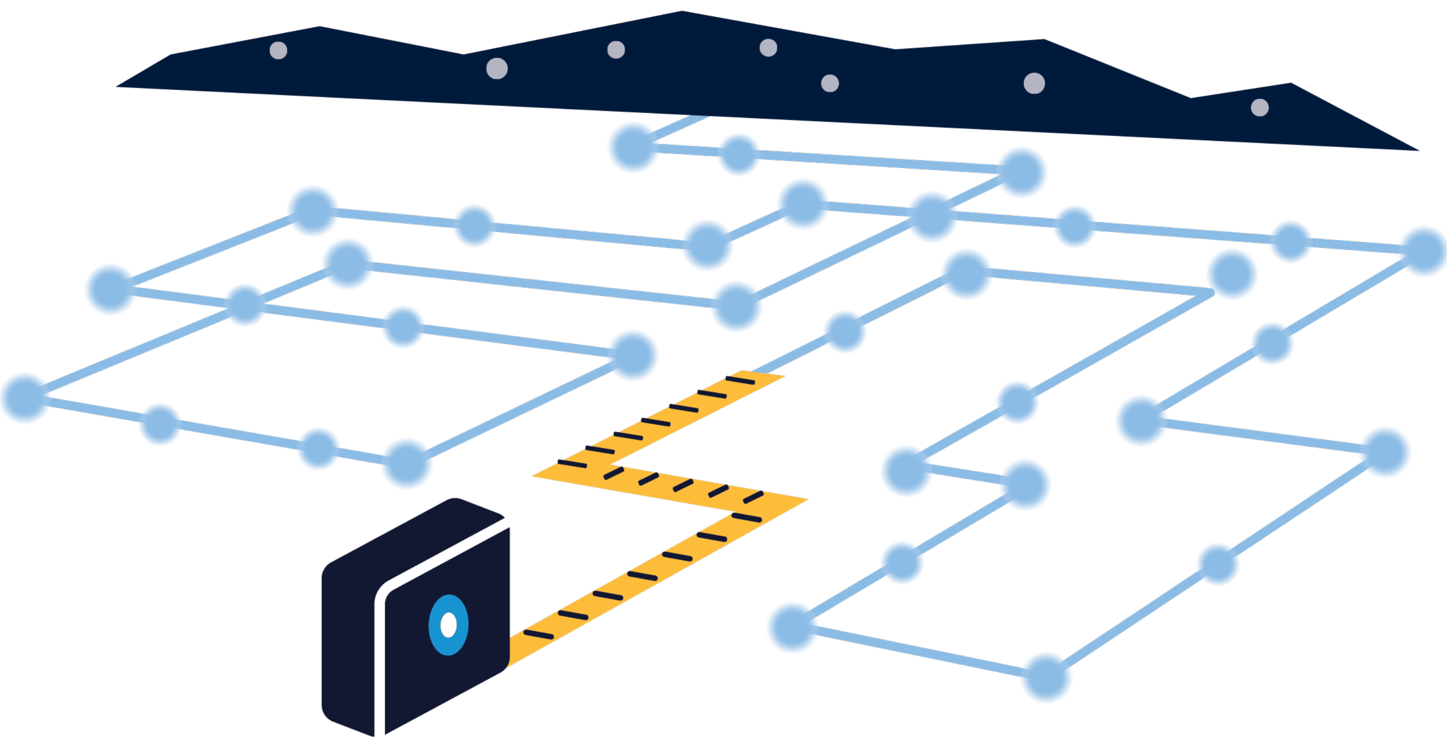
The Keys to Successful Passive House Implementation

Group B, Deliverable 33 Case Study 5



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Executive Summary

Imagine buildings so well constructed they need virtually no heating or cooling and can cut normal utility bills by 50%–80%. Now imagine these buildings are also so airtight there is almost no air leakage or outside street noise, yet they provide healthy, fresh, filtered air throughout the day whether windows or doors are open or not. Moreover, these buildings are not dark boxes with tiny windows, but light, bright, spacious structures with modern architectural design. Further, when paired with high efficiency all electric appliances and on-site photovoltaics (PV), these buildings can be virtually zero carbon emissions. And, last but not least, they can be new construction or retrofit and are adaptable to historic, traditional, and contemporary aesthetics as well.

Buildings like this are not the pipedreams of architects or environmentalists. In fact, these "passive houses" are common in some parts of the world. For more than 30 years, Passive House (PH) building strategies have been applied to single-family and multifamily homes, commercial and government offices, schools, skyscrapers, and other structures across the US and around the globe. The need for such buildings continues to increase as the world grapples with adapting to extreme weather conditions, wildfire smoke, antiviral air handling, energy grid outages, and other resiliency challenges. Yet despite these many advantages, buildings of this type are rare in the State of California. While the scope this case study was too narrow to address the numerous policy, regulatory, and market barriers, this is in part due to a misalignment between California's goals and policy objectives and state building codes.

Passive House is an international building standard applied to any type of building that is specifically designed to maximize occupant comfort and health while minimizing energy use. To be considered a Passive House, a building must meet certain energy and performance benchmarks that are based on building type, building use, and location. The result is a building that uses 50%–80% less energy than similar buildings built to code-minimum standards. Passive Houses have exceptionally high indoor air quality, maintain thermal comfort for extended time periods during power outages, and have superior acoustic performance in noisy urban areas. To achieve these results, Passive Houses utilize five primary design strategies[1]:

- Exceptionally high levels of insulation
- Well insulated window frames and window glazing
- Thermal bridge free design and construction[2]
- An airtight building envelope
- Ventilation systems with high efficiency heat- and energy-recovery

PH strategies can be applied to any type of structure from a single-family home to a high rise building or a government office, making them ideally suited to help California to achieve its bold climate and energy efficiency goals. Although Passive House projects are common in many parts of the world, they have yet to find their place in the California landscape even though the building envelope optimization, reduced HVAC demand,

[1] Passive House International. Active for More Comfort: Passive House information for property developers, contractors and clients. Accessed September 2021 https://passivehouse-international.org/upload/GRBR_EN_2018_Sammelmappe/GRBR_EN_2018_Sammelmappe.html

[2] According to Passipedia.org A thermal bridge is a localised area of the building envelope where the heat flow is different (usually increased) in comparison with adjacent areas (if there is a difference in temperature between the inside and the outside) such as studs and rafters.

and minimal building energy use required for Passive House certification align well with the intentions behind Title 24, California's Energy Code.

This report is intended to familiarize California stakeholders with examples of successful PH efforts in other states within the US and other countries and to identify best practices in PH design strategies and proliferation that may be useful as California works to achieve its long-term energy efficiency and carbon reduction goals. To establish best practices that may be applied in California, the research team conducted a literature review of articles, policy documents, conference proceedings, white papers, and cost analyses to find the best examples of successful PH implementations throughout North America, Europe, and Australasia. To identify similarities across these disparate locations, we then conducted interviews with 19 subject matter experts to understand the context, activities and outcomes associated with successful PH endeavors in their regions. Finally, we distilled their wide-ranging insights into four major tools that can be wielded to increase their prevalence and leverage their benefits: enacting policy, passing codes, utilizing catalysts to stimulate the market, and capacity building. Each of the four tools consists of multiple elements, which are discussed below.

1. **Policy** establishes the framework for planning strategies and designing codes and other regulations to ensure accomplishment of the goal.
   a. **Top-down alignment of goals and policies.** Passive House construction thrives best when it supports state and local goals and policies. Ideally, state goals and policy requirements establish minimum targets, while encouraging local governments to set their own even more stringent targets and to adopt code structures that drive market transformation based on performance rather than prescriptive requirements.
   b. **Bold policies and plans.** We profiled four regions with mini case studies, and our interviews indicate they have clear GHG reduction targets that are supported by well-defined policies and associated action plans designed to reduce emissions, including those arising from the built environment. The most effective regions also include financial penalties for noncompliance.[3]
2. **Codes** support policy by establishing minimum standards, metrics, and methods for measuring compliance.
   a. **Step codes with time-dependent performance targets.** Unlike California and other places that use triannual building code improvement cycles based on prescriptive mandates, regions with a proliferation of Passive House construction have switched to performance-based targets that outline increasingly rigorous compliance requirements and deadlines leading to an ultimate GHG reduction goal. The advantage of this approach is that rather than leaving people wondering what will be included in the next code cycle, it offers a clear direction and destination that provides advance notice and time for all market participants to take the steps necessary for compliance and innovation.
   b. **Passive House code compliance path.** Numerous green building certification programs promote energy efficiency and GHG reductions, and all have their place. In each of our case studies the profiled region provides a compliance pathway based on the enhanced performance of Passive House building design based on the five primary design strategies. Best practice efforts recognize the rigorous performance standards of Passive House certified projects and treat PH more favorably than other pathways requiring less stringent performance targets.

[3] Starting in 2024, New York City's Local Law 97 places a carbon emissions cap on most buildings larger than 25,000 square feet. Financial penalties are significant: (a) failure to report - $0.50/square foot/month; (b) providing false statements - $500,000; (c) exceeding emissions limit - $268/tCO$_2$e over the building's established limit. https://www1.nyc.gov/assets/buildings/apps/pdf_viewer/viewer.html?file=2014CC_AC_Chapter3_Maintenance_of_Buildings.pdf&section=conscode_2014

c. **Compliance targets based on performance metrics.** A key energy management adage states that you can't manage what you don't measure. The three most important PH performance metrics include:

   i **Greenhouse Gas Intensity** (GHGI) that measures the total amount of energy supplied to the building multiplied by that energy's carbon intensity;

   ii **Thermal Energy Demand Intensity** (TEDI) that measures building envelope performance based on the amount of heating or cooling that is required to maintain the building at a comfortable temperature; and

   iii **Energy Use Intensity** (EUI) that measures the total amount of energy externally provided to the structure for all end uses.

d. **Energy modeling alignment.** Energy modeling software packages come in numerous types. Because their underlying modeling algorithms are designed for different outputs, they necessarily often require different inputs. This mismatch can cause challenges when it comes to determining performance and code compliance. Consequently, clearly defined energy modeling guidelines must be developed to ensure alignment between the California-authorized CBECC-Res modelling software used for determining Title 24 compliance and the popular Passive House Planning Package (PHPP) model used for Passive House modeling. Likewise, energy modelling software must align with state and local codes and regulations and allow for a Passive House voluntary compliance pathway.

3. **Catalysts** stimulate market action through financial means or via other incentives.

   a. **Leading by example.** One of the most effective ways to transform a market is through government commitment and demonstration. This can take numerous forms including supporting climate goals by committing to build all new government buildings to Passive House standards, requiring existing buildings to be retrofitted to those standards, directing city staff to support the development of necessary green supply chains, and promoting interagency cooperation.

   b. **Financial support.** Virtually all successful efforts to promote Passive House construction have provided financial incentives to stimulate the market and help offset higher initial costs. In many cases those extra costs have been minor, particularly on subsequent projects, some of which show as little as 1%–2% higher costs that may be offset by lower operating costs. Common financial outlays include direct cash awards, salaried staff time, the services of budgeted programs, as well as financial support for numerous initiatives including capacity building efforts (discussed below). Other financial support may include utility and government incentives, reductions in fees and taxes, and access to financing. To extend budgets many efforts coordinate additional outside funding sources. Best practices include providing financial incentives for a limited amount of time so it is clear they will only be awarded to early adopters.

   c. **Nonfinancial incentives.** Nonfinancial incentives can also provide a stimulus. These include such things as expedited permitting, zoning exemptions and variances, reduced parking requirements, square footage or lot coverage bonuses, and concessions made during public benefit negotiations.

   d. **Competitions for cash and other awards.** The four case studies highlighted in this report include a competitive design process that awards financial and nonfinancial incentives to winning proposals for buildings designed to PH performance standards. This has been particularly effective when a competition pairs a state's pre-existing competitive framework for affordable housing funding with a performance-based construction approach.

   e. **Early examples of success.** All the above catalysts are generally directed at early adopters who act before the majority of the market. Their early projects can and should be used as examples to stimulate further Passive House efforts. Best practices require developers receiving any form of financial or nonfinancial incentive to submit project cost and performance data, to lead tours, to prepare case studies, and give presentations. Some ask recipients to share cost data from their next projects to demonstrate cost reductions on subsequent buildings as the development teams come up the learning curve.

4. **Capacity Building** strives to ensure the availability of people and resources necessary for the accomplishment of the goal.
   a. **Outreach and awareness.** Passive House is a new concept for many people and thus requires a coordinated outreach and awareness effort to ensure the stakeholders and public are familiar with the concept and the benefits. Efforts may include advertising, social media, lunch-and-learns, cocktail hours, project tours, and symposia. Outreach should also include dialogues with important trade and manufacturing groups to increase their engagement. Product manufacturers or PH service providers are often willing to give presentations and set up booths at trade association meetings to help educate the market.
   b. **Workforce education and training.** Because Passive House design strategies and practices differ from conventional building, they typically require advanced education for those involved in planning, development, architecture, engineering, construction, manufacturing, finance, and government. Best practices provide tuition offsets and/or paid staff time to encourage professionals and tradespeople to acquire the appropriate skills. These new topics and techniques could be incorporated into existing Workforce Education and Training programs administered by California Program Administrators.
   c. **Expert advisors.** Since it is impractical to provide training to address every scenario, the next best thing involves engaging expert advisors to guide project teams, answer questions, and help developers and other market actors to overcome barriers. These experts may include Certified Passive House Designers or Consultants (CPHD/CPHC) or experienced professionals who have completed multiple projects.
   d. **Supply chain development.** Passive House construction requires specialized construction materials that may not be readily available for early projects in some areas. Early efforts to stimulate market demand and accompanying supply often include new code requirements, outreach efforts, training, and commitments by state and local governments to procure the appropriate green building supplies and technologies for their own government-owned Passive House new construction and retrofits projects.

In all, this report presents four mini case studies on (1) Brussels, Belgium, (2) New York, US, (3) Vancouver, Canada, and (4) Pennsylvania, US to demonstrate how they have incorporated varying combinations of these tools into their region's strategic approach to achieving their climate goals (Table 1). While space considerations necessitated a high-level overview of their extensive actions and achievements, each mini-case study highlights particularly bright examples among their many efforts.

Table 1. Passive House Best Practices Toolkit

Tools	Key Element	Brussels	New York	Vancouver	Pennsylvania
Policy	Top-down alignment of goals and policies	✓	✓	✓	✓
	Bold policies and plans	✓	✓	✓	
Codes	Step codes with time-dependent performance targets	✓	✓	✓	
	Passive House code compliance path	✓	✓	✓	
	Compliance targets based on performance metrics	✓	✓	✓	

Tools	Key Element	Brussels	New York	Vancouver	Pennsylvania
	Energy modeling alignment	✓	✓	✓	
Catalysts	Leading by example	✓	✓	✓	✓
	Financial support	✓	✓	✓	✓
	Nonfinancial incentives	✓	✓	✓	
	Competitions for cash and other awards	✓	✓	✓	✓
	Early examples of success	✓	✓	✓	✓
Capacity	Outreach and awareness	✓	✓	✓	
	Workforce education and training	✓	✓	✓	
	Expert advisors	✓	✓	✓	
	Supply chain development	✓	✓	✓	

1. Introduction

Why be active when you can be passive? That might seem an odd question if you were speaking to someone about maintaining good health through proper diet and regular exercise, but when it comes to buildings the more passive they are the better. Passive buildings use less energy than standard code-built structures to maintain optimal temperatures and airflow. Called Passive Houses (PH), they are specifically designed to maximize occupant comfort and health while minimizing energy consumption and providing utility bill savings of up to 80%. When paired with solar or other renewable energy systems, Passive Houses can make zero net energy (ZNE) construction readily achievable. Moreover, their airtight construction means that there is almost no air leakage or outside street noise, yet they provide healthy, fresh, filtered air throughout the day whether windows or doors are open or not. All this makes them well suited for California as the State grapples with adapting to extreme weather conditions, wildfire smoke, antiviral air handling, energy grid outages, and other resiliency challenges.

While the phrase “Passive House” would seemingly apply only to residential homes, the term comes from the original German “Passivhaus” and refers to any ultra-low energy use building that meets certain energy and performance benchmarks. While Passive Houses are rare in California, worldwide there are more than 100,000 such buildings in all climate zones, and they range from single-family and multifamily homes to commercial and government offices, schools, skyscrapers to other types of structures (Figure 1).

Passive House is a voluntary international building standard based on building science principles and methodologies designed to craft structures with airtight, well-insulated envelopes and HVAC systems that include high-efficiency heat/energy recovery to better maintain temperatures and provide 24/7 fresh air exchange. When paired with high efficiency all electric appliances, solar photovoltaics and battery storage, Passive House buildings can be zero net carbon emissions and make minimal energy and demand impacts on the power grid. No matter the building type, use, size or location, Passive Houses utilize five primary design strategies:[4]

- Exceptionally high levels of insulation
- Well insulated window frames and glazing
- Thermal bridge free design and construction
- An airtight building envelope
- Ventilation systems with high efficiency heat- and energy-recovery

These basic Passive House design strategies underlie a fundamental approach to building that combines sustainability and whole systems philosophies with high-performance building science and rigorous construction methodologies. While there are numerous ways to incorporate these strategies into architectural planning, all of them rely on a combination of energy efficiency, passive solar design, and internal heat exchange to reduce the need for heating and cooling. Of course, these are just strategies, not actual performance standards.

[4] Passive House Institute US. “The Principles: Passive House Institute US.” What is Passive Building? Accessed August 2021, https://www.phius.org/what-is-passive-building/passive-house-principles.

Figure 1. Passive House Examples

Source *Vancouver, BC Passive House project photos from the Passive House Canada Project Database, (Projects Archive - Passive House Canada | Maison Passive Canada – https://www.passivehousecanada.com/projects/).*

In the US, there are two different sets of performance standards for Passive House certification. One, offered by the Passive House Institute US, Inc. (PHIUS), uses standards designed for the variety of North American climactic conditions. The other, offered by the international Passive House Institute (PHI), uses standards that were originally designed in Europe but are now considered universal. To accomplish this, PHI uses multipliers embedded in its software that can be customized for the local climate and local utility renewable energy grid capacity. This makes things simpler for policy makers and advocates to verify outcomes since every location on the planet does not require a unique set of target numbers. Both PHI and PHIUS standards yield buildings that are designed to maximize occupant comfort while minimizing energy use.

This paper briefly traces the history of the Passive House movement, considers the status of Passive House construction in California, and identifies four major tools, comprising 15 key elements, for successful widespread promotion and deployment of PH strategies. These insights were gathered through an extensive literature review and in-depth interviews with 19 PH experts within California, around the US, and across the world.[5] The results are illustrated with four mini case studies that highlight the mix and match execution of these ingredients in Brussels, Belgium; New York, US; Vancouver, Canada; and Pennsylvania, US.

2. Passive House in California

The first exploration of the building strategies that underlie Passive House began after the 1970s oil embargo with funding from the US Department of Energy (DOE) and the Canadian government to reduce dependence

[5] The list of experts consulted can be found at the end of this report under the heading of Contributors.

on foreign oil by building homes that used little or no energy. In the late 1980s and early 1990s the German Passivhaus Institut (PHI), advanced those strategies by developing a quantifiable performance standard for Central European climate zones. Applying these strategies, an Austrian physicist built the first Passive House in 1991. These developments spurred a spate of pioneering Passive House construction projects in several European countries, launched numerous PH associations and conferences, and accelerated the careers of many architects, engineers, building trade people, and other PH associated professions.

The first Passive House built in the United States followed 12 years later in 2003 in Urbana, Illinois. That initial American effort seeded the launch of numerous statewide and national PH associations, including the Passive House Institute US, the North American Passive House Network (NAPHN) and a multitude of associated training and certification programs for architects, engineers, consultants, builders, raters, and verifiers.

Since 2003, more than 5,000 Passive House projects have been completed worldwide, including approximately 1860 PH certified buildings.[6] In North America there are approximately 200 projects comprising approximately 1,650 individual housing units.[7] Yet, according the Passive House Database[8], fewer than 15 PH projects exist in California.[9] This comparatively low level of activity in California stands in sharp contrast to California's leadership role in the advancement of energy efficiency, load management, and decarbonization. This is despite the fact that Passive House design strategies directly support California's goals of energy efficiency and GHG reductions. Moreover, the building envelope optimization, reduced HVAC demand, and minimal building energy use required for Passive House certification align well with the intentions behind Title 24, California's Energy Code.

Despite these alignments, there are no major California utility-sponsored programs designed to directly support PH construction, and only a handful of grants have provided support for pilot efforts. Consequently, Passive House building and retrofitting remains a niche market, particularly in California. This is partly due to a misalignment between California's goals and policy objectives and state building codes. Title 24 offers builders two primary pathways to demonstrate project compliance: a prescriptive pathway that specifies the requisite building materials, standards and methods

The Challenge of Tracking PH Efforts

Passive House construction thrives when market transformation efforts can draw upon numerous demonstration projects and case studies showcasing innovations and documenting declines in project costs as PH becomes better integrated within building design, construction, and manufacturing efforts. However, data to support PH efforts in America remains sparse.

Obtaining actual numbers for Passive House projects within California and in other states across the US is challenging since multiple PH organization exist and because only certified projects tend to get logged in formal databases. Other projects may never be recorded due to owner privacy reasons; because the teams working on them simply aren't aware that formal databases exist; or because the teams don't have time or incentives to post them.

Comprehensive records only exist when processes and systems are established to collect and channel that information into central databases. This occurs when people are paid to track and maintain data and projects are required to be registered as part of a managed subsidy program such as those done by the Pennsylvania Housing Finance Agency (PHFA), New York State Energy Research & Development Authority (NYSERDA) or MassSave in Massachusetts.

[6] Passivhaus Dienstleistung GmbH. "Passive House Buildings." Passive House Database. Accessed September 2021. https://passivehouse-database.org/.
[7] Passive House Database, https://passivehouse-database.org/.
[8] Ibid.
[9] Interviews with national and California Passive House experts indicate that there are at least 70 Passive House projects completed or underway in California. Please see "The Challenge of Tracking PH Efforts" sidebar for more information.

to be used on a project, and a performance pathway that specifies maximum allowable building performance based on energy modeling.

Currently, to comply with Title 24, builders of PH projects in California cannot opt for the prescriptive compliance pathway. Instead, they must elect the performance pathway and use the state-mandated CBECC-Res software to calculate energy savings, which is challenging, since that software does not directly map to the modelling algorithms used for PH certification. Even though most PH projects ultimately exceed code requirements by wide margins, the performance pathway requires additional time and effort, which increases project costs and discourages adoption.

Recognizing this, the California Codes and Standards Enhancement (CASE) team began exploring the possibility of providing an alternative pathway for certified PH low rise single-family and multifamily residential projects to be included within the 2022 California Energy Code updates. The team modelled multiple prototypical homes in all 16 of California's climates to determine if homes built to PH standards could meet 2022 Code requirements to qualify as equivalent to the prescriptive pathway for residential buildings. The team also identified numerous barriers and potential solutions ranging from previously mentioned modeling software alignment to technical conflicts such as window shading and ventilation requirements, to practical considerations like training building inspectors.

In terms of energy savings, the study noted multiple challenges arising from aligning the Passive House Planning Package (PHPP) model with the CBECC-Res model, including model and input conversion issues that required rough approximations. Nonetheless, the initial review showed that low-rise multifamily structures built to Passive House standards could save 13%–20% in energy use compared to the 2019 baseline code, a 50% average reduction in heating demand, and a 47%–59% reduction of carbon emissions using PHPP metrics.[10] Despite these promising initial results, more work remains to be done before Passive House certification can be approved as an alternate pathway for California Energy Code compliance.

While providing an alternative pathway would remove a sizeable bottleneck to compliance, it is not the only factor limiting the proliferation of PH construction in California. Some of the other barriers include resistance and steep learning curves on the part of builders and inspectors, as well as a lack of awareness among architects, builders, owners, government employees, and other stakeholders.

It is not uncommon for people to resist changes when they are unfamiliar or unmotivated. Because builders have limited awareness of PH building science and construction methodologies, most argue to continue with business as usual. They advocate for maintaining their long-standing business practices and construction methods and will likely continue to do so until they are motivated to change through a combination of education, incentives, and disincentives. Likewise, manufacturers and retailers are not likely to create and sell high performance building materials and technologies until market demand increases; and market actors and stakeholders will not demand these things until they are aware of their existence and their benefits. This self-reinforcing cycle perpetuates that status quo and will continue to do so until someone provides education, incentives, or disincentives.

3. Best Practices in the Passive House Toolbox

To establish best practices for supporting the proliferation of Passive Houses in California, the research team conducted a literature review of articles, policy documents, strategic plans, laws, marketing campaigns, workforce training efforts, conference proceedings, white papers, case studies, and cost analyses. The

[10] North American Passive House Network (NAPHN). "Policy Resource Guide." Policymaker Resources. June 2019. https://naphnetwork.org/policymaker-resources/.

extensive effort considered successful PH implementations throughout North America, Europe, and Australasia, and sought to identify similarities across these disparate locations. We then conducted interviews with 15 subject matter experts to understand the context, activities, and outcomes associated with successful PH endeavors in their regions. We distilled their wide-ranging insights into four major types of tools: enacting policy, passing codes, leveraging catalysts, and capacity building.

- **Policy** establishes the framework for planning strategies and designing codes to ensure accomplishment of the goal.
- **Codes** support policy by establishing minimum standards, metrics, and methods for measuring compliance.
- **Catalysts** stimulate market action through financial means or via other incentives.
- **Capacity** building strives to ensure the availability of people and resources necessary for the accomplishment of the goal.

Each of the four tools consists of multiple elements. In all, the four mini case studies below demonstrate varying combinations of 15 key elements that together support the advancement of PH design strategies and the proliferation of PH construction. Those 15 key elements are noted below.

Policy

- **Top-down alignment of goals and policies.** Passive House construction thrives best when it supports state and local goals and policies. Ideally, state goals and policy requirements encourage local governments to set their own targets and to adopt code structures that drive market transformation based on performance rather than prescriptive requirements.
- **Bold policies and plans.** Each region profiled with a mini case study, and indeed all the regions represented by experts we consulted, have clear GHG reduction targets that are supported by well-defined policies and associated action plans that are designed to reduce emissions, including those arising from the built environment. The most effective regions also include financial penalties for noncompliance.

Codes

- **Step codes with time-dependent performance targets.** Unlike California and other places that use triannual building code improvement cycles based on prescriptive mandates, regions with a proliferation of Passive House construction have switched to performance-based targets that outline increasingly rigorous compliance requirements and deadlines leading to an ultimate GHG reduction goal. The advantage of this approach is that rather than leaving people wondering what will be included in the next code cycle, it offers a clear direction and destination that provides advance notice and time for all market participants to take the steps necessary for compliance and innovation.
- **Passive House code compliance path.** Numerous green building certification programs promote energy efficiency and GHG reductions, and all have their place. In each of our case studies the profiled region provides a compliance pathway based on the enhanced performance of Passive House building design. Best practice efforts recognize the rigorous performance standards of Passive House certified projects and treat PH more favorably than other pathways requiring less stringent performance targets.
- **Compliance targets based on performance metrics.** A key energy management adage states that you can't manage what you don't measure. The three most important performance metrics include

  - **Greenhouse Gas Intensity** (GHGI) that measures the total amount of energy supplied to the building multiplied by that energy's carbon intensity,
  - **Thermal Energy Demand Intensity** (TEDI) that measures building envelope performance based on the amount of heating or cooling that is required to maintain the building at a comfortable temperature, and
  - **Energy Use Intensity** (EUI) that measures the total amount of energy externally provided to the structure for all end uses.
- **Energy modeling alignment.** Energy modeling software packages come in numerous types. Because their underlying modeling algorithms are designed for different outputs, they necessarily often require different inputs. This mismatch can cause challenges when it comes to determining performance and code compliance. Consequently, energy modeling guidelines must be developed to ensure alignment with state and local codes and regulations and must allow for analysis of the Passive House voluntary compliance pathway.

Catalysts

- **Leading by example.** One of the most effective ways to transform a market is through government commitment and demonstration. This can take numerous forms including supporting climate goals by committing to build all new government buildings to Passive House standards, requiring existing buildings to be retrofitted to those standards, directing city staff to support the development of necessary green supply chains, and promoting interagency cooperation.
- **Financial incentives**. Virtually all successful efforts to promote Passive House construction have provided financial incentives to stimulate the market and help offset higher initial costs. In many cases those extra costs have been minor, particularly on subsequent projects, some of which show as little as 1%–2% higher costs that may be offset by lower operating costs. Common financial incentives include direct cash awards, salaried staff time, assistance from programs with separate budgets, as well as financial support for numerous initiatives including capacity building efforts (discussed below). Other financial incentives may include utility and government incentives, reductions in fees and taxes, and access to financing. To extend budgets many efforts coordinate additional outside funding sources. Best practices include providing financial incentives for a limited amount of time so it is clear they will only be awarded to early adopters.
- **Nonfinancial incentives.** Nonfinancial incentives can also provide a stimulus. These include such things as expedited permitting, zoning exemptions and variances, reduced parking requirements, square footage or lot coverage bonuses, and concessions made during public benefit negotiations.
- **Competitions for cash and other awards.** The four case studies highlighted in this report include a competitive design process that awards an RFP or other financial and nonfinancial incentives to winning proposals for buildings designed to PH performance standards. This has been particularly effective when a competition pairs a state's pre-existing competitive framework for affordable housing funding with a performance-based construction approach.
- **Early examples of success.** All the above catalysts are generally directed at early adopters who have acted before the majority of the market. Their early projects can and should be used as examples to stimulate further Passive House efforts. Best practices require developers receiving any form of financial or nonfinancial incentive to submit project cost and performance data, to lead tours, to prepare case studies, and give presentations. Some ask recipients to share cost data from their next

projects to demonstrate cost reductions on subsequent buildings as the development teams come up the learning curve.

Capacity

- **Outreach and awareness.** Passive House is a new concept for many people and thus requires a coordinated outreach and awareness effort to ensure the stakeholders and public are familiar with the concept and the benefits. Efforts may include advertising, social media, lunch-and-learns, cocktail hours, project tours, and symposia. Outreach should also include dialogues with important trade and manufacturing groups to increase their engagement. Product manufacturers or PH service providers are often willing to give presentations and set up booths at trade association meetings to help educate the market.
- **Workforce education and training.** Because Passive House design strategies and practices differ from conventional building, they typically require advanced education for those involved in planning, development, architecture, engineering, construction, manufacturing, finance, and government. Best practices provide tuition offsets and/or paid staff time to encourage professionals and tradespeople to acquire the appropriate skills.
- **Expert advisors.** Since it is impractical to provide training to address every scenario, the next best thing involves engaging expert advisors to guide project teams, answer questions, and help developers and other market actors to overcome barriers. These experts may include Certified Passive House Designers or Consultants (CPHD/CPHC) or experienced professionals who have completed multiple projects.
- **Supply chain development.** Passive House construction requires specialized construction materials that may not be readily available for early projects. Early efforts to stimulate market demand and accompanying supply often include new code requirements, outreach efforts, training, and commitments by state and local governments to procure the appropriate green building supplies and technologies for their own government-owned Passive House new construction and retrofits projects.

The following four case studies provide examples of how different governments around the world have applied these essential ingredients (

Table 2). While space considerations of this report necessitate a high-level overview of their extensive actions and achievements, each case study highlights one particularly bright example among their many efforts.

Brussels, Belgium catapulted from among Europe's worst to first in terms of building energy use by using a well-considered and well-funded Passive House design and construction competition.

New York State and New York City provide a powerful example of how state and local efforts work in tandem to achieve individual and shared climate action goals through effective alignment of policies and implementation efforts, including promoting PH design strategies to significantly reduce building energy use and carbon emissions from existing buildings.

Vancouver, **Canada** having studied the early successes of Brussels and New York, demonstrates the execution of a comprehensive climate action strategy employing PH design strategies to minimize energy use and maximize GHG reductions from new construction.

While **Pennsylvania's** statewide approach may be less comprehensive than the other examples cited here, their innovative idea of combining PH certification requirements into the state's competitive Low Income Housing Tax Credits scoring process has been emulated in dozens of states across the nation.

Table 2. Passive House Best Practices Toolkit

Tools	Key Element	Brussels	New York	Vancouver	Pennsylvania
Policy	Top-down alignment of goals and policies	✓	✓	✓	✓
	Bold policies and plans	✓	✓	✓	
Codes	Step codes with time-dependent performance targets	✓	✓	✓	
	Passive House code compliance path	✓	✓	✓	
	Compliance targets based on performance metrics	✓	✓	✓	
	Energy modeling alignment	✓	✓	✓	
Catalysts	Leading by example	✓	✓	✓	✓
	Financial support	✓	✓	✓	✓
	Nonfinancial incentives	✓	✓	✓	
	Competitions for cash in other words	✓	✓	✓	✓
	Early examples of success	✓	✓	✓	✓
Capacity	Outreach and awareness	✓	✓	✓	
	Workforce education and training	✓	✓	✓	
	Expert advisors	✓	✓	✓	
	Supply chain development	✓	✓	✓	

4. Brussels, Belgium: All the Right Moves

Brussels, Belgium may be best known as the capital of the European Union (EU), but it is also an international mecca for Passive House enthusiasts. In 2015, Brussels became the first place in the world to require that all new construction and renovations conform to Passive House standards. Of course, that history-making milestone didn't occur in a vacuum. Rather it arose through a steady stream of prior policy decisions and actions that trace back to 2004.

The story of Brussels' headline-grabbing success is best summed up by going "from worst to first." In a span of less than 10 years the region transformed itself from having among the lowest efficiency building stock in Europe to serving as a front runner and role model for the rest of the EU and the world. They did so by rapidly transforming a market, curbing building-related carbon emissions, creating thousands of new jobs, and catalyzing hundreds of new Passive House construction projects representing thousands of homes, businesses, and public buildings.

When knowledgeable government officials, planners, architects, and other green building professionals want to initiate Passive House efforts in their own local regions, they often begin by visiting Belgium. It is a natural early step since the Brussels effort provides a comprehensive roadmap for implementing the four major ingredients for success. Highlights of the Brussels effort include

1. Drafting energy policy to support climate goals, including code changes that integrate compliance paths for green building innovation;
2. Creating a program to stimulate passive construction through an annual competitive design process that yields exemplary projects with increasingly robust energy performance data and cost reductions;
3. Providing robust financial support through subsidies tax credits and green loans;
4. Requiring any projects receiving financial support to provide energy performance and cost data;
5. Capacity building through training and education to ensure a knowledgeable and skilled workforce;
6. Providing technical expertise and support to overcome obstacles; and
7. Supporting market transformation to ensure the ready supply of necessary building components.

The Brussels success story might be said to begin in December 2002 when the EU approved a directive requiring member states to address energy use through legislation within three years. Specifically, directive 2002/91/EC obliged Belgium, along with the rest of the EU member states, to reduce energy use and improve the energy performance of buildings (EPB) by tightening regulations, establishing minimum performance standards, instituting regular HVAC system inspections, and requiring EPB certification for new buildings, as well as when existing buildings are rented or sold.

In 2004, Brussels responded to the EU directive by adopting a new regional policy framework that laid the initial groundwork for their forthcoming effort. Their EPB package included the main elements mentioned above, as well as a visible high-level government commitment to promote energy efficiency and renewables by utilizing federal and regional funding, encouraging interagency cooperation, and promoting public awareness campaigns.

Brussels' first big move was launch of its Exemplary Buildings (BatEx) program in 2007. Designed to transform the market quickly, the Bat Ex program sought to achieve a critical mass of energy-efficient buildings using an iterative and easily replicable model. Central to the BatEx program was a government-sponsored design competition that offered a limited number of financial awards for project proposals for high efficiency public, commercial, and residential buildings.

The first year of the program was a test year; therefore, no minimum efficiency standards were set. Yet 21% of the winners complied with PH standards. As officials prepared for the next year's competition, they analyzed the previous year's proposals and began to tighten the requirements, a process that was repeated in each of the subsequent years. As a result, by 2009, 63% of winners were PH compliant with more each year after that. By 2013, six annual calls for proposals had yielded a total of "243 winning projects, representing more than

621,000 m^2 (6.7 million square feet) of new [and retrofit] PH construction including hundreds of homes, offices, schools and other buildings" (Figure 2).[11]

Figure 2. Brussels Passive House Projects

Source: Sebastian Moreno-Vacca, A2M+M2A

While execution of the BatEx program leveraged the entire EPB framework, it primarily relied on three pillars: financial, technical, and awareness. In 2007, BatEx provided €5 million per year ($5.7m) in subsidies to winning projects, and €29 million per year ($33m) for technical support, educational efforts, awareness campaigns, private sector cooperation, and zero-interest loans for low-income families to pursue energy-efficient renovation. By 2012, award funding reached €18 million a year with commensurate increases in industry support. Also by 2012 the cash infusion amounted to 16% of Brussels annual construction generating €319 million ($363m) in business and 1250 new jobs.[12]

The technical pillar consisted of two parts: subsidized education for market actors and free government-sponsored technical support to ensure project success. To prepare and educate the local workforce they partnered with and funded key actors and stakeholders from the public sector, academia, and industry, to develop workforce education and training programs. Meanwhile, technical consultants provided specialized assistance to help with financing, architecture, technology selection and engineering, green building methodologies, renewables, and cogeneration, as well as specialists to help with public and private sector projects for both residential and nonresidential buildings.

The awareness pillar involved extensive public outreach and engagement. In the early years, the Belgian public were skeptical of energy efficiency and considered it a luxury. Building professionals were even more reluctant, claiming the policy moved too quickly, that buildings would not pass airtightness tests, and that project costs would be too expensive. To counter this, BatEx was accompanied by an extensive marketing and outreach effort. One high visibility tool included *be.passive*, a magazine intended to familiarize developers, builders, and

[11] Code Innovations Partnership. "Brussels Exemplary Buildings Program + Passive House Law of 2011." Buildings Innovations Database. Accessed September 2021. https://www.buildinginnovations.org/policy/brussels-exemplary-buildings-program-passive-house-law-of-2011/

[12] Code Innovations Partnership. "Brussels Exemplary Buildings Program + Passive House Law of 2011." Buildings Innovations Database. Accessed September 2021. https://www.buildinginnovations.org/policy/brussels-exemplary-buildings-program-passive-house-law-of-2011/.

public officials with Passive House standards by providing examples of successful projects. Other efforts ranged from information fairs and academic symposia to flash mobs and advertising campaigns debunking myths and promoting new standards for comfort and energy efficiency.

The combined funding, training efforts, and awareness campaigns worked. After three successful rounds of annual project competitions, Belgian officials were convinced that high-efficiency projects could be delivered cost-effectively. Consequently, in 2009 they ordered that all new regional public buildings must be built to Passive House standards starting in 2010. In 2011 they upped the ante, requiring all new construction and significant renovation to meet Passive House standards by 2015. This last piece of legislation provided several years of advance notice to all market actors to allow time to prepare for the coming changes.

Since 2015, the market has matured and adapted to lessons learned by all the market actors. For example, while many of the fears expressed by those in the construction sector did not come to pass, their feedback regarding the difficulty of predicting adherence to strict airtightness criteria in advance led to a relaxation of those standards since other design criteria, as well a rigorous pre-and post-construction inspection system, have proven sufficient to achieve performance targets. Other feedback has yet to be incorporated. For instance, some architects and developers have voiced concerns that narrow specifications regarding required technologies have reduced their opportunities to innovate and find alternative solutions, whereas broader guidelines allowing for more experimentation to achieve performance targets could lead to further advances.

Meanwhile, PH strategies remain an integral component of Brussels's energy and climate strategies, as leaders advance their region's efforts by pursuing a roadmap for residential buildings that outlines mandatory performance targets to be met to achieve their overall legislated mandate that calls for an average of 100 kWh/m^2 by 2050. Another effort underway involves building specific documentation called a "housing passport" that records ownership, design specifications, and energy performance details that will be referenced and added to during sale, lease, renovation, etc.

Today in Brussels, in an environment where passive house has become normal, we see developers and designers who go beyond, to carbon neutral developments or even to regenerative design. In these and many other ways, Brussels continues to lead the advancement of PH strategies in Europe and around the world.

5. New York: An Integrated State and Local Effort

In 2009 Passive House enthusiasts congregated in New York City (NYC) for the first training for Certified PH Designers. Sooner after that group began convincing others to build to PH standards. The following year New York pioneered its first Passive House, a Landmarked Brownstone in Brooklyn. Today New York State (NYS) boasts 38 PH projects[13], with many of these projects located in New York City. Together NYS and NYC provide a master class in how to wield the four major tools in the PH toolbox and how to implement each of the 15 key elements. Between the state and the city, they check every item on our list of best practices including:

1. Shared goals at the state and local level, as well as closely aligned policy directives and strategic plans
2. Performance-based step codes that provide clear metrics and directives for market actors and stakeholders to prepare and act to ensure compliance
3. Explicit time-dependent targets with penalties for noncompliance
4. Extensive outreach to a vast array of stakeholders including local governments and boards, industry professionals, building owners, and manufacturers

[13] Passive House Database, https://passivehouse-database.org/.

5. A formally recognized alternative pathway for Passive House with accompanying energy modeling software
6. Tuition offsets to promote workforce education and training
7. A host of paid expert advisors and knowledgeable staff members motivated to overcome barriers
8. Demonstrable commitment to applying Passive House strategies (with or without certification) when retrofitting or building new structures
9. Orchestrated financial and nonfinancial incentives ranging from minor zoning variances, such as to accommodate thicker exterior walls, to competitive solicitations for innovative building designs worth millions of dollars
10. Requirements that recipients of these incentives provide project cost and performance data to establish baselines, track project performance, improvements over time, and provide examples of early success[14]
11. Supply-chain development and market transformation support, encouraged by all the above

These accomplishments and the accompanying rapid rise in PH construction link directly to New York State and New York City climate action goals. While both the state and city have long histories of innovative energy and climate endeavors, their climate initiatives converged in 2014.

In April 2014, the New York Public Service Commission announced a new major policy initiative called Reforming the Energy Vision (REV) that made energy efficiency and distributed energy resources key priorities for achieving the state's climate goals. REV established a strategic policy framework and set several goals, including a 40% reduction in GHG emissions below 1990 levels by 2030 and an 85% reduction by 2050.

REV launched New York State on a multiyear, multifaceted effort with different tracks focusing on enhanced building and energy efficiency, utility-scale and distributed renewable energy, sustainability and infrastructure modernization, transportation, and research and development. The goals and strategies established over the next five years were codified into law in 2019 when New York State passed the Climate Leadership & Community Protection Act (CLCPA). The CLCPA legally mandated limiting statewide GHG emissions to 40% of 1990 levels by 2030 and 85% of 1990 levels by 2050, as well as mandating 3000 MW of energy storage and 70% renewable electricity by 2030, 100% zero emission electricity by 2040, and establishing a plan for net zero GHG emissions across the state economy.

Among the many efforts spawned under REV, one of most relevant to the proliferation of PH construction began in 2016 when New York State Energy Research and Development Authority (NYSERDA) developed NYStretch. A statewide framework for stretch energy codes, NYStretch enables New York jurisdictions to adopt local building codes that exceed statewide codes to meet their local energy and climate goals. Ongoing NYStretch efforts also led to the creation of new energy performance metrics and establishment of alternative compliance pathways for projects to meet statewide metrics. PH approaches were explored in 2017–2018, and in 2020 full performance and prescriptive PH compliance pathways were established through the NYC 2020 Energy Conservation Code (NYECC).

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[14] The importance of sharing project cost and performance data for PH projects cannot be understated. Getting buy-in from key players during development requires data to prove the benefits of the PH approach, especially for sub-sectors like NYC multifamily projects. A working group in NYC collected, analyzed, and compared operational energy consumption and carbon emissions data from six multifamily PH case study buildings against conventionally built peers. In March 2021, Building Energy Exchange published *"Passive House: Connecting Performance to Financing"*, which reports "Passive House design can save up to 85% on heating and cooling costs and up to 60% on total energy use compared to conventional construction, presenting a compelling opportunity to improve cash flow in a market sector defined by lean operational budgets." Source: https://be-exchange.org/report/multifamily-passive-house-connecting-performance-to-financing/ .Accessed September 2021.

Meanwhile, New York City charted its own path in September 2014 when NYC Mayor Bill de Blasio unveiled "One City Built to Last: Transforming NYC Buildings for a Low-Carbon Future."[15] This bold initiative committed New York City to 80% reductions in GHG emissions by 2050 and set a deadline of 2025 to bring every major public building into compliance. These goals were monumental and placed enormous pressure on the city to reduce energy consumption and carbon emissions from the built environment. An inventory associated with the plan revealed that buildings represent nearly 70% of the city's emissions—and that an estimated 90% of the buildings in New York today will still exist in 2050. These facts dramatically reinforced the importance of retrofitting existing buildings and prompted the city to begin preparing effective and replicable strategies that could be applied across a broad spectrum of building types. It also prompted the city to begin exploring specific targets and financial penalties for noncompliance so that building owners would be motivated to find and apply solutions.

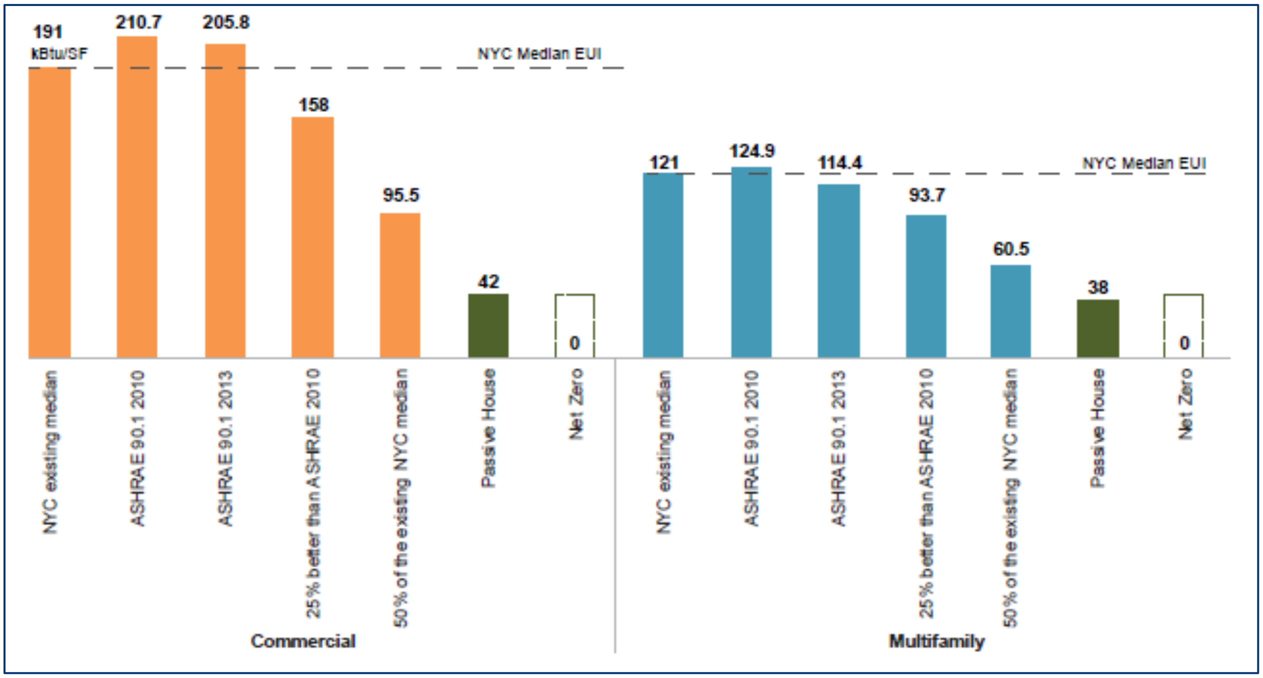
Although PH strategies did not originally figure prominently in NYC's initial One City pronouncement, a technical working group tasked with developing implementation plans drew on the Brussels BatEx Program and Passive House regulations when recommending the approach for New York City. This small start gathered momentum as PH advocates conducted extensive outreach efforts to familiarize politicians, government officials, building industry professionals, owners, and other stakeholders with the benefits of PH construction. Those efforts achieved an important milestone in 2016 when the Manhattan Borough Board resolved to support PH standards in local building codes. In 2017, the Brooklyn Borough Board passed a similar resolution.

Within just a few years, a rapidly expanding grassroots group of hundreds of architects, engineers, builders, and building owners worked with local NYC lawmakers to pass a series of local laws (LL) including: LL31-2016 that established energy use intensity (EUI) targets for new and existing buildings; LL32-2018 that called for stretch energy codes with future EUI targets; LL33-2018 that established a rating system to grade building energy performance based on the building's ENERGY STAR score, LL95--2019 that required buildings to display their ENERGY STAR scores established through benchmarking, and LL97-2019 that set absolute emissions limits and established building performance standards measured in emissions and rather than BTUs. These and other local laws came together in a 2019 recommendation for an alternative PH compliance path that proved influential in the state's ultimate approval of the full PH compliance pathway for New York State energy codes. Figure 3 shows comparisons prepared by the NYC Mayor's office to demonstrate the differences between PH performance and building built to code.

Since policy and codes mean little without concomitant financial support and skilled workers, both NYS and NYC initiated extensive efforts to achieve the desired results. Recognizing the need for a knowledgeable and trained workforce, NYSERDA funded a workforce education and training effort that contracted with 50 training providers to teach New Yorkers a wide range of energy efficiency related skills. Between 2014 and 2016 the program provided interested individuals with $500 in grant funding to offset tuition costs. More than 500 of the 20,000 people trained via the program applied the funding to an eight-day course for certification as a PH Designer or Consultant or another related PH specialty course. This bolus of cash stimulated the training of a critical mass of professionals qualified to work on PH construction projects.

[15] New York City, One City Built to Last,2014, accessed August 2021, https://www1.nyc.gov/assets/builttolast/downloads/OneCity.pdf

Figure 3. Median EUI of NYC Buildings Built to Code Compared to Passive House (kBtu/SF)



Source: NYC One City Built to Last, https://www1.nyc.gov/assets/builttolast/downloads/OneCity.pdf

This critical mass of trained professionals was essential for NYC to release a competitive RFP in 2016 for an affordable housing high rise in the East Harlem neighborhood of Manhattan that required the new construction project meet PH standards. The winning design, called Sendero Verde, includes three buildings, the tallest standing 37 stories, and it hosts nearly 700 units of permanently affordable for low- to moderate-income residents, as well as a community center for seniors and youth, a school facility, a publicly accessible elevated courtyard with a variety of active and passive recreation spaces, and community gardens to be conveyed to the City of New York upon completion. Once completed in late 2021, its developers claim that Sendero Verde will be the largest multifamily residential Passive House in the United States.

While new construction projects like the Sendero Verde high rise take many years to complete, retrofit projects are starting and finishing much faster. One early example of the commitment of both NYS and NYC to support retrofit PH projects is Casa Pasiva, a nine-building, 146-unit affordable housing project nearing completion at the time of writing. This $20 million project, undertaken by the Riseboro Community Partnership, is partially financed with $1.8 million in grant funding from RetrofitNY, a NYS program based on the Dutch Energiesprong[16] initiative, that earmarks $30 million to develop prefabricated low-cost modular, scalable, net-zero energy retrofit technologies and solutions that can be implemented with minimal resident disruption. Casa Pasiva is the first graduate of the RetrofitNY program.

For this project, Riseboro sought to bring the four-story multifamily property built in 1931 up to strict PH standards while retrofitting it without relocating any tenants. The project called for installing new induction cooktops and high efficiency windows, which are straightforward replacements. Updating the building's HVAC system and the remainder of the building envelope, however, was significantly more complicated. The project removed all existing radiators and other interior heating elements and replaced them with wall-mounted air source mini split heat pumps connected via ducts and refrigerant lines that climb the exterior of the buildings

[16] Energiesprong, accessed August 2021, https://energiesprong.org/

to a rooftop energy recovery ventilator and air purifier. All the ducting hides beneath a new airtight white exterior cladding coated in a high-tech paint that repels water and cleans itself when it rains. Because the cladding increased the overall exterior square footage, a sidewalk encroachment allowance was needed. Riseboro requested an eight-inch variance to accommodate thicker insulation and better ductwork, but was granted a workable, but less than optimal, four-inch allowance.

While these upgrades will greatly reduce the buildings' carbon footprint, the remodel will not be all electric. The buildings' domestic hot water systems will use new, highly efficient gas boilers with the existing plumbing system. When financially feasible, this system will be converted to all electric as well. Together, all the innovative improvements are expected to reduce annual energy costs by 60%–80% and save approximately $180,000 per year. Although Riseboro sought financing for Casa Pasiva from NYS and NYC housing agencies and the state's RetrofitNY program, New York's recently launched Commercial PACE program can provide private investment capital for similar projects.

Casa Pasiva not only demonstrates an early RetrofitNY project, but it also represents an emergent deep energy retrofit industry that achieves high performance results with less onsite installation time and minimal inconsistent on-site labor by focusing on designs that call for prefabricated components based on PH principles, such as highly insulative panels, and on integrated mechanical systems that are sized to satisfy the reduced electric loads in carefully controlled environments. Although prefabricated panels were not available in the US market when Riseboro applied for first round RetrofitNY funding, a second round of RetrofitNY solicitations forthcoming in late 2021 will require these solutions.

Although Sendero Verde and Casa Pasiva provide early examples of successful PH new construction and retrofit projects, scores of similar low energy intensity, low carbon emission building projects are now underway. Many of these projects have received funding from NYSERDA's Buildings of Excellence (BOE) Program, modelled after the Brussels' BatEx competition. Started in early 2019, the BOE program established a $40 million budget, to be distributed over three rounds of competition for the most innovative low energy use and zero carbon emitting multifamily buildings, with winning projects receiving up to $1 million each. To date, the program has completed two rounds of competition, awarding funds to 48 projects statewide, including low-rise, midrise, and high-rise structures. Most second-round winners featured PH designs.

In keeping with best practices, NYSERDA requires all project proposals to include a cost data workbook containing estimates of total construction costs, incremental costs compared to a business-as-usual baseline, anticipated incentives and tax credits, and an accounting of building attributes impacting performance. An analysis of the data reveals that after tax credits and incentives, more than half the properties achieve cost parity with business as usual, and a few projects achieve parity prior to the application of tax credits. Numbers such as these demonstrate the rapid decline in incremental costs, particularly for developers on their second and third projects. These results leave New York officials confident that PH projects using an integrated design process can bring cost differences down to 1%–2% over conventional construction costs without taking any savings from reduced operating costs into account. When those additional operational savings are also accounted for, PH projects become even more financially attractive, as well as future proofing those properties from compliance penalties under NYC's LL97, and potential new state regulations outside of NYC.

Of course, in their efforts to promote Passive House, New York enthusiasts are not relying on financial arguments alone. They also promote benefits such as improved occupant comfort, physical health benefits due to improved air quality, and psychological health benefits due to stress reductions resulting from quieter acoustics, particularly in dense urban areas.

Taken together, these many efforts demonstrate how New Yorkers have effectively aligned state and local efforts to achieve climate action goals, in part through the proliferation of PH design.

6. Vancouver, Canada: An Orchestrated Approach

The first certified Passive House in Vancouver was constructed in 2015. Within four years there were more than 1000 PH units built or in construction, and a similar number under development. The projects ranged from single family and multifamily homes to government and commercial structures, and even a 60-story skyscraper. As of 2021 there are 33 PH projects in the city, representing over one-third of all PH projects in British Columbia.[17] This near meteoric uptick in Passive House construction arose from a well-orchestrated initiative inspired by best practices from around the world.

Vancouver has long supported climate-oriented actions. The city published its first report on reducing carbon emissions in 1990 and adopted a formal climate action plan in 2005. In 2008, Vancouver committed to sustainable building processes and revised its building bylaws to allow voluntary alternative compliance pathways, including Passive House. Vancouver then passed a Green Rezoning policy in 2010, requiring all new rezoning for buildings to include LEED standards. Until this point, Passive House was just one of multiple options and not the first choice.

That began to change, however, when city staff noticed newly constructed LEED-certified buildings were not hitting their energy use or GHG reduction targets. Upon investigation, they discovered that because LEED certification relies on ASHRAE 90.1, which uses energy cost to calculate savings, building designers were opting for less expensive natural gas, a problem worsened by less-than-optimal building envelopes. Conversely, smaller code-compliant buildings performed better, indicating the importance of properly sealed and insulated buildings for Vancouver's coastal Canadian climate.

Passive House got its next big boost in 2011, when Mayor Gregor Robertson announced Vancouver's Greenest City Action Plan to make Vancouver the world's greenest city by 2020.[18] The plan established 10 major long-term goals to be accomplished by 2020, including reducing GHG emissions to 33% below 2007 levels and creating 20,000 new green economy jobs. For the built environment, the plan mandated that all new construction be carbon neutral and that existing buildings improve efficiency by 20%. Because more than half of Vancouver's carbon emissions come from building energy use, the city leaders knew they needed to devise and initiate an effective zero emissions building plan.

While both new construction and retrofits were essential to decarbonizing Vancouver's built environment, new construction was arguably of greater importance. Although deep energy retrofits may be more costly than specifying new standards at the start of a project, new construction represented a larger share of projected GHG emissions. When looking toward its carbon-free future, Vancouver's Greenest City Action Plan forecast that only 30% of the city's building stock would be built prior to 2010; an additional 30% would be built between 2010-2020, and 40% after that.

Moreover, unlike New York and Brussels, Vancouver enjoyed a head start when it came to a carbon-free electric supply thanks to British Columbia's legislation requiring the province's electric grid to be supplied with a minimum of 93% renewable energy. As a result, Vancouver's building policies focused on eliminating natural gas. Because gas-fired space heating was responsible for 65% of building emissions, Vancouver emphasized the importance of proper building envelopes and high efficiency all electric end uses—both of which were strengths associated with Passive House.

In response, the city took actions to incentivize Passive House construction and improve its base building codes. Things formally came together in 2016 when the Vancouver City Council approved the city's Zero

[17] Passive House Canada project database, accessed in September 2021. https://www.passivehousecanada.com/projects/.

[18] City of Vancouver, British Columbia, Greenest City Action Plan, 2010. See original and subsequent action plans at https://vancouver.ca/green-vancouver/greenest-city-action-plan-development.aspx

Emissions Building (ZEB) Plan.[19] To draft the plan, city planners drew upon both local insights and best practices learned in other parts of Canada and around the world, including New York and Brussels. The resulting plan outlined a comprehensive approach that incorporated virtually all 15 essential elements identified for this paper. Highlights of Vancouver's effort included:

1. Aligning bold climate goals and with detailed strategic plans
2. Initiating performance-based step codes with clear targets and dates, establishing time pressures for people to adjust and innovate to meet the goals
3. Establishing key metrics for measuring building performance
4. Creating formal alternative pathways for compliance, including a PH pathway
5. Setting the example with city buildings and procurement practices
6. Providing catalysts using a variety of financial and non-monetary incentives
7. Conducting extensive outreach and awareness efforts
8. Subsidizing training for government employees and those in the building professions
9. Removing barriers by empowering staff and hiring experts

The ZEB plan established three primary metrics for incrementally stepping down building GHG emissions to zero:

1. **Greenhouse Gas Intensity (GHGI)**: The total amount of energy supplied to the building (electricity and natural gas, hot water, or steam) multiplied by that energy's carbon intensity and is calculated as kg CO_2e/m^2 per year.
2. **Thermal Energy Demand Intensity (TEDI)**: The amount of heat required to keep the building comfortably warm (or cool) regardless of the efficiency with which it is produced. This represents building envelope performance. It is calculated as kWh/m^2 per year.
3. **Energy Use Intensity (EUI)**: The total amount of energy externally provided to a building for any use, calculated in gigajoules per square meter or GJ/m^2 per year.

Once the metrics were set, the ZEB plan leveraged British Columbia's BC Energy Step Code that permits local governments to adopt new opt-in code structures to drive market transformation based on different steps of performance rather than prescriptive ones.[20] This enabled Vancouver to the establish stepped targets and dates, at approximate five-year intervals, by which times different building types must hit increasingly rigorous performance targets for each metric (Table 3). To support compliance, Vancouver also introduced accompanying energy modeling guidelines to ensure the parameters used aligned with the established performance targets. Vancouver code officials considered the predetermined step codes to be essential for market transformation since providing clearly defined performance levels and schedules enabled industry leaders and other market actors to plan appropriately and innovate as necessary to achieve the desired outcomes.

[19] City of Vancouver, British Columbia. Zero Emissions Building Plan. July 12, 2016. https://vancouver.ca/files/cov/zero-emissions-building-plan.pdf.

[20] British Columbia, Energy Step Code: Building Beyond the Standard. https:// energystepcode.ca

Table 3. BC Step Codes

Step	Airtightness	Equipment and Systems	Envelope	Approximate Equivalency
Step 1: enhanced compliance	3.5 ACH_{50}	BCRC using 9.36.5 or ERS v15 ref. house (MEUI of 80 kWh/m²/year is likely, not required)	Report on TEDI and PTL (TEDI 50 kWh/m²/year is likely, not required)	Energy Guide Rating System, Built Green Bronze
Step 2: 10% beyond code	3.0 ACH_{50}	10% better than ERS v15 or MEUI – 60 kWh/m²/year	TEDI 45 kWh/m²/year or PTL – 35 W/ m²	Built Green Silver
Step 3: 20% beyond code	2.5 ACH_{50}	20% better than ERS v15 or MEUI – 45 kWh/m²/year	TEDI 40 kWh/m²/year or PTL – 30 W/ m²	ENERGY STAR®, Built Green Gold and Platinum
Step 4: 40% beyond code	1.5 ACH_{50}	40% better than ERS v15 or MEUI – 35 kWh/m²/year	TEDI 25 kWh/m²/year or PTL – 25 W/ m²	R2000
Step 5: 50% beyond code	1.0 ACH_{50}	No ERS option MEUI – 25 kWh/m²/year	TEDI 15 kWh/m²/year or PTL – 10 W/ m²	Passive House, Net-Zero Energy-Ready

Source: Based on information from https://www.energyadvisor.pro/bc-energy-advisor-contact-us/bc-step-code-builders-chart-energy-advisor/

Vancouver offered builders two pathways to achieve the specified targets. The first path focused on creating ultra-low energy use buildings using Passive House strategies and standards. The other promoted the creation of neighborhood renewable energy systems that employ renewable energy and a shared infrastructure to heat and cool multiple buildings or neighborhoods.

Based on their preliminary data gather efforts from elsewhere, Vancouver leaders determined setting goals and creating code structures were only the first steps. To ensure success they knew they would need to do considerably more to support Vancouverites during the transition, including in three key areas: demonstrating city leadership, providing an extensive array of market catalysts, and conducting a broad range of capacity building activities.

To demonstrate leadership, the city committed to (1) building all new city-owned facilities and Vancouver Affordable Housing Agency projects to Passive House standards; (2) requiring development partners working on mixed use projects with the city to pursue Passive House certification and low carbon fuel sources for any city portion of the project; and 3) directing city staff to initiate new procurement processes to support Passive House and zero emissions supply chains.

As discussed previously, catalysts stimulate market action through financial means or via other incentives. The ZEB plan identified an entire toolbox of catalysts and Vancouver leveraged them in multiple combinations, according to the needs of the project. The tools consisted of two parts: the criteria to be met and the reward for doing so. Criteria generally fell into three categories:

1. **Component Criteria.** These provide benefits for buildings that use specified elements such as high-efficiency windows and heat pumps for space and water heating. This approach helps to generate volume to stimulate market demand.
2. **Fixed Criteria.** These benefit developers who commit to specified criteria, such as Passive House certification. They are useful when optimal outcomes are clear and there are no delays when determining compliance.

3. **Competitions and Prizes.** These award funding for innovations above and beyond the baseline criteria. This is particularly useful for launching demonstration projects that test new approaches and, once successful, to help establish new baselines.

Vancouver got creative with the reward elements associated with each. While they were not reluctant to use financial incentives, the non-monetary incentives were often worth meaningful amounts of money to developers without the need for significant additional financial distributions. The non-monetary incentives Vancouver utilized included:

1. **Fees and taxes.** Depending on the criteria, developers might receive reductions in permit fees, development costs, levees, or taxes.
2. **Expedited permitting.** Because time equates to money, agreeing to shorter processing times can be a significant incentive.
3. **Exemptions and variances.** PH construction requires thicker walls and buildings necessarily require more square footage of floor area. Providing exemptions and variances for buildable areas, height requirements, setbacks, and neighborhood design guidelines can make sizeable differences in building designs and significant differences in project costs and profitability. Among the most useful was relaxing buildable area rules and increasing building height limits in certain neighborhoods to allow for additional stories so thicker walls did not mean less living space.
4. **Parking requirements.** Local governments can offer a variance to allow for a percentage of existing parking or leverage currently available incentives such as those offered for providing spaces for bicycle parking, ridesharing vehicles, and electric vehicle charging.
5. **Public benefit negotiations.** When negotiating public benefits for large projects, concessions can be given to incentivize PH developments.
6. **Financing.** Energy efficiency measures pay for themselves via reduced energy costs over time. However, developers often sell the buildings before they can recover their upfront costs. Although upgrade expenses can be passed along to the buyer within the purchase price, the higher selling price creates a disincentive to buyer and seller alike. To address this, Vancouver looked to Toronto, which overcame this split incentive dilemma by offering energy efficiency strata loans. These loans include city loan loss guarantees that carveout the costs of the EE upgrades and package them separately so that the loan can be paid down with the energy savings.

Vancouver found it was essential to offer incentives that would cover the incremental costs of early projects because they require something new. Developers must come up the learning curve and supply chains need to be developed. However, incentives work best when they are offered for a limited time. In Vancouver's case, the sweet spot appeared to be five years. This was long enough for anyone interested to plan on taking advantage of the incentive, but short enough that it would not be a permanent drain on the budget. Importantly, the time limit was made public to encourage prompt adoption.

Early adopters understood that receiving funding and other incentives was contingent not only on compliance with the stated criteria but also came with a stipulation that the developer provide project cost and performance data. Early adopters were also required to host technical tours and prepare case studies summarizing their designs, methodology, outcomes, successes, information gaps, and lessons learned on the project.

Vancouver also supported Passive House adoption through multiple interrelated capacity building efforts designed to increase awareness of Passive House strategies and benefits, educate the Vancouver workforce with appropriate skills, and remove obstacles to implementation. The effort began with scores of public engagements to familiarize political leaders, architects, engineers, builders, building owners, and other stakeholders. The engagements took many forms including lunch and learns, cocktail hours, tours, and dialogues. The dialogues also extended to component manufacturers. For instance, Vancouver representatives held multiple meetings with the Fenestration Association of British Columbia, an industry trade group, to speak with window manufacturers about a new line of products meeting Passive House standards since none were made locally at the start of the initiative.

Additionally, Vancouver learned from New York that it is vital to get early buy-in from people in the building trades by normalizing excellence and overcoming resistance through demonstrating more effective building techniques and explaining the benefits. To ensure builders, designers, consultants, and tradespeople acquired the knowledge and skills needed to meet the increasing targets of the BC Energy Step Code and build to Passive House standards, Vancouver subsidized half the cost of necessary courses, ranging from half-day trainings to semester long curricula. Vancouver also provided meeting space for Passive House trainings.

Another important early effort involved educating more than 100 city staff members about Passive Houses, including planners and building inspectors. This helped ensure that any Passive House project would be assigned knowledgeable staffers. Equally importantly, city staffers were encouraged to identify and remove as many administrative barriers to Passive House projects as feasible and appropriate. In a related move, Vancouver applied a learning from Brussels to ensure that experts were available to answer questions and consult with developers on projects.

These efforts quickly propelled Passive House implementation to new heights with more units being built every year. However, Passive House construction was only one integral component among many in Vancouver's bid to achieve its goal of 33% reductions in GHG emissions. The city fell short of its aspirational 2020 goal, ultimately achieving only a 12% decline in emissions. Nonetheless, Vancouver doubled down on its climate commitments and continued its forward push, releasing a new 2020 Climate Emergency Action Plan.[21] This new plan aims to put the city on track to cut carbon emissions by 50% by 2030, in part by reducing embodied energy in new buildings by 40% and eliminating the use of fossil fuels for space heating and hot water after 2025. That plan also relies upon Passive House strategies to accomplish its bold new objectives.

7. Pennsylvania: Aligning Incentives Yields Big Results

Pennsylvania does not have an extensive policy framework to support Passive House construction in the same way as Brussels, New York, and Vancouver. Nonetheless, the Keystone State has seen a sizable number of PH construction projects arising from a relatively simple adjustment to the state's point scoring system for ranking developer applications to fund the construction of affordable housing projects with Low Income Housing Tax Credits (LIHTC). The adjustment awards bonus points for projects designed to achieve Passive House certification and treats PH projects differently than other voluntary green construction systems.

Low Income Housing Tax Credits are federal government-sponsored incentives to help fund affordable housing projects across the US. The housing credit agency in each state considers new developer proposals for affordable housing and uses a qualified allocation plan (QAP) to score them based on state priorities including location, project type, target population served, and other goals. Project scoring criteria fall into two categories: mandatory and optional. The more criteria a proposal meets, the higher the score, and resultingly, the higher the likelihood of receiving funding.

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[21] City of Vancouver. Climate Emergency Action Plan Summary. 2020. https://vancouver.ca/files/cov/climate-emergency-action-plan-summary.pdf

The simplicity of this innovative approach is that it aligns the pre-existing, competitive framework for available funding with a performance-based construction approach that spurs voluntary developer submissions of PH projects without requiring any additional government funding. The approach also addresses important social and environmental equity considerations by ensuring residents living in affordable housing enjoy the benefits of healthier, more comfortable homes and lower utility bills.

The idea arose from a fortuitous admixture between PH enthusiasts and a long-standing desire to promote healthier and more energy efficient low-income housing on the part of the Pennsylvania Housing Finance Agency (PHFA), the group that decides which projects in Pennsylvania receive Low Income Housing Tax Credits. Because PHA rules target residents in low-income housing to pay no more than 30% of their incomes on rent and utilities, PFHA had been pushing developers to improve efficiencies in their buildings and reduce tenant energy costs for years.

In 2012, after co-developing, designing and building the first certified Passive House project in Pennsylvania, Philadelphia and Pittsburgh architects Tim McDonald and Laura Nettleton, along with about 20 other activists from around the state, approached PFHA and asked if PHFA could make all affordable housing “Net Zero Energy Capable” by 2030 and use Passive House as the tool to get there. They also communicated the building science principles, health and wellness benefits of PH design.

By 2014 a working group of PFHA employees, PH advocates, building industry leaders and other stakeholders had developed a way to adjust QAP scoring so projects adhering to PH design strategies would receive 10 points out of a total of 130 points awarded. In other words, if developers submitted a proposal designed for PH certification, they would receive an almost 8% competitive advantage over proposals without similar designs. Because competition among developers for tax credits is fierce, only a small percentage of applications would receive funding, so it would stimulate innovation on the part of developers who are always seeking ways to improve the scoring of their proposals.

Although some developers complained, PFHA stood firm. In the first year, those 10 bonus points proved sufficient to prompt 38% of all project applications to PH House designs and eight received funding although only seven were built. In the second year PFHA had approved funding for another 10 multifamily Passive House projects. In the third and fourth years, they funded another eight projects. Since 2015, PHFA has funded the construction of over 1000 units of affordable housing built to the Passive House standard.

When costs for these PH projects were compared to conventional market rate housing, for first-year projects (2015) the cost per square foot for PH projects ran $169/sq ft compared to $164/sq ft for conventional construction; a 2.5% difference. In the second year (2016), project cost differences flipped with the PH projects averaging 2% *less* than the code-built projects ($172/sf vs 182/sf). Other years have seen that percentage difference rise and fall slightly. Project cost differences naturally vary by year, but those cost differences diminish as builders become more familiar with PH design strategies and construction practices, and as prices for high efficiency building supplies decline and product availability and selection improves (Figure 4. Cost Comparison of Passive House and Conventional Projects in PennsylvaniaFigure 4**Error! Reference source not found.**).

Figure 4. Cost Comparison of Passive House and Conventional Projects in Pennsylvania

Source: data from PFHA. Graphics provided by Tim McDonald (Onion Flats Architecture) and Zach Semke (Semke Studio).

In the summer of 2015, after the success of the first round of PFHA funding, the team approached 39 other states to introduce the idea to all who would listen. As of September 2021, 20 states have used some version of this model,[22] but with mixed success due to variations in the way that they have applied the bonus point scoring to their own ranking systems. To ensure success with this approach, the experts we consulted pointed out two vital factors that must both be met:

1. The process for allocating funding for LIHTC projects must be competitive enough that any bonus points awarded for projects aligning with PH requirements can make the difference between a winning and losing proposal.
2. Passive House bonus points must be separate and above and beyond other points awarded. In other words, PH proposals must be awarded a higher number of points than the number of points given for projects seeking certification for less rigorous standards, such as ENERGY STAR® or LEED.[23] Awarding the same number of points for less stringent standards gives developers an easier option with the same reward, thereby undermining the central premise of this approach.

The Pennsylvania experience shows that different paths can be taken to drive successful Passive House market transformation. While the Brussels, New York, and Vancouver approaches leveraged all four tools—policy, codes, catalysts, and capacity—to one degree or another, Pennsylvania's transformation has not followed this path. Pennsylvania's approach was driven by motivated professionals who saw an opportunity to ensure low-income housing developers and occupants weren't left behind in the state's transition to energy efficiency, low carbon operations, and comfortable, healthy living environments. They engaged the right market players (PHFA, developers, industry professionals) at the right time. They developed a QAP policy approach that didn't require additional federal funding but rewarded creative proposals from LIH developers. They harnessed competition to drive cost-effective solutions that meet the needs of the market—and it has been wildly successful. Over six short years, Pennsylvania showed that PH projects could be delivered at cost parity to conventional projects—but with significant energy bill reductions and increases in occupant comfort. Their success has sparked nearly half the states in the country to try to mimic the results of the Pennsylvania PH QAP experiment. The next steps for Pennsylvania will be to take a more planful approach, to see if the

[22] Home Innovation Research Labs. "QAP Round-Up: Where NGBS is Recognized." QAP Recognition; Home Innovation Research Lab. Accessed August 2021.
https://www.homeinnovation.com/services/certification/green_homes/resources/ngbs_incentives_summary/qap_recognition
[23] The ENERGY STAR® name and mark are registered trademarks owned by the US EPA.

success in low-income housing can be translated over to other building sectors. This will require a focus on additional tools and key elements to help anchor Passive House market transformation throughout the state.

8. Conclusion

Together, the four case studies from Brussels, New York, Vancouver, and Pennsylvania exemplify a full range best practices for leveraging Passive House strategies to enact policy, pass codes, leverage catalysts, and build capacity that can help California to achieve its long-term energy efficiency and carbon reduction goals. California's initial, if incomplete, efforts to align the statewide CBECC-Res model with the Passive House Planning Package model have established a foundation for Passive House certification to serve as an approved alternate pathway for Title 24 compliance. While this represents a clear next step, those interested in advancing Passive House construction in the Golden State can look to the efforts in these other regions for inspiration and guidance as Californians seek to overcome other hurdles, including lack of awareness, building industry resistance, stakeholder education, public acceptance, policy and planning, funding, and incentive alignment as they strive to transform the market.

9. Contributors

The following professionals contributed to this report.

NAME	TITLE	ORGANIZATION
Bronwyn Barry, CPHD	Architect and Certified Passive House Designer (CPHD)	Passive House BB and The Passive House Network
Beverly Craig	Senior Project Manager, Low and Moderate Income Programs	Massachusetts Clean Energy Center
Danielle Donnelley	Manager of Sustainability Programs	Community Preservation Corporation
Greg Hale	Senior Advisor for Energy Efficiency Markets and Finance	NYSERDA
Chris Higgins, CPHC, LEED AP Homes	Senior Green Building Planner	City of Vancouver
Atalia Howe	Assistant Vice President, Initiatives and Impact Investing	Community Preservation Corporation
Elizabeth Kelly	Senior Policy Advisor	NYC Mayor's Office of Climate & Sustainability
Christian Kienapfel	Architect, Certified Passive House Designer (CPHD), LEED-AP, Dipl.-Ing. (FH) Architekt (Germany)	Paravant Architects
Jennifer Leone, AIA, LEED	Chief Sustainability Officer	New York City Department of Housing Preservation and Development
Mark Lyles	Senior Project Manager	New Buildings Institute
Timothy McDonald, RA, CPHC	President and Architect	Onion Flats
Sadie McKeown	Executive Vice President	Community Preservation Corporation
Sebastian Moreno-Vacca, AIA, NCARB	Architect and Founding Partner	A2M+M2A Architects
Sean Pander, P.Eng.	Green Building Program Manager	City of Vancouver
Clare Parry, CPHD Building Certifier	Sustainability Manager	Development Victoria
David Salamon, CPHC, CPHD	Architectural Designer and Passive House Specialist	Re:Vision Architecture
Jason Scheurer, CPHT	Building Scientist and Certified Passive House Tradesperson (CPHT)	BEST Techs Contracting Design Build Remodel, Inc.
Zachary Semke, CPHC, LEED AP	Director	Passive House Accelerator
Jeremy Shannon	Director of Sustainable Design and Resilience	NYC School Construction Authority

For more information, please contact:

Matthew Joyce
Director
Tierra Resource Consultants

Matthew.joyce@tierrarc.com
1501 North Broadway, Suite 300 | Walnut Creek, CA 94596

Mark Wilhelm
Director
Tierra Resource Consultants

mark.wilhelm@tierrarc.com
1501 North Broadway, Suite 300 | Walnut Creek, CA 94596