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Accelerating Market Transformation for High-Performance Building Enclosures

State of market, policy developments, and lessons learned from the Passive House movement

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September 2016

photo Sonia Zouari

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September 2016; revised May 2017

Editor: Roberta Franchuk
Cover Photo: Salus Clementine, Ottawa. Photo by Sonia Zouari.

Recommended citation: Frappé-Séneclauze, Tom-Pierre et. al. *Accelerating Market Transformation for High-Performance Building Enclosures: State of market, policy developments, and lessons learned from the Passive House movement*. The Pembina Institute, 2016.

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Acknowledgements

The authors would like to thank Nicole Flanagan (2016 Loran Scholar intern) and Bassam Javed (2015 PICS intern) for their invaluable research assistance in the preparation if this report.

These reviewers provided comments on the final draft of this report; we are grateful for their insight:

- Rob Bernhardt, Passive House Canada
- Christina Bollo, University of British Columbia
- Patrick Enright, City of Vancouver
- Graham Finch, RDH Building Science Inc.
- Mark Frankel, New Buildings Institute
- Katrin Klingenberg, Passive House Institute US
- Micah Lang, City of Vancouver
- Chris Mattock, Habitat Design + Consulting Ltd.
- Monte Paulsen, Red Door Energy Design Ltd.
- Jieying Wang, FPInnovations

The authors would also like to thank the 21 practitioners and policy makers who provided insights and perspective on the market during interviews conducted in August 2015; their names are listed in Appendix A.

This study was made possible by a Carbon Neutral Cities Alliance Innovation Fund grant from the Urban Sustainability Directors Network, a Greenest City grant from the Vancouver Foundation, and the support of the Real Estate Foundation of B.C.

Executive Summary

The challenge

Commercial, institutional, and residential buildings are responsible for about a third of carbon pollution in the U.S., and about a fifth of carbon pollution in Canada, constituting the largest source of emissions in North America.[1] Worldwide, they account for about a third of energy-related emissions[2], and continue to grow: over 80 billion square metres (900 billion square feet), will be built and rebuilt in urban areas by 2030, an area roughly equal to 60% of the current global building stock.[3]

As countries around the world strive to reduce climate impacts and urban air pollution, this construction spurt offers both challenges and opportunities. If construction standards do not evolve rapidly, inefficiencies will be locked in and could lead emissions from the building sector to double by 2050. At the same time, the nearly $80 trillion to be invested in this urban development represents a unique opportunity.

Enclosure-first approach

Heating and cooling loads generally account from a third to a half of energy use in buildings. Reducing these loads though enclosure improvements alone will therefore not be sufficient to meet deep energy reductions in the building stock; other end uses such as domestic hot water, lighting, ventilation, auxiliaries and plug loads will also need to be addressed. There are, however, several reasons to prioritize an enclosure-focused approach to energy efficiency:

- Building enclosures are long lasting and costly to refurbish, unlike other systems that can be more easily replaced as better technologies become available.
- Enclosures are simple systems; their performance does not depend on complex energy management systems and they are more tolerant to delayed maintenance.
- Reducing heating and cooling demand early in the design process allows for reduction of the size of space conditioning systems, reducing construction cost and ongoing energy demand.
- High-performance enclosures also offer significant non-energy benefits, such as thermal comfort, acoustic isolation, durability, and increased resiliency to power outages and extreme temperature events.

The Passive House standard

High-performance enclosures rely on relatively simple products and practices, most of which are already familiar to builders. Nevertheless, assembling these components to get maximal performance while ensuring durability and comfort represents a significant shift for the industry.

The international Passive House Institute and the Passive House Institute US are two of the main organizations driving innovation in high-performance building enclosures. These groups administer separate Passive House standards, both of which offer stringent guidelines for building energy efficiency including:

- maximum heating energy demand;
- maximum total site energy demand;
- minimum airtightness requirements, and
- requirements for thermal comfort.

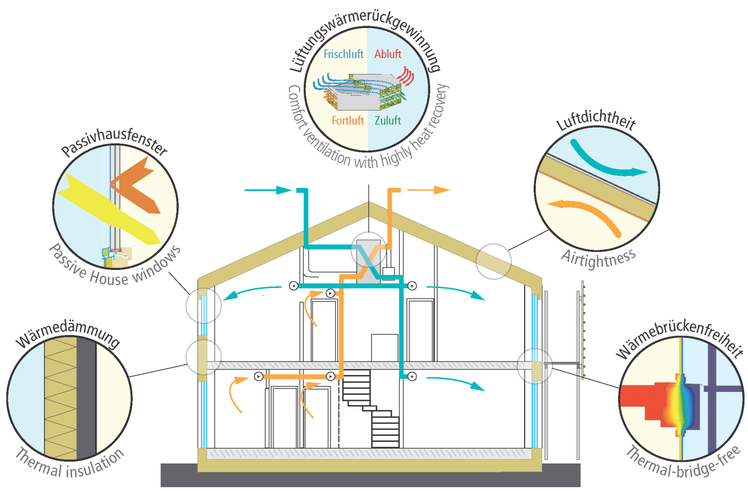


Figure 1: Passive House principles.

Source: PHI[4]

Buildings adhering to a Passive House standard use dramatically less energy than typical buildings, reducing heating energy requirements by **40% to 90%** (Figure 5) by utilizing an enclosure-first approach. Increasing adoption of these stringent standards for building enclosures represents the next step in a continuously evolving construction industry: an evolution, not a revolution.

State of the market

- Most passive buildings are residential projects (well over 3500 buildings worldwide and 300 in North America), but there is a growing number of commercial and institutional projects (over 500 worldwide and 30 in North America) (Figure 2).

- The number and size of certified Passive House projects has seen a rapid increase in North America in the last five years, and we expect this growth to accelerate. Mid-rise residential projects currently in construction will quadruple the number of Passive House certified units (Figure 3), and several more projects are expected to break ground in the next year. By the end of 2016, there will be nearly 2 million square feet of certified passive buildings in North America, three times more than in 2015.
- Demand and offerings for training of professionals and trades has also increased rapidly; there are currently over 1600 professionals and trades trained in Passive House design and construction in North America, with hundreds of new certifications expected in the next year (Figure 4).
- Several jurisdictions have put in place policies to support Passive House and high-performance enclosures in general, and there is growing political leadership on the role of standards and procurement policies to advance high-performance enclosures.

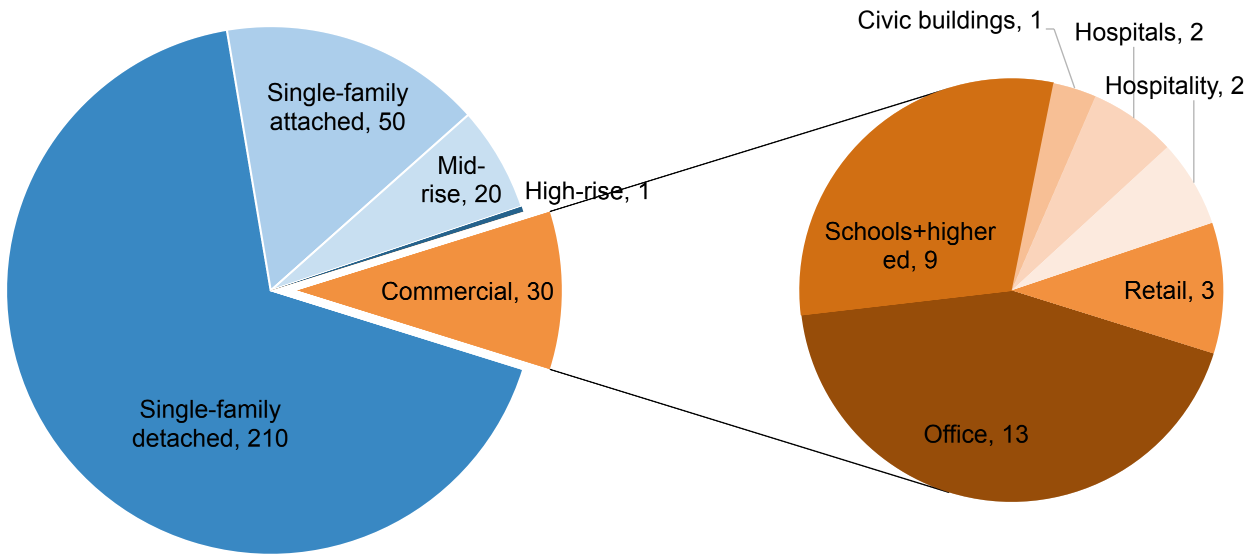
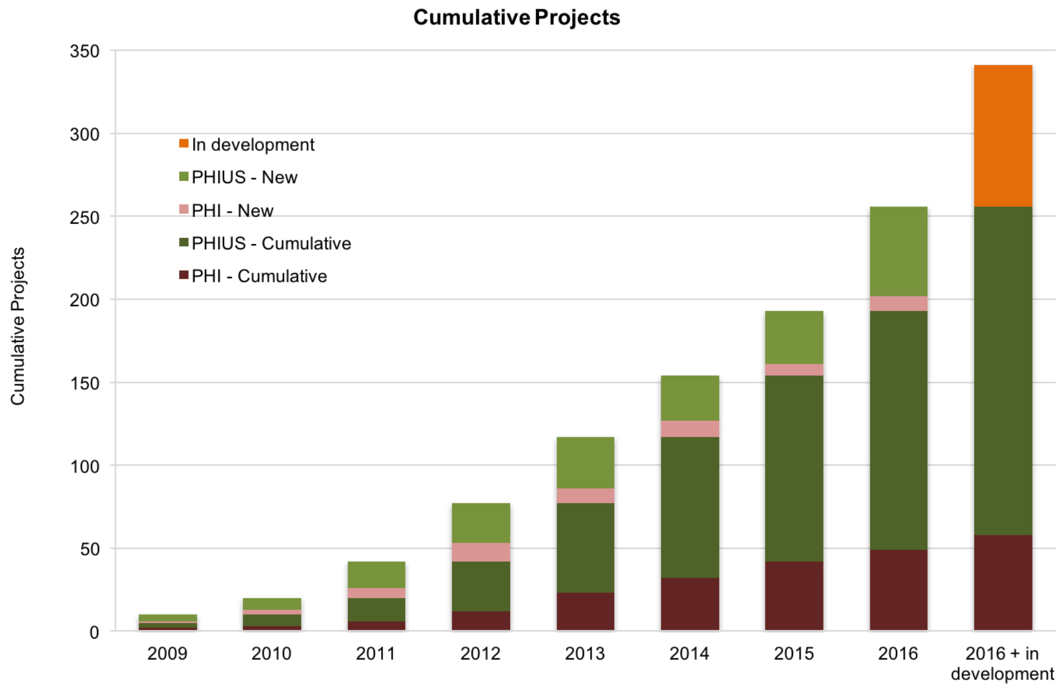


Figure 2. Estimate of the number and types of residential (left) and non-residential (right) passive buildings in North America (as of August 2016).


Cumulative Projects
Cumulative Projects
350
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250
200
150
100
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0
In development
PHIUS - New
PHI - New
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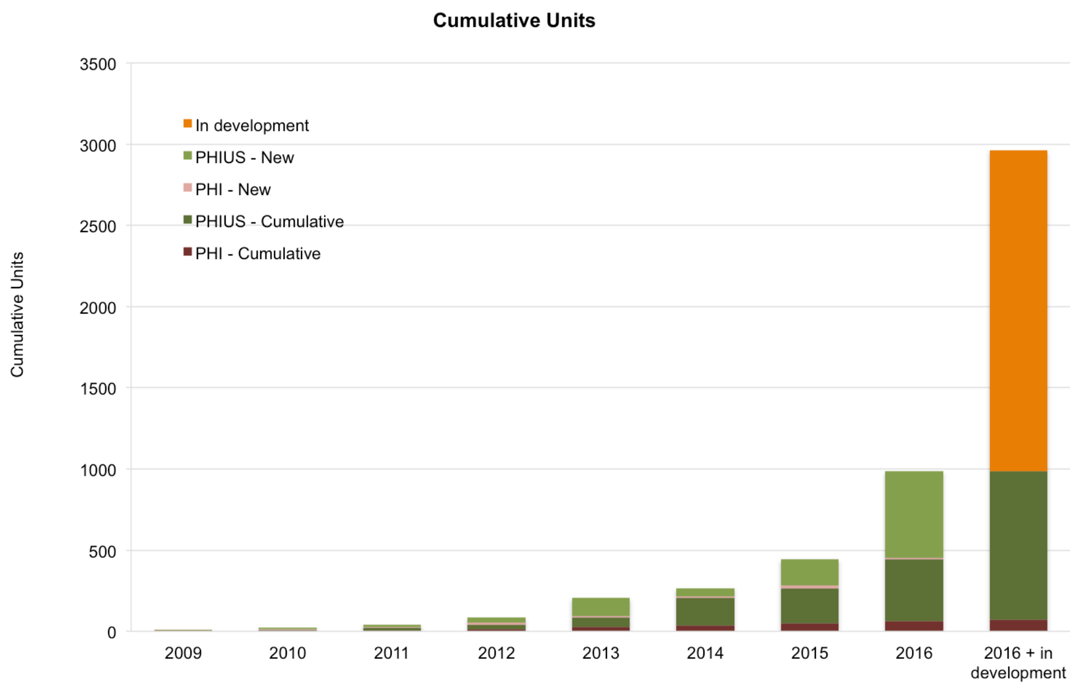
Cumulative Units
Cumulative Units
3500
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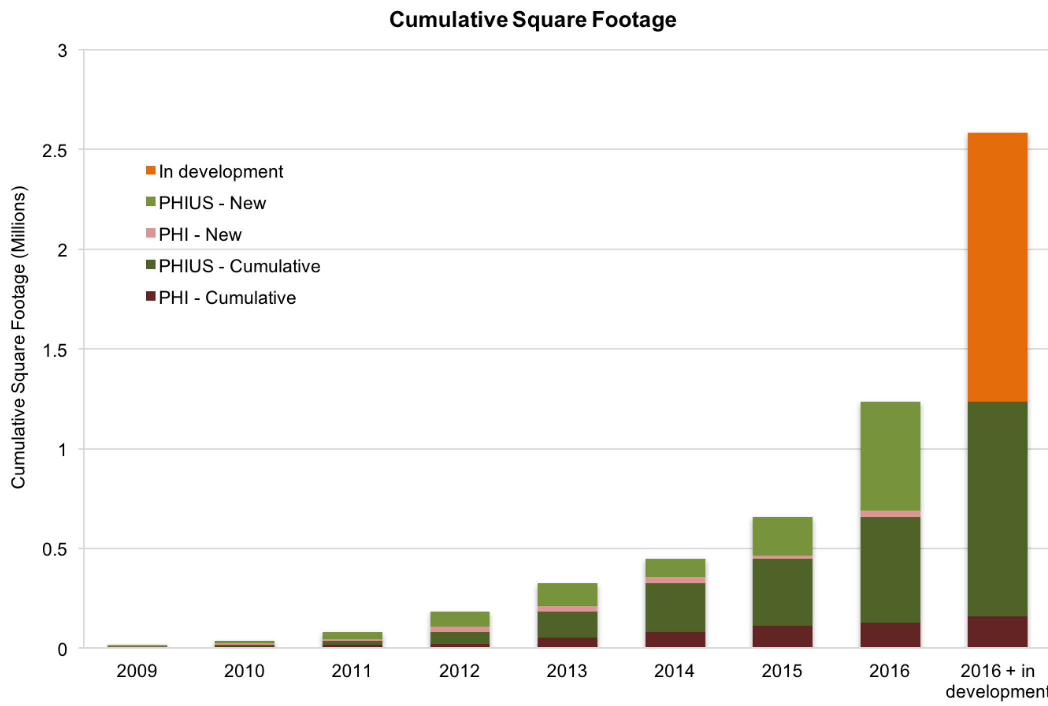

Figure 3. Growth in PHI and PHIUS+ 2015 certified Passive Houses in North America since 2009.

'In development' data includes an non-exhaustive scan of projects under development and seeking certification. Most are expected to reach completion (and possible certification) in the next one to three years.

Data sources: PHI, PHIUS and Passive House Canada

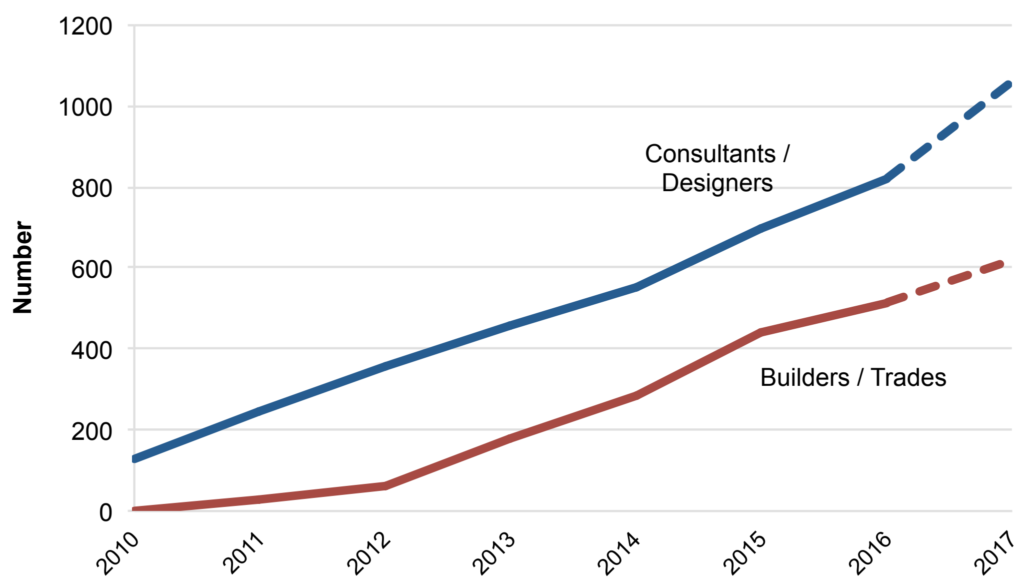

Figure 4. Growth in certified Passive House designers and trades in US/Canada since 2010.

Data: Passive House Canada and PHIUS[5]

Energy case for passive house

- Modelling studies show that passive design can reduce heating demand by 40% to 90% compared to typical current building practice. Monitoring of energy consumption in occupied units shows that heating loads for most projects studied are within ~10 kWh/m^2 of modelled values (Figure 5). As the systems involved are simple, the greatest source of variation generally comes from occupant behaviour.
- As the climate warms, passive strategies can be used to reduce cooling loads in conditioned buildings and reduce the risk of overheating in free-running buildings. These solutions can play a role in avoiding increased penetration of air-conditioning systems in regions where they historically had not been needed.

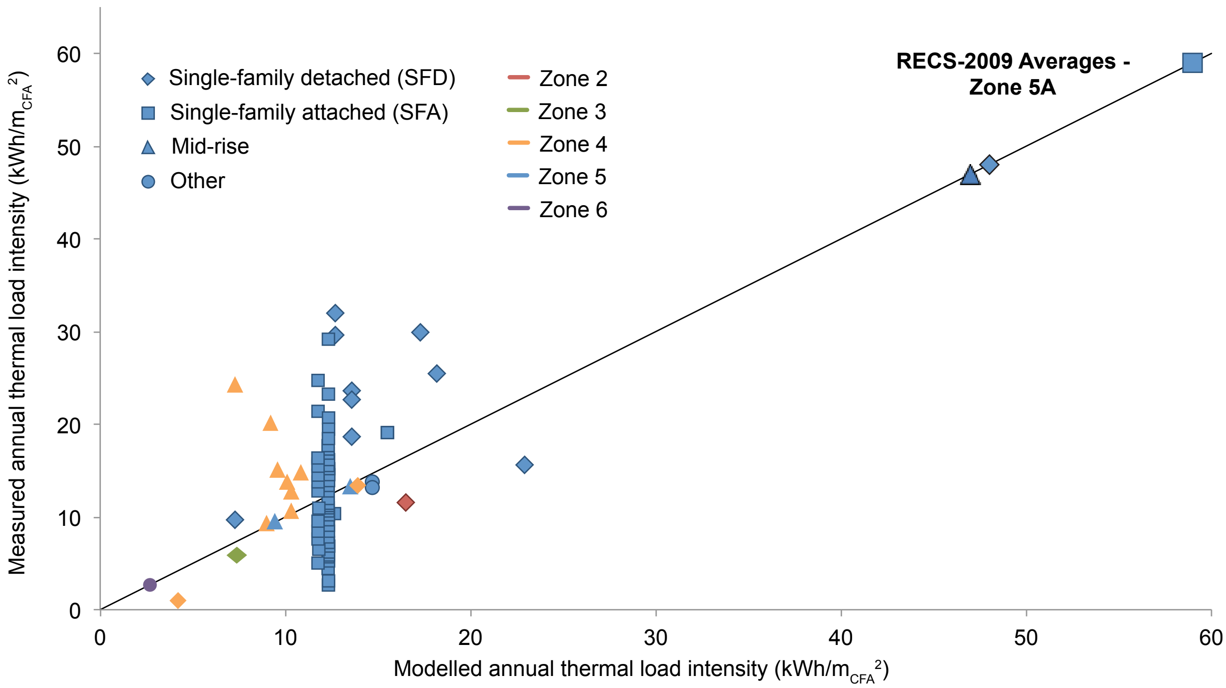

Figure 5: Comparison of measured to modelled thermal load intensity (TLI) for passive buildings.

The majority of buildings surveyed were located in climate zone 5A; the 2009 Residential Energy Consumption Survey (RECS) averages for this zone are shown to represent a typical U.S. building's performance in this climate. For most of the monitored project, the measured thermal load was within 10 kWh/m^2 of the modelled load. The average thermal load intensity (across all available measurement points) was 15.5 kWh/m^2: a 68% reduction from the RECS average. Points appearing in a vertical line result in cases where monitoring data is available for several individual units but the modelled thermal load intensity is only available for the buildings as a whole (and assigned as a default 'modelled' value for each unit).

Data sources: various, see references in Table 6

Business case for Passive House

- Detailed costing studies and anecdotal evidence from builders show that it is possible to build residential passive buildings within typical construction budgets; incremental cost estimates vary, but most are below 10%, and within normal budget variability.
- Given the low cost of energy in North America and continued failure to internalize the social cost of carbon, it can be difficult to make the business case for passive construction solely on the basis of energy cost savings. To complete the picture, we need costing studies that quantify potential maintenance cost savings associated with the higher quality components, as well as the decreased replacement costs resulting from simpler mechanical systems.
- While there is growing evidence of the fact that higher energy efficiency can increase sale values (see Section 11), better documentation of sales costs and time on market would help make the case for builders.
- Universal energy labelling would help provide validated information to compare the performance of different homes. This would also help communicate the relationship between quality construction, energy efficiency and non-energy benefits: comfort, air quality, durability and resilience.

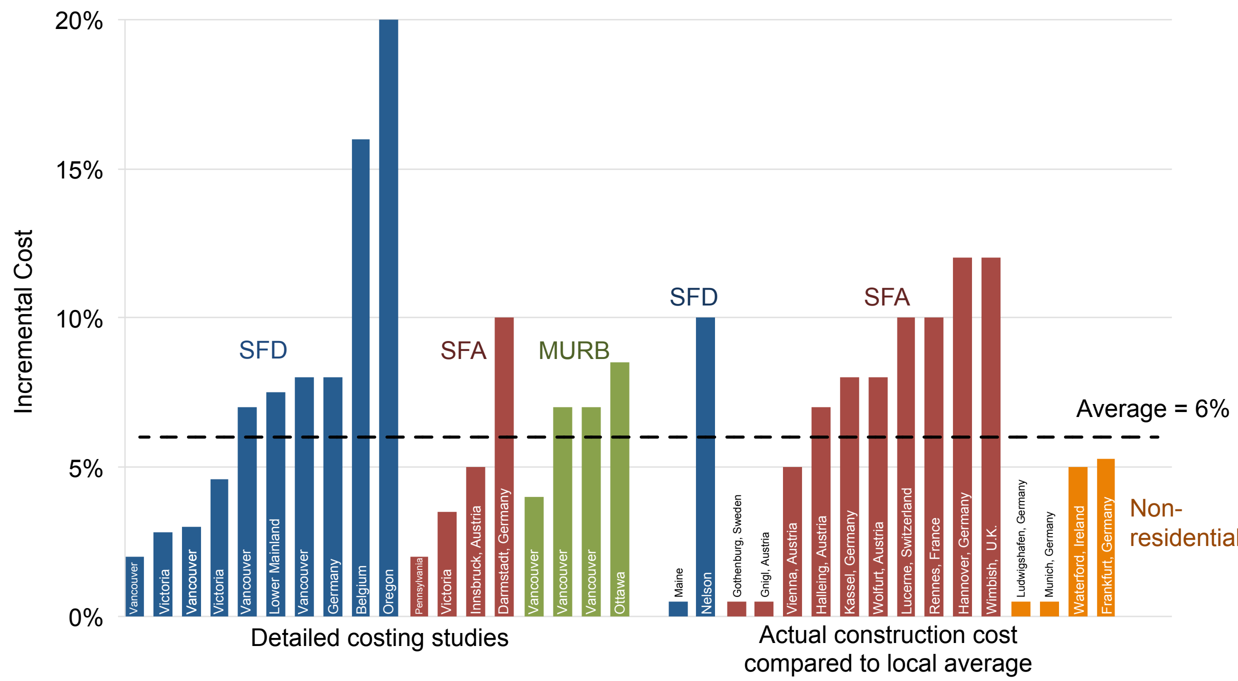

Figure 6. Estimated construction cost increment of passive buildings.

The average incremental cost, based on all studies and reported values found, was 6% of construction cost. Note that the baseline assumptions for what 'normal' construction practices (and associated costs) vary by location, and from study to study. See details in Table 8.

Data sources: various, see references in Table 8.

Quality control

Passive house construction raises the stakes: it provide great benefits if basic precautions are taken, but can also lead to underperformance if poorly executed. As passive approaches move from niche to broad adoption, certain quality controls will need to be integrated into building practices to mitigate the risk of moisture entrapment in walls and overheating, including:

- Air barrier testing, with strict airtightness requirements
- Proper accounting of thermal bridges and whole wall R-value calculations
- Involvement of a certified professional in the review of the enclosure design, or use of climate-appropriate pre-approved designs
- Design guidelines for passive cooling strategies including the sizing of south-facing windows, shading devices, cool roofs, etc.

Capacity building

Mainstreaming high-performance enclosures will require significant training across the construction industry, reaching beyond the occasional building code update seminar. Training capacity is in place, and is being scaled up to meet the growing demand. PHIUS and PHI provide a structure for training and networking of passive house practitioners in many areas of Canada and the U.S., and the number of Passive House trained trades and professionals is growing rapidly (Figure 4). Passive design is also being integrated into the curriculum of various trade, engineering, and architecture schools. This scale-up can also be supported by the creation of innovation excellence centres (such as BEEx in NYC, or that proposed by the City of Vancouver) that can act as clearinghouses for the dissemination of research and as hubs for education and outreach. These effort, however, are best coordinated when guided by energy codes roadmap, providing clarity on the next code iteration and on the end-goal performance they ultimately seek to achieve.

Accelerating change

Because retrofitting buildings is costly and complex, it is crucial that new buildings be built to the best standards as soon as possible. Each building allowed to be constructed at suboptimal efficiency is a 50+ year liability in a world that needs to be almost fully decarbonized within the next 30 years.

The pace of change that is called for to avoid this lock-in will be faster than what we have seen in the past — which will present both risks and rewards. The construction industry stands to gain in this transformation: as money moves from operational budgets to capital budgets, it also flows from the energy sector into the construction sector.

We have identified five early steps to be taken in supporting this market transition:

1. **Get more passive buildings on the ground.** Support the market segments that are already well underway (detached to mid-rise residential) or emergent (office, schools). Prioritize simple solutions that can be broadly applied, but also encourage projects that provide high visibility or break new ground: high-rise MURBs (multi-unit residential buildings), high-rise office, city halls, libraries. Collect basic data on the project economics and selected design strategy; work with research institutions to analyze this data and monitor energy use and indoor conditions after occupancy. Appendix C summarizes policies implemented by North American jurisdictions to incent uptake of Passive House and remove some of the existing code barriers to the technology (listed in Appendix D).

2. **Ensure markets and decision makers have access to energy information.** The market can't value what it can't measure or see. Require benchmarking, reporting, and disclosure of energy use, starting with larger buildings and adding smaller ones over time. Put in place home energy labelling requirements for homes at point of sale and

renovation. These will provides the feedback mechanisms needed to guide code evolution and facilitate valuation of energy efficiency for new and existing buildings.

3. **Free up additional capital to cover incremental costs.** Create the legislative structure to enable private industry to provide services combining lending and technical support (e.g. PACE model). Use government bonds to provide low-cost capital for loans and incentives and assess the potential for increased public revenues; the increased revenue and economic activity triggered will return more funds to public coffers (e.g. KfW model).
4. **Prepare the ground for regulation.** Set mid- and long-term targets to allow time for industry to prepare for policy development. Use information gathered from early projects to test economic and technical feasibility. Use benchmarking data to monitor impact of energy code change and market evolution.
5. **Create information sharing hubs offering training for industry and providing public education and outreach**. There is also need for a body to compile and analyze energy and costing data, to monitor the state of the market for high-performance components, and provide support for code development and design of demand-side management programs. These two functions can be joined, or assumed by different bodies, but in both cases they will likely play primarily a coordination role between various organizations providing the services.

Which building types to prioritize, and how

- From a ‘proof-by-numbers’ perspective, there is a strong case for the technical and financial feasibility of Passive House for ground-oriented, low-rise, and mid-rise residential buildings in North America. These market segments are rapidly growing and competing in the market, with limited incentives or policy drivers. With proper policy support and investment in builder training, passive approaches could be broadly adopted in the ground-oriented and mid-rise residential sector within a decade.
- Residential high-rise passive buildings are newly emerging but becoming more common, and more demonstration projects should be encouraged.
- For more complex building types, additional demonstration projects are needed to understand technical and market constraints. Public sector participation and leadership will be important (see Sections 9.1 and 11.2).

- Projects with high visibility that allow some access for the public are ideal candidates as they can increase awareness of passive design amongst the public and key market stakeholders. All social housing projects, community centers and civic facilities should be required to consider the feasibly of building the project to Passive House standard or comparable.

1. Introduction

Commercial, institutional, and residential buildings are responsible for about a third of carbon pollution in the U.S.,[i] and about a fifth of carbon pollution in Canada,[ii] constituting the largest source of emissions in North America.[6] Worldwide, they account for about a third of energy-related emissions,[7] and continue to grow: over 80 billion square metres (900 billion square feet), will be built and rebuilt in urban areas by 2030, an area roughly equal to 60% of the current global building stock.[8] Fifteen percent of this growth will occur in the U.S. and Canada.[9]

As countries around the world strive to reduce climate impacts and urban air pollution, this construction spurt offers both challenges and opportunities. If construction standards do not evolve rapidly, inefficiencies will be locked in and could lead emissions from the building sector to double by 2050.[10] At the same time, the nearly $80 trillion to be invested in this urban development[11] represents a unique opportunity. Countries and companies with the skills and knowledge to provide the needed building services while decreasing local air pollution and climate risks will have an important competitive advantage in local and global construction markets. Developing these solutions in North America is therefore not only an imperative from a climate and air quality perspective, but also a significant economic development opportunity.

One strategy to reliably reduce emissions from buildings at a low cost, while also improving durability, comfort, and resilience, is to improve the thermal performance of building enclosures. By increasing the insulation and airtightness of walls, roof, and windows, it is possible to reduce the energy used for heating buildings by up to 90% compared to common practice (Table 6). This 'passive' approach to thermal comfort—in contrast to active systems based on a constant supply of conditioned air by HVAC systems (Figure 7) —is the cornerstone of the passive house movement (see Box 1. Passive House basics) and a strategy used by thousands of green buildings around the world.

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[i] 12% of direct emissions from commercial, institutional and residential buildings, rising to 34% of total emissions when including emissions resulting from the production of electricity used in non-industrial buildings (or 2,338 $MtCO_2e$ in 2014)

[ii] Counting both direct and indirect emissions from electricity use, buildings account for ~17% of Canadian emissions.

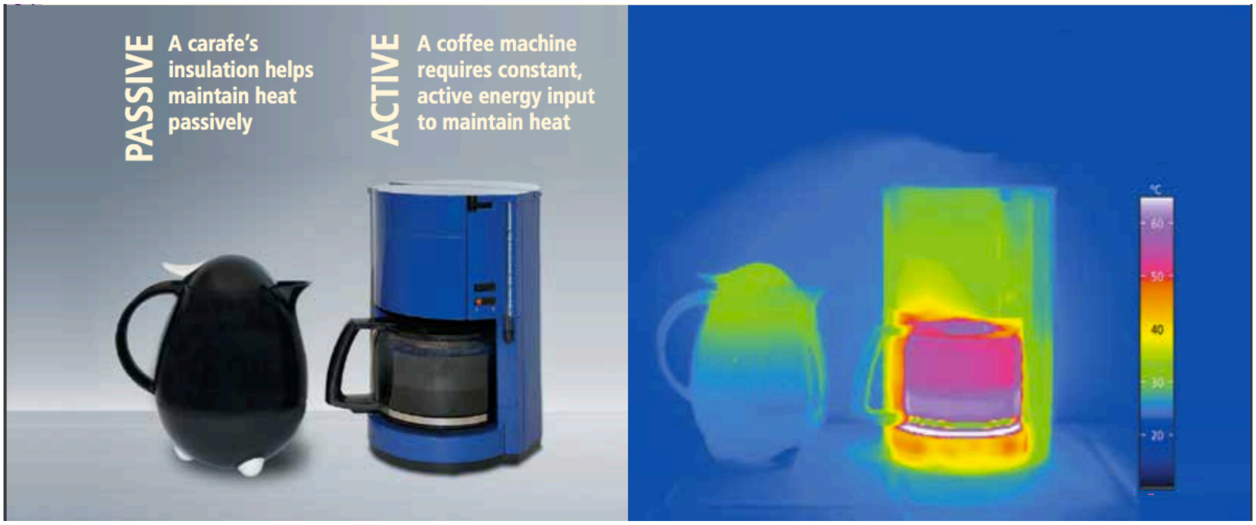

Figure 7. Passive vs. active approaches to climate control

Source: Passive House Institute[12]

Purpose, scope and structure of this report

This report investigates how public policy can be used to accelerate adoption of high-performance enclosures in the construction industry. To do so, we find it useful to consider lessons learned from the growth of the passive house movement in North America and Europe.

A couple of clarifications will help the reader in understanding the scope of this paper.

First, there are many 'passive design' strategies which can be integrated in high-performance buildings: daylighting, thermal mass, night ventilation, natural ventilation, shading, earth sheltering, cool towers, solar chimneys, earth tubes and phase change materials, to name only a few. Some of these strategies are directly addressed in the Passive House standards, others not. This report focuses on strategies related to enclosure design: level of insulation, airtightness, massing, orientation, and glazing. Other passive design strategies, such as shading and natural ventilation, will be briefly discussed for their role in mitigating the risks associated with super-insulated buildings such as overheating and moisture entrapment in walls.

High-performance enclosures are central to the Passive House standards, but they are also commonly used in high-performance construction more broadly, whether informed by other certification programs (LEED, R-2000, Built Green, etc.) or simply by construction best practices. Our discussion here is therefore not limited to the parameters set by the Passive House standards; for example, we discuss the value of airtightness measurement requirements in driving better enclosure design and construction practices, irrespective of the fact that the requirements implemented in North America to date do not specifically following Passive House methodologies or targets. That said, we see value in focusing more closely on lessons learned in the passive house community given its importance in policy development and capacity building in Europe, and given its rapid growth in North America. The Passive House standards also are the most rigorous with regards to enclosure performance; because the enclosure is among the longest lasting components of a building, maximizing its life cycle energy benefits will avoid locking in inefficiencies. Thus, to inform public policy, we are particularly interested in learning about the benefits and challenges of this 'best in class' standard. Many, if not all, of the lessons learned along the way will also be applicable to other high performance standards. Our primary concern here is not the adoption of a specific standard, but rather the dissemination of enclosure design best practices across the industry.[iii]

This report aims to provide decision-makers in government and industry a picture of the state of the passive house market (Section 2), an assessment of its energy benefits (Section 3), costs (Section 4), and risks (Sections 0 and 0), and a summary of barriers to market transformation and policy solutions advanced in Europe and North America (Sections 8 to 14).

Reducing emissions from buildings will require both de-carbonizing the energy supply and reducing energy demand across all energy end uses. This report, however, focuses primarily or the reduction of heating and cooling loads. The role of on-site renewables in reducing emissions and the need for strategies to address energy end uses beyond space heating (domestic hot water, lighting, plug loads, etc.) are briefly discussed in Box 2 and Box 3 below, but otherwise beyond the scope of this report.

Box 1. Passive House basics

The origins of passive house design date back over 40 years to the Saskatchewan Conservation House built in 1977 in Regina, Canada, by a team of researchers from the National Research Council and Saskatchewan Research Council.[13] The Saskatchewan Conservation House had an excellent standard of thermal insulation, an airtight building enclosure and one of the first heat recovery ventilation systems in the world. Tested 30 years later, the airtightness had not changed significantly, and the walls showed no sign of moisture accumulation.[14]

U.S. physicist William Shurcliff declared the technology and concept mature in 1988 and predicted

[iii] In this spirit, we will distinguish in this text the general design approach from the specific standards, by using Passive House (capitalized), to refer to the standards (and buildings meeting their certification criteria) and passive house (lower case) or passive building to refer to the general design approach developed by passive house practitioners across the world, irrespective of whether the resulting buildings meet all certification criteria.

further developments in materials, components and integrated minimized mechanical systems.[15]

These design principles were refined and further systematized by Bo Adamson and Wolfgang Feist, who founded the Passive House Institute (Passivhaus Institut) in 1996 in Darmstadt, Germany. In 2007, Katrin Klingenberg and Mike Kernagis co-founded Passive House Institute US (phius.org) which became the principal provider of passive house training and certification in North America. In 2015, PHIUS launched the PHIUS+ 2015 Passive Building Standard.[16] PHIUS+ 2015 is integrated with the DOE's ENERGY STAR, EPA Indoor airPLUS, and Zero Energy Ready Home (ZERH) programs, which are pre-requisites for certification (Figure 31).[17] Some of the innovations it brought includes cost-optimized climate-specific targets, maximum peak demand requirements, and on-site QA/QC requirements for certification. PHIUS and the Fraunhofer Institute for Building Physics also developed WUFI, software for certification that allows static and dynamic energy modelling and provides the capacity to do hygrothermal modelling.

Buildings adhering to Passive House standards use dramatically less energy than typical buildings due to a high level of insulation, high-performance windows with shading that modulate heat loss or gain, an airtight building enclosure, minimized thermal bridges, and continuous ventilation with energy recovery. Certification criteria differ between the two standards, but both are based on quantitative performance targets and a series of specific requirements for thermal comfort, humidity, noise, and user satisfaction (Appendix A).

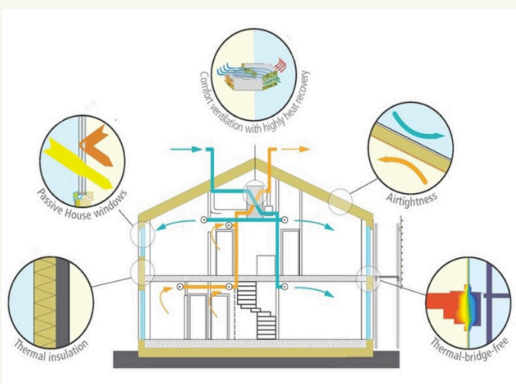

Figure 8. Passive House principles

Source: PHI[18]

Certification criteria (Passive House Institute)[iv]

Annual heating demand:	≤ 15 kWh/m^2 OR ≤ 10W/m^2
Annual cooling demand[v]:	≤ 15 kWh/m^2 + dehumidification contribution[vi]
Airtightness:	< 0.6 ACH @ 50 Pa
Total primary energy:	≤ 120 kWh/m^2
OR	
Total renewable primary energy (PER)[vii]:	≤ 60 kWh/m^2

In addition to these energy targets, certified buildings must meet specific requirements for thermal comfort, humidity, noise, and user satisfaction (see Table 27 in Appendix A).

Certification criteria (Passive House Institute US 2015)

Annual heating demand	< A kWh/m^2
Annual cooling demand (sensible + latent)	< B kWh/m^2
Peak heating load	< C W/m^2
Peak cooling load	< D W/m^2
Airtightness	≤ 0.05 cfm/sf enclosure @50Pa[viii,19]
Primary energy demand	≤ 6200 kWh/person[ix] for residential ≤120 kWh/m2 (38 kBTU/ft2) for commercial

Where A, B, C, and D vary by climate and energy costs (see Table 28 in Appendix A).

[iv] These are the metrics for the 'classic' Passive House certification. New classes called Passive House "Plus" and "Premium" were introduced in 2015. These are energy-positive standards, decreasing further the maximum allowable PER, and requiring on-site generation greater than the expected annual use. See Appendix A for more details.

[v] Alternatively, a building can comply by showing the steady-state cooling load is < 10 W/m^2 and the total cooling demand remains below a (generally more flexible) limit calculated in PHPP based on climate and air-change rates.

[vi] Variable limit value for the dehumidification fraction subject to climate data, necessary air change rate and internal moisture loads (calculated in PHPP).

[vii] In 2015, the standard shifted its total energy use intensity metric from 'primary energy use' to 'renewable primary energy (PER)'. Each standard combines the total site energy used for heating, cooling, dehumidification, DHW, lighting, auxiliary electricity and electrical appliances, but applies different factors to each of the energy supply sources. The PER factors were modified to better represent the complexity introduced by having a mix of intermittent renewables on the grid. Additional losses due to storage are considered when electricity is used at peak periods when renewable power is more limited (for example, during heating period in Europe). They are generally higher factors than primary energy factors, which explains in part the decrease in the target. At this stage, buildings can still certify using either metric. http://passipedia.org/certification/passive_house_categories/per

[viii] Increased to ⩽ 0.08 cfm/sf enclosure for buildings above 5 stories or non-combustible. Conversion to ACH will depend on volume of the house, but 0.05 cfm/sf enclosure is roughly equivalent to 1.3 ACH for a ~1,200 sqft home.

[ix] Where occupancy is determined by the number of bedrooms per unit, such that # occupant = # bedroom + 1

Other related standards

The Passive House standard has also inspired other national codes or programs such as Switzerland's Minergie[20] and Brussels' 2015 building code (see Section 9.3). Norway and Sweden have also created their own passive building standards (NS3700 and FEBY, respectively), relaxing slightly the PHI energy targets to account for their colder climate.[21] Canada's R-2000 certification for high-performance homes pre-dates the Passive House Institute, but is also inspired by a passive design approach (though the insulation and airtightness requirements are not as strict).[22]

Box 2. Focus on high-performance enclosure or on-site generation?

The benefits, and potential challenges, of highly insulated buildings vary by climate. While we try to address both cooling-dominated and heating-dominated buildings in this report, the majority of literature (and the geographic location of the authors) certainly bring a larger focus on the latter. And while we've attempted to capture the state of policy and markets across North America, many of the examples discussed are from the Pacific Northwest, where the authors are based.

Achieving deep emissions reductions in the building sector will require improving the energy efficiency of buildings and supplying the remaining demand through low-emissions energy sources. How far we should push for energy efficiency, versus developing renewables, depends on the availability, costs and environmental impacts of each.

Given the significant decrease in PV costs, this is no longer solely a question of energy policy, but has also become a practical question for net-zero builders aiming to optimize cost effectiveness and constructability. The bulk of the construction industry, however, is still far from that intersection point. The solar potential of different buildings also varies greatly based on roof area, shading, and insolation. Even in areas where grid electricity is relatively low-carbon, such as in B.C. and Québec, the significant environmental and social impact of new supply, and its increasing marginal cost, maintain a strong incentive to conserve, and to continue to raise standards for energy efficiency in buildings. Even as we do so, we will need to consider how to integrate on-site generation, and how trade-offs between efficiency and on-site generation can be negotiated.

Box 3. Focus on reducing heating and cooling, or other end uses?

Heating and cooling loads generally account from a third to a half of energy use in buildings (depending on building type and location; see Figure 9). Thus, enclosure improvements alone will not be sufficient to meet deep energy reductions in the building stock; other end uses such as domestic hot water, lighting, ventilation, auxiliaries and plug loads will also need to be addressed.[23] Passive House standards address other end uses indirectly by putting a cap on the total energy use intensity of the building (Box 1) – a performance-based approach also used in certain energy codes (see Section 0). Other strategies for reducing other end uses include energy efficiency regulations for DHW equipment and plug loads, provision of hot water from low-carbon district energy systems, prescription of maximum power densities for lighting, daylighting, dynamic energy feedback systems for occupants, rate structures, etc. These approaches are complementary to enclosure improvement, and beyond the scope of this document.

There are, however, several reasons to prioritize an enclosure-focused approach to energy efficiency. First, building enclosures are long lasting and costly to refurbish, unlike other systems which can be more easily replaced as better technologies become available. Second, enclosures are simple systems; their performance does not depend on complex energy management systems and they are more tolerant to delayed maintenance — a known source of under-performance in buildings that are not continuously optimized (i.e. most buildings). Third, reducing heating and cooling demand early in the design process will allow to reduce the size of space conditioning systems, reducing construction cost and ongoing energy demand. Fourth, high-performance enclosures also offer significant non-energy benefits, such as thermal comfort, acoustic isolation, durability, and increased resiliency to power outages and extreme temperature events (particularly for non-conditioned buildings).

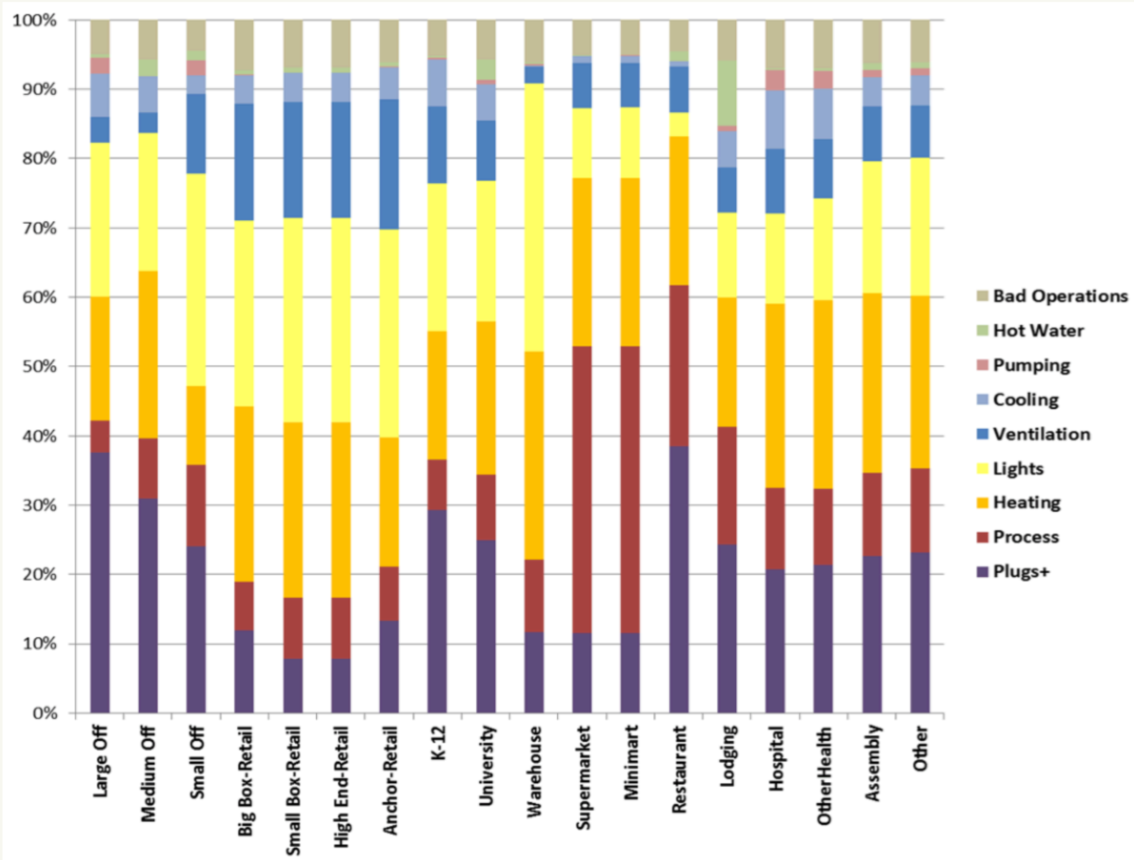

Figure 9. Energy end use for commercial buildings in the Pacific Northwest.

Energy end use is shown as a percentage of total energy use.

Source: New Buildings Institute[24]