RDH Technical Bulletin

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Case Studies of Energy Efficient Buildings

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Introduction

This technical bulletin summarizes a detailed analysis of 22 case studies of high performance buildings in the Pacific Northwest. In addition to the analysis of measured energy savings, estimates of incremental costs and common design features were also assessed. These case studies demonstrate success with deep energy retrofits in existing buildings, or achieving near net zero new construction. In addition to their ultra-low energy characteristics, cases were selected for their resilience to climate change and their replication potential across the Pacific Northwest. General recommendations for moving toward ultra-low energy consumption in the built environment are also included in this bulletin at the end of the document.

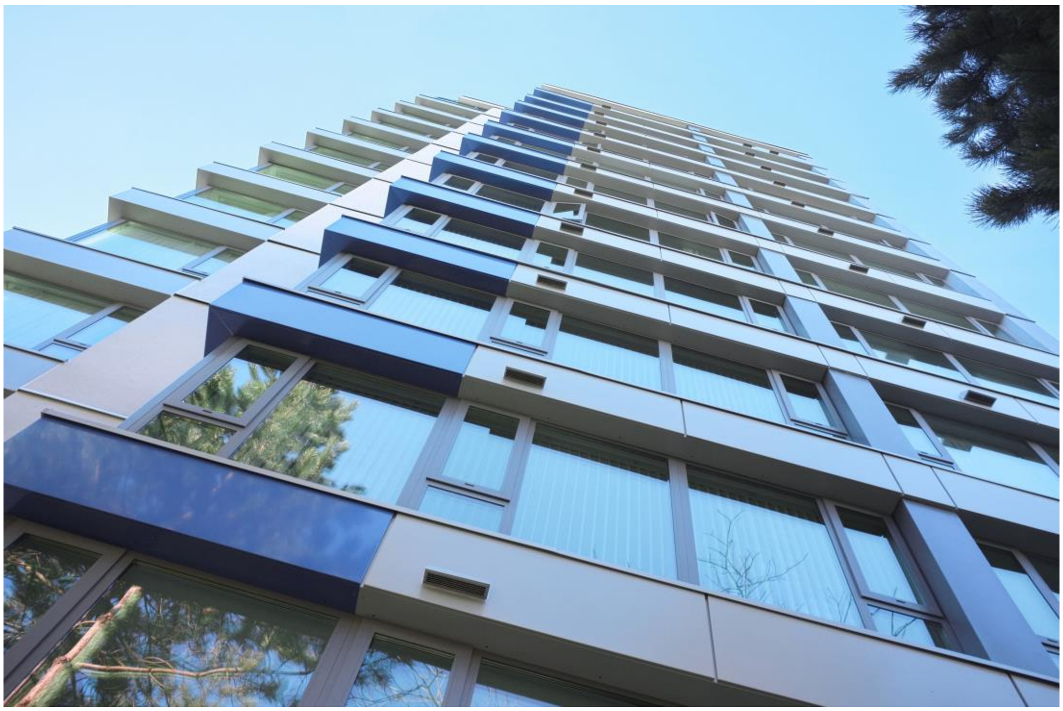

Figure 1: The Belmont Multi-unit Residential Building Retrofit in Vancouver, BC.

Methodology

Selection Criteria

The following initial criteria was used to select over 20 high-performance buildings in the Pacific Northwest. It was necessary that the buildings were either near net zero energy new construction or deep energy retrofits for existing buildings. Resilient design, replication potential, community benefits, and market transformation were considered important secondary criteria.

TABLE 1 SELECTION CRITERIA FOR HIGH PERFORMANCE CASE STUDIES		
CRITERION	DESCRIPTION	DATA SOURCE
Net zero energy new construction	New buildings demonstrate near zero-emissions (including Renewable Natural Gas) or near zero energy use	Energy bills
Deep energy retrofits for existing buildings	Minimum 30% reduction in energy and emissions, ideally optimizing life-cycle economics	Energy bills and baseline metrics
"Resilient" design	Design features incorporate climate change adaptation and resiliency to extreme weather events	Owner/design team survey
Replication potential – building type and regional representation	The building type is representative of a major component of building stock and construction across all jurisdictions	Market stats on building types, energy, emissions
Replication potential – design	The building type design/construction uses technologies that can be extended economy wide	Owner/design team survey, internal team expertise
Community benefits	The construction provides significant community economic benefits, job creation and improved quality of life	Owner/design team survey
Market transformation benefits	The construction approach could catalyze market transformation efforts	Stakeholder review

Data Collection

High performance buildings throughout the Pacific Northwest were identified through many channels. A list of approximately 30 buildings was created with the help of the following resources:

→ New Buildings Institute *Getting to Zero Database*

→ High Performance Buildings magazine

→ Northwest Energy Efficiency Alliance (NEEA)

→ Regional utilities and energy organizations

→ PNWER Energy & Environment working group network

A longer list was narrowed down to 22 case studies, due to the availability of data and in order to avoid duplication of similar building types in the same climate zone or jurisdiction. In future work, more cases may be added to fulfill project partners' interests in certain archetypes or regions. A map with the locations of all 22 cases is shown in Figure 2; Table lists the cases with their respective jurisdiction and climate zone. Two buildings outside the Pacific Northwest region were added as case studies with insulated concrete form (ICF).

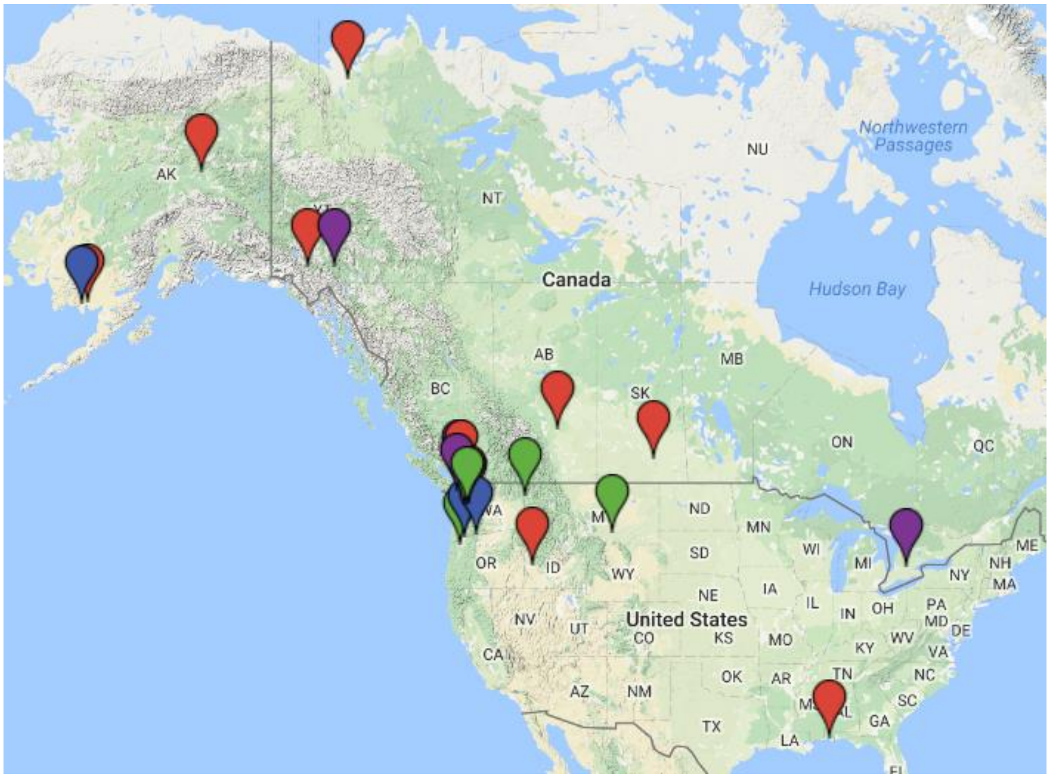

Figure 2: Map of Case Studies divided into single-family dwellings (red), educational and medical buildings (blue), multi-unit residential buildings (purple), and office buildings (green).

TABLE 2 CASE STUDY BUILDINGS INFORMATION				
NEW/RETROFIT	LOCATION	REGION	CLIMATE ZONE	YEAR COMPLETED
Single Family Dwellings (Houses)				
New	Regina	SK	7	2007
	Red Deer	AB	7	2008
	Haines Junction	YK	8	2013
	Inuvik	NWT	8	2013
	Burnaby	BC	5C	2013
	Dillingham	AK	8	2012
	Fairhope	AL	2A	2013
Retrofit	Vancouver	BC	5C	2014
	Boise	ID	6B	2011
Educational/Medical Buildings				
New	Seattle	WA	4C	2011
	Portland	OR	4C	2014
Retrofit	Hood River	OR	5B	2010
	Dillingham	AK	8	2014

TABLE 2 CASE STUDY BUILDINGS INFORMATION				
Multi-Unit Residential Buildings (MURBs)				
New	Issaquah	WA	4C	2012
	Whitehorse	YK	8	2010
	Waterloo	ON	6A	2006
Retrofit	Vancouver	BC	5C	2012
Office Buildings				
New	Seattle	WA	4C	2013
Retrofit	Salem	OR	4C	2010
	Billings	MT	6B	2006
	Bremerton	WA	4C	2011
	Priest River	ID	6B	2009

*These cases are outside the Pacific Northwest region.

Where possible, phone interviews were conducted with members of the project teams for each prospective case study. In some cases, there were many detailed resources available through articles and reports online, while others were highly dependent on contact with the building stakeholders. In very few cases, energy consumption data was available through the US Department of Energy *Building Performance Database*. In most cases, the utility bills were obtained directly from the building owner/operator. When possible (i.e. when monthly data was available), energy consumption was weather-normalized using a 30-year average weather year.

In addition to at least two years of energy consumption data broken down by fuel type, further information was obtained including: enclosure assembly, ventilation and mechanical systems, construction management practice, strategies for resilience to climate change, and project costs. Complex costing data was distilled down to hard construction costs for each project.

Energy Analysis

The energy consumption of each case study was collected from real utility bills or a trusted, government-related source. Once the data was weather normalized to account for variations in annual heating or cooling demand, the data was broken down into fuel types: electric, natural gas or other fossil fuels, and renewable energy (PV). In order to evaluate the case study energy consumption, appropriate baselines were chosen:

→ **New Construction**: case studies were compared to a baseline of code minimum energy requirements. The DOE Prototype Building Models ASHRAE 90.1 2013 from PNNL were used for each building type and climate zone in the new construction case studies.

→ **Retrofits**: case studies were compared to a baseline of existing buildings in their region and of the same building type. The table below lists the energy consumption surveys for residential and commercial buildings in both Canada and the United States that were used in the analysis.

TABLE 3	BASELINES FOR RETROFIT ENERGY ANALYSIS	
	UNITED STATES	CANADA
RESIDENTIAL	Residential Energy Consumption Survey (RECS)	Survey of Household Energy Use (SHEU)
COMMERCIAL	Commercial Buildings Energy Consumption Survey (CBECS)	Survey of Commercial and Industrial Energy Use (SCIEU)

Unfortunately, we could not obtain pre-retrofit utility bills for all the retrofitted case studies, so we maintained a consistent baseline methodology for all retrofit cases by using the surveys.[1] The energy surveys contain average annual energy consumption of a large sample of buildings of each type and region. In contrast, the actual retrofit case studies were typically below average energy performance prior to undergoing renewals – as reported by building operators. Thus, the actual percent improvement of the cases when compared to their pre-retrofit energy consumption would likely be higher than the percent savings obtained by comparing them to the average building baseline. As a result, the retrofit case study baselines provide a conservative estimate of energy savings.

In addition to energy consumption comparisons between the case studies and their baselines, we also calculated changes in greenhouse gas intensity (GHGI). For this we used provincial, territory, and state emissions factors for electricity and fossil fuels. Wood and solar energy were considered to have an emission factor of zero.

Costing Analysis

The construction costs of each case study were collected from public sources where available and supplemented with interviews with the construction teams. The construction costs were corrected to 2016 dollars assuming an inflation rate of 1.8% per year. The incremental construction costs were then determined for each building by comparing to the cost of new construction with building type and jurisdiction specific values. The baseline construction costs were determined from the following sources:

→ Altus Group 2016 Construction Cost Guide: used to determine the baseline construction costs for all buildings in Canadian jurisdictions by comparing with the most closely matching building archetype.

→ RSMeans 2014 Construction Costs: used to determine the construction cost baselines for educational and medical buildings, multi-unit residential buildings, and office buildings in US jurisdictions by comparing with per-square-foot construction costs.

→ US Census 2015: used to determine the construction cost baselines for single-family dwellings in US jurisdictions.

[1] The two single-family dwelling retrofit cases were compared to their pre-retrofit energy consumption since that data was available.

Analysis Results

Energy Analysis

In a very high level analysis, the 22 case study buildings were compared to their respective baseline buildings in order to obtain effective energy savings. The average energy savings of the case studies by building type were:

→ Single-Family Dwellings – 64%

→ Educational/Medical – 76%

→ Multi-Unit Residential Buildings – 50%

→ Offices – 84%

In addition to energy savings, the average greenhouse gas reduction for all 22 case studies was 70%.

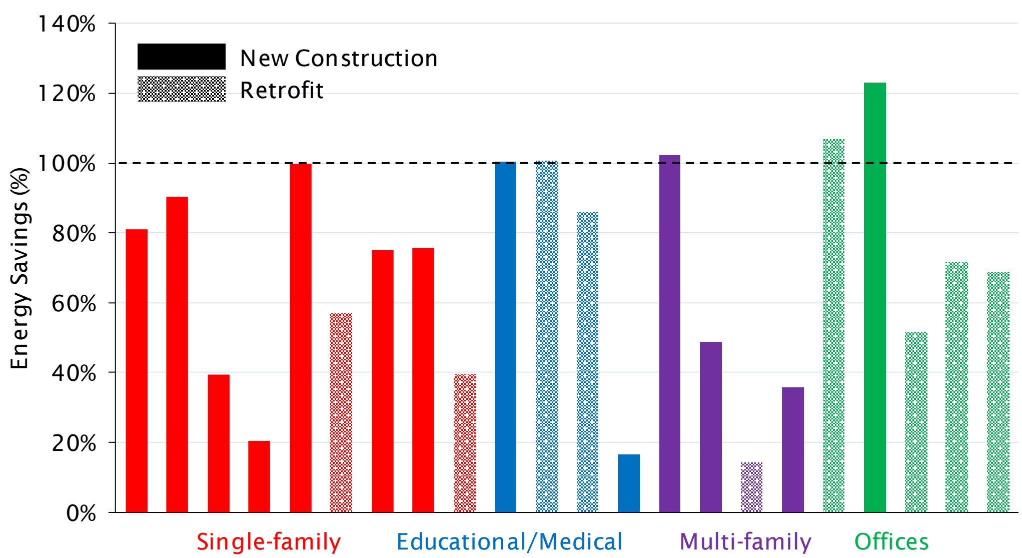

Figure 3: Energy savings of the case study buildings compared to their baselines. The chart is separated into four main building types: single-family dwellings (red), educational/medical (blue), MURBs (purple), and offices (green). The dashed line marks "net-zero" energy.

Figure 3, above, shows the energy savings of each case study calculated from real utility bills compared to building baselines as described in the Methodology. The cases with the lowest energy savings are conservative estimates that resulted from the choice of baseline. For example, the Belmont building has a measured energy savings of 20% over its pre-retrofit baseline (65% heating energy savings), although when compared to the SHEU average for high-rise MURBs, the energy savings is 14%. A total of six buildings have reached or surpassed the net-zero target (noted by the dashed line), meaning they generate more energy on site than they use from the grid.

Costing Analysis

Construction cost estimates were obtained from the project teams, then compared to building-specific baselines. The incremental costs of high performance new construction and retrofits from this high-level analysis is shown in Figure 4.

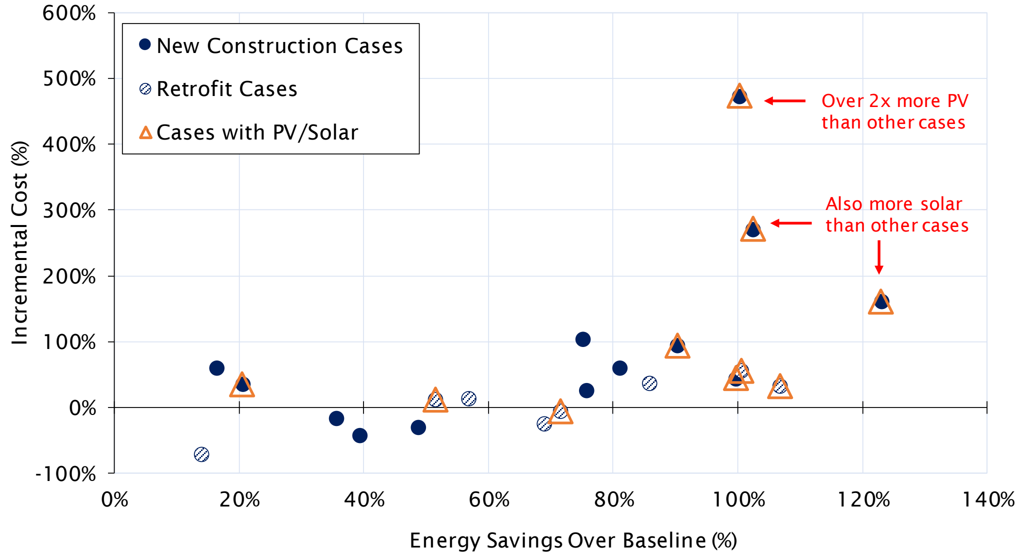

Figure 4: Incremental costs versus energy savings for high performance buildings. Solid markers represent new construction, while hashed markers represent retrofits. Cases with PV are shown with triangles.

Interestingly, there is no apparent difference between the incremental cost for new construction versus retrofits that achieve similar energy savings. The most notable trend is that the buildings with the most solar panels are by far the most expensive projects. This highlights the importance of lowering energy demand through enclosure and HVAC design before relying on renewable energy production.

The majority of the projects lie within ±100% of the construction costs of their respective baseline building (within the red rectangle), still quite a large range due to the high-level analysis method. Interestingly, six projects—three new construction, and three retrofit—actually saved on construction costs through their high performance designs when compared to average construction costs.

Common Design Elements

Building Features

Upon collecting and analyzing the 22 case studies, we noted the design features of the buildings. The goal of this task was to assess which design elements were the most commonly implemented in the high performance buildings. Figure 5 summarizes the design features that were tallied, in order of most common (left) to least common (right).

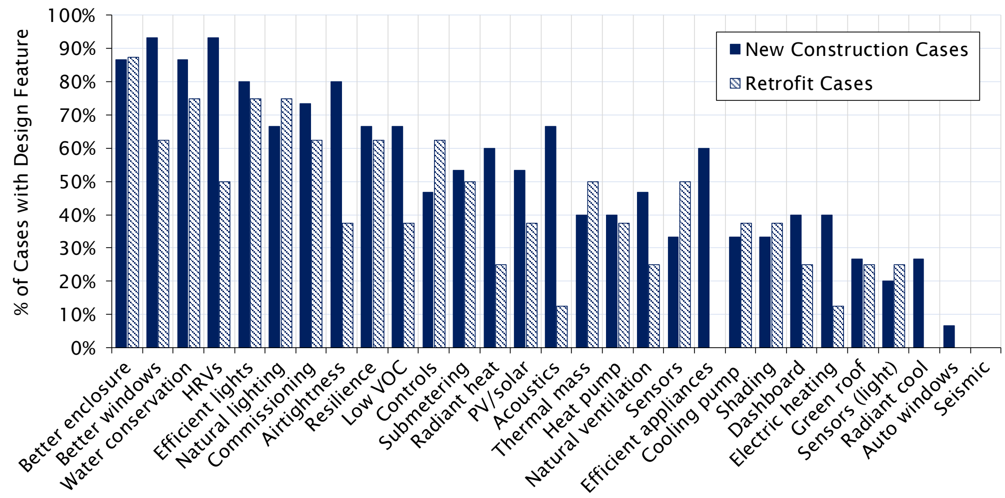

Figure 5: Common design features used in the case studies.

As one might expect, the amount of high performance design features does somewhat correlate to the % energy savings (Figure 6). There is a large spread in the trend, indicating that there are more factors at play here—namely, the fact that not all design features have the same effect on energy efficiency. It should also be noted that there may be other design features that we did not capture in our analysis.

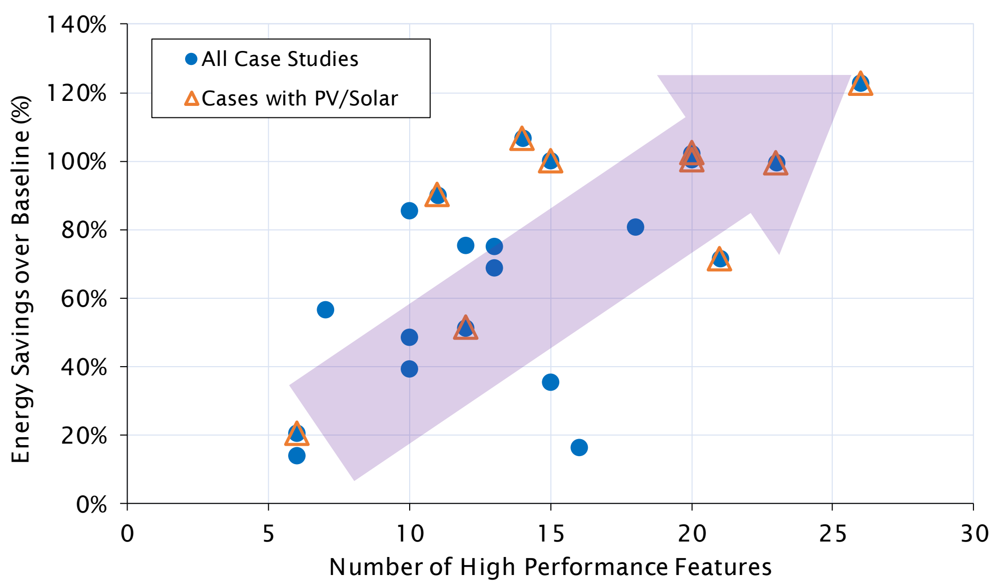

Figure 6: Correlation of the number of high performance features in each case study with the amount of energy savings.

Champions

In addition to high performance design features, we noticed an important trend in project management strategies. In nearly every case study, there was an individual or a small group of people who led the project and acted as a champion. These champions were integral in getting the project up and running, as well overcoming obstacles throughout the design, planning, construction, and certification phases (where applicable). In the experience of

RDH through our own projects, the effectiveness of champions—as well as clear project goals that the design team buys into—is essential to delivering high performance buildings. In order to achieve successful and broad-reaching energy efficient construction, we recommend developing policy framework that effectively supports these champions.

Figure 7: The Bullitt Center PV panel roof.

Future Work

The case study analysis contained herein aims to support and inform the achievement of ultra-low energy in the built environment of the Pacific Northwest. The next steps of this analysis are to:

→ Extrapolate the energy savings of the case studies throughout the Pacific Northwest to demonstrate the achievable savings, and

→ Estimate the economic benefits of carrying out high performance new construction and retrofits similar to these case studies throughout the Pacific Northwest.

As a preliminary recommendation for achieving ultra-low energy buildings, we recommend focussing on these top design features that aided in the success of the 22 case studies in this analysis (Table 4).

TABLE 4	MOST COMMON DESIGN FEATURES IN THE CASE STUDIES
CATEGORY	TOP DESIGN FEATURES
Enclosure	High performance walls
	High performance windows
	Air tightness
Mechanical	Heat recovery ventilation
	Commissioning
Lighting	Efficient light fixtures
	Natural lighting (daylighting)
Resilience	Water conservation
	Extreme weather resilience

These design features are the lowest hanging fruit in terms of ways to improve energy efficiency in buildings, although in order to achieve near net-zero performance, more extensive measures will need to be taken. An integrated design process led by a project champion is often required in addition to a prescriptive approach to achieve ultra-low energy, high performance buildings.

For additional information on this and other topics, please visit our website, rdh.com, or contact us at contact@rdh.com.

Acknowledgements

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