2600	1500
14	4A	6700	6000	6000		5400	5100		3900	2300	2400	2900	1900
15	7	11400	11200	10600		9600	9400		4000	2500	2700	2100	1200
16	4A	5400	4900	5000		4400	4100		2600	2600	2600	2700	1800
17	7	14000	13800	13100		11800	11800		4600	3000	3200	2300	1300
18	3B	4300	3500	3700	4000	3200	3000		2800	2200	2200	3100	2500
19	6B	7800	7600	7800		6600	5900	5000	3300	3200	3200	2700	1500
20	5B	8600	7600	7800		6500	6200	5000	3800	2600	3000	2900	1900
21	6B	9300	9200	9000		7700	7400	5800	3100	3300	3600	3100	1800
22	5B	8500	7800	7900		6600	6300	4900	3600	3200	3300	3200	1700
23	4B	18400	16000	16200	17600	14300	13600		5800	3500	3700	3500	1900
24	4B	6700	5800	6000	3900	5200	4900		3600	2700	3000	4300	2600
25	5A	10800	9700	9600		8400	7400	6700	3800	4800	4300	3700	2100
26	3C	7400	6000	6300	6400	5400	5100		3400	3400	3300	4000	2600
27	5A	11600	10500	10500		9100	8200	7600	4900	4400	4200	4200	2500
28	3B	4000	3200	3300	4000	2900	2700		1900	2400	2500	2000	1900
29	5B	8800	7900	8000		6700	6200	4800		3900	3400	4000	2200
30	4B	6800	6000	6100	7500	5300	5000		4000	2800	2900	4600	2600
31	3C	5300	4800	4900	5600	4300	4000		3200	3500	3300	3600	2900
32	4C	11600	10600	10400		8900	7900			4900	4500	4900	2900
33	3C	4800	4100	4200	5200	3700	3400		2500	3100	2400	3100	3000
34	5B	16100	15000	15200		12700	12200	9700	6600	5700	5200	5700	3200
35	6B	12700	12500	12000		10700	9100	8300	4600	5900	5200	4700	2600
36	3A	17000	15200	15500		13700	12700		8200	5500	7800	7200	4600
37	3B	4800	3800	4000	4700	3500	3300		2200	2800	2300	2600	2500
38	5B	13500	12500	12400		10700	9500	8100		6000	5600	5100	3400
39	3B	5100	3900	4000	4900	3500	3300			3800	3500	2900	2800
40	5B	16600	15100	15300		12800	12200	9700		6200	7000	6100	3800
41	6B	30800	30400	29500		25000	24700	18200		9000	8000	6100	3700
42	7	17000	16700	15900		14300	12300			6500	6400	5300	3000
43	5A	8300	7600	7600		6500	5700	4700		5900	5400	5800	3700
44	5A	14500	13000	13000		11300	9900	8600		6400	6400	6700	4500
45	5B	15700	14000	14300		11800	11200	8800		6500	6900	6200	3800
46	5B	16200	14500	14600		12400	11400	9400		6800	6400	6900	4200
47	4A	14900	13700	14100		12300	11100			7300	7200	8600	5900
48	5B	15400	14100	14500		12100	11000	9500		8100	7800	7800	4500
49	4A	14800	13200	13500		11900	11000			8800	8700	10200	6700
50	4C	22800	21100	20600		17800	15300			8000	7100	8800	5200

Table A.19: Combined site energy for heating and cooling for each project, depending on the building standard adopted.

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

Reduction of Heating + Cooling Demand, Final (Site Energy)

Prj ID	Climate Zone	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
		Baseline:	2018 IECC									
1	3B	-30.8%	-30.8%	0.0%	-38.5%	-38.5%		-38.5%	-53.8%	-53.8%	-15.4%	-38.5%
2	4C	-9.8%	-9.8%		-22.0%	-26.8%		-36.6%	-70.7%	-43.9%	-70.7%	-80.5%
3	6B	-1.8%	-1.8%		-16.1%	-16.1%	-33.9%	-55.4%	-75.0%	-51.8%	-82.1%	-87.5%
4	5B	-12.5%	-12.5%		-21.9%	-28.1%	-40.6%	-43.8%	-37.5%	0.0%	-43.8%	-68.8%
5	6B	0.0%	0.0%		-15.7%	-15.7%	-33.3%	-62.7%	-66.7%	-49.0%	-72.5%	-82.4%
6	2A	0.0%	0.0%		-14.8%	-22.2%		-29.6%	-14.8%	0.0%	-22.2%	-29.6%
7	6B	-2.6%	-3.8%		-15.4%	-16.7%	-32.1%		-80.8%	-62.8%	-83.3%	-91.0%
8	5B	-10.5%	-8.8%		-24.6%	-26.3%	-42.1%	-56.1%	-70.2%	-66.7%	-68.4%	-78.9%
9	7	-2.2%	-6.6%		-16.5%	-26.4%			-74.7%	-74.7%	-81.3%	-90.1%
10	2A	-2.2%	-4.3%		-17.4%	-21.7%		-54.3%	-54.3%	-54.3%	-30.4%	-54.3%
11	5B	-11.0%	-12.0%		-25.0%	-29.0%	-37.0%	-54.0%	-75.0%	-75.0%	-78.0%	-88.0%
12	3A	-25.0%	-23.2%		-32.1%	-35.7%		-58.9%	-57.1%	-57.1%	-48.2%	-66.1%
13	7	-1.3%	-6.0%		-16.7%	-18.0%			-78.7%	-78.0%	-82.7%	-90.0%
14	4A	-10.4%	-10.4%		-19.4%	-23.9%		-41.8%	-65.7%	-64.2%	-56.7%	-71.6%
15	7	-1.8%	-7.0%		-15.8%	-17.5%		-64.9%	-78.1%	-76.3%	-81.6%	-89.5%
16	4A	-9.3%	-7.4%		-18.5%	-24.1%		-51.9%	-51.9%	-51.9%	-50.0%	-66.7%
17	7	-1.4%	-6.4%		-15.7%	-15.7%		-67.1%	-78.6%	-77.1%	-83.6%	-90.7%
18	3B	-18.6%	-14.0%	-7.0%	-25.6%	-30.2%		-34.9%	-48.8%	-48.8%	-27.9%	-41.9%
19	6B	-2.6%	0.0%		-15.4%	-24.4%	-35.9%	-57.7%	-59.0%	-59.0%	-65.4%	-80.8%
20	5B	-11.6%	-9.3%		-24.4%	-27.9%	-41.9%	-55.8%	-69.8%	-65.1%	-66.3%	-77.9%
21	6B	-1.1%	-3.2%		-17.2%	-20.4%	-37.6%	-66.7%	-64.5%	-61.3%	-66.7%	-80.6%
22	5B	-8.2%	-7.1%		-22.4%	-25.9%	-42.4%	-57.6%	-62.4%	-61.2%	-62.4%	-80.0%
23	4B	-13.0%	-12.0%	-4.3%	-22.3%	-26.1%		-68.5%	-81.0%	-79.9%	-81.0%	-89.7%
24	4B	-13.4%	-10.4%	-41.8%	-22.4%	-26.9%		-46.3%	-59.7%	-55.2%	-35.8%	-61.2%
25	5A	-10.2%	-11.1%		-22.2%	-31.5%	-38.0%	-64.8%	-55.6%	-60.2%	-65.7%	-80.6%
26	3C	-18.9%	-14.9%	-13.5%	-27.0%	-31.1%		-54.1%	-54.1%	-55.4%	-45.9%	-64.9%
27	5A	-9.5%	-9.5%		-21.6%	-29.3%	-34.5%	-57.8%	-62.1%	-63.8%	-63.8%	-78.4%
28	3B	-20.0%	-17.5%	0.0%	-27.5%	-32.5%		-52.5%	-40.0%	-37.5%	-50.0%	-52.5%
29	5B	-10.2%	-9.1%		-23.9%	-29.5%	-45.5%		-55.7%	-61.4%	-54.5%	-75.0%
30	4B	-11.8%	-10.3%	10.3%	-22.1%	-26.5%		-41.2%	-58.8%	-57.4%	-32.4%	-61.8%
31	3C	-9.4%	-7.5%	5.7%	-18.9%	-24.5%		-39.6%	-34.0%	-37.7%	-32.1%	-45.3%
32	4C	-8.6%	-10.3%		-23.3%	-31.9%			-57.8%	-61.2%	-57.8%	-75.0%
33	3C	-14.6%	-12.5%	8.3%	-22.9%	-29.2%		-47.9%	-35.4%	-50.0%	-35.4%	-37.5%
34	5B	-6.8%	-5.6%		-21.1%	-24.2%	-39.8%	-59.0%	-64.6%	-67.7%	-64.6%	-80.1%
35	6B	-1.6%	-5.5%		-15.7%	-28.3%	-34.6%	-63.8%	-53.5%	-59.1%	-63.0%	-79.5%
36	3A	-10.6%	-8.8%		-19.4%	-25.3%		-51.8%	-67.6%	-54.1%	-57.6%	-72.9%
37	3B	-20.8%	-16.7%	-2.1%	-27.1%	-31.3%		-54.2%	-41.7%	-52.1%	-45.8%	-47.9%
38	5B	-7.4%	-8.1%		-20.7%	-29.6%	-40.0%		-55.6%	-58.5%	-62.2%	-74.8%
39	3B	-23.5%	-21.6%	-3.9%	-31.4%	-35.3%			-25.5%	-31.4%	-43.1%	-45.1%
40	5B	-9.0%	-7.8%		-22.9%	-26.5%	-41.6%		-62.7%	-57.8%	-63.3%	-77.1%
41	6B	-1.3%	-4.2%		-18.8%	-19.8%	-40.9%		-70.8%	-74.0%	-80.2%	-88.0%
42	7	-1.8%	-6.5%		-15.9%	-27.6%			-61.8%	-62.4%	-68.8%	-82.4%
43	5A	-8.4%	-8.4%		-21.7%	-31.3%	-43.4%		-28.9%	-34.9%	-30.1%	-55.4%
44	5A	-10.3%	-10.3%		-22.1%	-31.7%	-40.7%		-55.9%	-55.9%	-53.8%	-69.0%
45	5B	-10.8%	-8.9%		-24.8%	-28.7%	-43.9%		-58.6%	-56.1%	-60.5%	-75.8%
46	5B	-10.5%	-9.9%		-23.5%	-29.6%	-42.0%		-58.0%	-60.5%	-57.4%	-74.1%
47	4A	-8.1%	-5.4%		-17.4%	-25.5%			-51.0%	-51.7%	-42.3%	-60.4%
48	5B	-8.4%	-5.8%		-21.4%	-28.6%	-38.3%		-47.4%	-49.4%	-49.4%	-70.8%
49	4A	-10.8%	-8.8%		-19.6%	-25.7%			-40.5%	-41.2%	-31.1%	-54.7%
50	4C	-7.5%	-9.6%		-21.9%	-32.9%			-64.9%	-68.9%	-61.4%	-77.2%

	Average Values Across All Projects:										
Baseline:	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
2018 IECC	-9.4%	-9.2%	-4.4%	-21.4%	-26.6%	-39.1%	-52.8%	-57.8%	-55.7%	-56.6%	-70.6%

Table A.20: Reduction in combined site energy for heating and cooling for each project compared to the 2018 IECC baseline, depending on the building standard adopted.

Maximum Air Leakage - Volume-related Values (ACH50)

Prj ID	ASHRAE Climate Zone	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	Pretty Good House	2015 PHIUS+	2018 PHIUS+ Core	2021 PHIUS+ Core	2021 PHIUS+ Core Prescr.	PHI Low Energy Building	PHI Passive House
		ACH50 (n50) [1/h]												
1	3B	3.0	3.0	3.0	4.4	3.0	2.25		1.7	1.9	1.9	1.2	1.0	0.6
2	4C	3.0	3.0	3.0		3.0	2.00		1.5	1.7	1.7	1.1	1.0	0.6
3	6B	3.0	3.0	2.5		3.0	2.00	1.0	1.3	1.4	1.4	1.0	1.0	0.6
4	5B	3.0	3.0	3.0		3.0	2.00	1.0	1.4	1.5	1.5	1.0	1.0	0.6
5	6B	3.0	3.0	2.5		3.0	2.00	1.0	1.3	1.4	1.4	1.0	1.0	0.6
6	2A	5.0	5.0	4.0		3.0	2.75		1.4	1.6	1.6	1.0	1.0	0.6
7	6B	3.0	3.0	2.5		3.0	2.00	1.0	1.3	1.5	1.5		1.0	0.6
8	5B	3.0	3.0	3.0		3.0	2.00	1.0	1.3	1.4	1.4	0.9	1.0	0.6
9	7	3.0	3.0	2.5		3.0	2.00		1.2	1.3	1.3		1.0	0.6
10	2A	5.0	5.0	4.0		3.0	2.75		1.3	1.5	1.5	1.0	1.0	0.6
11	5B	3.0	3.0	3.0		3.0	2.00	1.0	1.4	1.6	1.6	1.0	1.0	0.6
12	3A	3.0	3.0	3.0		3.0	2.25		1.2	1.3	1.3	0.9	1.0	0.6
13	7	3.0	3.0	2.5		3.0	2.00		1.3	1.4	1.4		1.0	0.6
14	4A	3.0	3.0	3.0		3.0	2.25		1.3	1.5	1.5	1.0	1.0	0.6
15	7	3.0	3.0	2.5		3.0	2.00		1.1	1.3	1.3	0.8	1.0	0.6
16	4A	3.0	3.0	3.0		3.0	2.25		1.2	1.3	1.3	0.9	1.0	0.6
17	7	3.0	3.0	2.5		3.0	2.00		1.3	1.4	1.4	0.9	1.0	0.6
18	3B	3.0	3.0	3.0	4.4	3.0	2.25		1.0	1.1	1.1	0.7	1.0	0.6
19	6B	3.0	3.0	2.5		3.0	2.00	1.0	1.0	1.1	1.1	0.7	1.0	0.6
20	5B	3.0	3.0	3.0		3.0	2.00	1.0	1.1	1.2	1.2	0.8	1.0	0.6
21	6B	3.0	3.0	2.5		3.0	2.00	1.0	1.1	1.2	1.2	0.8	1.0	0.6
22	5B	3.0	3.0	3.0		3.0	2.00	1.0	0.8	0.9	0.9	0.6	1.0	0.6
23	4B	3.0	3.0	3.0	4.4	3.0	2.25		1.2	1.3	1.3	0.9	1.0	0.6
24	4B	3.0	3.0	3.0	4.4	3.0	2.25		1.3	1.4	1.4	0.9	1.0	0.6
25	5A	3.0	3.0	3.0		3.0	2.00	1.0	0.9	1.0	1.0	0.7	1.0	0.6
26	3C	3.0	3.0	3.0	4.4	3.0	2.25		0.9	1.0	1.0	0.7	1.0	0.6
27	5A	3.0	3.0	3.0		3.0	2.00	1.0	1.0	1.1	1.1	0.8	1.0	0.6
28	3B	3.0	3.0	3.0	4.4	3.0	2.25		0.8	0.9	0.9	0.6	1.0	0.6
29	5B	3.0	3.0	3.0		3.0	2.00	1.0	0.8	0.9	0.9		1.0	0.6
30	4B	3.0	3.0	3.0	4.4	3.0	2.25		1.2	1.4	1.4	0.9	1.0	0.6
31	3C	3.0	3.0	3.0	4.4	3.0	2.25		0.9	1.0	1.0	0.7	1.0	0.6
32	4C	3.0	3.0	3.0		3.0	2.00		0.9	1.0	1.0		1.0	0.6
33	3C	3.0	3.0	3.0	4.4	3.0	2.25		0.7	0.8	0.8	0.5	1.0	0.6
34	5B	3.0	3.0	3.0		3.0	2.00		1.0	1.1	1.1	0.7	1.0	0.6
35	6B	3.0	3.0	2.5		3.0	2.00	1.0	0.9	1.0	1.0	0.7	1.0	0.6
36	3A	3.0	3.0	3.0		3.0	2.25		0.8	0.9	0.9	0.6	1.0	0.6
37	3B	3.0	3.0	3.0	4.4	3.0	2.25		0.8	0.9	0.9	0.6	1.0	0.6
38	5B	3.0	3.0	3.0		3.0	2.00	1.0	1.0	1.1	1.1		1.0	0.6
39	3B	3.0	3.0	3.0	4.4	3.0	2.25		0.9	1.0	1.0		1.0	0.6
40	5B	3.0	3.0	3.0		3.0	2.00	1.0	0.9	1.0	1.0		1.0	0.6
41	6B	3.0	3.0	2.5		3.0	2.00	1.0	1.0	1.2	1.2		1.0	0.6
42	7	3.0	3.0	2.5		3.0	2.00		1.1	1.3	1.3		1.0	0.6
43	5A	3.0	3.0	3.0		3.0	2.00	1.0	0.8	0.9	0.9		1.0	0.6
44	5A	3.0	3.0	3.0		3.0	2.00	1.0	0.8	0.9	0.9		1.0	0.6
45	5B	3.0	3.0	3.0		3.0	2.00	1.0	1.0	1.1	1.1		1.0	0.6
46	5B	3.0	3.0	3.0		3.0	2.00	1.0	0.8	0.9	0.9		1.0	0.6
47	4A	3.0	3.0	3.0		3.0	2.25		0.6	0.7	0.7		1.0	0.6
48	5B	3.0	3.0	3.0		3.0	2.00	1.0	1.0	1.1	1.1		1.0	0.6
49	4A	3.0	3.0	3.0		3.0	2.25		0.8	0.9	0.9		1.0	0.6
50	4C	3.0	3.0	3.0		3.0	2.00		0.9	1.0	1.0		1.0	0.6

PHIUS+ standards provide maximum values in terms of surface-specific air leakage (q50). ACH50 values were calculated on a project-specific basis to allow comparison with other standards.

All requirements above are expressed with the same number of decimal figures. For standards that express their requirements with fewer decimal figures than others, the requirement is expressed to the maximum rounding error. For example, 0.01 equals to 0.014 (i.e. it does not equal to 0.010).

Table A.21: Volume-specific maximum air leakage allowed (ACH50) for each project, depending on the building standard adopted.

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Maximum Air Leakage - Surface Area-related Values (q50)

Prj ID	ASHRAE Climate Zone	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	Pretty Good House	2015 PHIUS+	2018 PHIUS+ Core	2021 PHIUS+ Core	2021 PHIUS+ Core Prescr.	PHI Low Energy Building	PHI Passive House
		(q50) [cfm/ft2]												
1	3B	0.097	0.097	0.097	0.142	0.097	0.073		0.054	0.060	0.060	0.040	0.034	0.021
2	4C	0.107	0.107	0.107		0.107	0.071		0.054	0.060	0.060	0.040	0.037	0.023
3	6B	0.124	0.124	0.104		0.124	0.083	0.041	0.054	0.060	0.060	0.040	0.043	0.026
4	5B	0.117	0.117	0.117		0.117	0.078	0.039	0.054	0.060	0.060	0.040	0.041	0.025
5	6B	0.125	0.125	0.104		0.125	0.084	0.042	0.054	0.060	0.060	0.040	0.043	0.027
6	2A	0.192	0.192	0.154		0.115	0.106		0.054	0.060	0.060	0.040	0.040	0.025
7	6B	0.123	0.123	0.103		0.123	0.082	0.041	0.054	0.060	0.060		0.043	0.026
8	5B	0.128	0.128	0.128		0.128	0.085	0.043	0.054	0.060	0.060	0.040	0.044	0.027
9	7	0.135	0.135	0.112		0.135	0.090		0.054	0.060	0.060		0.047	0.029
10	2A	0.201	0.201	0.161		0.121	0.111		0.054	0.060	0.060	0.040	0.042	0.026
11	5B	0.116	0.116	0.116		0.116	0.077	0.039	0.054	0.060	0.060	0.040	0.040	0.025
12	3A	0.135	0.135	0.135		0.135	0.101		0.054	0.060	0.060	0.040	0.047	0.029
13	7	0.129	0.129	0.107		0.129	0.086		0.054	0.060	0.060		0.045	0.027
14	4A	0.123	0.123	0.123		0.123	0.092		0.054	0.060	0.060	0.040	0.043	0.026
15	7	0.142	0.142	0.118		0.142	0.095		0.054	0.060	0.060	0.040	0.049	0.030
16	4A	0.133	0.133	0.133		0.133	0.100		0.054	0.060	0.060	0.040	0.046	0.028
17	7	0.128	0.128	0.107		0.128	0.086		0.054	0.060	0.060	0.040	0.045	0.027
18	3B	0.166	0.166	0.166	0.243	0.166	0.124		0.054	0.060	0.060	0.040	0.057	0.035
19	6B	0.162	0.162	0.135		0.162	0.108	0.054	0.054	0.060	0.060	0.040	0.056	0.034
20	5B	0.150	0.150	0.150		0.150	0.100	0.050	0.054	0.060	0.060	0.040	0.052	0.032
21	6B	0.146	0.146	0.121		0.146	0.097	0.049	0.054	0.060	0.060	0.040	0.050	0.031
22	5B	0.199	0.199	0.199		0.199	0.133	0.066	0.054	0.060	0.060	0.040	0.069	0.042
23	4B	0.140	0.140	0.140	0.205	0.140	0.105		0.054	0.060	0.060	0.040	0.049	0.030
24	4B	0.128	0.128	0.128	0.187	0.128	0.096		0.054	0.060	0.060	0.040	0.044	0.027
25	5A	0.176	0.176	0.176		0.176	0.118	0.059	0.054	0.060	0.060	0.040	0.061	0.038
26	3C	0.180	0.180	0.180	0.264	0.180	0.135		0.054	0.060	0.060	0.040	0.062	0.038
27	5A	0.158	0.158	0.158		0.158	0.105	0.053	0.054	0.060	0.060	0.040	0.055	0.034
28	3B	0.207	0.207	0.207	0.304	0.207	0.155		0.054	0.060	0.060	0.040	0.072	0.044
29	5B	0.208	0.208	0.208		0.208	0.139	0.069	0.054	0.060	0.060		0.072	0.044
30	4B	0.130	0.130	0.130	0.190	0.130	0.097		0.054	0.060	0.060	0.040	0.045	0.028
31	3C	0.183	0.183	0.183	0.268	0.183	0.137		0.054	0.060	0.060	0.040	0.063	0.039
32	4C	0.179	0.179	0.179		0.179	0.120		0.054	0.060	0.060		0.062	0.038
33	3C	0.226	0.226	0.226	0.332	0.226	0.170		0.054	0.060	0.060	0.040	0.078	0.048
34	5B	0.163	0.163	0.163		0.163	0.109	0.054	0.054	0.060	0.060	0.040	0.057	0.035
35	6B	0.182	0.182	0.152		0.182	0.121	0.061	0.054	0.060	0.060	0.040	0.063	0.039
36	3A	0.204	0.204	0.204		0.204	0.153		0.054	0.060	0.060	0.040	0.071	0.044
37	3B	0.196	0.196	0.196	0.287	0.196	0.147		0.054	0.060	0.060	0.040	0.068	0.042
38	5B	0.169	0.169	0.169		0.169	0.113	0.056	0.054	0.060	0.060		0.059	0.036
39	3B	0.187	0.187	0.187	0.275	0.187	0.140		0.054	0.060	0.060		0.065	0.040
40	5B	0.173	0.173	0.173		0.173	0.115	0.058	0.054	0.060	0.060		0.060	0.037
41	6B	0.155	0.155	0.129		0.155	0.103	0.052	0.054	0.060	0.060		0.054	0.033
42	7	0.141	0.141	0.118		0.141	0.094		0.054	0.060	0.060		0.049	0.030
43	5A	0.199	0.199	0.199		0.199	0.133	0.066	0.054	0.060	0.060		0.069	0.043
44	5A	0.212	0.212	0.212		0.212	0.141	0.071	0.054	0.060	0.060		0.073	0.045
45	5B	0.165	0.165	0.165		0.165	0.110	0.055	0.054	0.060	0.060		0.057	0.035
46	5B	0.196	0.196	0.196		0.196	0.131	0.065	0.054	0.060	0.060		0.068	0.042
47	4A	0.274	0.274	0.274		0.274	0.205		0.054	0.060	0.060		0.095	0.058
48	5B	0.158	0.158	0.158		0.158	0.106	0.053	0.054	0.060	0.060		0.055	0.034
49	4A	0.205	0.205	0.205		0.205	0.154		0.054	0.060	0.060		0.071	0.044
50	4C	0.184	0.184	0.184		0.184	0.123		0.054	0.060	0.060		0.064	0.039

IECC and PHI provide maximum values in terms of volume-specific air leakage (ACH50, aka n50). Q50 values were calculated on a project-specific basis to allow comparison with PHIUS+ standards

All requirements above are expressed with the same number of decimal figures. For standards that express their requirements with fewer decimal figures than others, the requirement is expressed to the maximum rounding error. For example, 0.01 equals to 0.014 (i.e. it does not equal to 0.010).

Table A.21: Surface area-specific maximum air leakage allowed (q50) for each project, depending on the building standard adopted.

Maximum Allowed Air Leakage

Maximum Air Leakage Allowed By Building Standard

Median Values Across All Projects	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	Pretty Good House	2015 PHIUS+	2018 PHIUS+ Core	2021 PHIUS+ Core	2021 PHIUS+ Core Prescr.	PHI Low Energy Building	PHI Passive House
Volume-related	3.0	3.0	3.0	4.4	3.0	2.0	1.0	1.0	1.1	1.1	0.9	1.0	0.6
Surface-related	0.162	0.162	0.156	0.264	0.158	0.107	0.054	0.054	0.060	0.060	0.040	0.055	0.034

IECC and PHI provide maximum values in terms of volume-specific air leakage (ACH50, aka n50). Q50 values were calculated on a project-specific basis to allow comparison with PHIUS+ standards

PHIUS+ standards provide maximum values in terms of surface-specific air leakage (q50). ACH50 values were calculated on a project-specific basis to allow comparison with other standards.

All requirements above are expressed with the same number of decimal figures. For standards that express their requirements with fewer decimal figures than others, the requirement is expressed to the maximum rounding error. For example, 0.01 equals to 0.014 (i.e. it does not equal to 0.010).

Table A.22: Median values for volume-and surface area-specific maximum air leakage allowed for each project, depending on the building standard adopted.

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Systems Other Than Heating + Cooling (Site Energy)

Prj ID	Home Appliances	DHW	On-site Energy Production From Mandated PV System***											
	*	*, **	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
	kWh/y	kWh/y	kWh/y											
1	1500	425				0								
2	1725	625												
3	1850	425												
4	1850	425												
5	1950	425												
6	2025	625												
7	3325	425												
8	2250	625												
9	2225	425												
10	2350	825												
11	2475	625												
12	2400	625												
13	3250	425												
14	2375	625												
15	2350	625												
16	2600	825												
17	3100	825												
18	2450	1050				3222								
19	2850	1050												
20	2625	825												
21	2825	825												
22	3000	1250												
23	2725	1250				3785								
24	2650	1050				4770								
25	3000	825												
26	2750	1050				3577								
27	2975	1050												
28	3175	1050				4188								
29	3300	825												
30	2625	1250				4143								
31	2550	1250				3854								
32	2975	825												
33	2550	1050				4088								
34	3025	1050												
35	3100	1050												
36	3275	1250												
37	3075	1050				4987								
38	2775	825												
39	3325	1050				5060								
40	2725	825												
41	2700	825												
42	2800	825												
43	2775	1050												
44	3050	1050												
45	3300	1050												
46	3175	1050												
47	3150	825												
48	2875	1250												
49	2775	1050												
50	3000	825												

* Assumed to be the same for all building standards.

** Assumes HPWH. It does not include variations in heating/cooling demand for HPWH installed inside the building thermal envelope.

*** Assumed to generate 20% less than in ideal conditions, due to e.g. imperfect orientation, tilt, and/or surrounding shading elements.

Table A.23: Energy consumption / production other than heating and cooling considered by project in the EUI analysis.

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Energy Use Intensity (EUI, Source Energy)

Prj ID	2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
	[kWh/y*ft2]											
1	12.9	11.3	11.3	12.9	10.9	10.9		10.9	10.1	10.1	12.1	10.9
2	21.8	20.4	20.4		18.7	18.1		16.7	12.0	15.7	12.0	10.6
3	26.6	26.2	26.2		23.5	23.5	20.1	16.1	12.4	16.8	11.0	10.0
4	15.1	14.0	14.0		13.1	12.6	11.5	11.2	11.8	15.1	11.2	9.0
5	19.3	19.3	19.3		17.3	17.3	14.9	11.1	10.5	12.9	9.8	8.5
6	13.1	13.1	13.1		12.1	11.6		11.1	12.1	13.1	11.6	11.1
7	28.1	27.6	27.3		25.2	24.9	22.0		12.8	16.2	12.3	10.8
8	18.5	17.2	17.4		15.4	15.2	13.3	11.6	9.8	10.3	10.1	8.8
9	21.7	21.4	20.6		19.0	17.3			9.2	9.2	8.0	6.6
10	14.1	13.9	13.8		12.7	12.3		9.6	9.6	9.6	11.6	9.6
11	21.5	19.7	19.5		17.4	16.7	15.4	12.6	9.2	9.2	8.7	7.0
12	13.9	11.6	11.8		11.0	10.6		8.6	8.7	8.7	9.5	7.9
13	29.2	28.9	27.8		25.3	25.0			10.8	10.9	9.8	8.1
14	14.7	13.6	13.6		12.7	12.3		10.5	8.0	8.2	8.9	7.4
15	21.4	21.1	20.2		18.7	18.4		10.4	8.2	8.5	7.6	6.2
16	12.6	11.9	12.1		11.2	10.8		8.6	8.6	8.6	8.8	7.5
17	25.4	25.1	24.1		22.3	22.3		12.1	9.8	10.1	8.8	7.4
18	10.9	9.8	10.1	6.0	9.4	9.1		8.8	8.0	8.0	9.2	8.4
19	13.7	13.4	13.7		12.3	11.5	10.4	8.4	8.3	8.3	7.7	6.3
20	14.0	12.8	13.1		11.6	11.2	9.8	8.4	7.0	7.5	7.4	6.2
21	13.8	13.7	13.5		12.1	11.8	10.1	7.2	7.4	7.7	7.2	5.8
22	12.4	11.8	11.8		10.6	10.3	8.9	7.7	7.3	7.4	7.3	5.8
23	20.3	18.2	18.3	16.2	16.6	16.0		8.9	6.8	7.0	6.8	5.3
24	9.2	8.4	8.6	2.5	7.9	7.6		6.4	5.7	5.9	7.1	5.6
25	12.7	11.7	11.6		10.6	9.7	9.1	6.6	7.5	7.0	6.5	5.1
26	9.6	8.4	8.6	5.7	7.9	7.6		6.2	6.2	6.1	6.7	5.5
27	13.1	12.1	12.1		11.0	10.2	9.7	7.5	7.0	6.9	6.9	5.5
28	6.9	6.2	6.3	3.4	5.9	5.8		5.1	5.5	5.6	5.2	5.1
29	10.6	9.9	9.9		8.9	8.5	7.3		6.6	6.2	6.7	5.2
30	8.6	7.9	8.0	5.8	7.4	7.1		6.3	5.4	5.4	6.8	5.2
31	7.3	6.9	6.9	4.4	6.5	6.2		5.6	5.8	5.7	5.9	5.3
32	11.0	10.3	10.1		9.0	8.3			6.2	5.9	6.2	4.8
33	5.7	5.3	5.3	3.2	5.0	4.8		4.2	4.6	4.1	4.6	4.5
34	13.7	13.0	13.1		11.4	11.1	9.4	7.3	6.6	6.3	6.6	4.9
35	11.3	11.1	10.8		9.9	8.9	8.3	5.9	6.7	6.3	5.9	4.5
36	14.3	13.1	13.3		12.1	11.5		8.5	6.7	8.2	7.8	6.1
37	5.8	5.2	5.3	2.5	5.0	4.8		4.1	4.5	4.2	4.4	4.3
38	11.0	10.4	10.3		9.2	8.4	7.5		6.2	5.9	5.6	4.5
39	6.0	5.3	5.3	2.7	5.0	4.9			5.2	5.0	4.6	4.6
40	12.6	11.7	11.8		10.2	9.9	8.3		6.1	6.6	6.0	4.6
41	21.2	21.0	20.4		17.6	17.4	13.4		7.7	7.1	5.9	4.5
42	12.7	12.6	12.1		11.1	9.8			6.3	6.2	5.5	4.1
43	7.1	6.7	6.7		6.0	5.6	5.0		5.7	5.4	5.6	4.4
44	10.5	9.7	9.7		8.7	7.9	7.2		5.9	5.9	6.1	4.9
45	11.3	10.3	10.5		9.1	8.8	7.4		6.1	6.3	5.9	4.6
46	10.0	9.2	9.2		8.1	7.6	6.7		5.4	5.2	5.4	4.1
47	8.4	7.9	8.1		7.3	6.7			5.0	5.0	5.6	4.4
48	8.4	7.9	8.0		7.0	6.5	5.9		5.3	5.1	5.1	3.7
49	7.4	6.8	6.9		6.3	5.9			5.0	5.0	5.6	4.2
50	10.4	9.7	9.5		8.5	7.5			4.6	4.3	4.9	3.5

Median Values Across All Projects:

2018 IRC / IECC	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
[kWh/y*ft2]											
12.70	11.73	11.82	4.43	10.95	10.25	9.36	8.51	6.91	7.01	6.84	5.47

Table A.24: Energy use intensity by project, depending on the building standard adopted.

Source EUI Reduction Compared To 2018 IECC

Prj ID	2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
	%										
1	-12.4%	-12.4%	0.0%	-15.5%	-15.5%		-15.5%	-21.7%	-21.7%	-6.2%	-15.5%
2	-6.2%	-6.2%		-14.0%	-17.1%		-23.3%	-45.0%	-27.9%	-45.0%	-51.2%
3	-1.3%	-1.3%		-11.4%	-11.4%	-24.1%	-39.4%	-53.3%	-36.8%	-58.4%	-62.2%
4	-7.3%	-7.3%		-12.8%	-16.4%	-23.7%	-25.6%	-21.9%	0.0%	-25.6%	-40.2%
5	0.0%	0.0%		-10.7%	-10.7%	-22.7%	-42.8%	-45.5%	-33.4%	-49.5%	-56.2%
6	0.0%	0.0%		-7.5%	-11.2%		-15.0%	-7.5%	0.0%	-11.2%	-15.0%
7	-1.7%	-2.6%		-10.4%	-11.3%	-21.6%		-54.5%	-42.4%	-56.3%	-61.5%
8	-7.0%	-5.8%		-16.3%	-17.5%	-28.0%	-37.3%	-46.6%	-44.3%	-45.5%	-52.5%
9	-1.7%	-5.1%		-12.8%	-20.4%			-57.9%	-57.9%	-63.0%	-69.8%
10	-1.3%	-2.6%		-10.3%	-12.9%		-32.2%	-32.2%	-32.2%	-18.0%	-32.2%
11	-8.4%	-9.2%		-19.1%	-22.1%	-28.2%	-41.2%	-57.3%	-57.3%	-59.5%	-67.2%
12	-16.2%	-15.1%		-20.9%	-23.2%		-38.3%	-37.1%	-37.1%	-31.3%	-42.9%
13	-1.1%	-4.8%		-13.4%	-14.5%			-63.2%	-62.7%	-66.4%	-72.3%
14	-7.2%	-7.2%		-13.4%	-16.5%		-28.9%	-45.4%	-44.3%	-39.2%	-49.5%
15	-1.4%	-5.6%		-12.5%	-13.9%		-51.5%	-61.9%	-60.5%	-64.7%	-71.0%
16	-5.7%	-4.5%		-11.3%	-14.7%		-31.7%	-31.7%	-31.7%	-30.6%	-40.8%
17	-1.1%	-5.0%		-12.3%	-12.3%		-52.4%	-61.4%	-60.3%	-65.3%	-70.9%
18	-10.3%	-7.7%	-45.2%	-14.1%	-16.7%		-19.2%	-26.9%	-26.9%	-15.4%	-23.1%
19	-1.7%	0.0%		-10.3%	-16.2%	-23.9%	-38.5%	-39.3%	-39.3%	-43.6%	-53.8%
20	-8.3%	-6.6%		-17.4%	-19.9%	-29.9%	-39.8%	-49.8%	-46.5%	-47.3%	-55.6%
21	-0.8%	-2.3%		-12.4%	-14.7%	-27.0%	-47.9%	-46.3%	-44.0%	-47.9%	-57.9%
22	-5.5%	-4.7%		-14.9%	-17.3%	-28.2%	-38.4%	-41.6%	-40.8%	-41.6%	-53.3%
23	-10.7%	-9.8%	-20.5%	-18.3%	-21.5%		-56.3%	-66.6%	-65.7%	-66.6%	-73.7%
24	-8.7%	-6.7%	-72.8%	-14.4%	-17.3%		-29.8%	-38.5%	-35.6%	-23.1%	-39.4%
25	-7.5%	-8.2%		-16.4%	-23.2%	-28.0%	-47.9%	-41.0%	-44.4%	-48.5%	-59.5%
26	-12.5%	-9.8%	-40.9%	-17.9%	-20.5%		-35.7%	-35.7%	-36.6%	-30.4%	-42.9%
27	-7.0%	-7.0%		-16.0%	-21.8%	-25.6%	-42.9%	-46.1%	-47.4%	-47.4%	-58.2%
28	-9.7%	-8.5%	-50.9%	-13.4%	-15.8%		-25.5%	-19.5%	-18.2%	-24.3%	-25.5%
29	-7.0%	-6.2%		-16.2%	-20.1%	-30.9%		-37.9%	-41.8%	-37.1%	-51.1%
30	-7.5%	-6.6%	-32.3%	-14.1%	-16.9%		-26.2%	-37.5%	-36.5%	-20.6%	-39.3%
31	-5.5%	-4.4%	-39.0%	-11.0%	-14.3%		-23.1%	-19.8%	-22.0%	-18.7%	-26.4%
32	-6.5%	-7.8%		-17.5%	-24.0%			-43.5%	-46.1%	-43.5%	-56.5%
33	-8.3%	-7.1%	-43.9%	-13.1%	-16.7%		-27.4%	-20.2%	-28.6%	-20.2%	-21.4%
34	-5.5%	-4.5%		-16.9%	-19.3%	-31.7%	-47.1%	-51.5%	-54.0%	-51.5%	-63.9%
35	-1.2%	-4.2%		-11.9%	-21.4%	-26.1%	-48.1%	-40.4%	-44.5%	-47.5%	-59.9%
36	-8.4%	-7.0%		-15.3%	-20.0%		-40.9%	-53.4%	-42.7%	-45.5%	-57.6%
37	-11.2%	-9.0%	-57.0%	-14.6%	-16.8%		-29.1%	-22.4%	-28.0%	-24.6%	-25.8%
38	-5.8%	-6.4%		-16.4%	-23.4%	-31.6%		-43.9%	-46.2%	-49.1%	-59.1%
39	-12.7%	-11.6%	-55.5%	-16.9%	-19.0%			-13.7%	-16.9%	-23.2%	-24.3%
40	-7.4%	-6.5%		-18.9%	-21.8%	-34.2%		-51.6%	-47.6%	-52.1%	-63.5%
41	-1.2%	-3.8%		-16.9%	-17.8%	-36.7%		-63.5%	-66.4%	-72.0%	-79.0%
42	-1.5%	-5.3%		-13.1%	-22.8%			-50.9%	-51.4%	-56.7%	-67.9%
43	-5.8%	-5.8%		-14.8%	-21.4%	-29.7%		-19.8%	-23.9%	-20.6%	-37.9%
44	-8.1%	-8.1%		-17.2%	-24.7%	-31.7%		-43.5%	-43.5%	-41.9%	-53.8%
45	-8.5%	-7.0%		-19.5%	-22.4%	-34.4%		-45.9%	-43.9%	-47.4%	-59.4%
46	-8.3%	-7.8%		-18.6%	-23.5%	-33.3%		-46.0%	-48.0%	-45.5%	-58.8%
47	-6.4%	-4.2%		-13.8%	-20.1%			-40.3%	-40.8%	-33.4%	-47.7%
48	-6.7%	-4.6%		-16.9%	-22.5%	-30.2%		-37.4%	-38.9%	-38.9%	-55.8%
49	-8.6%	-7.0%		-15.6%	-20.4%			-32.2%	-32.8%	-24.7%	-43.5%
50	-6.4%	-8.3%		-18.8%	-28.2%			-55.6%	-59.0%	-52.6%	-66.1%

Median Values Across All Projects:

2021 IRC / IECC	2024 IRC / IECC	California Title 24	EnergyStar 3.2	DOE ZERH v2	PGH	2021 PHIUS+ Core Prescr.	2018 PHIUS+ Core	PHIUS+ 2021 Core	PHI Low Energy Building	PHI Passive House
-6.8%	-6.4%	-43.9%	-14.7%	-18.4%	-28.2%	-37.8%	-43.5%	-42.1%	-44.3%	-54.7%

Table A.25: Reduction of energy use intensity by project and building standard adopted, compared to the 2018 IECC baseline.

Project Selection*

Prj ID	ASHRAE Climate Zone	Site Energy Demand For Heating + Cooling: A - Prescriptive Approach	B - Performance-based Approach	Difference: Prescriptive comp. to Performance-based	Project Selection	Project Envelope Specs: TFA	Form Factor	Envelope Assemblies Considered**: Under Slab / Floor	Wall	Ceiling / Roof
		2021 PHIUS+ Core Prescr.	PHI Low Energy Building		Prescriptive / Performance-Based Within +/-20% Of Each Other					
		kWh/y				ft2	ft2/ft2	ft2		
1	3B	800	1100	-27.3%	No	572	4.6	641	1170	685
2	4C	2600	1200	116.7%	No	680	4.8			
3	6B	2500	1000	150.0%	No	681	5.1			
4	5B	1800	1800	0.0%	Yes	834	4.9	996	1852	1009
5	6B	1900	1400	35.7%	No	887	4.3			
6	2A	1900	2100	-9.5%	Yes	938	3.9	1067	1306	1073
7										
8	5B	2500	1800	38.9%	No	1066	3.8			
9										
10	2A	2100	3200	-34.4%	No	1264	3.7	760	2623	914
11	5B	4600	2200	109.1%	No	1401	4.6			
12	3A	2300	2900	-20.7%	No	1429	4.2	1578	2464	1619
13										
14	4A	3900	2900	34.5%	No	1513	4.9			
15	7	4000	2100	90.5%	No	1541	4.0			
16	4A	2600	2700	-3.7%	Yes	1604	3.9	1961	1563	2046
17	7	4600	2300	100.0%	No	1619	4.5			
18	3B	2800	3100	-9.7%	Yes	1640	5.9	2589	3188	2589
19	6B	3300	2700	22.2%	No	1962	3.0			
20	5B	3800	2900	31.0%	No	1977	4.1			
21	6B	3100	3100	0.0%	Yes	2149	3.0	1559	2774	1566
22	5B	3600	3200	12.5%	Yes	2354	3.0	1269	2147	1461
23	4B	5800	3500	65.7%	No	2525	3.2			
24	4B	3600	4300	-16.3%	Yes	2598	3.5	2829	3046	2829
25	5A	3800	3700	2.7%	Yes	2650	2.9	1451	2313	1292
26	3C	3400	4000	-15.0%	Yes	2681	3.0	1811	3010	2220
27	5A	4900	4200	16.7%	Yes	2747	3.7	1387	3321	3263
28	3B	1900	2000	-5.0%	Yes	2751	3.4	1742	3123	2218
29										
30	4B	4000	4600	-13.0%	Yes	2855	3.7	3271	3058	3275
31	3C	3200	3600	-11.1%	Yes	2875	3.1	1512	2792	1753
32										
33	3C	2500	3100	-19.4%	Yes	3357	2.4	332	3132	2355
34	5B	6600	5700	15.8%	Yes	3379	3.5	1855	3737	1905
35	6B	4600	4700	-2.1%	Yes	3428	2.8	1666	3031	2093
36	3A	8200	7200	13.9%	Yes	3452	5.4	3555	8404	4275
37	3B	2200	2600	-15.4%	Yes	3521	2.7	1723	2728	2434
38										
39										
40										
41										
42										
43										
44										
45										
46										
47										
48										
49										
50										

* Projects were included in the comparison if the site enegy for heating + cooling of A and B was within 20% of each other

** Most recurring building envelope assemblies across all projects. Individual projects have other types of assembly (e.g. exterior wall of conditioned crawl space), which were ignored for this analysis.

Table A.26: Specs of the 18 projects used in the Resource Efficiency comparison.

R-values By Project And Assembly

Prj ID	A - Prescriptive Approach			B - Performance-based Approach			R-values Avoided Using Performance-based Apprach To Achieve Similar Performance		
	2021 PHIUS+ Core Prescr.			PHI Low Energy Building					
	Under Slab / Floor	Wall	Ceiling / Roof	Under Slab / Floor	Wall	Ceiling / Roof	Under Slab / Floor	Wall	Ceiling / Roof
	R-value			R-value			R-value		
1									
2									
3									
4	21	39	69	34	36	70	13	-3	1
5									
6	8	22	51	0	20	27	-8	-2	-24
7									
8									
9									
10									
11									
12									
13									
14									
15									
16	16	32	63	16	32	65	0	0	2
17									
18	11	25	54	0	25	38	-11	0	-16
19									
20									
21	26	44	76	12	36	58	-14	-8	-18
22	19	37	68	21	33	63	2	-4	-5
23									
24	14	30	60	8	28	61	-6	-2	1
25	25	45	76	12	36	76	-13	-9	0
26	14	30	60	4	24	43	-10	-6	-17
27	23	43	75	41	40	70	18	-3	-5
28	11	26	56	0	20	50	-11	-6	-6
29									
30	13	28	58	12	24	50	-1	-4	-8
31	17	27	56	0	25	38	-17	-2	-18
32									
33	14	38	69	0	25	31	-14	-13	-38
34	20	43	74	21	30	63	1	-13	-11
35	24	29	59	17	34	69	-7	5	10
36	13	25	54	12	24	56	-1	-1	2
37	11	39	69	0	20	43	-11	-19	-26
38									
39									
40									
41									
42									
43									
44									
45									
46									
47									
48									
49									
50									

A - Prescriptive Approach	R-values derived from 2021 PHIUS+ Prescriptive requirements
B - Performance-based Approach	R-values derived from energy analysis (i.e. PHPP model), in order to meet PHI Low Energy Building goals (Heating Demand, Cooling Demand)

Average R-value Avoided Thanks To Performance-based Approach		
Under Slab / Floor	**Wall**	**Ceiling / Roof**
R-value		
-5	-5	-10

Table A.27: R-values by building assembly for the projects used in the Resource Efficiency comparison

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Insulation Avoided By Project And Assembly

Using Performance-based Apprach

Prj ID	Surface Area Per Component / Project			Insulation Avoided (Thickness)*			Insulation Avoided**			
	Under Slab / Floor	Wall	Ceiling / Roof	Under Slab / Floor	Wall	Ceiling / Roof	Under Slab / Floor	Wall	Ceiling / Roof	Total
		ft2			in			ft3		
1										
2										
3										
4	996	1852	1009	3.5	-0.5	0.5	305	-80	45	270
5										
6	1067	1306	1073	-1.5	0	-6.5	-140	0	-610	-750
7										
8										
9										
10										
11										
12										
13										
14										
15										
16	1961	1563	2046	0	0	1	0	0	180	180
17										
18	2589	3188	2589	-2.5	0	-4.5	-565	0	-1015	-1580
19										
20										
21	1559	2774	1566	-3	-1.5	-5	-405	-360	-685	-1450
22	1269	2147	1461	0.5	-0.5	-1	60	-90	-125	-155
23										
24	2829	3046	2829	-1	0	0.5	-245	0	125	-120
25	1451	2313	1292	-3	-2	0	-380	-400	0	-780
26	1811	3010	2220	-2	-1	-4.5	-315	-260	-870	-1445
27	1387	3321	3263	4.5	-0.5	-1	550	-145	-285	120
28	1742	3123	2218	-2.5	-1	-1.5	-380	-270	-290	-940
29										
30	3271	3058	3275	0	-0.5	-2	0	-130	-570	-700
31	1512	2792	1753	-4	0	-5	-525	0	-765	-1290
32	332	3132	2355							0
33	332	3132	2355	-3	-3	-10.5	-85	-820	-2160	-3065
34	1855	3737	1905	0.5	-3	-3	85	-980	-495	-1390
35	1666	3031	2093	-1.5	1.5	3	-215	400	550	735
36	3555	8404	4275	0	0	1	0	0	375	375
37	1723	2728	2434	-2.5	-4.5	-7	-375	-1070	-1490	-2935
38										
39										
40										
41										
42										
43										
44										
45										
46										
47										
48										
49										
50										

* Insulation thicknesses were calculated assuming EPS under slab (4.1 R/in), Mineral wool boards (4.1 R/in) as continuous insulation for exterior walls, and cellulose fiber (3.5 R/in) as loose-fill insulation for ceilings.

** Volumes listed are calculated to he closest 5 cubic foot increment, and include 5% construction waste.

Average Insulation Avoided Thanks To Performance-based Approach			
Under Slab / Floor	Wall	Ceiling / Roof	Total
cubic feet (ft3) per project			
-150	-230	-450	-830

Table A.28: Insulation avoided by project and type of assembly included in the Resource Efficiency comparison.

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Upfront Costs Avoided By Project

Using Performance-based Apprach

Prj ID	Under Slab / Floor	Wall	Ceiling / Roof	Total Insulation Cost Avoided	Emu Boost Fees (energy analysis)	Balance Performance vs Prescriptive
		*			**	***
1						
2						
3						
4	$5,300	-$1,700	$100	$3,700	$2,600	$6,300
5						
6	-$2,400	$0	-$1,200	-$3,600	$2,800	-$800
7						
8						
9						
10						
11						
12						
13						
14						
15						
16	$0	$0	$400	$400	$3,000	$3,400
17						
18	-$9,700	$0	-$2,100	-$11,800	$3,800	-$8,000
19						
20						
21	-$6,900	-$7,900	-$1,400	-$16,200	$3,100	-$13,100
22	$1,100	-$1,900	-$200	-$1,000	$2,800	$1,800
23						
24	-$4,200	$0	$300	-$3,900	$3,300	-$600
25	-$6,500	-$8,700	$0	-$15,200	$2,900	-$12,300
26	-$5,400	-$5,700	-$1,800	-$12,900	$2,900	-$10,000
27	$9,500	-$3,100	-$600	$5,800	$3,200	$9,000
28	-$6,500	-$5,900	-$600	-$13,000	$2,700	-$10,300
29						
30	$0	-$2,800	-$1,200	-$4,000	$3,600	-$400
31	-$9,000	$0	-$1,600	-$10,600	$4,300	-$6,300
32						
33	-$1,400	-$18,000	-$4,500	-$23,900	$4,400	-$19,500
34	$1,500	-$21,500	-$1,000	-$21,000	$2,500	-$18,500
35	-$3,700	$8,800	$1,200	$6,300	$3,400	$9,700
36	$0	$0	$800	$800	$4,500	$5,300
37	-$6,400	-$23,500	-$3,100	-$33,000	$2,700	-$30,300
38						
39						
40						
41						
42						
43						
44						
45						
46						
47						
48						
49						
50						

		Average Upfront Costs		
*	Costs avoided for insulation material, assuming EPS under slab ($17.25/ft3), mineral wool boards at walls ($21.99/ft3), and cellulose fiber at ceiling ($2.12/ft3). Labor costs excluded.			
**	Fee for energy analysis at design stage. Cost of certification excluded for both approaches.	Total Insulation Cost Avoided	Emu Boost Fees (energy analysis)	Balance Performance vs Prescriptive
***	Includes fee for energy analysis listed. Certification fees excluded.	-$8,500	$3,250	-$5,250

Table A.29: Cost analysis including energy modeling fees and insulation avoided, used in the Resource Efficiency comparison.

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APPENDIX B - CALIFORNIA RESULTS

This Appendix is provided as a separate file from the Report.

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