

Roadmap to Resilient Ultra-Low-Energy Buildings with Deep Integration of Renewables

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Dr. Andreas Athienitis, P.Eng., FCAE
Concordia University

Dr. James Bambara
Concordia University

Dr. Rosamund Hyde, P.Eng.
Stantec

Dr. Chris Kennedy, P.Eng., FCAE
University of Victoria

Andrew Pape-Salmon, P.Eng., MRM, FCAE
University of Victoria



THE CANADIAN ACADEMY OF ENGINEERING
L'ACADÉMIE CANADIENNE DU GÉNIE

Executive Summary

Objectives, Audience, and Scope

This roadmap provides strategic recommendations for the energy transition of buildings toward net-zero operating emissions. The recommendations aim to decrease life-cycle costs, improve energy efficiency, and increase resilience.

The primary audience is Canadian government officials responsible for energy and building policy, standards development and verification organizations, agencies delegated to implement legislation for buildings, and professional regulators and associations. The guidance is applicable to all Canadian jurisdictions.

The scope of the guidance applies to the construction of new buildings and the renewal of existing buildings, as well as distributed energy infrastructure and demand-side measures implemented by energy utilities. The focus is on buildings and connected on-site or neighbourhood clean energy systems. The roadmap aligns with provincial/territorial building and safety policy and energy-sector regulation of demand-side management programs that influence the design and renewal of buildings and community clean energy infrastructure.

Overview of the Roadmap

Section 1, “Introduction,” defines the scope of the roadmap, with a focus on buildings, but extending well beyond the historic responsibilities of building design engineers. Tangible outcomes include a building stock that will use new and efficient ways of heating/cooling and powering infrastructure; achieve net-zero emissions; minimize life-cycle costs; maintain public safety; achieve objectives of building and safety codes and standards; and integrate with clean energy supplies that are resilient to natural disasters and climate change. The role of engineers is to provide technical insight and evidence in policy development processes and to engage with experts from non-engineering fields.

Section 2, “A 2030 Vision for Canada,” presents the possibilities for Canada’s future as a resilient, energy-efficient, decarbonized nation, noting differences between provinces/territories and comparing the current situation with geographically similar regions at higher levels of decarbonization. To help Canada speed up its decarbonization process, government policy can support technological tools and resources such as clean electricity, biogenic carbon, and carbon-free fuels, as well as energy efficiency, district heating and cooling, and electrical generation and storage at the building and community scale.

Section 3, “Goals and Measurable Outcomes,” presents the current and potential future states in a number of subcategories, such as integration with renewable energy and electric vehicles, evaluation of design processes and building performance, resilience in simulated and actual events, grid decarbonization, clarification and rationalization of codes governing the built environment, and a transition to performance-based codes. Building codes and electrical codes need to work together to enable technologies such as on-site generation and storage, backup power, and integration with electric vehicles. Buildings should be prepared for community clean energy systems in urban areas with waste heat sources and sinks and where renewable energy may be harvested in future years. An urgent item is the introduction of thermal storage (including thermal mass) in building codes as it relates to resilience parameters such as building time constants (how fast a building interior changes temperature when a differential exists between inside and outside). Thermal energy as part of community energy systems also needs exploration, as flexibility and cost-effectiveness are much greater than in buildings themselves. The introduction of electric vehicles also needs to be addressed in building and electrical codes.

Section 4, “Case Studies from Buildings and Communities,” summarizes four novel and high-performing building or community-scale projects in Alberta, Ontario, Québec, and British Columbia. Drake Landing Solar Community in Okotoks, Alberta, delivers energy and decarbonization performance similar to or better than that of Sweden’s overall building stock. It uses solar thermal seasonal storage, achieving nearly 100% solar fraction for heating. The West 5 sustainable community in London, Ontario, features energy-efficient buildings, heat pumps, building-applied photovoltaic solar panels, and integrated electric vehicles. It demonstrates that innovations in microgrid business models and adaptations to code limitations are necessary to efficiently integrate renewable energy into communities. The Varennes Library in Varennes, Québec, exports solar electricity from a building-integrated photovoltaic system to the grid, achieving net-zero energy performance by displacing more primary energy than electricity imported from the grid. The Williams Lake Net Zero Building Retrofit provided an office for the BC Ministry of Children and Family Development in an existing building that was converted from a disused retail facility. It combines efficient mechanical and electrical systems, optimized building design, and integrated renewable energy systems to. All of these projects accessed funding from either federal or provincial sources, federally funded academic collaborations, federal agency research programs, or a combination.

Section 5, “Market Uptake of Net-Zero-Carbon and Net-Zero-Energy or Low-Energy Buildings,” provides an overview of decarbonization certification programs and summarizes recent progress. It also reviews a major position paper on decarbonization published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), including key positions and recommendations.

Section 6, “Principles for Policy-Makers and Institutions,” presents a detailed description of five principles that can guide policy development at all five levels of government to achieve the vision of resilient, ultra-low-energy, and decarbonized buildings. The principles focus on integrating demand-side and supply-side resource planning; fostering competition and enabling innovation through performance outcomes; allocating jurisdictional and institutional responsibility; leveraging building life-cycle investment triggers; and facilitating data-driven, outcomes-based policy-making. The principles also acknowledge the importance of peak load in addition to energy requirements, as it is peak load that determines the impact on electricity generation and distribution network capacity and the total cost to society and consumers. Zero-emission and ultra-low-energy systems have high fixed costs and low variable or operating costs. Their overall cost is highly correlated with hourly peak energy demand, as opposed to total annual or average hourly energy use.

Section 7, “Call to Action and Roadmap for Engineers,” proposes an expanded role for engineers to support an orderly, cost-effective, and resilient transition to ultra-low-energy buildings, distributed energy resources, and decarbonization. It also provides a call to action for engineering leadership, innovation, and active participation in informing policy-makers and policy-making.

The Five Principles – Background and Scope

The proposed principles are the essence of the roadmap. Governments may consider implementing any or all of the principles into their buildings and energy policies in a manner that is suitable for the legislative and institutional framework of their jurisdiction. The principles are not prescriptive and can be implemented via one or more pathways. An analogy is provided of a bullet train, the Trans-Canada Highway, and a bike path network, which illustrate different implementation options, paces of change, and costs. In all cases, there is an orderly transition to resilient, ultra-low-energy, and net-zero-carbon buildings and community energy infrastructure.

The Canadian Academy of Engineering invites government policy-makers to involve professional engineers across Canada to review and apply these principles in their professional practice. Affordably decarbonizing

Canada will require change in every area of engineering and will prompt the exploration of connections between areas that have been treated as disconnected. Whereas in the past, building and safety code compliance represented adequate diligence as a design practice, engineers now need to understand the interactions between energy demand in buildings and supply options. Added complexity arises from the impact of a changing climate on the construction sector and energy supply reliability and resilience. Furthermore, professional practice must adapt to changing risk assessment and risk management requirements, the pace at which resilient decarbonization needs to occur, and how this rapid change necessitates dynamic policy development processes and code evolution.

The Five Principles – Overview and Areas of Focus

Principle #1: Facilitate Integrated Demand-Side and Supply-Side Resource Planning

Provincial/territorial governments and their regulatory partners, including regional, local/municipal, and Indigenous governments and buildings and energy regulators, are well positioned to partner for integrated energy and emissions planning that considers both the demand side in buildings and the supply side in energy infrastructure. This minimizes costs and maximizes resilience at all levels—for building occupants and owners, the construction industry, community energy utilities, and public utilities. The federal government could support consistency for this planning with guidelines and cost sharing. The planning could encompass all relevant regulatory and institutional regimes that apply to buildings (e.g., land-use zoning, building codes, asset management and replacement, public utility regulation, taxation) and be refined for different buildings sub-sectors, such as private residential, rental and social housing, commercial, and institutional.

Principle #1 requires engineers to bring a thorough knowledge of both demand-side and supply-side measures to increase building performance, enabled by inclusive public policy. Engineers can review their own area of expertise and identify the broad-brush and detailed performance attributes they need to design to. This feeds into a collaborative process of planning that considers decarbonization as well as policy goals, such as energy system reliability and resilience, safety, housing supply, public health, economic diversification, flexibility, and adaptability. The planning process must also consider capacity and annual resources for new energy system networks and societal and building costs.

Principle #2: Focus on Performance Outcomes that Foster Competition and Enable Innovation

This principle empowers professionals to deliver desired outcomes by leveraging existing regulatory measures, such as the “alternative solutions” allowed under the National Building Code of Canada. New codes and standards would be performance-based where possible. For example, ASHRAE Standard 100, Energy and Emissions Building Performance Standard for Existing Buildings, is entirely performance-based and provides flexibility for building owners and managers to optimize performance in their own way. This supports an innovation mindset, versus strictly complying with regulatory requirements.

Principle #2 focuses attention on multiple performance metrics that can be used to evaluate trade-offs when considering conflicting priorities. Engineers can advance better solutions with more co-benefits when they design for performance optimization rather than following prescriptive requirements. Engineers can also choose to address the fragmented responsibility for buildings between design, construction, and operations by being involved in the management of buildings, rather than limiting their scope to design and construction at the new-build and major renovation stages. Involvement in the operation of buildings will enable engineers to access building performance data that can inform improvements in the design process. For example, some design strategies accepted under prescriptive codes will become less effective as climate change continues; engineers who are guided by performance-based codes and are aware of actual performance numbers can work with

academics, equipment vendors, and building operators to find more suitable strategies. This innovation ecosystem approach will promote greater productivity and efficiency in the context of a changing climate, and professional norms will ensure regulatory authorities have less difficulty harmonizing across jurisdictional boundaries. To support cost-effectiveness, engineers can communicate challenges to regulatory authorities, as well as performance shortfalls, without revealing specific solutions that may be proprietary to the design firm involved. Engineers should also inform authorities about energy supply choices that align with the decarbonization targets, including community energy systems, that may lead to more economic, resilient, and climate-adaptable performance.

Principle #3: Efficiently Allocate Jurisdictional and Institutional Responsibility

The global imperative for taking action on climate change and the Canadian priority to address the housing affordability crisis can both be enhanced by avoiding inefficient duplication of government interventions and allocating responsibility to the highest jurisdiction that is practical, influential, and efficient. This principle is enhanced by coupling it with the innovation ecosystem described in the previous principle, which promotes competition and continuous improvement. Government intervention at the highest practical level can also be the most impactful, avoiding over-regulation of individual buildings and construction and instead influencing the infrastructure and supply of affordable energy resources.

Engineers working in building design as well as the broader built environment have a vested interest in an orderly transition for governments and institutions to implement the desired outcomes, working to decrease code confusion, unexpected performance deficiencies, and impacts of energy supply infrastructure. Some changes may be disruptive and engineers can play an important role in bridging to resilient, efficient and decarbonized buildings and energy systems.

Principle #4: Leverage Existing Investment Triggers in the Building Life Cycle

The cost of mobilization for building construction means that efforts to increase energy efficiency, decarbonize, and increase resilience would benefit from piggybacking on existing investment triggers, such as end-of-life capital asset replacement. This also minimizes the incremental cost of achieving the desired outcomes through existing market practices that respond to multiple government policy objectives. Finally, it prevents sunk costs due to stranded assets that are still functional, where options exist to decarbonize and make them resilient until replaced. It requires planning in a manner similar to asset management or depreciation report requirements for stratified housing (e.g., condominiums) in several jurisdictions, as well as regulated design and equipment standards that reflect optimum performance.

Principle #4 supports aligning timing of building improvements across performance objectives with existing regulatory and market triggers for investment, thereby achieving economies of scale. Improved efficiencies in professional service and labour and the potential for multi-objective benefits of capital assets could make updating buildings for decarbonization more financially feasible. This principle must also address utility changes, including capacity expansion and the deployment of new community energy utilities.

Principle #5: Facilitate Data-Driven, Outcomes-Based Codes and Standards

The roadmap promotes the expansion of building performance data to inform future codes and standards, influence the design of buildings and energy systems, and track and continuously improve performance. There is immense untapped potential for data in several areas, from risk-informed land-use planning to the commissioning of buildings following construction and renewal. A focus on availing performance data could yield significant dividends by replacing cumbersome processes to develop and evolve building codes and

standards with measured data and significantly improving institutional capacity to support an affordable and resilient energy supply system.

Principle #5 explores the collection, analysis, synthesis, and use of building performance data. Building design engineers are invited to take a role in gathering data that can support an improved orderly transition to a new and renewed building stock and connected energy systems. This data can be used to confirm code compliance; to prompt a review of building efficiency, health, or comfort; and to highlight the proven market value of higher-performing buildings, including energy supply flexibility and the integration of buildings, electric vehicles, and thermal sources and sinks. In turn, data can be used to inform future building and electrical codes based on measured and direct evidence.

The Role of Engineers

The roadmap proposes an expanded role for engineers to support an orderly, cost-effective, and resilient transition to ultra-low-energy buildings, distributed energy resources, and decarbonization. The profession is ideally suited to be a core partner of governments, institutions, and buildings-sector associations, for the following reasons:

- The engineering profession interacts with all aspects of the roadmap and serves multiple buildings and energy-sector stakeholders.
- Engineering practice collectively bridges government, institutional, and sectoral silos and provides service in a manner that addresses a diversity of drivers for building design and operations.
- Professional practice aligns with codes of ethics, which include, as an example from one province, an obligation to “hold paramount the safety, health, and welfare of the public, including the protection of the environment and the promotion of health and safety in the workplace.”¹
- Professional advice supports multiple objectives and goals in policy, regulation, codes, and standards.
- Engineers are in a unique position to catalyze meaningful action on policy goals while highlighting limitations of design solutions in the context of management practices, regional differences, and a changing climate.

A Call to Action

The roadmap provides a call to action for engineering leadership, innovation, and active participation in informing policy-makers and policy-making. This form of leadership was previously in place under the Bridging Government and Engineers Committee, an initiative of Engineers Canada, which participated in federal government policy-making processes. While Engineers Canada no longer sponsors the committee, the initiative could serve as a template to extend to efforts with provincial/territorial governments that hold significant influence on public policy in the domain of buildings.

Many engineers in Canada support the construction and renewal of buildings, recently amplified due to the housing shortage and the pandemic renovation boom, both of which benefited from government investment. This call to action asks engineers to:

- Collectively establish a vision for professional practice to support future-proofing buildings against various risk factors through ultra-low-energy design, energy resilience, and decarbonization.

¹ Engineers and Geoscientists BC. n.d. Code of Ethics. Accessed 2022. <https://www.egbc.ca/Complaints-Discipline/Code-of-Ethics/Code-of-Ethics>.

- Individually evaluate risk factors and mitigation measures associated with building design across the broad performance metrics highlighted. This is aligned with the risk management approach championed by engineering professional regulators in their practice guidance.
- Measure the performance of buildings, learn from the data, support property owners and managers in optimizing day-to-day operations, and enable ongoing service contracts that pay for themselves through efficiencies.
- Bring their expertise and measured performance data to policy development processes and participate in the development of codes and standards.
- Draw on the examples offered in the case studies to collaborate with academics in proposing demonstration projects for buildings that go beyond current standard practice and support research and innovation.
- Collaborate with the Canadian Academy of Engineering to establish a vision for an innovation ecosystem to explore potential new design strategies and business models.

The roadmap marks the beginning of the formal implementation of this work under the leadership of the Canadian Academy of Engineering.

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Contents

- Executive Summary i**
 - Objectives, Audience, and Scope..... i
 - Overview of the Roadmap i
 - The Five Principles – Background and Scope..... ii
 - The Five Principles – Overview and Areas of Focus..... iii
 - The Role of Engineers v
 - A Call to Action v

- 1. Introduction 1**

- 2. A 2030 Vision for Canada 4**
 - The Resilience Imperative..... 10

- 3. Goals and Measurable Outcomes 14**

- 4. Case Studies from Buildings and Communities 20**
 - Case Study #1: Drake Landing Solar Community..... 21
 - Case Study #2: West 5 Net-Zero Community and Smart Grid Project 24
 - Case Study #3: Varennes Library – Canada’s First Net-Zero Energy Institutional Building 28
 - Case Study #4: Ministry of Children and Family Development Williams Lake Net Zero Building Retrofit.... 32

- 5. Market Uptake of Net-Zero-Carbon and Net-Zero-Energy or Low-Energy Buildings 40**
 - Market Update of Established Green Building Standards 40

- 6. Principles for Policy-Makers and Institutions 44**
 - Government Policy Measures..... 44
 - Key Influencers 51
 - Principle #1: Facilitate Integrated Demand-Side and Supply-Side Resource Planning 54
 - Principle #2: Focus on Performance-Based Outcomes that Foster Competition and Enable Innovation..... 58
 - Principle #3: Efficiently Allocate Jurisdictional and Institutional Responsibility 61
 - Principle #4: Leverage Existing Investment Triggers in the Building Life Cycle 65
 - Principle #5: Facilitate Data-Driven, Outcomes-Based Codes and Standards..... 67
 - Policy Roadmap to Resilient, Ultra-Low-Energy Buildings..... 70

7. Call to Action and Roadmap for Engineers71
References75

Appendices

Appendix A: Roadmap Advisory Committee

Appendix B: 2019 Montreal Workshop Position Paper

Appendix C: 2019 Montreal Planning Workshop Agenda and Communiqué

Appendix D: 2021 Communities Workshop Agenda

Appendix E: Examples of Government Policy Measures

Appendix F: Key Influencers

Appendix G: 2022 Pacific NorthWest Economic Region Annual Summit Panel Discussion

Appendix H: 2020 Montreal Symposium Proceedings

1. Introduction

This roadmap provides strategic recommendations for the energy transition of buildings toward net-zero operating emissions. The recommendations aim to decrease costs, improve energy efficiency, and increase resilience.

The roadmap includes:

- A compelling and achievable vision for a resilient and decarbonized building stock in Canada in 2030 and beyond.
- Indicators of success and measurable outcomes of benefits to society and building owners.
- Illustrative case studies of buildings and communities that align with the vision and the indicators.
- A market update of established green building standards.
- Principles to inform public policy and key influencer organizations.
- A call to action to the engineering profession to lead the transformation and establish an innovation ecosystem for the design and renewal of buildings.

The primary intended audiences of the roadmap are:

- Canadian government officials responsible for energy and building policy.
- Standards development and verification organizations.
- Agencies delegated to implement legislation for buildings.
- Professional regulators and associations.

The guidance is applicable to **all Canadian jurisdictions**, regardless of economic factors, demographics, building condition, construction activity, and specific mandates, and governments at all five levels: federal, provincial/territorial, regional, local/municipal, and Indigenous.

The intent is to inform related strategy, policy, legislation, regulation, and investment of government; building and energy codes and standards; guidelines for professional engineering oversight of building design, construction, management, and renewal; and energy and load management in buildings, including distributed energy generation and storage and electric vehicle charging and integration.

The roadmap aims to align with and support Canada's *2030 Emissions Reduction Plan: Clean Air, Strong Economy*² as well as comprehensive provincial policy documents, such as BC's *CleanBC Roadmap to 2030*³ and Nova Scotia's *Environmental Goals and Climate Change Reduction Act*.⁴

The scope of the guidance applies to the construction of new buildings and the renewal of existing buildings, as well as distributed energy infrastructure and demand-side measures implemented by energy utilities, namely operational carbon emissions from buildings. The authors also note the emerging area of embodied carbon in

² Environment and Climate Change Canada. 2022. 2030 Emissions Reduction Plan: Canada's Next Steps for Clean Air and a Strong Economy. Accessed November 2022. https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf.

³ CleanBC. 2021. Roadmap to 2030. Accessed 2022. https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_roadmap_2030.pdf.

⁴ Government of Nova Scotia. 2022. Sustainable Prosperity in Nova Scotia: Progress Report on the Environmental Goals and Climate Change Reduction Act. Accessed 2022. <https://novascotia.ca/nse/progress-report/docs/2022-progress-report-environmental-goals-climate-change-reduction-act.pdf>.

building materials and equipment, which is outside the scope but necessary for future consideration. The focus is on buildings and connected on-site or neighbourhood clean energy systems. The roadmap aligns with provincial/territorial building and safety policy and demand-side management programs to influence the design and renewal of buildings and community clean energy infrastructure.

The authors' perspectives are those of practising engineers in the buildings and energy utilities sectors (demand-side management), academic researchers, and a government policy practitioner. Several authors are also Fellows of the Canadian Academy of Engineering (CAE), a non-profit professional association and the primary sponsor of this work. The CAE aims to inform a timely, standardized, reliable, and cost-effective transition of the buildings sector to net-zero greenhouse gas emissions, while increasing resilience against climate change and other natural disasters.

The major challenge is to accelerate the transition to net-zero-carbon, resilient communities, while maximizing innovation and maintaining public safety, reliability of energy supplies, affordability, and quality of life. Another challenge is to coordinate across multiple levels of government and to harmonize the work of dozens of institutions to support a common direction that maximizes the interests of Canadians.

Potential outcomes of this roadmap and the proposed transition of the buildings sector include:

- Enhance energy efficiency, load management, and interaction with community energy networks.
- Achieve net-zero emissions from buildings over the next decade.
- Minimize the cost to building owners, occupants, taxpayers, and ratepayers.
- Enable opportunities to mitigate transportation emissions through electric vehicle charging at buildings.
- Install on-site or community clean energy and/or energy storage to increase the resilience of buildings' energy supply.

From a social and economic standpoint, the guidance aims to:

- Address equity considerations broadly (e.g., provide access to solutions across all buildings and communities).
- Mitigate risks for buildings (e.g., failure due to natural hazards or economic obsolescence due to substandard energy efficiency) and their users.
- Avoid unintended consequences that compromise other values (e.g., energy supply reliability).
- Maximize regulatory efficiency and minimize unnecessary market interventions by government.
- Optimize roles for institutions and registered professionals that implement legislation.
- Enhance opportunities for leadership that could accrue to resilient construction, real estate, and building operations industries.
- Maximize the value of engineering practice to support the vision and partner with government and institutions.

The roadmap was conceived in 2014 at the Pacific NorthWest Economic Region (PNWER) summit.⁵ It was elaborated at subsequent PNWER summits in 2017,⁶ 2018,⁷ and 2022⁸. The PNWER has also sponsored research in the University of Victoria civil engineering department on the embodied energy and emissions of buildings.

In 2019, the CAE became the primary sponsor of the roadmap, which broadened it from a regional to a national initiative. The roadmap was further developed at the CAE thought leaders forum in 2019⁹ and symposia in 2020¹⁰ and 2021¹¹ organized by Concordia University's Centre for Zero Energy Building Studies (over 500 participants in total). A wealth of evidence was documented in the peer-reviewed published proceedings of the 2020 symposium¹² (see Appendix H).

The roadmap incorporates feedback from an advisory group comprising representatives from industry, government, professional and standards development organizations, and academia (see Appendix A). It was also informed by consultation at the PNWER 2022 summit.¹³ The draft roadmap was shared with CAE Fellows and the advisory committee for comment in mid-2023 and presented at the CAE annual conference in 2023.¹⁴

⁵ Pacific NorthWest Economic Region Foundation. 2014. Energy & Environment Working Group Proceedings. PNWER Annual Summit, Whistler, BC, July 21–24, 2014. Accessed 2022.

https://www.pnwer.org/uploads/2/3/2/9/23295822/energy_and_environment_-_final.pdf.

⁶ Pape-Salmon, A. 2017. Roadmap to Resilient, Ultra-Low Energy Buildings in the Pacific Northwest. PNWER Annual Summit, Portland, OR, July 23–27, 2017. Accessed 2022. https://www.pnwer.org/uploads/2/3/2/9/23295822/andrew_pape-salmon-energy_environment_session.pdf.

⁷ Pape-Salmon, A., and Reis, E. 2018. PNWER Roadmap to Resilient, Ultra-Low Energy Buildings in the Pacific Northwest. PNWER Annual Summit, Spokane, WA, July 22–26, 2018. Accessed 2022.

https://static.sched.com/hosted_files/2018pacificnorthwesteconomicregi/b3/Andrew%20Pape-Salmon%2C%20Ministry%20of%20Municipal%20Affairs%20and%20Housing%20-%20Presentation.pdf.

⁸ Canadian Academy of Engineering. 2022. Bridging Silos to Catalyze Decarbonization and Resilience of Buildings. Accessed 2022. <https://www.cae-acg.ca/bridging-silos-to-catalyze-decarbonization-and-resilience-of-buildings/>.

⁹ Canadian Academy of Engineering. 2019, April 23. Communiqué – Canadian Roadmap For Resilient Buildings. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2019/04/CAE-Communique-2.pdf>.

¹⁰ Canadian Academy of Engineering. 2021, June 3. 2nd Communiqué: Canadian Roadmap for Resilient Buildings. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/10/2020-communication.pdf>.

¹¹ Canadian Academy of Engineering. 2021, October 12. CAE Roadmap to Resilient Ultra-Low Energy Built Environment with Deep Integration of Renewables in 2050 – Low-Carbon and Positive Energy Resilient Communities Webinar. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/10/CAE-ROADMAP-WEBINAR-PROGRAM-WITH-BIOS.pdf>.

¹² Athienitis, A.K. 2020. Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

¹³ Pacific NorthWest Economic Region Foundation. 2022. 31st PNWER Annual Summit. Accessed 2022. <https://www.pnwer.org/2022-summit.html>.

¹⁴ Canadian Academy of Engineering. 2023. Roadmap to Resilient, Ultra-Low Energy Buildings. CAE Conference and Induction Ceremony of New Fellows, University of Victoria, Victoria, BC, June 20, 2023. Accessed 2023. <https://www.cae-acg.ca/wp-content/uploads/2023/07/CAE-Conference-June-2023.pdf>.

2. A 2030 Vision for Canada

Chris Kennedy and Andreas Athienitis

Climate change adaptation and mitigation necessitate a transformation of Canadian energy systems. The development of low-carbon, climate-resilient built environments in Canada can be envisioned by framing the essential role of buildings and communities in the context of this broader transition. In 2020, greenhouse gas (GHG) emissions related to energy used in buildings accounted for 87.8 Mt of Canada’s total GHG emissions,¹⁵ increasing to about 130 Mt when emissions related to building use of off-site electricity generation are included.¹⁶ There is a need to change the design of buildings, land use, transportation systems, and industry, with an emphasis on eliminating fossil fuels, increasing energy efficiency, and bolstering resilience.¹⁷ For the design of new buildings and retrofit of existing buildings, this means rigorously adding these attributes—resilient, carbon-neutral, and ultra low energy—to existing building requirements.

Transformation of Canada’s energy supply system will require the elimination of GHG emissions from fossil fuel combustion by increasing the use of clean electricity, biogenic carbon, and carbon-free fuels (see Figure 1). There are two distinct strategies for decarbonization. One strategy is for electricity generated from renewable or carbon-free sources to be used in the electrification of buildings, transportation, and industry, especially where power requirements are low to medium intensity. The other strategy entails the use of biogenic carbon, such as biomass or biofuels, and other carbon-free fuels, such as hydrogen derived in a manner that is free of carbon.

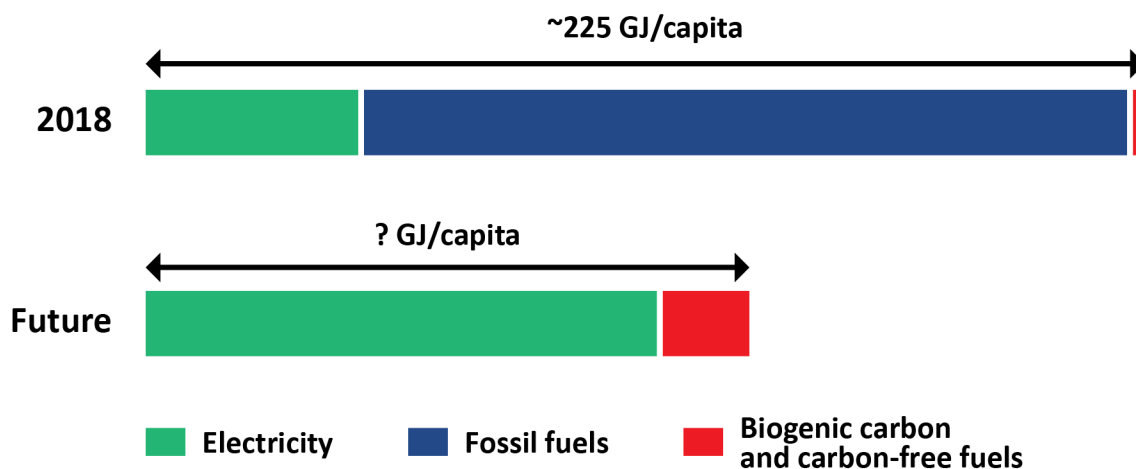


Figure 1: Conceptual transformation of Canada’s annual end-use energy under deep decarbonization.

It is important to emphasize that the metrics in Figure 1 refer to annual consumption of energy, as opposed to instantaneous capacity of energy systems and peak demands of consumers. This is a significant design consideration for energy systems and energy-using systems.

¹⁵ Government of Canada. n.d. Greenhouse Gas Emissions. Accessed 2022. <https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html>.

¹⁶ Environment and Climate Change Canada. 2022. 2030 Emissions Reduction Plan: Canada’s Next Steps for Clean Air and a Strong Economy. Accessed November 2022. https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf.

¹⁷ Resilience is defined as the capacity to withstand or recover quickly from a shock.

To meet its climate goals, Canada must greatly reduce annual per capita energy consumption while replacing conventional fossil fuels with clean electricity, biogenic carbon, and carbon-free fuels. Another critical aspect of Canada's energy transformation will be substantial improvements in energy efficiency, leading to a reduction in end-use energy per capita. Gains in energy efficiency will be required due to costs and potential constraints of increasing the supply of carbon-free electricity, thermal energy, and carbon-free fuels, as well as limits in the availability of biogenic carbon.

Some energy savings will be automatically achieved through electrification—for example, due to the higher efficiency of electric vehicles and heat pumps—particularly when coupled with efficient and zero-carbon electricity supplies such as hydroelectricity. Other improvements to energy efficiency will also be achieved through better building design and retrofits. Canada can expect to reduce its end-use energy consumption from current levels of approximately 225 GJ/capita, by of the order 100 GJ/capita (see Figure 1).

Strategies for transforming Canada's energy system and increasing energy efficiency can be seen from a comparison of Canadian energy use to energy use in Norway and Sweden. These two Scandinavian nations have climates similar to many Canadian provinces but are on average more advanced in addressing climate change than most of Canada. Sweden employs relatively equal proportions of energy from electricity; fossil fuels; and biofuels, solid waste, and heat, while its total per capita end-use energy (132 GJ/capita) is 58% of Canada's (Figure 2). Scandinavian cities like Copenhagen, Stockholm, and Helsinki supply nearly all of their space heating through district heating, and Sweden provides about half of overall space heating through district heating. Whereas Sweden has a notably high overall use of biofuels, Norway has a greater emphasis on electricity use (78 GJ/capita), while also having a lower per capita energy use (162 GJ/capita) than Canada. There is potential for Canada to follow both the electrification and biogenic/carbon-free fuels approaches in its energy system transformation. The choice of electrification or biogenic/carbon-free sources varies depending on the local context, including total electricity and thermal demands.

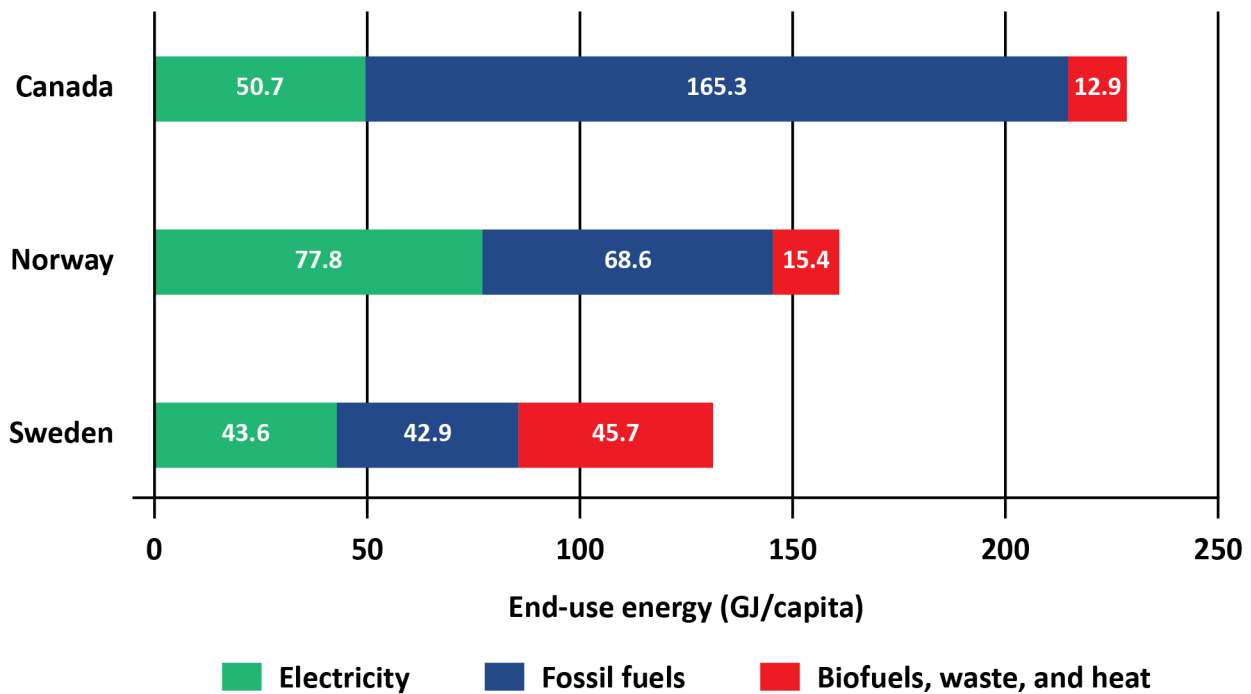


Figure 2: Comparison of per capita total end-use energy by source for Canada, Norway, and Sweden in 2019. Energy data from the International Energy Agency;¹⁸ population data from the World Bank.¹⁹

Differences between the electrification strategy and the biofuel strategy are particularly apparent in the buildings sector. In both Norway and Sweden, only about 5% of energy use in buildings comes from fossil fuels (Figure 3). Canada’s use of fossil fuels per capita in buildings is about 11 times that of Norway and 17 times that of Sweden, although there are significant differences across Canadian provinces. In Norway, about 80% of the building energy supply comes from electricity (44 GJ/capita), generated largely by hydropower. Electricity is also the largest source of energy for Swedish buildings (25 GJ/capita), but biofuels, solid waste, and heat supply over 40% of energy requirements, often through district-heating systems. Sweden is a notable example, as electricity demand is considerably lower as a result of broad deployment of district heating for thermal energy demands. Canada can draw on the success of these Scandinavian countries in decarbonizing its buildings, while also having several different pathways suited to different provinces and regions. Land use and transport are also major factors in the different pathways.

¹⁸ International Energy Agency. n.d. Data and Statistics. Accessed 2022. <https://www.iea.org/data-and-statistics>.

¹⁹ World Bank. n.d. DataBank: World Development Indicators. Accessed 2022. <https://databank.worldbank.org/source/world-development-indicators>.

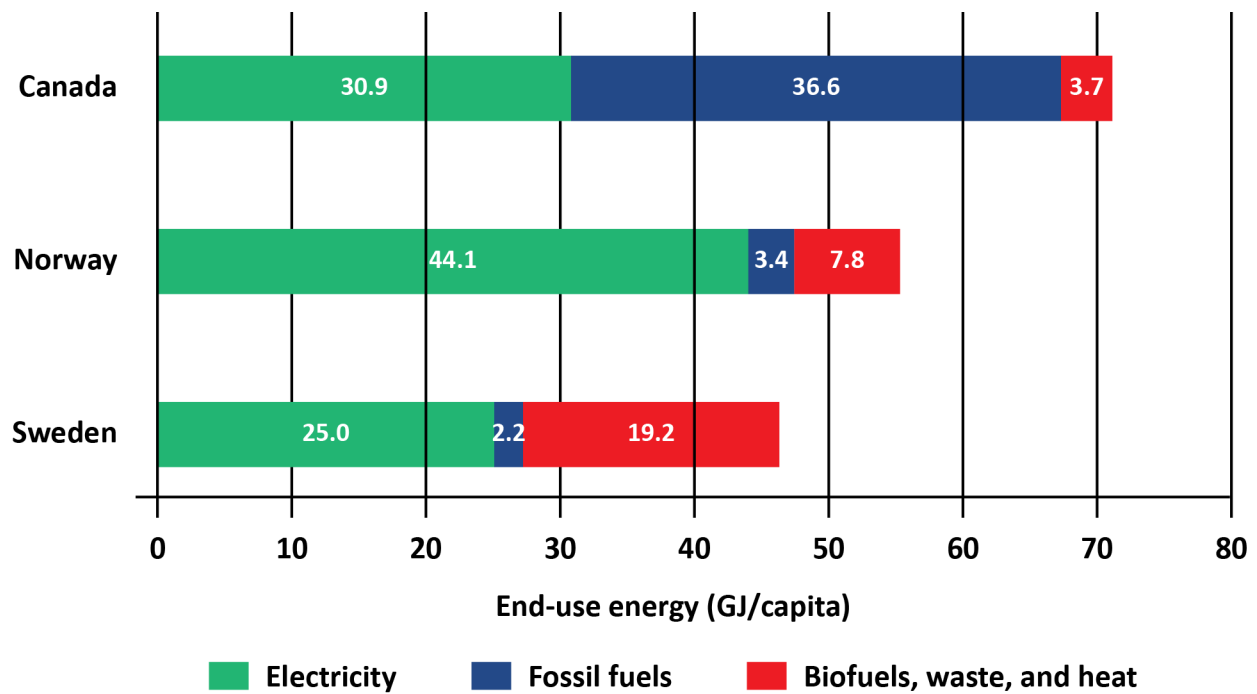


Figure 3: Comparison of per capita building energy use by source for Canada, Norway, and Sweden in 2019. Includes energy use by residential, commercial, and institutional buildings. Energy data from the International Energy Agency;²⁰ population data from the World Bank.²¹

GHG emissions for several countries, including Sweden and Norway, are given in Figure 4, while a comparison between provinces is shown in Figure 5. Floor area per capita is another important parameter to consider, as it relates to density of the urban form and land use.

²⁰ International Energy Agency. n.d. Data and Statistics. Accessed 2022. <https://www.iea.org/data-and-statistics>.

²¹ World Bank. n.d. DataBank: World Development Indicators. Accessed 2022.

<https://databank.worldbank.org/source/world-development-indicators>.

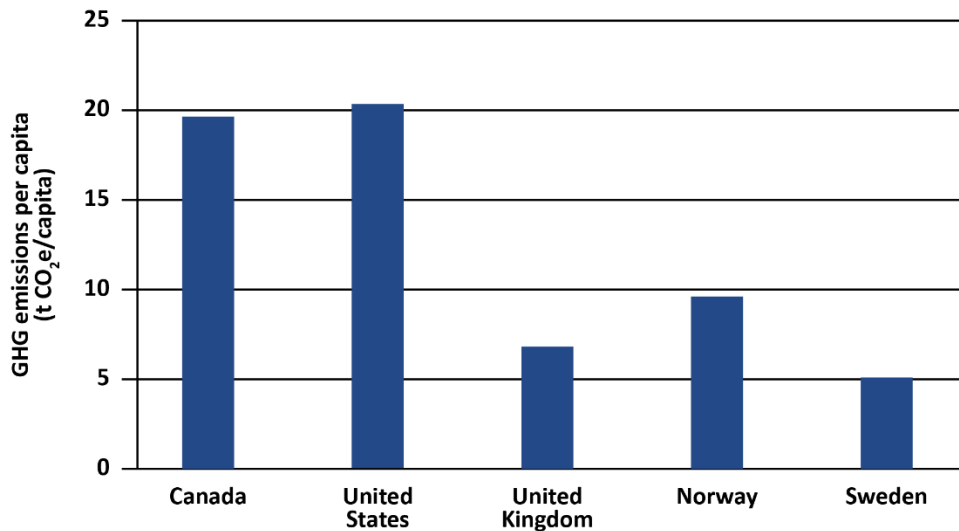


Figure 4: Total production-based greenhouse gas (GHG) emissions per capita by country in 2018.²²

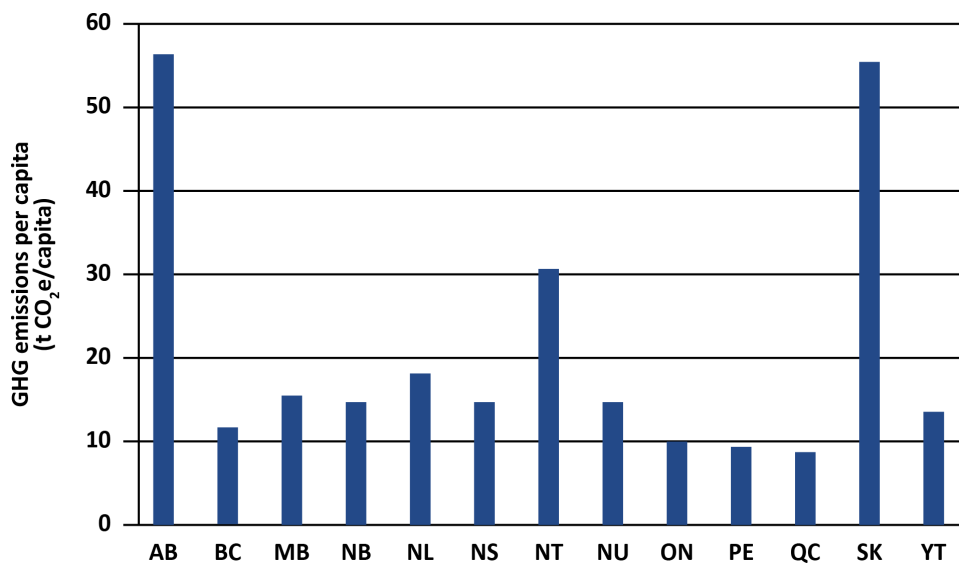


Figure 5: Total production-based greenhouse gas (GHG) emissions per capita by Canadian province or territory in 2020.²³

GHG emissions vary significantly by province depending on economic activities, in particular the oil and gas sectors and the type of energy used. Figure 5 shows that Alberta and Saskatchewan produce almost six times as many GHG emissions per capita as Québec and Ontario due to the large oil and gas industries and the widespread use of fossil fuels for power generation and heating. The average carbon intensity of electricity in Canada is just over 100 t CO₂e/GWh. Through access to hydropower, nuclear power, and renewables, many provinces have low-carbon electricity, including the three provinces with the largest populations: BC, Ontario, and Québec. Only in Alberta, Saskatchewan, Nova Scotia, and New Brunswick are electricity grids highly

²² Organisation for Economic Co-operation and Development. 2021. Country Notes: Progress in the Transition to Net Zero Greenhouse Gas Emissions in 2050. In: OECD Regional Outlook 2021: Addressing COVID-19 and Moving to Net Zero Greenhouse Gas Emissions. Accessed 2022. <https://www-az.oecd.org/regional/oecd-regional-outlook-2021-17017efe-en.htm>.

²³ Environment and Climate Change Canada. 2022. National Inventory Report 1990–2020: Greenhouse Gas Sources and Sinks in Canada. Accessed 2022. https://publications.gc.ca/collections/collection_2022/eccc/En81-4-2020-3-eng.pdf.

dependent on fossil fuels, making decarbonization through electrification more challenging. There are plans to phase out coal-powered electricity in Alberta, Nova Scotia, and New Brunswick, but decarbonizing buildings through electrification in all provinces will necessitate substantial changes. These changes will focus on the use of building- or community-scale renewable energy generation for resilience requirements, including low-carbon thermal energy systems. Distributed modular or micro-reactors may also become viable energy sources for both electricity and heat when these advanced nuclear technologies are proven commercially (post-2040). Such thermal electric power plants should be designed as combined heat and power or cogeneration ready and be sized and located so as to use most of the energy produced.

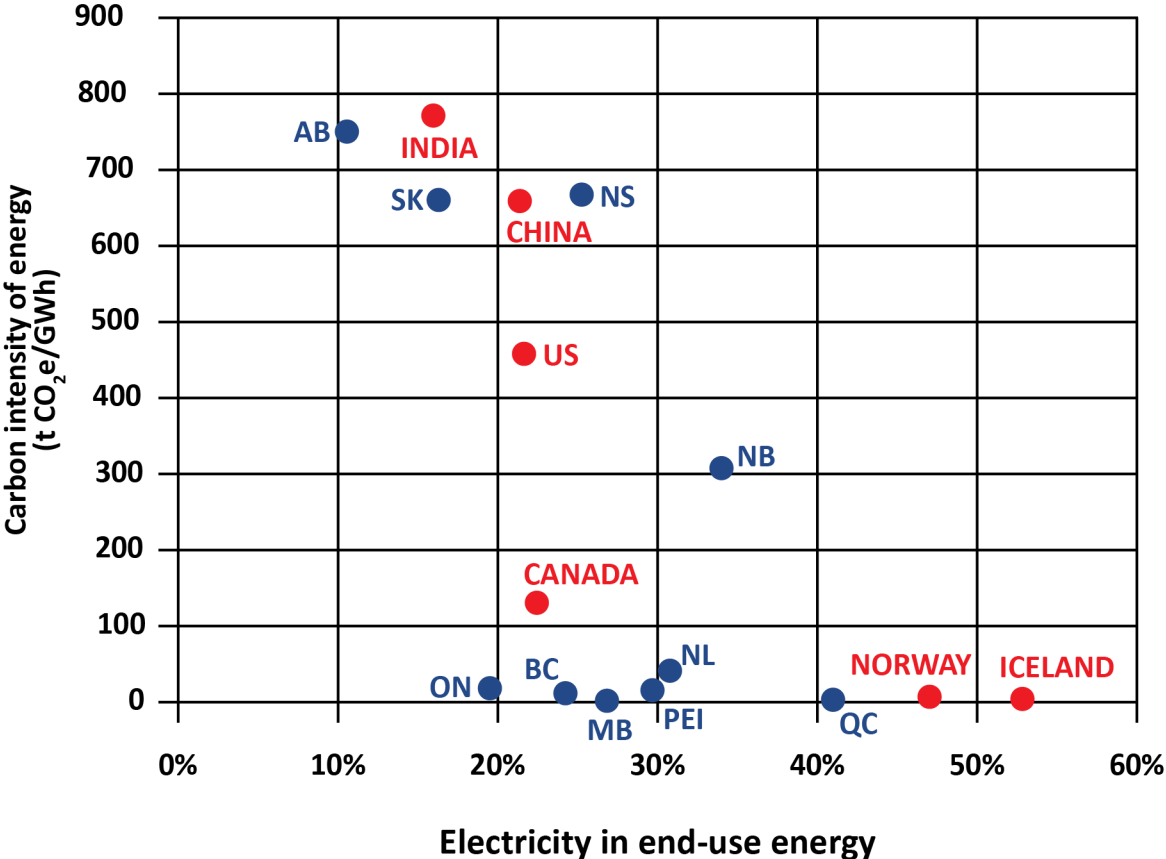


Figure 6: Progress of selected countries, including both large emitters and low-carbon leaders, and Canadian provinces toward carbon-free electrification. End-use energy is for all sectors.²⁴

Figure 6 suggests it is much easier to achieve very low emissions in the electricity sector if a jurisdiction has access to hydroelectric, geothermal, and/or nuclear technologies for most of its electricity supply. In addition, a study by the Ontario Society of Professional Engineers suggests that retail electricity prices can be kept affordable if all base load electricity demand is provided by dependable generation sources.²⁵ The study also points out that some generation technologies can produce prodigious amounts of clean thermal waste energy that can be recovered economically to decarbonize low-temperature heat demands.

²⁴ Adapted from: Brousselle, A., Brunet-Jailly, E., Kennedy, C., Phillips, S.D., Quigley, K., and Roberts, A. 2020. Beyond COVID-19: Five Commentaries on Reimagining Governance for Future Crises and Resilience. Canadian Public Administration 63(3):369–408. <https://doi.org/10.1111/capa.12388>.

²⁵ Ontario Society of Professional Engineers. 2022. Electricity Supply Mix Study: The Retail Price Impact of Net-Zero Supply Options. <https://ospe.on.ca/wp-content/uploads/2022/12/Ontario-Electricity-Supply-PRINT.pdf>.

The solutions needed to achieve decarbonization depend on the energy profile of the load being decarbonized, the characteristics of the current energy supply system, and the availability of local renewable energy. For instance, provinces with a hydro-dominant power supply can benefit greatly from implementing energy efficiency to free up large amounts of low-carbon electricity that can be used to decarbonize elsewhere. This reduces the need for new low-carbon energy supply infrastructure, which often carries a higher cost and material consumption (embodied emissions) than implementing energy-efficiency measures. For example, distributed solar energy generation on buildings with on- or off-site storage is ideal for providing the electricity needed to power heat pumps or electric vehicles (EVs), which will increasingly be at home due to more teleworking. It is quite feasible for homes and small institutional buildings, such as the net-zero-energy, all-electric Varennes Library (see the case study in Section 4), to power several EVs, thus helping decarbonize the transportation sector in addition to the building sector. There are also thermal energy systems that supplement centralized biofuel pipelines, such as thermal solar energy, centralized heat pumps, thermal district energy, and thermal storage—for example, the Thompson Rivers University low-carbon district energy system.²⁶

The Resilience Imperative

Generation and storage of renewable and zero-carbon energy on building and community scales will be important in all provinces due to climate change and an increasing number of extreme weather events. One of the challenges in phasing out fossil fuels is that reducing the diversity of energy sources or carriers makes communities more vulnerable to extreme events, such as forest fires and ice storms (see Figure 7). This challenge may become particularly critical if provinces pursue strong electrification strategies using only grid-scale electricity supply. A community with 100% of its end-use energy coming from provincial electricity grids is highly vulnerable to shocks. In urban areas, community-scale microgrids and district heating with thermal energy storage can add more resilience, where densities permit.

²⁶ Creative Energy. 2023. Creative Energy Certificate of Public Convenience and Necessity for the Thompson Rivers University Low-Carbon District Energy System and Thompson Rivers University Exemption. British Columbia Utilities Commission. Accessed February 2024. <https://www.bcuc.com/OurWork/ViewProceeding?applicationid=961>.



Figure 7: Experiences from forest fires²⁷ to ice storms²⁸ have shown how vulnerable electricity grids can be to extreme weather events. Building- and community-scale electricity generation and storage will be essential for making communities resilient to climatic shocks and extreme weather events.

The need for backup generation capacity remains a fundamental requirement for decarbonized energy supply systems. Canadian communities can employ three strategies to remain resilient while phasing out the use of fossil fuels:

1. Building-scale electricity generation and storage, EV integration, and grid support. By combining building-integrated photovoltaics and battery storage with advanced energy efficiency, buildings can be designed to generate and store much of their electricity needs. In the event of major disruptions to provincial power grids, buildings can then maintain basic essential functions using solar and energy storage systems such as batteries, connected EVs, and hydrogen. Energy storage is also important in optimizing energy flows with building needs and smart grids, thus facilitating penetration and integration of intermittent renewable energy resources, such as wind and solar. Buildings will increasingly be active prosumers in the power system, with a role in local energy storage and production. By adapting their behaviour to contribute positively to the operation of the grid, they simultaneously contribute to its resilience, affordability, and efficiency. EVs may also function as short-term (hours-long) backup power sources in the future. As noted previously, there are thermal energy analogies.

2. Community-scale electricity and thermal generation and storage. In higher-density communities and regions with poor solar access, buildings can be connected to community-scale smart grids²⁹ and community energy systems. Buildings with larger rooftops, such as schools and warehouses, can be used as a source of community electricity and thermal energy generation and storage. Other local-scale power sources, such as wind, tidal power, and biomass, can also be harnessed when provincial power grids are impacted.

²⁷ Roberts, D. 2019, October 22. 3 Key Solutions to California’s Wildfire Safety Blackout Mess. Vox. Accessed 2022. <https://www.vox.com/energy-and-environment/2019/10/22/20916820/california-wildfire-climate-change-blackout-insurance-pge>.

²⁸ Hydro-Québec. 2018, January 5. Twenty Years Ago, Québec Was Battered by an Ice Storm [press release]. Accessed 2022. <http://news.hydroquebec.com/en/press-releases/1313/twenty-years-ago-quebec-was-battered-by-an-icestorm/>.

²⁹ Engineers and Geoscientists BC. 2022. Practice Advisory: Electrical Considerations for Decarbonizing Existing Part 3 Buildings. Accessed 2022. <https://tools.egbc.ca/Practice-Resources/Individual-Practice/Guidelines-Advisories/Document/01525AMW5K7OKYS6AQCFYXR4QVJBNKNMH/Electrical%20Considerations%20for%20Decarbonizin%20Existing%20Part%203%20Buildings>.

3. Biogenic methane and carbon-free fuels. Carbon-free energy sources other than electricity can be designed and used in ways that provide resilience to acute shocks and chronic stresses. Examples include using wood stoves and biogenic methane as a backup for heat pumps; powering district energy systems with renewable or non-GHG-emitting energy sources; and harvesting waste heat from industry, power plants, and building cooling systems. Net-zero-emission fuels may be more cost-effective to store for extended periods to address energy needs during extreme and/or prolonged weather events.

The new low-carbon energy supply will include a mix of building-integrated renewable energy generation and storage and community-level centralized generation and storage. Power can be supplied either by intermittent renewable energy resources (e.g., solar) plus storage or by stored dispatchable energy resources (e.g., biomass, solid waste). Electricity storage is crucial and must be able to provide electricity during periods of low generation, such as days/weeks of low wind or solar energy availability, as well as during emergencies. Backup power can be supplied either from stored energy resources (e.g., biomass, hydrogen, thermal storage) or using renewable natural gas/biogas/biomethane and hydrogen from the pipeline network. Such a pipeline can be transformed into a net-zero-carbon backup energy source if fossil natural gas is replaced with synthetic or biologically derived renewable methane, including hydrogen enrichment, provided that the pipeline material is compatible with hydrogen.

For biogenic methane, building emissions at the point of combustion need to be fully offset by measurable, incremental, and verified reductions in GHGs at the source of the biogenic materials. This raises the question of tracking Scope 3 emissions³⁰ and retiring Scope 3 emission reductions after the environmental attributes of biogenic methane are sold to building owners, managers, and tenants who have no physical control of those emissions. Building owners can control Scope 1 emissions, while the energy utility providing purchased energy controls Scope 2 emissions.³¹

Solar thermal energy seasonal storage, such as at the Drake Landing Solar Community (see the case study in Section 4), provides the opportunity to store solar energy when it is abundant in the summer for use in the winter and a strong basis of thermal resilience. District heating systems such as at Drake Landing can also harvest other heat sources.

Among the options to increase the energy resilience of buildings, there is an opportunity for a combination that right-sizes the capacity of equipment with the cost and resilience of fuels—for example, battery storage operating critical electrical loads and system control with backup fuels providing space heating. Alternatively, heat can be captured or produced from renewable or non-GHG-emitting sources elsewhere and used in the building, with minimum complications to the building owner. During Canadian winters, buildings can use small amounts of electricity from a backup battery system, but not without heat; some stored electricity is also required to operate the heating control systems. Serious consideration of resilient heating options is critical for public safety.

³⁰ Scope 1 GHG emissions are produced by sources that are owned or controlled by the government—for example, emitted from the combustion of fuels in vehicles or in buildings. Scope 2 GHG emissions are those generated indirectly from the consumption of purchased energy (e.g., electricity, heating, cooling). Scope 3 GHG emissions are indirect, such as emissions produced in the supply chain of the goods and services we buy.

³¹ Government of Canada. n.d. Government of Canada's Greenhouse Gas Emissions Inventory. Accessed 2023. <https://www.canada.ca/en/treasury-board-secretariat/services/innovation/greening-government/government-canada-greenhouse-gas-emissions-inventory.html>.

The transport sector is among the largest contributors to GHG emissions in Canada.³² However, within the great challenge of mobility decarbonization, opportunities arise. The energy stored in battery and hydrogen fuel cell vehicles, in addition to energy stored at future refuel stations, provides the opportunity to store large amounts of renewable power. This stored energy can serve as backup power to support the grid in emergencies, but it also has the potential to assist the grid in periods of peak power demand or to store excess power generation. Since the new low-carbon energy supply will require backup energy, early-stage planning to integrate the new mobility infrastructure could lead to higher energy and resource use efficiencies and/or lower overall costs. The solutions should be implemented in a gradual, phased manner and appropriately weighed in the decision-making process based on key performance indicators, such as life-cycle cost, emission analysis, and supply chain criticality.

Other dimensions of resilience of buildings against climate change and natural disasters include the ability of the building envelope to withstand extreme weather events from structural, moisture control, and durability standpoints; the ability of the ventilation system to maintain indoor environmental quality to filter and remove contaminants such as wildfire smoke, ground-level ozone (i.e., smog), toxins, mould, and viruses; the ability to maintain healthy indoor living environments, particularly regarding overheating; and the ability of the building to withstand seismic events, prevent collapse, and preserve life safety. In some cases, building resilience includes enabling post-disaster operations, going beyond life safety and health. This roadmap does not address these aspects and focuses only on the resilience of energy supplies, also a necessary component of disaster response and recovery.

³² Government of Canada. n.d. Greenhouse Gas Emissions. Accessed 2022. <https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html>.

3. Goals and Measurable Outcomes

Rosamund Hyde

A key Canadian climate-change-related goal is reducing building-related emissions to net zero by 2050. Many interacting approaches, involving energy efficiency, renewable energy, and system integration, will be required to achieve the ultimate goals of resilient, ultra-low-energy, net-zero-emission buildings. Designers working on new buildings and major retrofits will need to use site- and community-scale modelling to understand how each building will change under future conditions, how buildings will interact with the systems around them, and how the community as a whole will perform under normal operating conditions and during disruptive events. This could include air quality advisories, wildfires, earthquakes, hurricanes, flooding, heat waves, power outages, water shortages, and pandemics, either separately or in combination. Increased simulation capacity is necessary to support new strategies for code development and enforcement at all levels and across jurisdictions, as well as the movement to a decarbonized grid. Alignment will need to be improved between the roles and responsibilities of community planning and building design professionals in the process of designing, commissioning, and operating buildings.

The main transitions foreseen in meeting resilient, ultra-low-energy, net-zero-emissions goals for buildings are summarized in Table 1. They are presented in terms of preliminary performance metrics that can be determined and replicated by professional practitioners across Canada. They represent a means of determining whether the buildings sector is moving in the right direction, toward the vision presented in Section 2. The metrics are based on science, not politics, and should be widely accepted across Canada for different building types and across buildings-sector stakeholders. Therefore, they are suitable for measurement by buildings-sector professionals. The authors assert in Section 5 that the collection of data on these areas of performance is a high priority for the short term, possibly as a requirement of building and/or electrical codes in Canada. Not only will the Canadian buildings sector be able to verify its transition toward the vision, but the metrics could also inform future government policy.

Building codes and electrical codes need to work together to enable technologies such as on-site generation and storage, backup power, and integration with electric vehicles. An urgent item is the introduction into building codes of thermal storage (including thermal mass) as it relates to resilience parameters such as building time constants (how fast a building interior changes temperature when a differential exists between inside and outside). The introduction of electric vehicles, with their capacity for energy storage, energy flexibility services for smart grids, and potential role in emergency power generation, also needs to be addressed in building and electrical codes.

Table 1: Main Transitions Foreseen in Meeting Resilient, Ultra-Low-Energy, Net-Zero-Emissions Goals for Buildings

Transition: Net-Zero Emissions		
<i>Toward high-performance, efficient buildings with integrated energy storage, renewable energy use, and electric vehicle (EV) charging capacity.</i>		
From	To	Metric
Buildings are designed to use only grid electricity and on-site consumption of fossil fuels ³³	New buildings and major retrofits are designed to decarbonize by using the full potential of energy conservation, energy efficiency, on-site renewable generation, purchased energy from zero-carbon fuels, and energy storage in normal operation while providing EV charging capacity ³⁴	Percentage of new buildings and major retrofits using the full potential of energy efficiency, energy storage, and renewable energy and providing adequate EV charging capacity
Site and regional renewable energy is recognized to a limited extent	Site and regional renewable energy is prioritized in urban planning and early-stage design with respect to building orientation, envelope strategies, windows, landscaping, and on-site renewables ³⁵	Average annual percentage of operating energy under normal conditions supplied by site or regional renewable energy
Smart buildings and microgrids are not optimally connected with the grid	Smart buildings, microgrids, and community energy systems help stabilize and decarbonize the system and reduce the need for new central energy supplies ³⁶	Percentage of smart buildings that are connected interactively to smart grids

³³ Building codes mandate efficiency standards only, not fuel choice, and electric codes focus only on safety objectives.

³⁴ Athienitis, A., Wang, L., Ge, H., and Bambara, J. 2020. Design and Operation of Resilient and Flexible Buildings. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

³⁵ Hachem-Vermette, C. 2020. Design Strategies for Climate Resilient Neighborhoods. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

³⁶ Anjos, M. 2020. Integration of Smart Buildings into the Energy Grid. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

Transition: Net-Zero Emissions		
<i>Toward coordinated grid and built environment decarbonization strategies.³⁷</i>		
From	To	Metric
Uncertain grid decarbonization path	Utilities commit to specific grid and energy supply decarbonization paths informed by projections of changes in buildings' grid and thermal load and interaction ³⁸	Percentage of energy supply delivered to consumers through utilities with confirmed decarbonization commitment

Transition: Increase Energy-Related Resilience		
<i>Toward buildings designed for predictable resilience at site and community scales.</i>		
From	To	Metric
Buildings are designed for normal operation	Buildings are designed to provide safety and comfort during disruptions ³⁹	Percentage of new buildings designed to be resilient (initially to generate their power and heat for a certain period)
Building response to disruptions is unpredictable	Building response to disruptions designed using modelling ⁴⁰	Percentage of new buildings with a predictable response to disruptions

³⁷ Kennedy, C., and Pape-Salmon, A. 2020. Jurisdictional Responsibility for Improving the Resilience of Buildings to Climate-Related Power Outages. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

³⁸ Environment and Climate Change Canada. 2022. 2030 Emissions Reduction Plan: Canada's Next Steps for Clean Air and a Strong Economy. Accessed November 2022. https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf.

³⁹ Kesik, T., Pearl, D., O'Brien, L., Oliver, A., Ferron, Y., and Harvey, W. 2020. The Challenges of Developing Thermal Resilience Policies, Protocols and Procedures for Buildings. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

⁴⁰ Zhe Liu, J., Li, C., and Touchie, M. 2020. Passive Strategies to Improve Multi-Unit Residential Buildings Thermal Comfort Resilience in Future Climate Scenarios. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

Transition: Increase Energy-Related Resilience*Toward buildings designed for predictable resilience at site and community scales.*

From	To	Metric
Limited urban modelling and limited data integrated from building modelling	Community response (including building response) to normal and disrupted operations is reliably modelled using a calibrated, integrated urban platform ^{41,42}	Percentage of the urban population living in communities with reliable, verified urban modelling

Transition: Change Building Design and Evaluation Processes*Toward building design and evaluation processes that support accountability and continuous improvement in a changing environment.*

From	To	Metric
Training and trained supervision for subdisciplines in low supply	Established subdisciplines that are adequately trained, staffed, and certified (e.g., building energy modelling, energy manager, airtightness, envelope, comfort, climate risk assessment)	Percentage of advertised positions for credentialed subdisciplines filled within one month
Buildings designed without modelling or with compliance modelling only	Building performance is modelled (including changing climate conditions) to optimize whole-building performance as part of the design process ⁴³	Percentage of new buildings designed using modelling and simulation software as a design tool, accounting for future climatic conditions

⁴¹ Eicker, U., Schumacher, J., Dabirian, S., Shirzadi, N., Samareh Abolhassani, S., Hosseinihaghghi, R., Javadian, S., and Panchabikesan, K. 2020. Planning and Simulation of Net-Zero, Carbon Neutral and Resilient Communities. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

⁴² Architectural Institute of British Columbia and Engineers and Geoscientists BC. 2018. Whole Building Energy Modelling Services. Joint Professional Practice Guidelines. Accessed 19 June 2023. <https://www.egbc.ca/app/Practice-Resources/Individual-Practice/Guidelines-Advisories/Document/01525AMW7JPMODAJKVYBCLHGRA24FJPH3/Whole%20Building%20Energy%20Modelling%20Services>.

⁴³ Rouleau, J., Gosselin, L., and Blanchet, P. 2020. Lessons Learned with Respect to the CAE Roadmap from the Monitoring of a High-Performance Social Housing Building in Quebec City. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

Transition: Change Building Design and Evaluation Processes

Toward building design and evaluation processes that support accountability and continuous improvement in a changing environment.

From	To	Metric
Building performance is not tracked	Building performance is tracked, made public, ⁴⁴ and used to calibrate the as-built model and to verify and optimize performance, leveraging building information modelling (BIM) capability where possible ⁴⁵	Percentage of three-year-old buildings with a BIM-based calibrated model
Fragmented responsibility for building performance over the service life	Technical continuity between the design, construction, commissioning, and operation phases by reducing professional silos and improving warranty approaches	Percentage of new buildings with a technical continuity strategy in place
Fragmented budgeting between capital costs and operating costs	An integrated budget strategy to ensure energy conservation measures are covered in the capital budget	Percentage of new buildings with an integrated budget strategy in place

Transition: Evolve Building Codes and Electrical Codes

Toward building and electrical code strategies that support near- and long-term goals.

From	To	Metric
Multiple definitions of net-zero energy complicate code development and adoption	Definitions adopted for net-zero-energy and net-zero-energy-ready buildings ⁴⁶	Level of acceptance of definitions by the construction and utilities communities

⁴⁴ City of Vancouver. n.d. Carbon Pollution Limits and Reporting for Existing Large Commercial and Multi-Family Buildings. Accessed 2022. <https://vancouver.ca/green-vancouver/green-large-commercial-and-multi-family-buildings.aspx>.

⁴⁵ Hyde, R. 2020. Building Operation and Occupant Behavior. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

⁴⁶ Barssoum, M., Knudsen, H., Macdonald, I., Marjaba, G., Vuong, E., and Wills, A. 2020. Supporting the Development of Net-Zero Energy Ready Building Codes. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

Transition: Evolve Building Codes and Electrical Codes*Toward building and electrical code strategies that support near- and long-term goals.*

From	To	Metric
Codes based on past performance of a reference building under past conditions	Future-oriented building codes that are performance-based and reference absolute targets (e.g., net-zero carbon) ⁴⁷	Percentage of new or renewed floor space for which the jurisdiction has signalled an intention to adopt the ultimate goal, along with stepping stones to reach that goal via tiers
Airtightness is the only code requirement that can be proven in advance of an occupancy permit	Occupancy approval based on performance-based building codes, proving compliance by reliably modelling performance under anticipated changing conditions	Percentage of new and renewed buildings receiving performance-based code approval with verification of performance during the commissioning period ⁴⁸
Codes and standards are lodged with levels of government and particular regulations for reasons of history and inertia	Allocate responsibility to governments and regulations in a manner that supports optimized energy performance of buildings on both the demand side and the supply side ⁴⁹	Code policy is reviewed and updated across levels of government and jurisdictions, and a policy roadmap is established for each provincial/territorial jurisdiction

Transition: Redesign Energy Billing Practices to Support a Net-Zero Goal*Toward energy billing practices that make better use of zero-emission energy during low demand periods.*

From	To	Metric
Billing practices that exacerbate the amount of curtailed energy in low- or zero-emission-energy systems	Billing practices that encourage consumers to better utilize curtailed zero-emission energy	The amount of curtailed energy as a percentage of productive energy use

⁴⁷ Charron, R. 2020. Expanding Performance-Based Step-Codes Beyond Energy Efficiency Using a Forward-Looking Reference Building. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

⁴⁸ CSA Group. 2021. CSA Z320-11 (R2021): Building Commissioning. Accessed June 2023. <https://www.csagroup.org/store/product/2703258/>.

⁴⁹ Kennedy, C., and Pape-Salmon, A. 2020. Jurisdictional Responsibility for Improving the Resilience of Buildings to Climate-Related Power Outages. In: Proceedings, Montreal Symposium. CAE Symposium on Roadmap to Resilient Ultra-Low Energy Built Environment With Deep Integration of Renewables in 2050, Montreal, QC, October 16, 2020. Accessed 2022. <https://www.cae-acg.ca/wp-content/uploads/2021/02/Roadmap-Symposium-Proceedings.pdf>.

4. Case Studies from Buildings and Communities

Andreas Athienitis, James Bambara, and Lukas Allan

This section presents case studies of four Canadian buildings and communities that have achieved, almost achieved, or exceeded net-zero energy:

1. Drake Landing Solar Community (Okotoks, Alberta)
2. West 5 Net-Zero Community and Smart Grid Project (London, Ontario)
3. Varennes Library (Varennes, Québec)
4. Ministry of Children and Family Development (MCFD) Williams Lake Net Zero Building Retrofit (Williams Lake, British Columbia)

The case studies have been well documented, including energy use and renewable energy production data. They represent major innovations in project development, design, and operation and demonstrate some of the technological possibilities for decarbonization in Canada. This is achieved through combinations of very high energy efficiency, solar energy seasonal storage, and building-integrated renewable energy systems. The case studies contain important lessons on the evolution of low-carbon buildings and communities in Canada and are useful for establishing different pathways.

Although the emphasis of the projects was operational energy targets (net-zero energy based on on-site renewable energy systems), carbon-neutral operation is expected to be simultaneously achieved. The intent is not to present these projects as perfect models to be copied, but rather as living labs that provide important lessons that can guide engineers and other stakeholders toward a path of decarbonization and resilience.

Case Study #1: Drake Landing Solar Community

Development: The Drake Landing Solar Community (DLSC) in Okotoks, Alberta, was designed by an international team led by Natural Resources Canada (NRCan). To see the DLSC through to fruition, NRCan (through CanmetENERGY, the Program of Energy Research and Development, and the ecoENERGY Technology Initiative) established partnerships with innovative, environmentally conscious companies with long-standing, credible reputations. Ground was broken in the spring of 2005, with operation beginning in the summer of 2007. The DLSC was the first community in North America to use seasonal storage of solar energy, which overcomes the obstacle of less sunlight during the winter. The innovation of the project was recognized by several awards, including the Energy Globe World Award (2011), the International Energy Agency Solar Award (2013), the Canadian Solar Industries Association Solar Thermal Project of the Year (2006), the Federation of Canadian Municipalities Sustainable Communities Award (2006), and the International Awards for Liveable Communities Gold Award (2005).

In Canada, approximately 86% of greenhouse gas (GHG) emissions in the residential sector are from space and water heating, due to the widespread use of fossil fuels.⁵⁰ The DLSC demonstrates the technical feasibility of achieving conventional fuel energy savings of more than 90% by using solar energy collected in the summer to provide residential space heating the following winter. The DLSC comprises 52 single detached homes, with space and water heating supplied mostly by solar energy. Six different house models were available to buyers, with an average above-grade floor area of 145 m². The houses were built to meet Canada's R-2000 performance standard, with upgraded building envelopes, higher insulation, low-e argon-filled double-pane windows, energy recovery ventilation, and improved airtightness and construction details. This was estimated to reduce space heating load by 30% compared with baseline houses at the time of construction.

As shown in Figure 8, each house has two solar thermal collectors to heat domestic hot water, and the adjoining garages are equipped with a total of 800 flat-plate unglazed solar thermal collectors to harness solar energy for space heating, with seasonal storage. A simplified schematic of the main components of the solar seasonal storage heating system is shown in Figure 9. During the warmer months, the heated water is distributed from the solar collectors to the short-term storage tank and then to the seasonal energy storage system, comprising 144 boreholes that extend 37 m below ground and cover an area 35 m in diameter. As the heated water travels through the borehole piping, heat is transferred to and stored in the surrounding earth, where the temperature reaches 80 °C by the end of the summer. When winter arrives and the homes require space heating, the heated water stored in the earth passes to the short-term storage tank in the energy centre and is then circulated to the homes through the district heating loop. A 22 kW photovoltaic (PV) array is installed on the roof of the energy centre to offset the energy used for pumps. The hot water and space heating systems are backed up with high-efficiency gas-fired water heaters.

⁵⁰ Natural Resources Canada, Office of Energy Efficiency. 2018. Residential Single Detached GHG Emissions by Energy Source and End Use. Accessed 2022.

<https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=HB§or=res&juris=00&rn=7&page=0>.



Figure 8: Houses and adjoining garages equipped with rooftop solar thermal collectors for hot water and space heating, respectively.

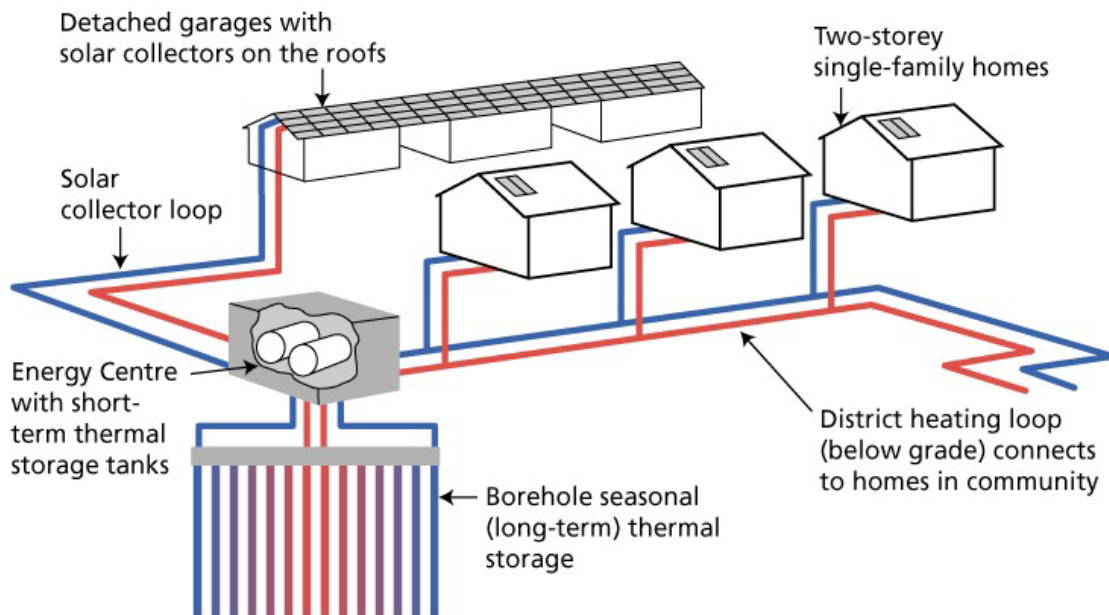


Figure 9: Schematic of the solar seasonal storage heating system.

During the design phase, a detailed Transient System Simulation Tool (TRNSYS) model was developed to simulate system operation and optimize some of the main design parameters, including solar collector area, short-term storage size, and number and depth of boreholes. Because solar energy is collected in the summer and stored for the winter, the size of the solar collector area is significantly reduced compared with solar installations that are designed to satisfy short-term energy needs during the winter. The ability to easily access detailed system operating data and compare actual operation against predicted operation is extremely valuable for the successful commissioning and efficient operation of such energy systems.

Monitored operation: The DLSC has been closely monitored since its commissioning in 2007, and performance data for the first 10 years can be found in Drake Landing Solar Community: 10 Years of Operation.⁵¹ Since the boreholes require time to charge with solar heat, initial performance was below what could be expected when the system achieved steady operating conditions. After approximately three years, the average borehole temperature reached 80 °C by the end of each summer, at which point the boreholes supplied over 85% of the houses' space heat. The combination of solar hot water and efficient fixtures and appliances reduced the gas used for hot water by 40% to 60%. The use of solar energy displaces a significant amount of natural gas for heating, which reduces GHG emissions by approximately 5 tonnes per house.⁵²

Lessons learned: The optimal size of a seasonal energy storage like the DLSC in a region such as Alberta depends on the price of natural gas, so a larger system could be more cost-effective. Subsequent feasibility studies show that larger systems of similar design can deliver solar energy at about half the cost due to economies of scale. Generally, such a project will be cost-effective when it is larger (e.g., four to five times the number of households) and denser, to reduce distribution losses. A more optimal design will also place the seasonal storage at the centre of the community, thus requiring an integrated urban plan. Including the builder, land developer, and municipality in the project planning process from the beginning helped build confidence in the project and market acceptance of the unfamiliar technologies being applied. In addition, early-design-stage simplified modelling tools are needed to assess the potential contributions from solar energy.

Overall, the system has demonstrated the reliable operation of a high-solar-fraction solar district heating system with seasonal thermal storage in a very cold climate. In addition to overcoming some of the long-standing obstacles in the use of solar energy at high-latitude locations, seasonal energy storage systems increase resilience, as uninterrupted home heating can be provided in case of emergencies. Equipping houses with additional PV plus battery storage would ensure the seasonal storage system could operate for prolonged periods while being disconnected from the grid.

⁵¹ Mesquita, L., McClenahan, D., Thornton, J., Carriere, J., and Wong, B. 2017. Drake Landing Solar Community: 10 Years of Operation. ISES Solar World Congress, Abu Dhabi, UAE, October 29–November 2, 2017. Accessed 2022. <https://proceedings.ises.org/paper/swc2017/swc2017-0033-Mesquita.pdf>.

⁵² Molenbroek, E., Stricker, E., and Boermans, T. 2011. Primary Energy Factors for Electricity in Buildings: Toward a Flexible Electricity Supply. Ecofys Netherlands BV. https://www.researchgate.net/publication/281476047_Primary_energy_factors_for_electricity_in_buildings_toward_a_flexible_electricity_supply.

Case Study #2: West 5 Net-Zero Community and Smart Grid Project

Development: The West 5 community in London, Ontario, began in 2013 as an ambitious dream. The goal was to build a net-zero-energy mixed-use community powered by solar electricity, with electric vehicles (EVs) for transportation and a microgrid based on a novel business concept. The energy-efficient buildings would be heated and cooled with air-source heat pumps. The team attracted Sifton Properties, which initiated the development. The team hired 90 students and worked with 11 universities on a feasibility study to show that it was cost-effective to build communities with a lighter footprint. An initial concept for the community is shown in Figure 10. The nearly 20% completed development is shown in Figures 11 and 12.

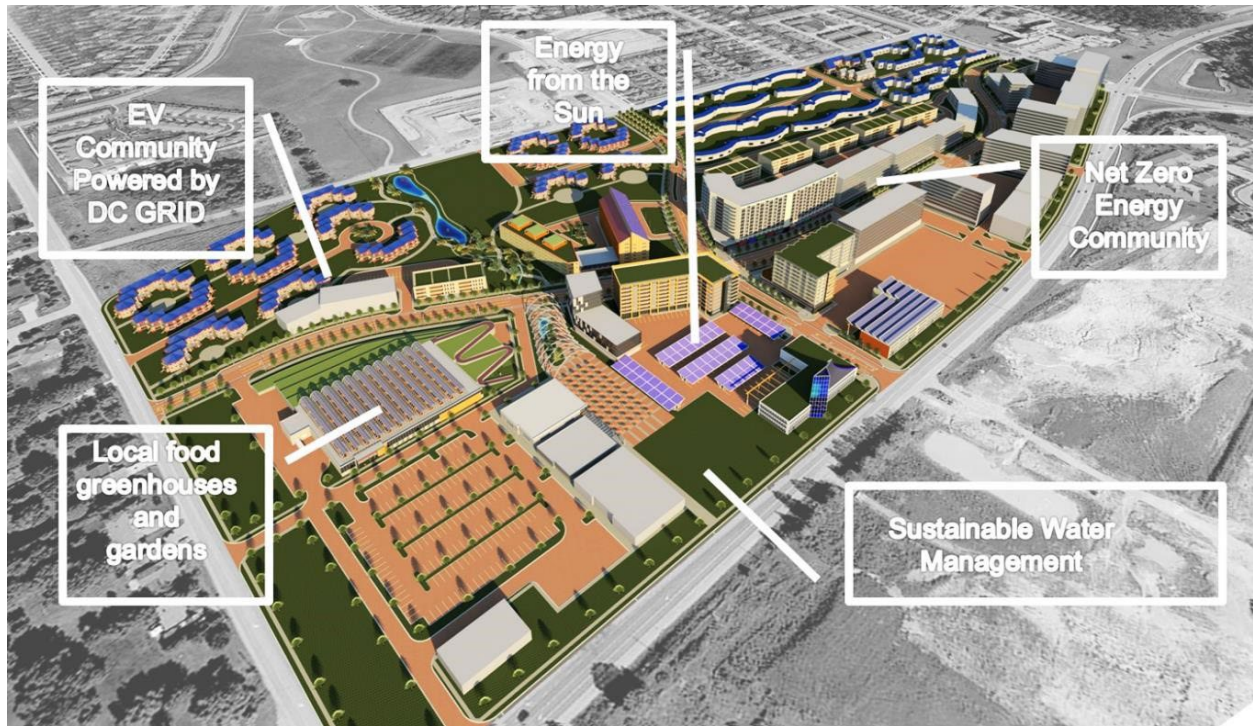


Figure 10: Initial concept for the West 5 community.⁵³

⁵³ Courtesy of Milfred Hammerbacher, s2e Technologies, July 3, 2022.



Figure 11: The partly completed West 5 development.⁵⁴



Figure 12: Various buildings in the West 5 community.⁵⁵

The plan is for the entire community to consume a maximum of 10 MW of power, which will be produced in the community through solar means. That solar power will be generated using photovoltaic (PV) panels on the roofs of buildings, including a parking garage, and solar arrays incorporated into many of the building facades. When

⁵⁴ Courtesy of Milfred Hammerbacher, s2e Technologies, July 3, 2022.

⁵⁵ Courtesy of Milfred Hammerbacher, s2e Technologies, July 3, 2022.

built out in 10 to 15 years, the neighbourhood will have 41,800 m² of commercial space, a central park, and 2,000 households consisting of townhouses, condominiums, apartments, and retirement residences. Initially, the objective of the developer, Sifton Properties, was to create “a smart, healthy and walkable community,” but its agenda expanded to include net zero when it partnered with s2e Technologies, which focuses on sustainable community development.

The West 5 microgrid project began as a feasibility study supported by the Federation of Canadian Municipalities’ Green Municipal Fund. The study considered the viability of implementing a microgrid within the community that would integrate DC-connected PV generation. The study proceeded in parallel with the buildout of the 70-acre West 5 community. It focused on integration of PV production behind the meter coupled with DC loads such as EV charging and street lighting, as well as within buildings. With the support of a research team at Western University, PSCAD dynamic modelling was undertaken to understand the implications of a behind-the-meter DC loop within the community.

Hybrid DC/AC microgrid: Based on a preliminary positive outcome from the feasibility study, the next step was to apply to NRCan’s Smart Grid Fund to develop and implement a hybrid DC/AC microgrid. There are several benefits of having a DC grid in a community with an increased number of DC loads. The main barrier is the economics, with the cost of new technologies and associated safety controls being more expensive before widespread adoption. The microgrid development is now funded by the Smart Grid Demonstration and Deployment Program. The lead for the project is the local distribution company, London Hydro. Although the technical feasibility of establishing a PV-supplied DC loop behind the meter of multiple buildings in West 5 was considered viable, the regulatory aspects of this approach had not been considered in the study. Further development of the preliminary design with London Hydro encountered limitations from a regulatory standpoint, including restrictions on transferring energy behind meters and under or above public roads. This led to a consensus that behind-the-meter design was not acceptable from a regulatory standpoint.

The design was then reconfigured to a feeder-connected storage configuration, which will be the energy management topology. This configuration will tie a 1.5 MW/1.5 MWh battery at 27.6 kV into the Talbot feeder that supplies the community. There is also a second Wonderland feeder in a redundant loop to the community, which is unable to support the significant amount of distributed energy resource generation that is now tied into the Talbot feeder. These constraints will require the microgrid controller to manage the behind-the-meter net-metered PV production in the event of a grid outage or a transfer of the community to the backup feeder. Ultimately, the microgrid will be an opportunity for London Hydro to explore and test the use of energy storage as a means of providing stability on a feeder and will demonstrate the use of load management within a community as a means of providing grid resiliency.

High-performance building design: The net-zero design of the West 5 community reduces loads on the London grid and maintains a low GHG footprint for the site. Compared with code-minimum building performance, the net-zero design improvement for the currently constructed buildings (1, 2, 3, and 4) is a reduction of approximately 200 tonnes of GHGs on an annual basis, excluding an offset created by rooftop PV. Much of the energy savings were the result of using air-source heat pumps in place of natural gas heating. Other energy features at West 5 include LED lighting, smart controls, building siting for solar gain, low window-to-wall ratios, and anti-thermal bridging measures in areas like balconies. The energy use intensities for the buildings are approximately 124 kWh/m² for Building 1 (3,545 m² office; 2,206 m² retail), 92 kWh/m² for Building 2 (4,189 m² health/institutional), and 91 kWh/m² for Building 4 (13,185 m² multi-family; 1,754 m² retail). As the West 5 buildout continues, emission offsets will continue to increase.

PV energy generation: Solar power will be generated from PV panels on the roofs of buildings, including a parking garage, and solar arrays incorporated into many of the facades. The net-metered PV capacity at West 5 is currently about 1.7 MW, with a 2021 yield of 900 kWh/kW_p, with properly oriented rooftops at a maximum 1,150 kWh/kW_p. Between Buildings 1, 2, 3, and 4, the PV production for 2021 offset about 75 tonnes of GHG emissions from the Ontario grid. With the addition of Building 15/16 and EVE Park, an 84-unit net-zero condominium neighbourhood, the PV capacity will approach 3 MW. Eight AC-tied Level 2 EV chargers have been installed, and vehicle-to-grid energy storage capabilities can be tested.

Buildings 1, 2, and 4 consume approximately 2.457 million kWh/year, and total solar electricity production is currently 1.53 million kWh/year, which makes the community net-zero energy based on an estimated primary energy factor of about 2.3 for Ontario.⁵⁶ Ontario's primary energy factor, which accounts for the extraction of the energy carrier; its transport to the utilization site; and processing, storage, generation, transmission, distribution, and delivery, is approximately 2.3.^{57,58} Therefore, on-site solar electricity production would be equivalent to 3.52 million kWh/year being produced at the current grid energy mix. This results in a net-positive design, even for buildings with a high energy-use intensity and limited space for installing PVs, such as the multi-storey commercial and residential buildings already built. While the low-rise townhouse component readily meets net-zero targets, buildings such as the 10-storey 115-unit residence still consume more energy than they produce. The difference is overcome through community net metering, where energy is shared between buildings to achieve net-zero goals across the development.

Lessons learned: The micro-utility business model represents a promising innovation. Today, the long-term payback of a net-zero-energy community is appealing, but many real estate developers do not consider life-cycle costs in the decision-making process. At EVE Park, an innovative business model was developed in response to the 10% to 20% additional capital investment required to achieve net-zero designs. To eliminate this upfront cost, a micro-utility was created. The micro-utility owns all energy generation equipment and major loads such as heat pumps, water heaters, and appliances, thereby reducing the developer's initial capital costs. The homeowner pays a smart fee, which is charged by the micro-utility to cover the cost of the additional capital. The fee is lower than the utility bills of a conventional home and provides future-proofing against rising energy costs. Continued technological advancements also support the net-zero shift, since the solar roof panel standard was 275 W five years ago but is now closer to 500 W, making it easier to achieve net zero with building-integrated PVs on facades and roofs.

The main barriers to implementing net-zero design no longer are technological but rather stem from society's difficulty to change the status quo. For instance, regulatory barriers such as net metering, jurisdictional requirements for short-circuit fault treatment of PV, and not being able to install wires under a public road provided the most significant challenges and limited the adopted designs. It was found that involving as many stakeholders as possible from the start of the project is essential to minimize problems and delays. Nevertheless, resilience measures will require further research for novel cost-effective solutions.

⁵⁶ Primary energy factor is the ratio between primary energy and produced electricity. It accounts for conversion thermal losses and distribution losses. For example, one locally generated kWh is equivalent to 2.3 kWh of primary energy in the Ontario energy mix.

⁵⁷ Government of Ontario. 2020. Ontario Energy Quarterly: Electricity in Q1 2020. Accessed 2022. <https://www.ontario.ca/page/ontario-energy-quarterly-electricity-q1-2020>.

⁵⁸ Sifton. n.d. Community Map. West 5. Accessed 2022. <https://west5.ca/live/community-map>.

Case Study #3: Varennes Library – Canada’s First Net-Zero Energy Institutional Building

Development: The city of Varennes is an off-island suburb of Montreal (latitude 45° N). With its growing population, Varennes needed a new library to replace its aging one. Between 2010 and 2011, a team of municipal representatives, CanmetENERGY researchers, academics, and industry partners was formed, and an integrated design process was adopted through several design charrettes. From the beginning, the objective was to make the library the first demonstration net-zero-energy institutional building in Canada with a building-integrated solar system. The NSERC Smart Net-Zero Energy Buildings Strategic Research Network⁵⁹ was represented by a team from Concordia University, which guided the development of the overall energy concept for a 2,100 m² two-storey building. Two key concepts determined the overall shape of the building and the integration of the technologies:

1. The design team estimated the annual energy consumption of a highly energy-efficient library at around 70 kWh/m²/year, resulting in an anticipated energy consumption of about 140,000 kWh/year. To reach net zero (based on the strictest definition, in which the energy produced in an average year is at least equal to the energy consumed), the building would need a 110–120 kW system that would generate about 1,200 kWh/year per kW.⁶⁰ Based on solar potential maps from Natural Resources Canada, with a photovoltaic (PV) system optimally tilted and oriented due south, this would require a roof area of 700–800 m², with PV panels of about 15% to 16% efficiency (common at the time). A more widely used definition of net-zero-energy balance is based on primary energy. PV technology is developing so quickly, and costs decreasing, that in 2024, PV panels with 20% to 22% efficiency are easily available, meaning that a roof area of about 600 m² would be adequate if the building were built in 2024.
2. The depth of the building would need to be 6–10 m to promote deep daylight penetration⁶¹ and night free cooling through motorized windows on opposite facades.

The early design charrettes served to develop a common vision for the net-zero-energy building and implement it into a practical design for the local climate. Key energy features were also decided:

- The roof slope was set at close to 40° and directed near due south to optimize PV electricity production while reducing snow accumulation.
- Facades would generally use triple-glazed low-e argon-filled wood-framed windows to minimize thermal losses in winter, and the south facade would have double-glazed low-e argon-filled windows to increase passive solar gains.
- Window sizes would be optimally selected to provide sufficient views to the exterior without excessive heat gains or losses or visual discomfort.
- The target maximum energy consumption for lighting was set to < 7 W/m².
- A ground source heat pump and building-integrated PV/thermal (BIPV/T) systems would be used to reduce energy consumption for space conditioning.

⁵⁹ Natural Sciences and Engineering Research Council of Canada (NSERC). NSERC Smart Net-Zero Energy Buildings Strategic Research Network. Accessed 2022. <http://www.solarbuildings.ca>.

⁶⁰ Natural Resources Canada. n.d. Photovoltaic Potential and Solar Resource Maps of Canada. Accessed 2022. <https://natural-resources.canada.ca/our-natural-resources/energy-sources-distribution/renewable-energy/solar-photovoltaic-energy/tools-solar-photovoltaic-energy/photovoltaic-potential-and-solar-resource-maps-canada/18366>.

⁶¹ Athienitis, A.K., and O’Brien, W. 2015. Modeling, Design, and Optimization of Net-Zero Energy Buildings. Berlin, Germany: Ernst & Sohn. <https://onlinelibrary.wiley.com/doi/book/10.1002/9783433604625>.

To condition the space, the design team selected a radiant slab for both heating and cooling on the southern perimeter of the building and an underfloor air displacement system for the rest of the upper floor; the first floor uses overhead diffusers. Fresh air was to be supplied by a dedicated outdoor air system based on the occupancy determined by CO₂ readings.

Opening and awards: The library, shown in Figure 13 with key energy-intensity operational results, was inaugurated on May 16, 2016. It achieved LEED Gold certification and won Awards of Excellence from the Urban Development Institute of Québec and the Association of Consulting Engineering Companies–Canada.⁶² A schematic of the key energy technologies implemented is shown in Figure 14.

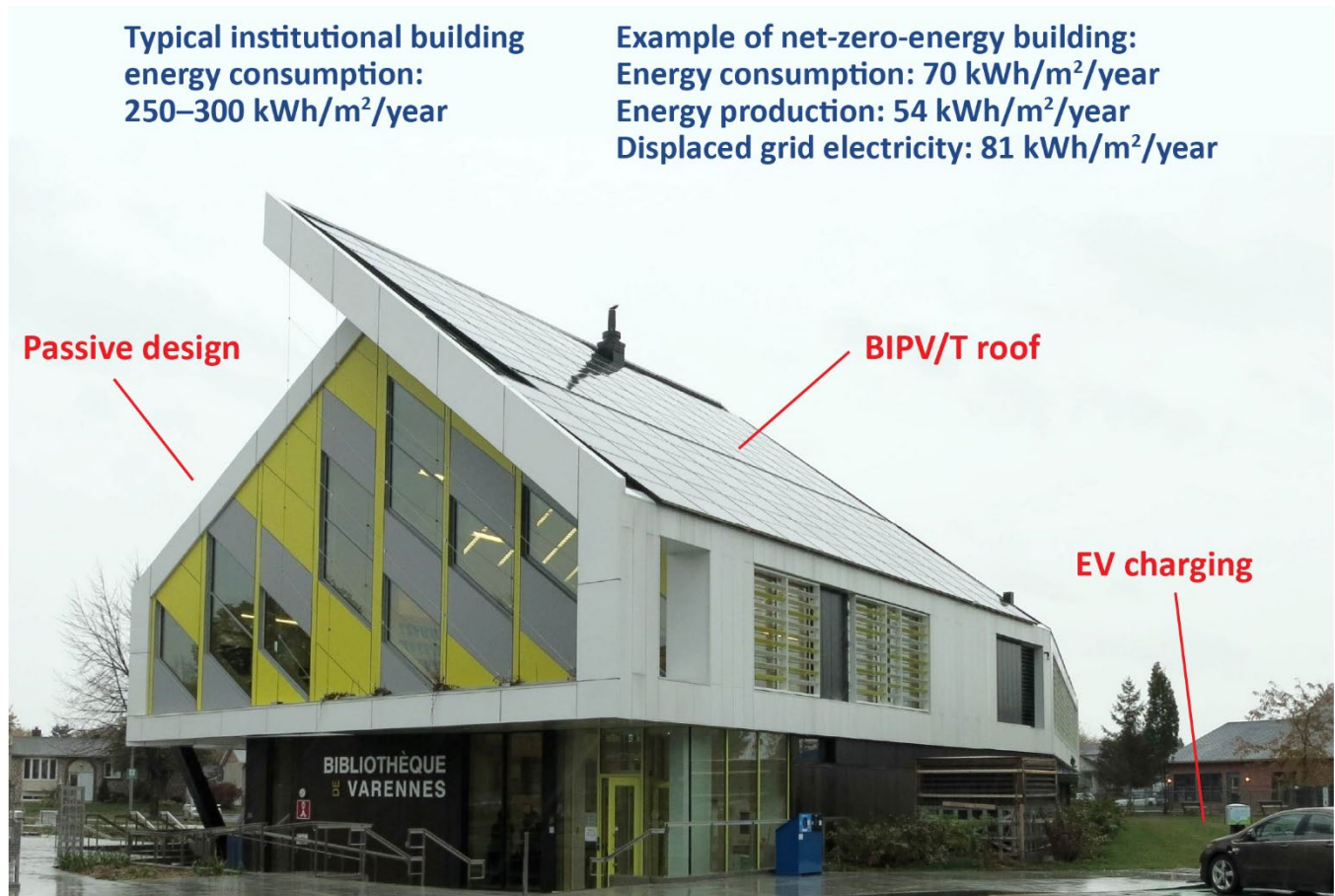


Figure 13: Varennes Library, with important annual energy statistics highlighted. BIPV/T = building-integrated photovoltaic/thermal; EV = electric vehicle.

⁶² Stantec. 2016, December 2. Varennes Net-Zero Library – Award of Excellence. Canadian Consulting Engineer. Accessed 2022. <https://www.canadianconsultingengineer.com/features/varennes-net-zero-library-award-excellence/>.

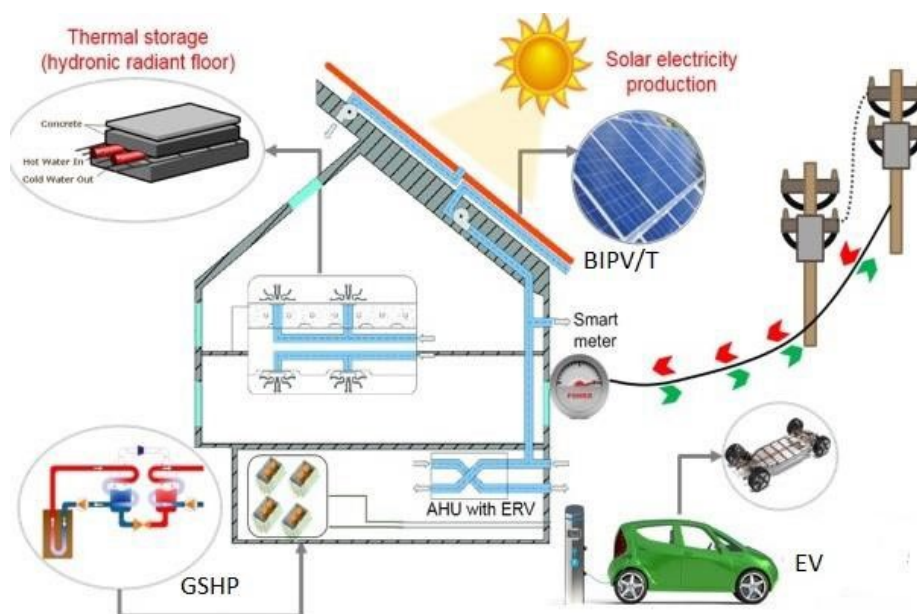


Figure 14: Varennes Library energy schematic cross-section illustrating key technologies implemented, including a building-integrated photovoltaic/thermal (BIPV/T) system, ground source heat pump (GSHP), and electric vehicle (EV) charging. AHU = air handler unit; ERV = energy-recovery ventilator.

Summary of energy performance:⁶³ The Varennes Library produces electricity from a 110.5 kW_p BIPV system, in which heat is also recovered from a section of the array and used to preheat the fresh-air intake. The building's many architectural and mechanical features were integrally designed to achieve the net-zero-energy target over a five-year averaging period. Several key decisions were made at the early design stage, including the shape, area, and orientation of the roof. This maximizes electricity production from the BIPV system (partial BIPV/T, with heat recovery), and the design layout promotes daylight penetration, natural ventilation, and free cooling. Operational energy-use intensity is 70 kWh/m²/year based on data measured since 2016. Energy production is about 54 kWh/m²/year, resulting in primary energy displaced equal to 81 kWh/m²/year (for a primary energy factor of 1.5 for Québec), making this a net-zero-energy building. The average Canadian building in the commercial/institutional category, which includes libraries, consumes over 300 kWh/m² of energy.⁶⁴ The Varennes Library is 100% electrical (geothermal heat pumps are the main heating and cooling source). Smart energy management for such a building is important since the utility will buy up to 50 kW of power (any excess amount is provided at no charge).

Lessons learned: Buildings that are near net-zero energy now can become net-zero energy or net-positive energy in the future as more advanced controls and more efficient equipment replace deprecated controls and equipment. For example, if the building were built in 2022, PV panels with an efficiency of at least 20% would have been used (compared with 16% for the installed system), meaning that for the same roof surface area, about 20% more electricity would be produced. Thermal and electrical storage solutions, in conjunction with predictive control of the HVAC system, can be added to better harness opportunities for load shifting and grid

⁶³ Dermardiros, V., Athienitis, A.K., and Bucking, S. 2019. Energy Performance, Comfort, and Lessons Learned From an Institutional Building Designed for Net Zero Energy. *ASHRAE Transactions* 125(1):682–695. <https://link.gale.com/apps/doc/A584980324/AONE>.

⁶⁴ Natural Resources Canada, Office of Energy Efficiency. n.d. Survey of Commercial and Institutional Energy Use (SCIEU) – Buildings 2014 – Data Tables. Accessed 2022. <https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/scieu/2014/tables.cfm>.

flexibility.⁶⁵ Net-zero-energy buildings as prosumers are becoming more common and are incentivized by dynamic tariffs offered by utilities.

The role of net-zero-energy and high-performance buildings will be paramount in the near future as more building-integrated decentralized renewables are connected to the grid. Renewable energy sources such as solar and wind are highly variable and can impose a burden on the grid when demand is low. However, such buildings can act as regulators of demand to aid the utility by employing energy flexibility concepts such as optimally controlling their thermal and/or electrical storage systems and integrating electric vehicles with smart charging stations.

⁶⁵ Athienitis, A.K., Dumont, E., Morovat, N., and Lavigne, K. 2020. Development of a Dynamic Energy Flexibility Index for Buildings and Their Interaction With Smart Grids. ACEEE Summer Study 2020 on Energy Efficiency in Buildings, Virtual, August 17–21, 2020.
https://www.researchgate.net/publication/343725542_Development_of_a_dynamic_energy_flexibility_index_for_buildings_and_their_interaction_with_smart_grids.

Case Study #4: Ministry of Children and Family Development Williams Lake Net Zero Building Retrofit

Development: The Ministry of Children and Family Development (MCFD) Williams Lake Net Zero Building Retrofit project in Williams Lake, BC, was designed to be the first net-zero-energy building completed by the Government of BC.⁶⁶ The project was developed in alignment with the government’s policy to reduce operational greenhouse gas (GHG) emissions across its entire building portfolio, with a 50% reduction by 2030 and an 80% reduction by 2050, compared with 2007 levels.⁶⁷ Additionally, the government hoped to fulfill one of the goals of its 2018 Build Smart strategy to complete a building showcasing a net-zero deep-energy retrofit by 2023.⁶⁸ Finally, the project sought to serve as an experimental space for high-efficiency commercial buildings in colder Canadian climates.⁶⁹ After its completion in September 2021, the project earned several awards for innovative sustainability, including an ACEC-BC Award for Engineering Excellence (2022), a Premier’s Innovation and Excellence Award (2022), and Grands Prix du Design Silver and Gold Awards.^{70,71,72}

The objective of the project was to provide a new space for the William’s Lake MCFD offices. In 2019, the government purchased a vacated single-storey retail building that had been constructed in 2000. The building is approximately 1,500 m² and was previously occupied by Sears and Fabricland (see Figure 15).⁷³ The original construction included a poorly insulated building envelope, conventional mechanical and electrical systems, and limited envelope openings that imposed dependency on artificial lighting and ventilation.⁷⁴ A key retrofit design consideration was William’s Lake’s design heating-degree-day (HDD) range of 4,420–5,829, much colder than Vancouver’s HDD range of 2,467–3,065 (based on previous 25-year averages).⁷⁵

⁶⁶ TWD Technologies. n.d. Williams Lake Net Zero Energy Building. The ACEC-BC Awards. Accessed April 11, 2024. <https://acecbcawards.com/2022-awards/2022-buildings/williams-lake-net-zero-energy-building/>.

⁶⁷ CleanBC. n.d. B.C. Is Rising to the Challenge of Climate Change. Accessed April 11, 2024. <https://cleanbc.gov.bc.ca/>.

⁶⁸ Government of Canada. 2017. Build Smart – Canada’s Buildings Strategy: A Key Driver of the Pan-Canadian Framework on Clean Growth and Climate Change 2017. Accessed April 11, 2024. <https://publications.gc.ca/site/eng/9.838037/publication.html>.

⁶⁹ BC Ministry of Citizens’ Services, Real Property Division. 2023. Williams Lake Net Zero Energy Building [PowerPoint slides].

⁷⁰ TWD Technologies. n.d. Williams Lake Net Zero Energy Building. The ACEC-BC Awards. Accessed April 11, 2024. <https://acecbcawards.com/2022-awards/2022-buildings/williams-lake-net-zero-energy-building/>.

⁷¹ BC Ministry of Citizens’ Services, Real Property Division. 2023. Williams Lake Net Zero Energy Building [PowerPoint slides].

⁷² Thibodeau Architecture + Design. n.d. NetZero Carbon Neutral Building Retrofit, Williams Lake, BC. INT Design. Accessed April 11, 2024. <https://int.design/en/projects/netzero-carbon-neutral-building-retrofit-williams-lake-bc/>.

⁷³ BC Ministry of Citizens’ Services, Real Property Division. 2023. Williams Lake Net Zero Energy Building [PowerPoint slides].

⁷⁴ BC Ministry of Citizens’ Services, Real Property Division. 2023. Williams Lake Net Zero Energy Building [PowerPoint slides].

⁷⁵ BC Ministry of Citizens’ Services, Real Property Division. 2023. Williams Lake Net Zero Energy Building [PowerPoint slides].



Figure 15: The original retail building.⁷⁶

The prime consultant for the project was Thibodeau Architecture + Design, which worked closely with the government, the general contractor, and the design consulting team.⁷⁷ The general contractor was Lauren Bros. Construction, a local contractor whose intimate knowledge of the area and local suppliers greatly benefited the project's successful and on-schedule completion.⁷⁸ FWD Engineering provided the project's energy assessment study and designed the building's new mechanical and electrical systems.⁷⁹ The design team also included specialist consultants for the building envelope, solar photovoltaic (PV) systems, geothermal heat pumps, civil work, structural upgrades, building acoustics, and landscape architecture.⁸⁰

Net-zero study: FWD Engineering conducted a comparative energy assessment study using energy models developed with eQUEST software, supplemented with manual calculations for specific thermal performance inputs.⁸¹ The following retrofit design cases were modelled:⁸²

- **Baseline:** The existing building's performance under new occupancy conditions, implementing only necessary changes for office use, such as updated schedules and plug loads, additional window openings, and like-for-like replacement of failing mechanical equipment.
- **Minimum standard:** The existing building if upgraded only to comply with current energy code minimum standards.
- **Deep retrofit:** A model using deep retrofit techniques with the goal of a 40% to 60% reduction in modelled building energy use compared with the baseline.

⁷⁶ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

⁷⁷ Thibodeau Architecture + Design. n.d. NetZero Carbon Neutral Building Retrofit, Williams Lake, BC. INT Design. Accessed April 11, 2024. <https://int.design/en/projects/netzero-carbon-neutral-building-retrofit-williams-lake-bc/>.

⁷⁸ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

⁷⁹ Thibodeau Architecture + Design. n.d. NetZero Carbon Neutral Building Retrofit, Williams Lake, BC. INT Design. Accessed April 11, 2024. <https://int.design/en/projects/netzero-carbon-neutral-building-retrofit-williams-lake-bc/>.

⁸⁰ Thibodeau Architecture + Design. n.d. NetZero Carbon Neutral Building Retrofit, Williams Lake, BC. INT Design. Accessed April 11, 2024. <https://int.design/en/projects/netzero-carbon-neutral-building-retrofit-williams-lake-bc/>.

⁸¹ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

⁸² Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

- **Net-zero ready:** The “deep retrofit” design case with further high-efficiency measures, targeting an 80% reduction in modelled building energy use compared with baseline.
- **Net zero:** The “net-zero ready” design case plus a solar PV system to generate the remaining energy required for building operation on site (100% building energy use reduction).

The predicted energy use of all modelled options can be seen in Figure 16. All three advanced retrofit options show significant energy savings via improvements to the building envelope and switching to high-efficiency electric heat pump and heat-recovery-ventilation HVAC systems.⁸³ The remaining reduction in energy usage from the “deep retrofit” design case to the “net-zero ready” design case is attributed to changing from an air-source heat pump to a ground-source heat pump, which is more efficient and reduces the need for supplemental heat.⁸⁴

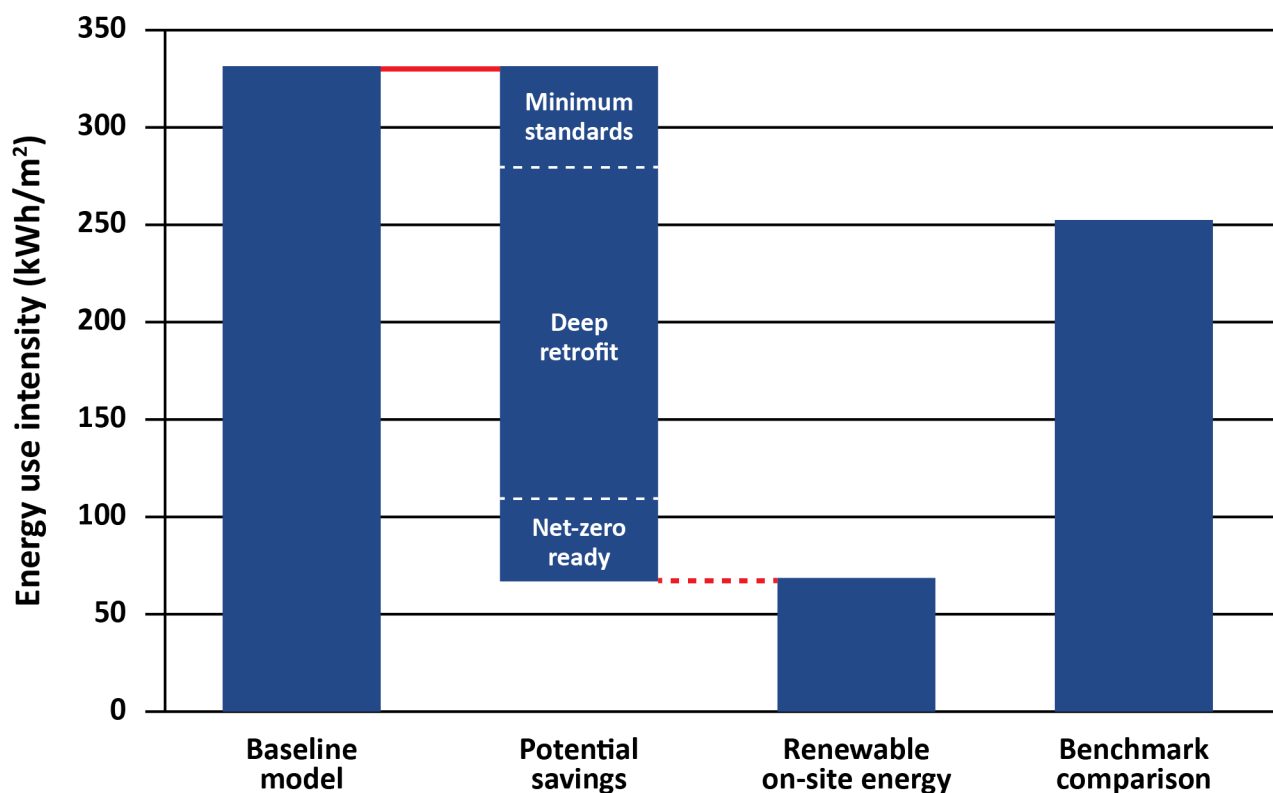


Figure 16: Estimated energy usage of the various energy retrofit modelled design cases.⁸⁵

The “deep retrofit” design case was predicted to reduce GHG emissions by 97% from the baseline, with only a small further improvement in the “net-zero ready” design case to a 98% reduction (see Figure 17) [6].⁸⁶ The

⁸³ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

⁸⁴ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

⁸⁵ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

⁸⁶ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

significant reduction in GHG emissions in all three advanced retrofit options are primarily from the conversion to electric HVAC systems instead of natural gas, as BC’s electricity is generated from renewable hydropower.⁸⁷

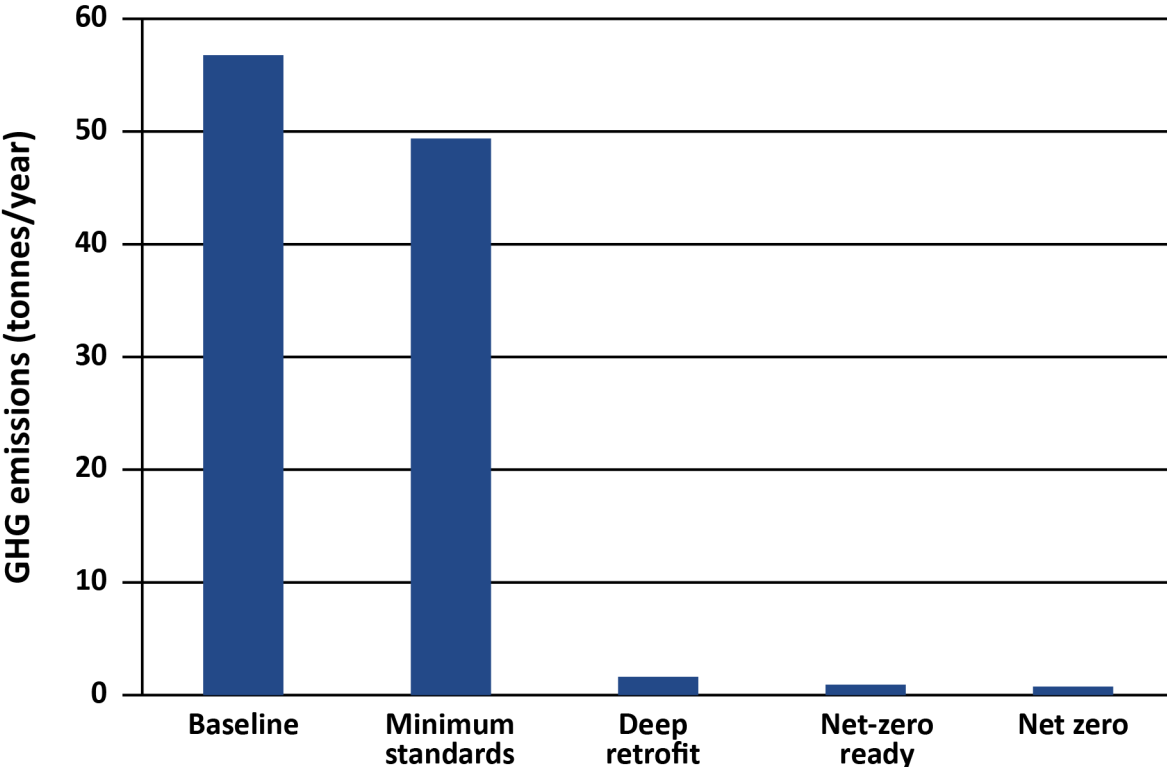


Figure 17: Estimated greenhouse gas (GHG) emissions for the various energy retrofit modelled design cases.⁸⁸

See Table 2 for the energy usage and financial breakdown of all modelled design cases. A financial analysis indicated that all three advanced retrofit options were unlikely to result in a positive financial return when comparing energy cost savings to the significant initial capital investment.⁸⁹ This issue is amplified by the fact that electricity is currently more expensive than natural gas.⁹⁰ Although the “deep retrofit” and “net zero” design cases yield similar reductions in GHG emissions, the “net zero” design case boasts significantly greater energy cost savings, with only a 6.36% higher initial capital cost.⁹¹ The government decided to proceed with the “net zero” option due to the improved energy cost savings, alignment with its goal of completing a showcase

⁸⁷ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.
⁸⁸ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.
⁸⁹ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.
⁹⁰ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.
⁹¹ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

net-zero retrofit project, and the potential for additional learning opportunities beyond direct financial analysis.⁹²

Table 2: Energy Modelling and Financial Analysis Results Summary for Different Design Cases⁹³

	Baseline	Minimum standards	Deep retrofit	Net-zero ready	Net zero with solar PV
Electricity (MWh)	191	154	162	98	0
Gas (GJ)	1,100	957	0	0	0
Total (kWh)	497,000	420,000	162,000	98,000	0
Energy use intensity (kWh/m²)	331	280	108	65	0
Reduction from baseline	0%	15%	67%	80%	100%
Greenhouse gas (GHG) emissions (tonnes/year)	56.9	49.4	1.7	1.0	0
GHG emissions reduction	0%	13%	97%	98%	100%
Annual energy costs	\$33,500	\$27,900	\$27,000	\$12,200	\$0
Annual cost savings	\$0	\$5,600	\$6,500	\$21,300	\$33,500
Capital cost	\$7,732,234	\$8,115,167	\$8,902,496	\$9,138,992	\$9,468,122

Project design: The “net zero” option, including a solar PV system generating 100,000 kWh/year, was designed to reduce net energy usage by 497,000 kWh/year and GHG emissions by 56.9 tonnes/year, representing a 100% reduction from baseline in both categories.⁹⁴ The primary design features used to achieve these reductions are listed below and shown in Figure 18:⁹⁵

- Wall insulation increased from R-17 to R-50 and roof insulation increased from R-31 to R-73.
- Airtightness improved to minimize infiltration.
- Cascadia Clips incorporated as cladding attachments to avoid envelope thermal bridging.
- Operable high-performance triple-glazed windows (window-to-wall ratio of 12.7%).
- Solatube skylights installed to maximize daylighting and reduce artificial lighting loads and the need for larger windows that can lead to significant heat loss.
- High-efficiency HVAC systems, including heat-recovery ventilation, occupancy sensors, and a ground source heat pump set with optimized controls and variable speed drives.

⁹² Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

⁹³ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

⁹⁴ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

⁹⁵ BC Ministry of Citizens’ Services, Real Property Division. 2023. Williams Lake Net Zero Energy Building [PowerPoint slides].

- Fifteen high-end DC motor fan–operated terminal heating and cooling units to provide an energy-efficient perimeter temperature zone for year-round comfort.
- Nearly 30 variable air volume boxes with hydronic reheat coils for optimum efficient indoor air quality and thermal zoning control.
- A ground source heat pump consisting of 30 vertical boreholes ranging from 160 ft to 300 ft deep to provide 264 MBH in heating and 470 MBH in cooling.
- New electrical systems, including LED lighting, electrical service upgrades, optimized lighting controls, and electric vehicle charging stations.
- Solar PV system generating 100,000 kWh/year to offset remaining building energy demands.

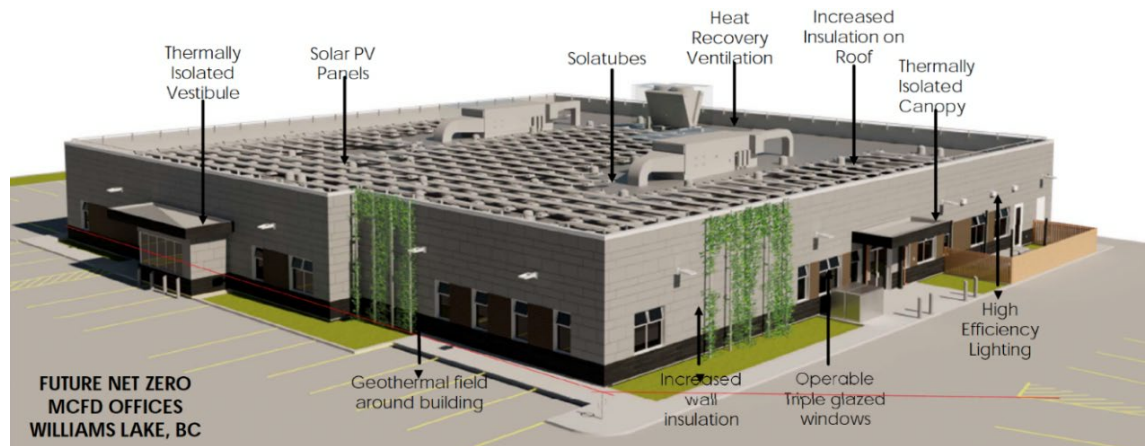


Figure 18: Rendering of retrofitted Ministry of Children and Family Development (MCFD) offices, with key high-energy-efficiency design aspects highlighted.⁹⁶

The immediate inclusion of a solar PV system was driven largely by the need to strengthen the building’s structure to support the added roof weight. Performing these reinforcements at a later stage was considered impractical.⁹⁷ The solar PV system is lightweight to minimize structural upgrades and is designed to function throughout the year without regular adjustment or cleaning, even during the winter, when large amounts of snow could cover solar panels and prevent electricity generation.⁹⁸

Triple-glazed windows were not essential to achieve net zero and had a high installation cost relative to energy savings compared with double-glazed windows.⁹⁹ However, after discussion with the government, triple-glazed windows were selected to prioritize improving occupant comfort.¹⁰⁰ Another design consideration was the potential risks of installing a ground-source heat pump given limited maintenance experience in BC and

⁹⁶ BC Ministry of Citizens’ Services, Real Property Division. 2023. Williams Lake Net Zero Energy Building [PowerPoint slides].

⁹⁷ L. Allan and R. Tamimi, interview and discussion, December 4, 2023.

⁹⁸ L. Allan and R. Tamimi, interview and discussion, December 4, 2023.

⁹⁹ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

¹⁰⁰ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

uncertainties in geothermal system performance.¹⁰¹ Mitigation strategies included a preliminary drilling program, a backup electric boiler, and specialized training for operations staff.¹⁰²

Lessons learned: FWD Engineering performed a two-year energy performance review of the MCFD building in 2023. It found that while the building achieved carbon-neutral operation (100% reduction in GHG emissions), it fell short of its net-zero-energy consumption target. The building used more energy than expected, and its solar PV system generated less energy than designed.¹⁰³ Key factors for underperformance of energy usage targets are listed below and shown in Figure 19:¹⁰⁴

- **Solar PV system underperformance:** The solar PV system produced approximately 20% less energy than expected, possibly due to underestimating snow and the impact of low solar radiation in winter and/or improper configuration of the solar system inverters.¹⁰⁵ A size increase of the system is not possible, as BC Hydro has a 100,000 kWh maximum capacity for power grid interconnection.
- **Boiler controls:** The electric boiler backup was activating far more frequently than modelled, seemingly caused by changes to heating set points and improper configuration of controls. The issue has been resolved but cannot be verified until data is gathered from future winter seasons.
- **Non-optimization of geothermal heat pump:** Certain geothermal and heating loops are continuously operating at 100% speed to maintain minimum flow requirements, resulting in additional energy usage during low-load periods and non-ideal temperature differentials in the geothermal field. This was an oversight in the design, and though improvement is possible, it is unlikely that pre-construction energy-usage estimates can be achieved.
- **Saturday occupancy:** The building was designed for weekday occupancy only, but in practice it is also occupied on Saturdays, which increases energy usage above modelled expectations.
- **Variation in building use:** Expected plug loads, schedules, and HVAC controls (e.g., pumps, fans, ventilation) can change to optimize occupant comfort, sometimes increasing or decreasing energy usage and adding a margin of error to pre-construction energy estimates.

¹⁰¹ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

¹⁰² Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

¹⁰³ Pullinger, M. 2023. Two Year Energy Performance Review – Williams Lake MCFD Building. FWD Engineering Ltd.

¹⁰⁴ Pullinger, M. 2023. Two Year Energy Performance Review – Williams Lake MCFD Building. FWD Engineering Ltd.

¹⁰⁵ Pullinger, M. 2020. Net Zero Ready Study for Ministry of Children and Family Development, 280A 3rd Avenue, Williams Lake, BC. FWD Engineering Ltd.

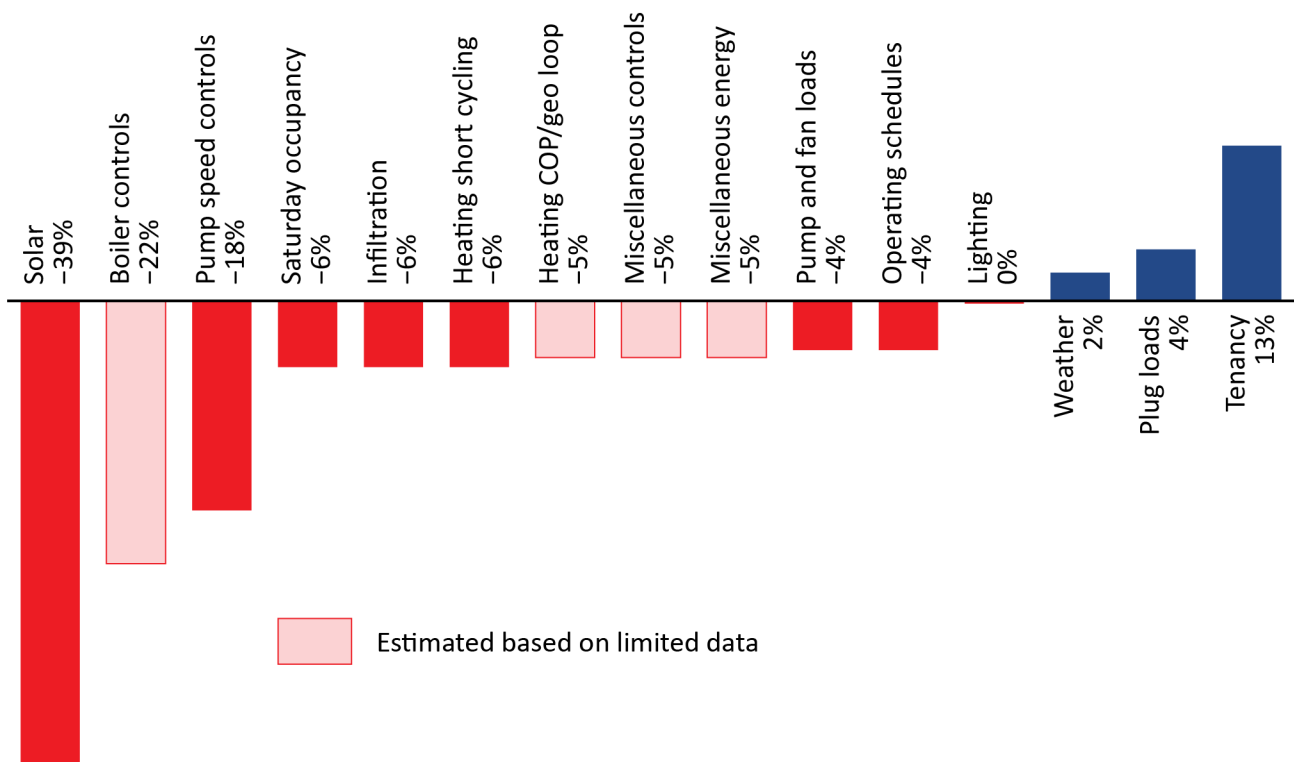


Figure 19: Discrepancies between pre-construction “net zero” estimates and actual energy use.¹⁰⁶ COP = coefficient of performance.

The project highlights the potential of high-performance zero-carbon buildings in Northern climates, surpasses the goal of an 80% reduction in GHG emissions, and provides valuable insights into the design of future projects. However, it falls short of the marketed net-zero-energy target. Financially, there is little justification to continue improving the building toward true net zero. However, further building optimization could provide a greater understanding of emerging technologies such as geothermal heat pumps and solar PV systems.

The primary benefit of this project is the insights provided into designing buildings near the net-zero mark. The sustainable construction industry often seeks perfect performance targets, sometimes creating scenarios in which a large portion of a project’s resources are used to marginally improve a building’s performance a few percentages beyond the economically optimal level. As seen with the MCFD project, this effort doesn’t guarantee results, possibly requiring an adjustment in industry expectations regarding pre-construction energy modelling accuracy. As similar retrofit projects are undertaken on a wider range of BC’s building stock, the emphasis must be on efficiently reducing GHG emissions with less focus on achieving specific marketed energy goals.

¹⁰⁶ Pullinger, M. 2023. Two Year Energy Performance Review – Williams Lake MCFD Building. FWD Engineering Ltd.

5. Market Uptake of Net-Zero-Carbon and Net-Zero-Energy or Low-Energy Buildings

Market Update of Established Green Building Standards

Construction of net-zero-carbon and net-zero-energy buildings is already technically and economically viable in Canada, with well over 1 million m² of building space already certified (Table 3). There are some differences in the approaches to certification, and care should be taken to distinguish between net-zero-carbon, net-zero-energy, and net-zero-energy-ready buildings—which may still require installation of renewable energy systems to reach net zero. Nonetheless, market uptake of such buildings has grown in Canada since 2018.

Table 3: Floor Area of Net-Zero-Carbon, Net-Zero-Energy, Net-Zero-Energy-Ready, and Passive House-certified buildings as of May 2022

Organization	Region	Program	Total floor area (m ²)
Canada Green Building Council	Canada	Zero Carbon Building Standards	1.1 million
Canadian Home Builders' Association	Canada	Net Zero Energy and Net Zero Energy Ready	230,000
International Living Future Institute	International	Zero Carbon Certification	46,000
International Passive House Association	International	Passive House certification	3 million+

As shown in Table 3, as of May 2022, over 1.1 million m² of floor space was certified under the Canada Green Building Council's Zero Carbon Building Standards. The number of buildings registering for this certification increased from just under 200,000 m² in 2018 to almost 700,000 m² in 2021 (see Figure 20). The Canada Green Building Council has both design-based and performance-based zero-carbon certification systems but is phasing out the design-based approach.¹⁰⁷

¹⁰⁷ Canada Green Building Council. n.d. Zero Carbon Building Standards. Accessed 2022 <https://www.cagbc.org/our-work/certification/zero-carbon-building-standard/>.

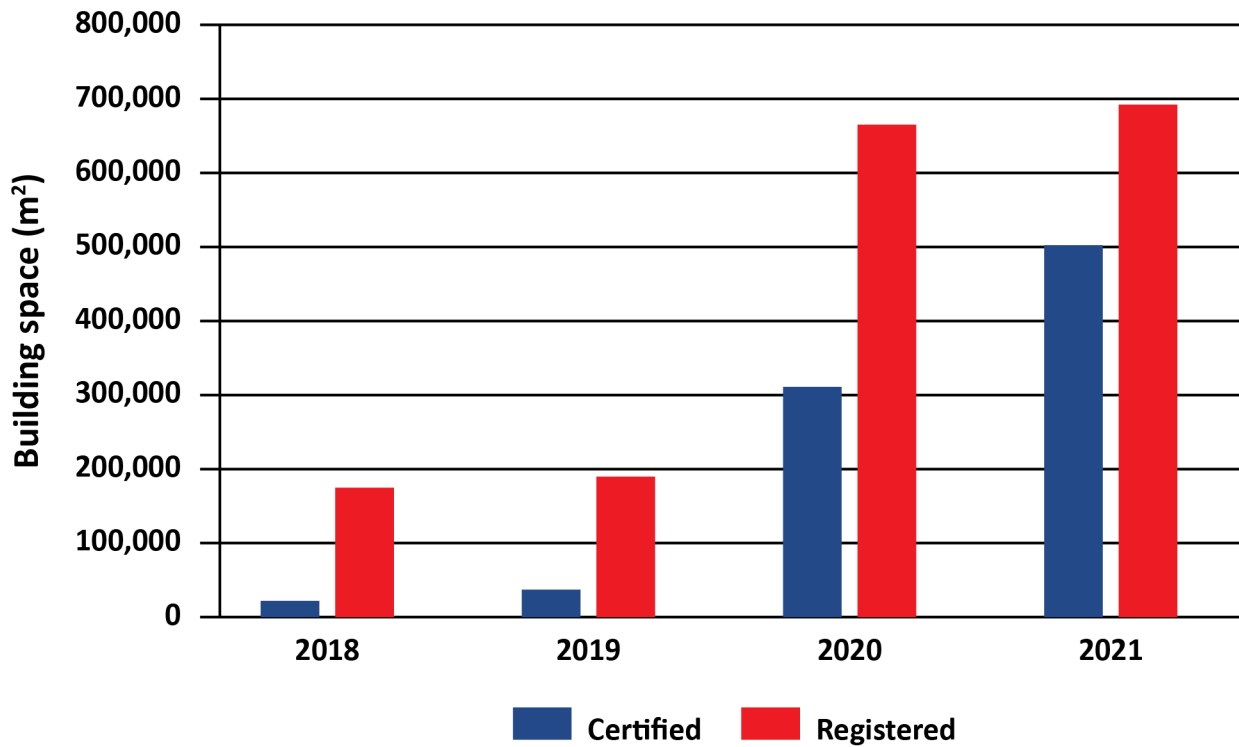


Figure 20: Building space registered for or certified to Zero Carbon Building Standards by the Canada Green Building Council

As of May 2022, the Canadian Home Builders' Association recorded 209 Net Zero Energy homes, and 693 Net Zero Energy Ready homes. The heated floor area of the 902 homes was 229,495 m². Figure 21 shows progress with the Canadian Home Builders' Association's labelling scheme from the pilot in 2016 to the end of 2021 (first 758 homes).

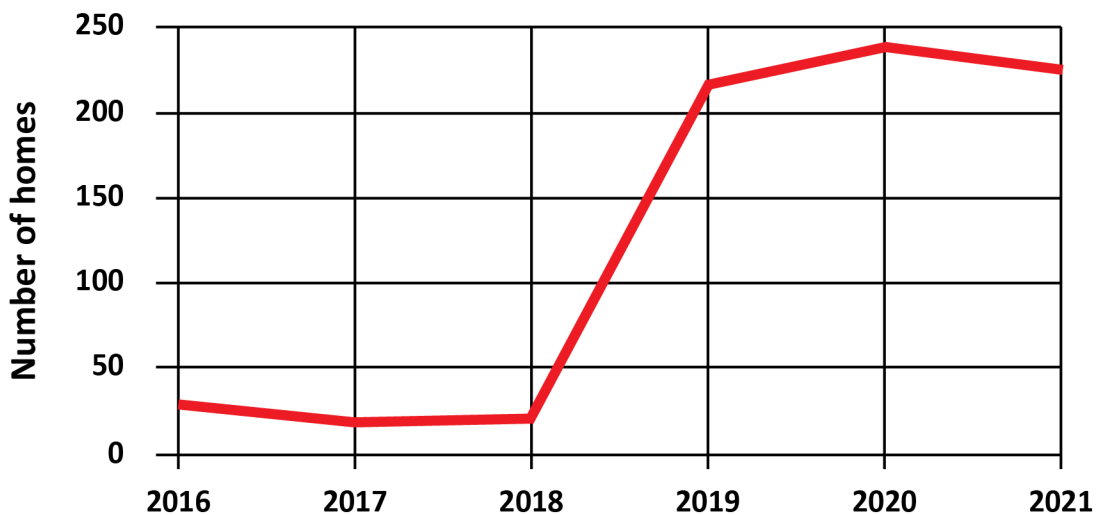


Figure 21: Number of units (homes or apartments) recorded by the Canadian Home Builders' Association as Net Zero Energy or Net Zero Energy Ready from 2016 to 2021.

Several international initiatives are also relevant to the Canadian net-zero building markets. The most rigorous international certification scheme for a zero-carbon building is probably that of the Seattle-based International

Living Future Institute.¹⁰⁸ Its performance-based standard requires the decarbonization of both operational and embodied carbon emissions. As of May 2022, Zero Carbon Certification was being pursued for projects representing a floor area of approximately 2 million m². Among approximately 90 projects around the world registered for Zero Carbon Certification, six are in Canada.

Although not a zero-carbon or zero-energy certification, the very-low-energy goals of Passive House certification can readily help to render a building zero carbon, through the addition of photovoltaic panels. Globally, as of January 2022, 33,000 units have been certified based on the Passive House Institute's certification criteria.¹⁰⁹ The treated floor area of Passive House-certified buildings now exceeds 3 million m².

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) plays an influential role in developing and promoting market adoption of best practices, standards, and design methodologies for high-performance low-carbon and energy-efficient buildings. ASHRAE has recently released a position paper on building decarbonization,¹¹⁰ and ASHRAE BC has published a related guide, *Building Sustainability & Resilience Guide*.¹¹¹ Major ASHRAE positions and recommendations are listed below.

Positions:

- By 2030, the global built environment must halve its 2015 greenhouse gas (GHG) emissions, whereby all new buildings must be net-zero GHG emissions in operation, widespread energy-efficiency retrofits of existing assets must be well underway, and embodied carbon of new construction must be reduced by at least 40%.
- By 2050 at the latest, all new and existing assets must be net-zero GHG emissions across the whole life cycle.
- Building decarbonization provides benefits beyond reducing GHG emissions, including reduced indoor and outdoor air pollution, energy savings, improved community health and well-being, enhanced social responsibility, and increased property valuation.

Recommendations:

- Implement building electrification, such as switching from natural gas heating to electric heat pumps.
- Use renewable energy resources both on and off site.
- Optimize building envelope, orientation, and geometry to reduce energy use and maximize solar potential.
- Use grid-integrated control systems to optimize building energy storage and increase demand flexibility. Buildings can use energy storage (within the building as well as electric vehicles and associated refuel

¹⁰⁸ International Living Future Institute. n.d. Zero Carbon Certification Overview. Accessed 2022. <https://living-future.org/zero-carbon/zero-carbon-certification/>.

¹⁰⁹ International Passive House Association. n.d. Passive House Certification Criteria. Accessed 2022. https://passivehouse-international.org/index.php?page_id=150.

¹¹⁰ American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2022. ASHRAE Position Document on Building Decarbonization. Accessed 2022. https://www.ashrae.org/file%20library/about/ashrae_building_decarbonization_pd_2022.pdf.

¹¹¹ American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), British Columbia Chapter. 2022. Building Sustainability & Resilience Guide. Accessed 2022. <https://static1.squarespace.com/static/54762199e4b0f6ed696bf031/t/62fd59afd2fc2d056da51b2a/1660770738485/ASHRAE-BC+Building+Sustainability+%26+Resilience+Guide+-+Rev+1.1.pdf>.

infrastructure) to modify their electric loads to match the availability of low-carbon electricity and/or reduce peak loads.

- Increase adoption of building codes and policies to move toward net-zero operational emissions.

6. Principles for Policy-Makers and Institutions

Andrew Pape-Salmon

So far, the roadmap has presented the vision of a future state for buildings in Canada (Section 2), the measurable benefits and outcomes of that vision (Section 3), four case studies of buildings and communities (Section 4), and Canadian market uptake (Section 5). Building on this, Section 6 submits five key principles that governments can use to develop supportive policy, legislation, regulations, institutional and fiscal frameworks, programs, and public sector leadership. These interventions are collectively referred to as government policy measures. They are summarized in the first subsection below.

Government Policy Measures

All five levels of government have jurisdiction to influence the outcomes sought through this roadmap. The primary areas of responsibility of each are as follows:

- Federal:
 - Primary level responsible for the national fiscal framework, including federal taxation and carbon taxation in some provinces and territories.
 - Delegation of jurisdiction to territorial and Indigenous governments.
 - Infrastructure investment (leveraging provincial/territorial, municipal/regional, and Indigenous investment).
 - National equipment energy-efficiency standards.
 - Governance for development and publication of harmonized construction codes and building, plumbing, fire, and energy model codes.
 - Scientific research and development.
 - Data and statistics.
 - Interprovincial trade.
 - Energy-efficiency, decarbonization, and resilience programs.
- Provincial/territorial:
 - Primary level responsible for building construction and real estate sectors, energy sector, climate mitigation, and disaster risk reduction and resilience.
 - Sales and carbon taxation and assessment for property taxation.
 - Delegation of jurisdiction to municipal/regional and some Indigenous governments.
 - Authority having jurisdiction for construction regulation, including regulation of national model building codes, electrical codes, other safety standards, equipment energy-efficiency standards, and variations to national codes and standards.
 - Institutions and professional governance.
 - Energy efficiency, decarbonization, and resilience programs.
- Regional (varies by province/territory):
 - Regional planning for land use, growth, parks, transportation, community energy, and emissions and resilience.
 - Management of regional airsheds, where applicable.

- Water, storm water, sewage treatment, solid waste, and recycling.
 - Public education on climate change and decarbonization.
 - Coordination of municipalities and engagement of Indigenous governments.
 - Building inspections in non-municipal areas.
- Municipal/local:
 - Land development planning, development permit area guidelines, neighbourhood planning, and zoning.
 - Building bylaws and inspections and, in some cases, electrical and gas safety inspections.
 - Community energy and emissions planning.
 - Indigenous (varies by community):
 - Housing policy, building and safety standards, community planning, and resource management.

Tables 4 and 5 illustrate the types of government policy measures that are used to influence the energy efficiency of buildings and promote decarbonization.

Table 4 summarizes demand-side measures that are applied on the building side of the energy meter. These apply to an audience of building owners, managers, and sometimes tenants. Appendix E includes a citation to government policy websites and documents that explain each measure. The responsible governing party is noted in the middle column, illustrating a significant overlap between levels of government. The target audience for each measure is noted in the third column. A detailed description of each measure is beyond the scope of this roadmap, which instead focuses on principles, noting that the determination of policy measures and even the description is unique to each jurisdiction.

Table 4: Demand-Side Measures (Building Scale) for Efficiency, Decarbonization, and Resilience

Measure	Responsible Party	Target Audience
Carbon pricing	Federal and provincial/territorial governments	The public – energy consumption
Utility rate design and rates	Utilities and public utility commissions	Utilities – rate design
		The public – operations
Equipment efficiency standards	Federal and provincial/territorial governments	Manufacturers, contractors, and the public
Utility demand-side management programs, including efficiency and fuel switching	Utilities and public utility commissions	The public and contractors
Financing (e.g., property-assessed clean energy financing)	Federal, provincial/territorial, and municipal/regional governments	The public – capital upgrades
Building codes	Federal, provincial/territorial, municipal/regional, and Indigenous governments	Builders and manufacturers

Measure	Responsible Party	Target Audience
Electrical codes	Provincial/territorial, municipal/ regional, and Indigenous governments	Electrical designers and trades
Planning and reach codes (carbon)	Municipal/regional and Indigenous governments	Developers and builders
Research and development, deployment, and commercialization	Federal and provincial/territorial governments, utilities, and public utility commissions	Manufacturers and builders
Distributed energy, vehicle to grid, and thermal and electrical storage	Utilities and public utility commissions	The public – capital and operating
Government procurement and infrastructure investment	Federal, provincial/territorial, municipal/regional, and Indigenous governments	Manufacturers and contractors

Table 5 summarizes supply-side measures that influence the sources and emissions of energy resources that are purchased by building owners, managers, and tenants. These are introduced by provincial/territorial governments and public utilities, often “natural monopolies” that are regulated by public utility commissions under provincial/territorial legislation. These are all “enabling measures” for demand-side measures, as they affect the price of purchased energy, influence emissions factors, provide community energy supplies, and facilitate distributed energy resources on the customer side of the energy utility meter.

Table 5: Supply-Side or Enabling Measures (Sub-national Scale) for Decarbonization and Resilience

Measure	Responsible Party	Target Audience
Energy management system for network (system control)	Utilities	Utilities
Carbon tax on supply	Federal and provincial/territorial governments	Utilities – upstream emissions
Clean electricity standard	Provincial/territorial governments, utilities, and public utility commissions	Electric utilities
Greenhouse gas emissions cap for gas utilities	Provincial/territorial governments, utilities, and public utility commissions	Gas utilities and gas district energy
Microgrids, storage, and net metering	Public utility commissions	Electric utilities
Community energy systems (net-zero carbon)	Local, utilities, and public utility commissions	Developers
Grid hardening (risk mitigation)	Utilities	Utilities
Government infrastructure investment in capacity and energy supply decarbonization	Federal and provincial/territorial governments	Utilities

These demand-side and supply-side measures can work in tandem to achieve the roadmap goals, as illustrated in Figure 22. The x-axis illustrates the proportion of emissions each measure influences, while the y-axis illustrates the proportion of total building stock each measure influences.

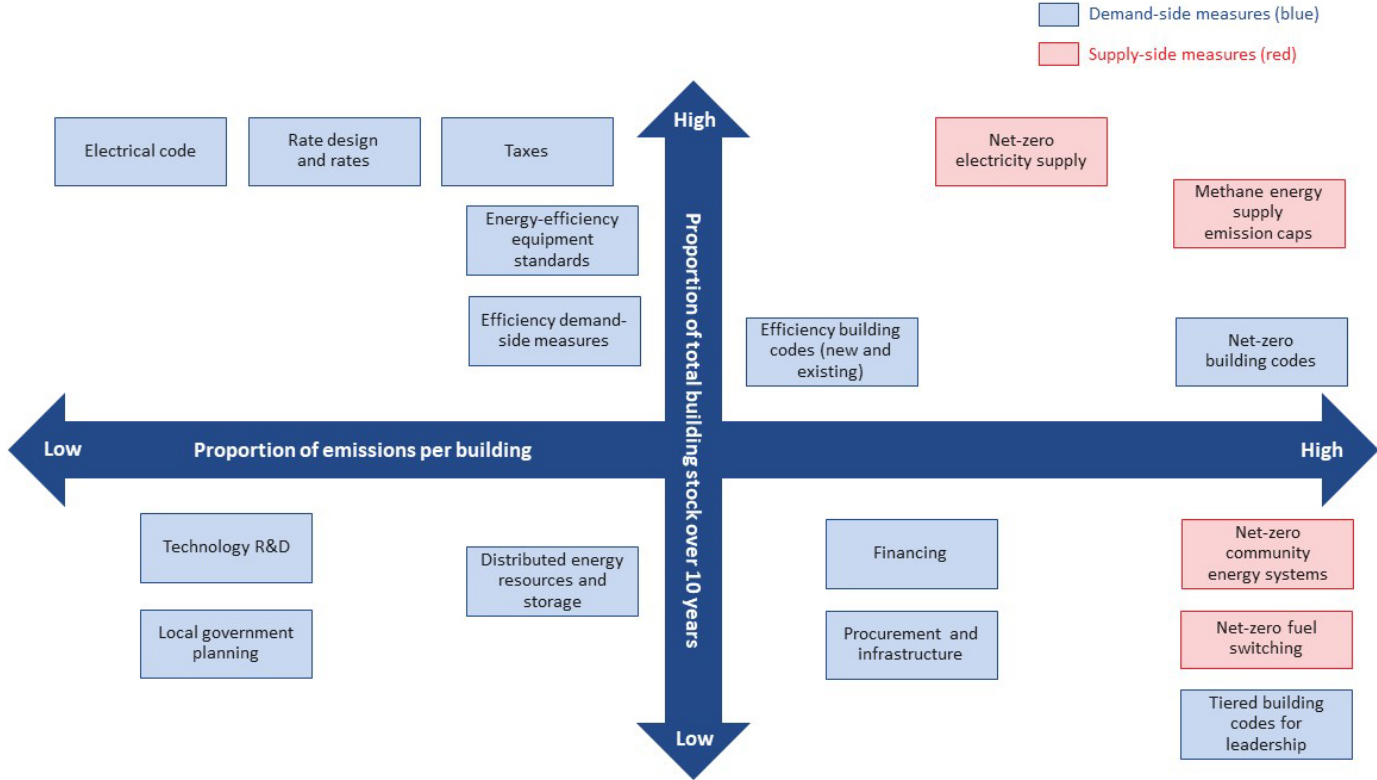


Figure 22: Government policy measures for efficiency and decarbonization of buildings.

The top-right quadrant in Figure 22 lists measures with the highest potential overall emissions emission reductions (high proportion of emissions and high proportion of total building stock), and the bottom-left quadrant lists measures with the lowest potential overall emission reductions (low proportion of emissions and low proportion of total building stock). Starting at the top-left quadrant and moving clockwise, we detail these interventions and how they affect building emissions.

Top-left quadrant (low proportion of emissions reductions and high proportion of total building stock)

Electrical code: The Canadian Electrical Code, produced by the Canadian Standards Association, sets out standards for the safety of electrical workers and building occupants and promotes consistency in electrical installations across Canada. It is adopted by provincial/territorial, municipal/regional, and Indigenous governments in regulation. The most recent edition was published in 2024.¹¹² This is relevant to the roadmap in cases where electrification and storage are used a means of reducing greenhouse gas (GHG) emissions, as the Canadian Electrical Code enables safe, reliable and resilient electrification.

¹¹² CSA Group. 2024. Canadian Electrical Code, Part I: Safety Standard for Electrical Installations (CSA C22.1:24). 26th ed. Accessed 2024. https://www.csagroup.org/store/product/CSA_C22.1%3A24/.

Rate design and rates: The public utility regulator sets rates (prices) for utilities that sell fuels or types of energy to consumers in buildings. Rate design determines components of energy expenditure such as energy and demand charges and connection charges for new service in buildings. For thermal energy systems, new rate structures must be considered that focus on low temperature use, incentives for installing low-temperature piping returns, and other measures that maximize the opportunity to harvest low-grade and low-waste energy sources and to make distribution systems more cost-effective. Both can influence energy and fuel choice and overall consumption. They apply to all buildings. Energy consumption is the principal source of GHG emissions in buildings. Rate design will be very important if we want to reduce the amount of curtailed (unused) zero-emission energy and minimize the use of high-cost zero-emission energy and capacity, particularly during peak periods.

Taxes: This is the domain the federal and provincial/territorial ministries of finance or revenue, with sales taxes applied to energy purchases and carbon taxes applied to the majority of building energy use. Taxes affect the relative cost of different energy sources, which affects choice and consumption. They apply to all buildings. There are also tax credits, such as the BC clean buildings tax credit, which applies to major retrofits.¹¹³ These programs act as a consumption subsidy for non-emitting energy, though they have much more limited reach, as they rely on voluntary uptake.

Energy-efficiency equipment standards: These include federal (Natural Resources Canada) and provincial/territorial *Energy Efficiency Act* standards that apply to new equipment installed in new construction or replacement of existing assets. This includes imported products and transfer of products between provincial/territorial jurisdictions, triggering federal (Natural Resources Canada) legislation. It applies to a proportion of buildings each year when equipment is installed or replaced, but it will touch most buildings over time, as equipment life is shorter than building life. The impact on building emissions is due to lower energy consumption, but it doesn't prescribe fuel choice.

Efficiency demand-side management: This includes programs that promote energy efficiency, including education, incentives, and financing. They also support governments and standards development organizations in revising and implementing codes and standards. The programs are often led by public utilities, as authorized through provincial/territorial legislation, but they can also include government programs such as the Canada Greener Affordable Housing program and Oil to Heat Pump Affordability program. These apply only to those buildings that participate in the program. However, over time, a large proportion of the building stock is expected to participate due to widespread availability of subsidies such as appliance rebates.

Top-right quadrant (high proportion of emissions reductions and high proportion of total building stock)

Net-zero electricity supply: The electrical grids of BC, Yukon, Manitoba, Québec, and Newfoundland and Labrador have been predominantly hydroelectric for several decades, with very low production emissions and zero consumption emissions. Some jurisdictions have policy or legislation mandating low emissions from electricity systems, such as the BC announcement to create a 100% non-emitting electricity standard.¹¹⁴ This policy measure ensures that other policy measures that promote switching from fossil fuels to electricity deliver GHG emission reductions. Other provincial/territorial electrical grids use unabated fossil fuels for a substantial

¹¹³ Government of British Columbia. n.d. Clean Buildings Tax Credit. Accessed 2023.

<https://www2.gov.bc.ca/gov/content/taxes/income-taxes/corporate/credits/clean-buildings>.

¹¹⁴ CleanBC. 2021. Roadmap to 2030. Accessed 2022. https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_roadmap_2030.pdf.

share of supply; electricity use in buildings then has moderate to high production emissions, despite consumption emissions being zero. These grids are transitioning toward low- and zero-carbon electricity supplies, bolstered by the 2023 federal budget. Provincial/territorial governments may require legislation to mandate decarbonization of the electrical grid, reinforced by public utility regulators. The impact for decarbonizing buildings is most pronounced when the starting fuel source for the electric grid is coal or oil and is transitioned to renewable or nuclear energy. It can also include natural gas with carbon capture and storage, renewable natural gas, or hydrogen-sourced power plants. These apply to all buildings. The extent of emission reductions depends on the proportion of energy use from electricity. A 100% electric building could be fully decarbonized with such a measure. The use of nuclear energy for base-load energy demand has advantages that offset the higher capital costs of nuclear capacity. Nuclear energy is weather-independent, so it can achieve reliability and resiliency requirements for the energy supply with less storage and other supporting equipment. Nuclear energy produces about twice as much zero-emission waste heat as electricity output, so it can also supply most of the heat to buildings if the reactors are sited closer to loads and a district heating system is available. Passively safe nuclear designs will be needed to attract public support for locating the reactors in industrial or commercial areas.

Methane energy supply caps: Modelled on the CleanBC *Roadmap to 2030*,¹¹⁵ this supply-side measure gradually reduces the net-emissions intensity of fuels transported in natural gas pipelines and compressed and liquified gases. This may include blending of fossil fuels such as natural gas with renewable natural gas and hydrogen. While in-building methane combustion produces consumption emissions and there may be fugitive production and transportation emissions, net emissions to the atmosphere are reduced through the use of renewable natural gas. This reduces other emissions from sources such as landfills, sewage treatment plants, and forestry, among others. Use of carbon capture and storage also reduces emissions from large sources under the influence of gas utilities. Hydrogen combustion produces zero consumption emissions and has variable production emissions similar to electricity. These innovations apply to all buildings that have a natural gas, propane, or district energy connection; they have a significant emission reduction potential. As the proportion of carbon-abated methane increases in a network or system, the magnitude of emission reductions per building and across the building stock increases. A 100% abated gas blend, coupled with 100% net-zero electricity supply, could address 100% of emissions in the building stock.

Efficiency building codes (new and existing): These include energy-efficiency standards at the time of construction or alterations to existing buildings. They apply to a small proportion of the building stock each year but can yield significant emission reductions per building, including zero or net-zero emissions. BC is moving toward regulating building emissions via performance-based standards, phasing them in for new buildings over three tiers (in 2022, 2027, and 2032), leading to ultra-low-energy buildings. Few jurisdictions have building code standards for existing buildings, but these will be introduced in Canada in 2025.¹¹⁶ Over a 10-year time frame, efficiency building codes could influence more than half of the building stock, including both new and existing buildings. The impact on building emissions is due to lower energy consumption, but it doesn't prescribe fuel choice. If efficiency measures are evaluated based on the avoided cost of new generation and distribution system upgrades, more aggressive action could be justified.

¹¹⁵ CleanBC. 2021. Roadmap to 2030. Accessed 2022. https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_roadmap_2030.pdf.

¹¹⁶ Canadian Commission on Building and Fire Codes. 2020. Final Report – Alterations to Existing Buildings: Joint CCBFC/PTPACC Task Group on Alterations to Existing Buildings. National Research Council Canada. Accessed 2023. <https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/codes-canada-publications/final-report-alterations-existing-buildings>.

Net-zero-emissions building codes: Net-zero-emissions building codes would add a GHG intensity standard to building standards in addition to energy efficiency. This would influence fuel choice to allow a variety of decarbonization options, including electrification, low carbon-fuels and district energy.¹¹⁷ This could have a substantial impact on building emissions over a 10-year time frame.

Bottom-right quadrant (high proportion of emissions reductions and low proportion of total building stock)

Financing: Financing programs are direct subsidies to lower the cost of investment in reducing energy use or emissions. They include government-backed programs such as property-assessed clean energy financing made available to building owners to install energy-efficiency, decarbonization and resilience technologies and measures. They are accessed voluntarily, applying to only a small proportion of the building stock annually, but can deliver deep emission reductions of a similar or greater magnitude than the building code.

Procurement and infrastructure: Government procurement of goods and services and construction and renovation of buildings can drive market transformation toward efficient, decarbonized buildings.

Net-zero community energy systems: This local energy supply model provides thermal energy to buildings, mainly for new construction, and offers an opportunity for deep decarbonization potential compared with natural gas. Consumption emissions are zero, and production emissions can be minimized through the use of renewable energy resources or carbon abatement. Existing buildings can be retrofitted to accept district energy, provided the temperature is sufficient for the mechanical system. Early action to encourage design or modifications that require lower supply and return temperatures will give buildings more options as thermal networks are expanded. Community energy systems are owned by public utilities, municipal/local governments, and owners of large buildings and campuses.

Net-zero fuel switching: This is an emerging measure that enables utilities to incentivize fuel switching in existing buildings or new construction to use zero-carbon fuels. For example, BC's *Greenhouse Gas Reduction Regulation* enables public utilities to offer such incentive programs and cover the costs across the entire rate base.¹¹⁸ The CleanBC program previously provided direct subsidies to builders for efficient, zero-emission houses.¹¹⁹

Tiered building codes for local leadership: Recently taking effect in British Columbia, tiered building codes regulate carbon in a building regulation or bylaw led by municipal/regional or Indigenous governments. These are ideally informed by voluntary provincial/territorial building codes but allow local governments to adopt one of the leadership tiers in advance of prospective or planned provincial/territorial-wide adoption. Emission reductions can be significant per building, but they apply only to new construction in the communities of the participating municipal/regional and Indigenous governments, so the overall impact is small. As an example,

¹¹⁷ CleanBC. 2021. Roadmap to 2030. Accessed 2022. https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_roadmap_2030.pdf.

¹¹⁸ Government of British Columbia. n.d. Greenhouse Gas Reduction Regulation. Accessed 2023. <https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/greenhouse-gas-reduction-regulation>.

¹¹⁹ CleanBC. n.d. CleanBC Better Homes New Construction Program. Accessed 2023. <https://www.betterhomesbc.ca/rebates/cleanbc-new-construction/>.

amendments to the BC Building Code effective May 1, 2023, include a new GHG reduction objective and voluntary targets for estimated annual emissions per square metre of floor area.¹²⁰

Bottom-left quadrant (low proportion of emissions reductions and low proportion of total building stock)

Technology R&D: Research and development provide the basis for transformative or disruptive technologies, such as heat pumps fuelled by biogenic methane or hydrogen. These technologies can reduce emissions outside the energy sector, which are substantial due to recent wildfires. Research and development are funded by the federal government, universities, provincial agencies, and public utilities. They facilitate regional, continental, or global collaboration and can affect all aspects of building emissions over longer time frames, with technology adoption.

Local government planning: Local government planning defines long-term urban design, building types and orientation, density, and community infrastructure such as district energy. In several cities, development requests for higher density than allowed under zoning bylaws trigger local government policies that can include decarbonization objectives. The City of Vancouver’s Green Buildings Policy for Rezonings is an example, predating building code requirements that have since been adopted for all new construction.¹²¹

Distributed energy resources and storage: Distributed energy resources and storage are building-specific or neighbourhood systems for electricity that mimic district thermal energy. They include distributed resources such as solar photovoltaics or cogeneration, battery storage, and resilient electrical microgrids that can operate autonomously—for example, during a grid outage. They can also be used to control smart appliances such as space and water heaters that can be turned off for short periods. These are often considered to be demand-side measures by utilities (downstream of the meter), but they could also be owned or implemented by public utilities.

Key Influencers

While the source of significant change is frequently enabled by government policy, the bulk of the change process and ongoing momentum is further catalyzed by institutions, including professional regulators. These changes ultimately lead to market transformation, shifts in consumer demand, and changes to industry products and services. A brief description of such institutions is provided below, and a detailed list is included in Appendix F.

The primary arms of government include Crown corporations, non-profit agencies, tribunals, and other levels of government that provide functions that are formally delegated through legislation. These can include enforcement of building codes and safety standards for equipment, oversight of professional registrants via provincial/territorial regulatory bodies, maintenance of data repositories to support vital market functions, regulation of natural monopoly energy providers, and arbitration of appeals. Effectively, these organizations are policy-makers, but with a narrower scope than the government that establishes their governing legislation. They play vital leadership roles and are key influencers for the roadmap.

¹²⁰ Energy Step Code Council. n.d. BC Energy Step Code Requirements. Accessed 2023. <https://energystepcode.ca/requirements/>.

¹²¹ City of Vancouver. n.d. Policy: Green Buildings Policy for Rezonings. Accessed 2023. <https://guidelines.vancouver.ca/policy-green-buildings-for-rezonings.pdf>.

Some major decarbonization options are district heating and cooling and thermal energy storage. Many existing district heating and cooling systems are owned by governments, military bases, and colleges and universities across the country. These can be decarbonized and serve as visible demonstrations across the country.

The second category are organizations that oversee self-governing professions, also established by legislation. These include provincial/territorial engineering regulators that oversee ethical and professional practice, along with Engineers Canada, which provides accreditation of engineering schools. Professional regulators can play a substantial role in guiding buildings-sector professionals to lead or preside over the transition highlighted in this roadmap. The case study of British Columbia is exemplary. The self-governing status of engineers was modified in 2021 under the *Professional Governance Act*, which mandated that Engineers and Geoscientists BC and five other professional regulators enhance or establish a standardized code of ethics, council procedures, continuing professional development, firm registration, and other requirements.¹²² These equip Engineers and Geoscientists BC to play a greater leadership role in regulating the profession and shaping the future, with significant overlap with this roadmap in areas such as climate change risk mitigation, letters of assurance for the building code, and whole-building energy modelling and building enclosure engineering professional practice guidelines.¹²³ Architects are also key influencers, as they are responsible for the building envelope in the context of building codes. In British Columbia, architects are the registered professional of record for the envelope of complex buildings, and they often take on the role of coordinating registered professional for new building construction, overseeing the work of other professionals of record.¹²⁴

A third category is standards development organizations and certification organizations accredited by the Standards Council of Canada,¹²⁵ the American National Standards Institute,¹²⁶ and other organizations around the world.¹²⁷ With expert input, standards development organizations develop model consensus standards that include test procedures, minimum performance standards for buildings and equipment, and professional practice guidelines. Certification organizations verify and provide certification that products and professionals meet the standards and guidelines of standards development organizations. Standards development organizations are generally non-profit, and in some cases, they are cross-subsidized by certification organizations that operate at arm's length. The two most prominent standards and code development organizations in Canada are Codes Canada, operated by the National Research Council, and the Canadian Standards Association (CSA), operated under CSA Group. Model codes and standards are not mandated until federal, provincial, and territorial legislation and regulations reference them but engineers can reference them voluntarily as part of best engineering practice. Model codes play a vital role in promoting harmonization across

¹²² Office of the Superintendent of Professional Governance. n.d. Professional Governance Act. Accessed 2022. <https://professionalgovernancebc.ca/about/professional-governance-act/>.

¹²³ Engineers and Geoscientists BC. n.d. Buildings. In: Guidelines and Advisories. Accessed 2022. <https://www.egbc.ca/app/Practice-Resources/Individual-Practice/Guidelines-Advisories#buildings>.

¹²⁴ Government of British Columbia. n.d. Letters of Assurance. Accessed 2023. <https://www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/bc-codes/letters-of-assurance>.

¹²⁵ Standards Council of Canada. n.d. Accreditation. Accessed 2022. <https://www.scc.ca/en/accreditation>.

¹²⁶ American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). n.d. Three ASHRAE Professional Certifications Earn ANSI Accreditation. Accessed 2022. <https://www.ashrae.org/about/news/2016/three-ashrae-professional-certifications-earn-ansi-accreditation>.

¹²⁷ European co-operation for Accreditation. n.d. Who Are We? Accessed 2022. <https://european-accreditation.org/about-ea/who-are-we/>.

jurisdictions, reducing trade barriers, increasing productivity, and reducing costs for Canadians. This is recognized by the Canadian Free Trade Agreement Regulatory Reconciliation and Cooperation Table.¹²⁸

The fourth category of key influencers is research and educational institutions, including academia. These institutions are parties to the innovation ecosystem, which includes the innovation continuum of research and development, demonstration, commercialization, and deployment. Educational institutions, industry and government research agencies, research funders, and umbrella organizations build content and momentum for innovation that can become common practice when commercialized. An example of innovation collaboration can be found with low-emissivity windows that reduce heat loss and solar heat gain; these were a space-age technology in the late 1990s and are currently the minimum standard.¹²⁹

The fifth category is investment fund governance, including investment agencies and institutional investment fund managers that apply environmental, social, and governance criteria to determine their investment portfolios. Investment regulators establish governance expectations and criteria to align with the public interest and promote related strategies, risk management, metrics, and targets within the organizations they regulate. An example is the Canadian Securities Administrators' 2021 consultation on proposed climate-related disclosure requirements.¹³⁰ By extension, institutional investment organizations can also fuel market transformation. For example, the Canada Infrastructure Bank's \$2 billion fund for green infrastructure and building retrofits includes components for public and commercial buildings and zero-emission vehicles.¹³¹ Special purpose funds co-fund buildings-sector investments, including the Canada Mortgage and Housing Corporation, BC Housing's BC Builds program, the Federation of Canadian Municipalities' Green Municipal Fund, and the Atmospheric Fund. The Atmospheric Fund established Efficiency Capital Corporation, which offers risk management instruments for building retrofits, including engagement of prequalified professionals that specialize in energy efficiency.¹³² Industry associations such as the Building Owners and Managers Association provide a forum for integrating the various real estate interests and enabling action.

In many provinces and territories, Crown corporation energy utilities play a key role in advancing public policy objectives and fuelling demand-side measures. These include energy conservation; efficiency; load management; fuel switching; district energy; zero-emission vehicle fuels; and enabling measures for privately owned on-site generation, storage, and microgrids. Utility regulators indirectly influence these types of initiatives for investor-owned utilities. Some utilities have historically provided on-bill financing for roadmap-related building improvements, as summarized in a paper by the Pacific Institute for Climate Solutions.¹³³

¹²⁸ Canadian Free Trade Agreement. n.d. Regulatory Reconciliation and Cooperation. Accessed 2022. <https://www.cfta-alec.ca/regulatory-reconciliation-cooperation/>.

¹²⁹ RDH Building Science. n.d. Transforming the Window and Glazing Markets in BC Through Energy Efficiency Standards and Regulations. Accessed 2022. <https://www.rdh.com/resource/transforming-the-window-and-glazing-markets-in-bc-through-energy-efficiency-standards-and-regulations/>.

¹³⁰ Ontario Securities Commission. Canadian Securities Regulators Seek Comment on Climate-Related Disclosure Requirements. Accessed 2022. <https://www.osc.ca/en/news-events/news/canadian-securities-regulators-seek-comment-climate-related-disclosure-requirements>.

¹³¹ Canada Infrastructure Bank. n.d. Green Infrastructure. Accessed 2022. <https://cib-bic.ca/en/sectors/green-infrastructure/>.

¹³² Efficiency Capital. n.d. Building Energy Savings. Accessed 2022. <https://efficiencycap.com/>.

¹³³ Efe, S., ur Raheem, I., Wan, T., and Williamson, C. 2015. Cheaper Power Bills, More Jobs, Less CO₂: How On-Bill Financing Done Right Can Be a Quick Win for British Columbia. Pacific Institute for Climate Solutions. Accessed 2022. <https://pics.uvic.ca/sites/default/files/uploads/publications/On-Bill%20Financing%20FINAL.pdf>.

The seventh group of key influencers includes agencies that implement demand-side measures and distributed energy resources to influence the decision-making of property owners, property managers, and sometimes tenants. These include “efficiency utilities” such as Efficiency Manitoba and Efficiency Nova Scotia, municipal/regional government transformation initiatives such as the Federation of Canadian Municipalities’ Low Carbon Cities Canada,¹³⁴ technical support organizations such as the Zero Emissions Innovation Centre, property-assessed clean energy programs such as Nova Scotia PACE,¹³⁵ and zero-carbon-energy fuel development organizations such as the BC Clean Energy and Major Projects Office and QUEST Canada.

Principle #1: Facilitate Integrated Demand-Side and Supply-Side Resource Planning

Each of the five levels of government has distinct jurisdiction and measures to influence the building construction and real estate markets. Collectively, they can catalyze the achievement of the metrics and outcomes covered in Section 2. This requires a common policy and planning framework.

The first principle calls for provincial/territorial governments to lead the development of integrated demand-side and supply-side roadmaps for the buildings sector, in consultation with subject matter experts, and create interfaces with utility grids and zero-emission vehicles in the energy supply and transportation sectors, respectively. Furthermore, it calls for the federal government to provide capacity support to those lead jurisdictions and empower local and Indigenous governments to participate.

The authors have developed the following objectives and strategies to guide this integrated planning for the buildings sector:

Objective	Strategies
<p>Establish common measurable goals across multiple levels of government. This allows all five levels of government to harmonize the targeted outcomes of their measures to increase the overall effect. It also allows for multiple levels of scrutiny to achieve the same targeted outcomes.</p>	<ul style="list-style-type: none"> • Establish consistent metrics and common targets for efficiency, resilience, and decarbonization. • A risk management framework¹³⁶ could be added to consider unintended consequences of other policy goals, such as those noted below under “Maximize co-benefits.” • Structured decision-making could be applied to co-optimize the least-economic-cost solutions against other objectives. • A simplified approach is a “balanced scorecard” method.¹³⁷

¹³⁴ Green Municipal Fund. n.d. Low Carbon Cities Canada (LC3). Accessed 2022. <https://greenmunicipalfund.ca/low-carbon-cities-canada-lc3>.

¹³⁵ Nova Scotia PACE. PACE Programs. Accessed 2022. <https://novascotiapace.ca/pace-programs/>.

¹³⁶ Midgard Consulting Inc. 2022. BCUC Proceeding #922 – FortisBC Inc. 2021 LTERP and LT-DSM Plan: Residential Consumer Intervener Association Evidence Submission. Accessed 2022. https://docs.bcuc.com/Documents/Proceedings/2022/DOC_66228_C8-6-RCIA-Evidence-Submission.pdf.

¹³⁷ Pape-Salmon, A., Montgomery, J., Henderson, E., and Lepage, R. 2018. Roadmap to Resilient, Ultra Low Energy Buildings in the Pacific Northwest. 1st International Conference on New Horizons in Green Civil Engineering, Victoria, BC, April 25–27, 2018. Accessed 2022. <https://www.uvic.ca/ecs/civil/assets/docs/profiles/andrewps/resilient-low-energy-buildings-in-pnw-paper.pdf>.

Objective	Strategies
<p>Minimize the overall cost to society. This includes incremental capital costs of achieving desired outcomes; transaction costs for policy interventions; ongoing costs of operations, energy, and maintenance; opportunity costs; and costs of unintended consequences, such as reduced durability that leads to more frequent capital replacement.</p>	<ul style="list-style-type: none"> • Scenario planning and modelling could be done nationally, with granularity at the provincial/territorial level, to provide a consistent approach across all 13 provincial/territorial jurisdictions. • Both the BC and federal governments have completed cost-minimization analyses for their decarbonization plans. These analyses are limited in focus to the single issue of least-cost decarbonization, despite resultant impacts on energy system reliability, safety, equity/inequity of impacts, and resilience. • The expansion or deployment of thermal/district energy systems can be much more cost-effective than electrification of heating when taking full account of the expansion to generation and grid capacity. Full-cost accounting yields many other solutions that have been largely overlooked. The fact that Canada lags behind other industrialized countries in such technology should not negate its consideration. • Individual energy utilities have also done scenario planning across the economy, such as the Guidehouse study for FortisBC,¹³⁸ BC Hydro’s Electrification Plan,¹³⁹ and the ICF study for the Canadian Gas Association.¹⁴⁰
<p>Consider optimizations and solutions from a buildings-sector standpoint across multiple policy frameworks and institutions. This can be achieved by framing integrated plans around the circumstances of building owners, occupants, and other stakeholders. These optimizations and solutions are the source of investment in and construction of buildings by property managers, building owners, and developers.</p>	<ul style="list-style-type: none"> • The scope of integrated planning could flip from the current horizontal silos of institutions across multiple consumer sectors to vertical silos of the sectors themselves across all institutions (see Table 6). • This approach could be achieved by merging the work of the <i>CleanBC Roadmap to 2030</i>, Canada’s <i>2030 Emissions Reduction Plan: Clean Air, Strong Economy</i>, building strategies of major local governments, gas utility decarbonization plans and electric utility electrification plans, and other policy goals noted below.

¹³⁸ Guidehouse. 2020. Pathways for British Columbia to Achieve Its GHG Reduction Goals. Accessed 2022. <https://www.cdn.fortisbc.com/libraries/docs/default-source/about-us-documents/guidehouse-report.pdf>.

¹³⁹ Government of British Columbia. 2021. New Plan Makes It Easier to Switch From Fossil Fuels to Made-in-B.C. Clean Electricity. Accessed 2022. <https://news.gov.bc.ca/releases/2021PREM0059-001861>.

¹⁴⁰ Canadian Gas Association. 2021. Potential Gas Pathways to Support Net-Zero Buildings in Canada. Accessed 2022. <https://www.cga.ca/wp-content/uploads/2021/11/Potential-Gas-Pathways-to-Support-Net-Zero-Buildings-in-Canada-CGA-October-2021.pdf>.

Objective	Strategies
<p>Maximize co-benefits for other policy goals beyond energy efficiency and decarbonization.</p> <p>These could include energy system reliability and resilience, safety, housing supply, public health (e.g., indoor air quality), economic renewal, flexibility and adaptability, circular economy, and comprehensive resilience.¹⁴¹ This is the opposite of tunnel vision around a single policy goal, such as decarbonization. Governments collectively have multiple areas of market intervention through legislation, and decarbonization and resilience must not compromise aspects such as public safety. This honours the sector-specific approach of this roadmap, which notes that investors aim to achieve more than one performance improvement when investing in buildings, rarely pursuing just decarbonization.</p>	<ul style="list-style-type: none"> For new and existing buildings, improvements such as a high-performance building envelope, airtightness, balanced air pressure, elimination of thermal bridges, heat-recovery ventilators, heat pumps, and peaking units also improve resilience, as well as indoor air quality and comfort. Excellent examples are available from BC Housing.^{142,143,144}
<p>Leverage all sources of data to track performance, inform policies, and avoid leakage.</p>	<ul style="list-style-type: none"> This links to Principle #5, to ensure that planning is informed by evidence and data, with policy adjustments made after to address conflicts.

Table 6: Governance of the Buildings Sector – Parallel Regulatory Frameworks

Regulatory frameworks for buildings	Building sub-sectors			
	Residential	Commercial	Institutional	Rental and social housing
Land use planning	Regional, municipal/local, and Indigenous government planning			Governments providing land
New construction	Building codes, advanced energy-efficiency and decarbonization standards and programs			
Equipment	Federal and provincial/territorial energy-efficiency programs and standards			
Asset management	Mandatory depreciation report	N/A	Capital asset management framework	

¹⁴¹ Elaboration of these co-benefits are topics for future research, starting with circularity of materials (life-cycle energy and emissions) and the structural and life-safety resilience of buildings against acute shocks.

¹⁴² BC Housing. n.d. Building Enclosure Design Guide: Wood-Frame Multi-Unit Residential Buildings. Accessed 2022. <https://research-library.bchousing.org/Home/ResearchItemDetails/2001>.

¹⁴³ BC Housing. 2019. Residential Design and Construction Guides. In: Categories > Technical Research. Accessed 2022. <https://research-library.bchousing.org/>.

¹⁴⁴ BC Housing. 2019. BC Energy Step Code: Design Guide Supplement S3 on Overheating and Air Quality. Accessed 2022. <https://www.bchousing.org/publications/BC-Energy-Step-Code-Guide-Supplemental.pdf>.

Regulatory frameworks for buildings	Building sub-sectors			
	Residential	Commercial	Institutional	Rental and social housing
Building renewal	Building codes, equipment energy efficiency standards, tax credits			+ Design guidelines, rent increase restrictions, government funds
Real estate	Real estate labelling	Benchmarking	Greening government buildings	Tenant protection
Electricity supply	Public utility commissions (planning, projects, supply, rates), clean electricity standard			
Fossil fuels, other methane, and hydrogen	Public utility commissions (planning, projects, supply, rates), carbon cap (emerging)			
Distributed and district energy	Public utility commission (planning, projects, supply, rates), net metering, government ownership, connection bylaws			

There will be variations in approaches across provincial/territorial governments, synonymous to a roadmap with three modes of transport, all representing routes to the same destination at different paces:

1. **The fastest pathway to resilience and decarbonization (“bullet train”).** This approach involves front-loading costs and achieving targets with regulatory measures that limit market choices—for example, the City of Vancouver’s Zero Emissions Building Plan.¹⁴⁵ This is a highly proactive approach that could position jurisdictions as leaders, with spinoff economic benefits such as investment from environmental, social, and governance institutional financing that rewards early adopters. The downsides are technology risk and the potential for stranded investment, should the jurisdiction drive fledgling solutions that ultimately fail or perform suboptimally under future market conditions. It also risks jurisdictions acting outside their appropriate sphere of influence, such as local governments driving energy supply planning. Finally, there may be issues related to social equity, as the heavy emphasis on regulation could lead to unintended consequences such as costs being borne by those least able afford them.
2. **A balanced approach (“Trans-Canada Highway”).** This approach is suitable for all Canadian jurisdictions, with a combination of “carrots,” such as tax credits; evaluation of readiness; and mid-term “sticks” in sub-sectors with the capacity to embrace a regulatory approach and geographic areas with accessibility and acceptance. An example is the CleanBC *Roadmap to 2030*. This is heavily weighted on demand-side measures as a means of adapting to future market conditions, including decarbonization of supplies and climate change.
3. **A cost-minimization approach (“bike path network”).** This approach is education- and incentive-oriented, with mounting pricing measures that will gradually influence investment decisions and rear-

¹⁴⁵ City of Vancouver. n.d. Zero Emissions Buildings. Accessed 2022. <https://vancouver.ca/green-vancouver/zero-emissions-buildings.aspx>.

loading internationally driven performance standards in regulation. This provides significant leeway for the buildings sector to autonomously adapt to changing market conditions, leading to a version of the International Energy Agency's framework for net-zero emissions by 2050.^{146,147} However, it also places significant cost pressure on future generations, as well as risk of economic hardship from being unable to react to global conditions. The best analogy for this example is the lack of government intervention in the global oil industry until major unexpected events occur, such as the COVID-19 pandemic and the war in Ukraine (with its major impact on fuel prices and energy infrastructure becoming Russian war targets). The challenges for governments are highlighted in initiatives such as the BC *Fuel Price Transparency Act* retail pilot.¹⁴⁸

Principle #2: Focus on Performance-Based Outcomes that Foster Competition and Enable Innovation

This principle focuses on modernizing the way building performance is determined, designed, and measured.

Many energy codes for buildings have performance-based standards, with singular metrics such as energy consumption per square metre of conditioned floor area or heat loss/gain through a building envelope. Examples of such codes are ASHRAE 90.1, ASHRAE 189.1, the National Energy Code of Canada for Buildings, EnerGuide for Houses, and local government reach codes. This is in contrast to prescriptive standards that specify requirements for building components. Examples of such standards are minimum RSI values for roofs, walls, crawl spaces, or foundation walls, or specific U-values for individual windows. All of these can be replaced with effective performance U-values or RSI values for the overall building enclosure.

Performance standards are often specified in tables, with metrics that inform building design by professionals. They replace dozens of pages of prescriptions and menus, which are conducive to broad application both with and without professional oversight. Performance standards require investment in professional oversight that owners, managers, and developers may endeavour to avoid in favour of “cookie-cutter” prescriptions and menus. However, professional oversight is intended to optimize designs, minimize overall costs, and implement innovative solutions, offsetting the costs of professional services.

There continues to be a role for prescriptive requirements for houses and low-rise buildings, as provided in Part 9 of the National Building Code of Canada (NBC) model code. By definition, these buildings do not require the work of a registered professional, so objectives and standards are set out in specific language.

Building performance objectives beyond energy efficiency are rarely specified in terms of performance metrics. These include the health and safety of occupants, fire and structural protection of the building, accessibility for people with disabilities, and water efficiency. Other performance aspects are defined in interconnection requirements from public utilities, energy and safety standards for equipment, design guidelines by municipalities, and others. While energy efficiency can be optimized through performance standards, the lack of

¹⁴⁶ International Energy Agency. 2021. Net Zero by 2050: A Roadmap for the Global Energy Sector. Accessed 2022. <https://www.iea.org/reports/net-zero-by-2050>.

¹⁴⁷ International Energy Agency. 2021. Net Zero by 2050: A Roadmap for the Global Energy Sector [slides]. Accessed 2022. https://iea.blob.core.windows.net/assets/84c1a929-670a-4321-b7fd-a681f60ebe8e/NZE2050_launch_slides.pdf.

¹⁴⁸ Government of British Columbia. n.d. Fuel Price Transparency Act. Accessed 2022.

<https://www2.gov.bc.ca/gov/content/industry/natural-gas-oil/responsible-oil-gas-development/15626>.

performance standards in other categories does not allow for trade-offs to “co-optimize” multiple performance objectives.

Canada has taken steps toward performance-based codes with the implementation of an objectives-based code.

Since 2005, the NBC has included objectives, sub-objectives, and functional statements, supporting an evolution toward performance-based outcomes. This has been reinforced by documented analysis of the intent of each code provision and an application statement. Converting the NBC to an objectives-based format has made it more accommodating to innovation by clarifying its scope, as well as the intent behind its requirements. In NBC 2020, the five objectives are safety, health, accessibility, fire and structural protection of buildings, and environment.

In NBC 2005, the approach shifted from “equivalencies” in performance to a new “alternative solutions” compliance path in Division C. This permitted the use of materials, equipment, systems, methods of design, and construction procedures that provide at least equivalent performance as the “acceptable solutions” in Division B.¹⁴⁹ The analysis and proof of equivalency are often completed by registered professionals and submitted to the authority having jurisdiction.

Authorities having jurisdiction vary in their acceptance of alternative solutions. Some interpret it widely, including allowing variances in building size and use (known as “innovative solutions”¹⁵⁰). Some jurisdictions, such as Vancouver, BC, and Surrey, BC, may also allow the services of certified professionals to supplement local government compliance oversight.¹⁵¹ Others are cautious about the acceptance of alternative solutions with respect to the avoidance of risk and liability. In BC, local governments have “immunity concerning approval of certified building plans” under section 743 of the *Local Government Act*, protecting them from liability if a registered professional certified that the plans complied with provincial building regulations.¹⁵²

A purely performance-based approach would enable trade-offs for benefits such as design innovation, market competition, and cost reduction, all in the interest of co-optimizing outcomes. This would require empowering the professional community to lead design solutions across all institutional silos, careful coordination of policy-makers at all levels of government, and removal of duplicate and inflexible regulatory interventions and institutions that prevent such co-optimization.

The former CEO of Southern Company (the second-largest energy utility in the United States) is quoted as recommending an innovation approach to decarbonization, as opposed to a regulated approach that gets a compliance mindset.¹⁵³

Ultimately, this principle calls for establishing an “innovation ecosystem” that is premised on performance-based standards for desired outcomes sought through government interventions. Design professionals in the

¹⁴⁹ National Research Council Canada, Institute for Research in Construction. 2015. Canada’s National Model Construction Codes Development System. Accessed 2022. <https://ircc.info/Doc/IBCS.pdf>.

¹⁵⁰ Author’s terminology, included in research reports not released publicly.

¹⁵¹ Engineers and Geoscientists BC. n.d. Certified Professional Program. Accessed 2022. <https://www.egbc.ca/Practice-Resources/Programs-Resources/Certified-Professional-Program>.

¹⁵² Government of British Columbia. 2015. Local Government Act, RSBC 2015, Chapter 1. Accessed 2022. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/r15001_18.

¹⁵³ Fanning, T. 2022, January. Fanning at EEI Financial. Public Utilities Fortnightly. Accessed 2022. <https://www.fortnightly.com/fortnightly/2022/01/fanning-eei-financial>.

buildings sector would be empowered to lead this innovation in the design, management, and renewal of buildings.

The ecosystem would anticipate future conditions and enable adaptable design solutions, as opposed to a compliance mindset that is rigidly focused on current requirements and historic market conditions. For example, climate change impacts are increasing, and predictions of baseline conditions that current buildings will face in two to three decades are available. Yet, codes are currently based on historic weather data, which may lead to “dead ends.” This could result in obsolescence due to factors such as excessive energy costs or overheating that cannot be repaired. Fortunately, the 2025 national model construction codes are poised to incorporate climate projections to inform building design, which is necessary given the long operating life of buildings.

Adaptive design solutions would respond to future risks and projected vulnerability to build in resilient mitigation measures that minimize future “damage costs” with a moderate “control cost.” An Insurance Bureau of Canada study compared the cost of mitigating the impact of climate change with the benefits of avoiding it, finding a ratio of 6 to 1 across the study scope.¹⁵⁴ Considered another way, the cost to address risk factors in advance of a natural disaster are as low as one-sixth the cost of repairs after. A more recent study puts the multiplier of damage costs to mitigation costs at 13 to 1.¹⁵⁵

Ultimately, the innovation ecosystem could inform the prioritization of limited investment in the buildings sector. Far too often, building owners and managers face competing or conflicting objectives and do not have the opportunity or enough information to co-optimize. The regulatory framework with the biggest stick or the incentive scheme with the largest carrot informs limited investment dollars, along with short-term benefits to the investor.

This may result in short-term market activity in response to incentives that is disproportionate to the value to society and that may cause unintended consequences. These consequences could even also compromise other objectives, including those with long-term benefits.

The engineering community and other professional communities have a unique insight into the conflicts between regulatory frameworks, suboptimal performance outcomes, future conditions, and dead ends. By extension, these professions are uniquely positioned to communicate the issues to all levels of government, if appropriately resourced to do so.

In summary, the following strategies are recommended under this principle:

- Establish common performance metrics across all categories of building performance outcomes and regulatory frameworks.
- Harmonize regulatory frameworks to avoid conflicts preventing co-optimization.
- In the spirit of “alternative solutions” in the NBC, empower buildings-sector professionals to design to those goals and co-optimize design across objectives and regulatory frameworks.
- Maximize flexibility on pathways to achieve goals for those objectives, enhancing innovation, increasing competition, and minimizing costs.
- Establish an “innovation ecosystem” within key professional and institutional communities.

¹⁵⁴ Federation of Canadian Municipalities. 2020. Investing in Canada’s Future: The Cost of Climate Adaptation at the Local Level. Accessed 2022. <https://data.fcm.ca/documents/reports/investing-in-canadas-future-the-cost-of-climate-adaptation.pdf>.

¹⁵⁵ Canadian Climate Institute. n.d. Damage Control: Reducing the Costs of Climate Impacts in Canada. Accessed 2022. <https://climateinstitute.ca/reports/damage-control/>.

- Develop adaptive design solutions and avoid prescriptions with dead ends, despite known changing conditions.
- Focus on risk identification, vulnerability assessment, and mitigation versus exposure to recovery and damage costs.
- Communicate extensively with government on potential adjustments to policy frameworks to enhance performance, innovation, and resilience, as opposed to a compliance mindset.

Principle #3: Efficiently Allocate Jurisdictional and Institutional Responsibility

A natural extension to Principle #1 around integrated demand-side and supply-side planning is to efficiently allocate responsibility between the five levels of government and their associated regulatory frameworks and institutions.

The first strategy is to facilitate an **orderly transition of the buildings and energy sectors and avoid fragmentation**. In doing so, government interventions in the market would align with the ultimate goals of the integrated plan. This is possible with strong provincial/territorial leadership in harmonizing with national model codes and standards and delegating jurisdiction to other levels of government (e.g., municipal/regional, Indigenous).

Despite the initiation of a Modernization Strategy in 2014 and the introduction of the *Building Act* in 2015, the building regulatory system in BC continues to have significant fragmentation. This is due to both a lack of guidance on the implementation of provincial building codes by local authorities and significant influence by other regulatory systems. For example, the BC Energy Step Code provides a technical roadmap to the transformation of energy-efficiency standards to net-zero-energy-ready construction by 2032.¹⁵⁶ This multi-jurisdictional coordination effort was influential in the development of the tiered energy codes in NBC 2020 and the National Energy Code of Canada for Buildings 2020. This illustrates a second strategy to **harmonize government levers at multiple levels of government**.

Provincial/territorial effort to promote consistency takes time, and interim steps of other levels of government may appear to be contradictory. For example, the BC Energy Step Code is implemented by the authority of both the BC government and local governments, with the BC government setting out a technical roadmap with multiple steps and local governments mandating one of the steps in bylaw. This has led to a diversity of bylaws that may appear to show disharmony on the surface, as illustrated in Figure 23. However, subsequent editions of the BC Building Code, issued every five years, reset the steps (to step 3 in 2023), and the early adopter communities have prepared the market for that mandate.

¹⁵⁶ Home Performance Stakeholder Council. n.d. Home. Accessed 2022. <https://homeperformance.ca/>.

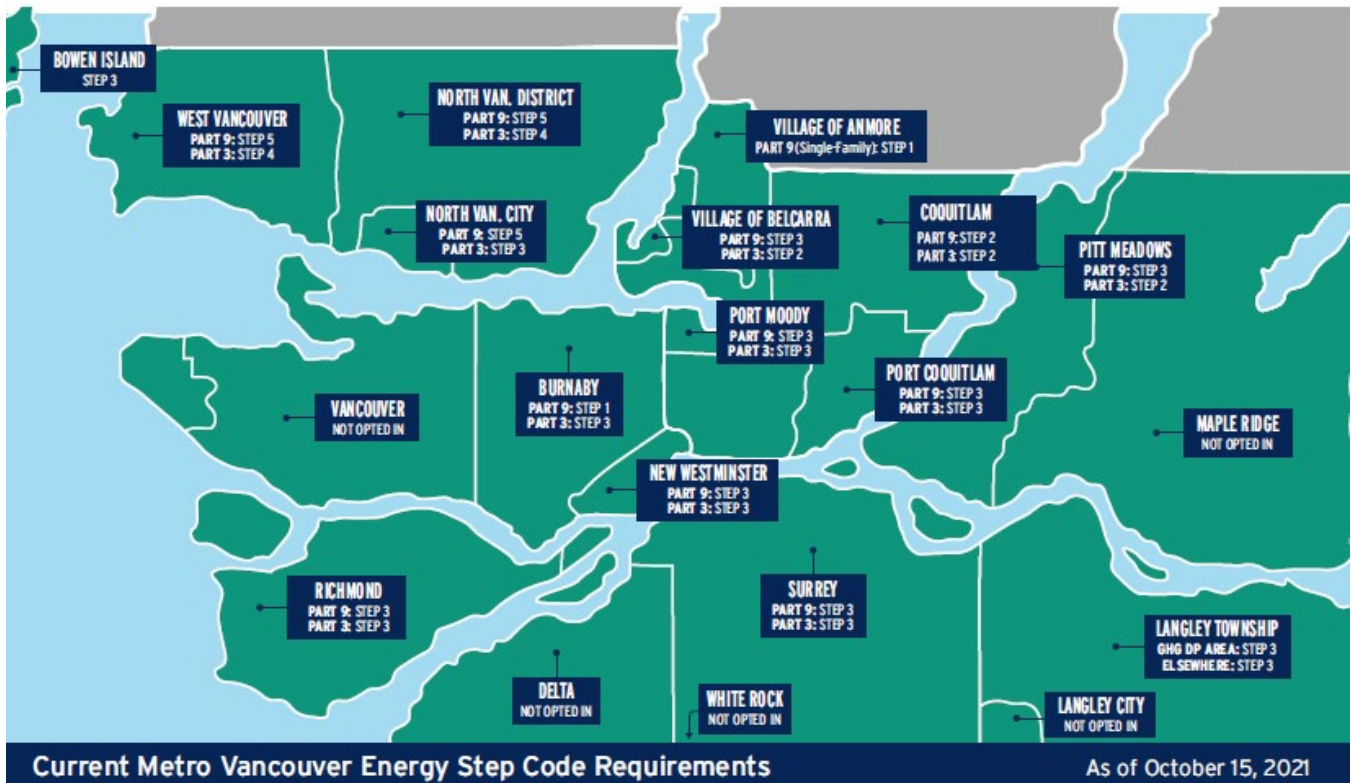


Figure 23: Fragmented BC Energy Step Code implementation in Metro Vancouver as of October 15, 2021.¹⁵⁷

Ten of these local governments have added to their bylaws a “low-carbon energy system” option that allows builders to reduce energy-efficiency requirements in exchange for not installing natural gas. While this results in the decarbonization of buildings and lowers the capital cost of construction, it does so at the expense of energy-efficiency standards. This reduces the affordability of energy for future building owners and occupants. It also inserts local governments into provincial energy resource planning, which could result in significant and unintended consequences related to energy system reliability, planning, investment in distribution systems, and concerns about stranded assets. These practices are misaligned with Principle #1 around integrated planning that would reduce demand and decarbonize energy supplies simultaneously.

Conflict within and fragmentation between the city halls of British Columbia has created an impetus for the evolution of policy and leadership by the provincial government, culminating in the *CleanBC Roadmap to 2030*. This informs the third strategy, to **allocate responsibility to the highest practical point of governance**, as that jurisdiction will have the largest influence for a given institutional cost. It also avoids incompatible directions and fragmentation that can compromise public support, avoids overlapping interventions and unnecessary implementation costs, and aligns with a deliberate effort to focus on areas with the greatest impact, known as the “surgical” approach to policy-making.

Figure 24 depicts a hypothetical example of allocating responsibility to the highest point of governance. The first triangle illustrates the target audiences of policy intervention, with the top representing all buildings in a jurisdiction, such as British Columbia with over 2 million households. The second triangle illustrates the policy

¹⁵⁷ Homebuilders Association Vancouver. 2022. BC Energy Step Code Implementation Across the Region: Step Code Introduction. https://havan.ca/wp-content/uploads/2022/03/GR21_StepCodeRequirements-March15-2022.pdf.

measures and their relative impact by stakeholder in terms of market transformation. For example, at the top, the carbon tax results in a small change of emissions but applies to all households; at the bottom, caps and portfolio standards on energy utilities have the largest impact per regulated or affected party, enabling administrative efficiency.

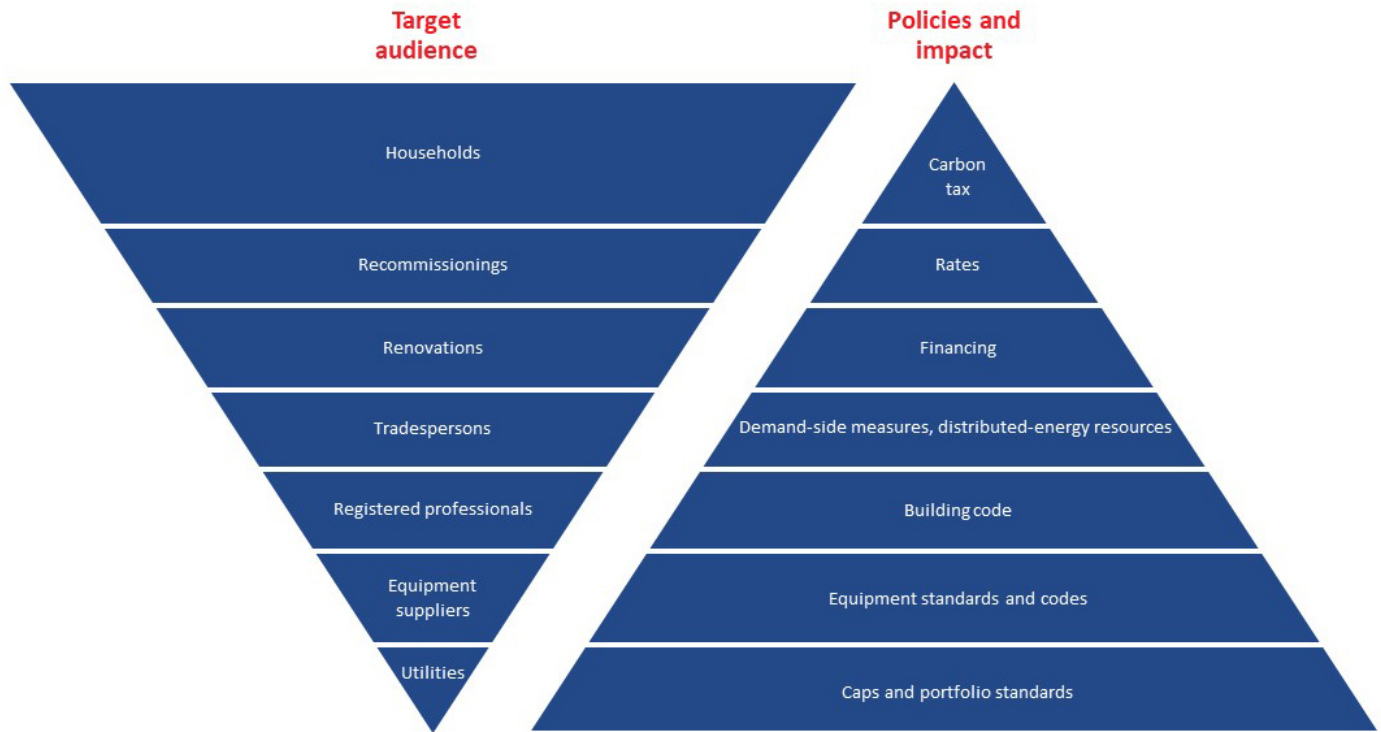


Figure 24: Approach for influencing the market at the highest practicable jurisdiction of influence (BC example based on author knowledge).

The levels in the double-triangle diagram are (from top to bottom) (example audience figures from BC):

- **Households:** The total consumer base, influenced by carbon taxes.
- **Recommissionings:** Hundreds of thousands of homes and buildings installing controls such as smart thermostats and energy management software through recommissioning efforts, influenced by rates.
- **Renovations:** approximately 50,000 buildings undergoing major renovations within a year, influenced by financing, demand-side measures, distributed-energy resources, and future building codes.
- **Tradespersons:** Tens of thousands of tradespersons influenced by demand-side measures in particular, including trade-ally programs of energy utilities and the Home Performance Stakeholder Council.¹⁵⁸
- **Registered professionals:** Thousands of architects and engineers designing new buildings, regulated by building and electrical codes.
- **Equipment suppliers:** Tens of equipment suppliers, including manufacturers, wholesalers, and distributors—anyone influenced by energy-efficiency standards for equipment within the jurisdiction (e.g., federal, provincial/territorial).
- **Utilities:** Less than 10 major gas and electric utilities, influenced primarily by caps on emissions and portfolio standards for zero-carbon fuels.

¹⁵⁸ Home Performance Stakeholder Council. n.d. Home. Accessed 2022. <https://homeperformance.ca/>.

The CleanBC *Roadmap to 2030* embraces this approach and provides an impetus for an orderly transition across all levels of government. Before it was released, in the absence of coordinated action on energy utility emissions, several suboptimal interventions were made to influence utility emissions at the bottom of the “Policies and impact” triangle.

The fourth strategy aims to **support social equity in the implementation of policies and regulations and prevent disproportionate impacts on vulnerable populations, building and housing types, and regions**. This is not easy to do at the provincial/territorial level; therefore, local and Indigenous governments could also be empowered to flexibly apply sub-national mandates. While this goes against the principle of applying policies at the highest practicable level of governance, empowering communities creates opportunities for leadership and enhances resilience to regional risk factors. Codes and standards can be adapted to provide such flexibility for leadership and reflect local conditions, such as the tiered energy codes.

In summary, this principle includes the following strategies:

- Facilitate an orderly transition of the buildings and energy sectors.
- Harmonize government levers at multiple levels of government.
- Allocate responsibility to the highest practicable point of governance.
- Support social equity in the implementation of policies and regulations.

The traditional “market transformation” approach^{159,160} was coined by the US and Canadian federal governments to drive permanent improvements in the energy efficiency of equipment and buildings. It starts with the early adoption of new technologies and design practices and builds market share toward mass adoption of the most effective approaches. The extent of market transformation is determined by market-readiness indicators known as the five As of market transformation: availability, accessibility, awareness, affordability, and acceptance. Different government and energy utility levers support different stages of the market transformation during the process of fulfilling these indicators. Figure 25 illustrates a new approach to market transformation that includes integrated demand-side and supply-side measures, keeping energy resource mixes and costs outside the scope of the strategic effort.

¹⁵⁹ Natural Resources Canada. n.d. A Market Transformation Roadmap for Windows, Space Heating and Water Heating Technologies: Paving the Road to a Low Carbon Economy. Accessed 2022. <https://www.nrcan.gc.ca/energy/regulations/21290>.

¹⁶⁰ Natural Resources Canada. n.d. Market Transformation: Improving Energy Performance in Windows, Space Heating and Water Heating Equipment. Accessed 2022. <https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-regulations/market-transformation/21296>.

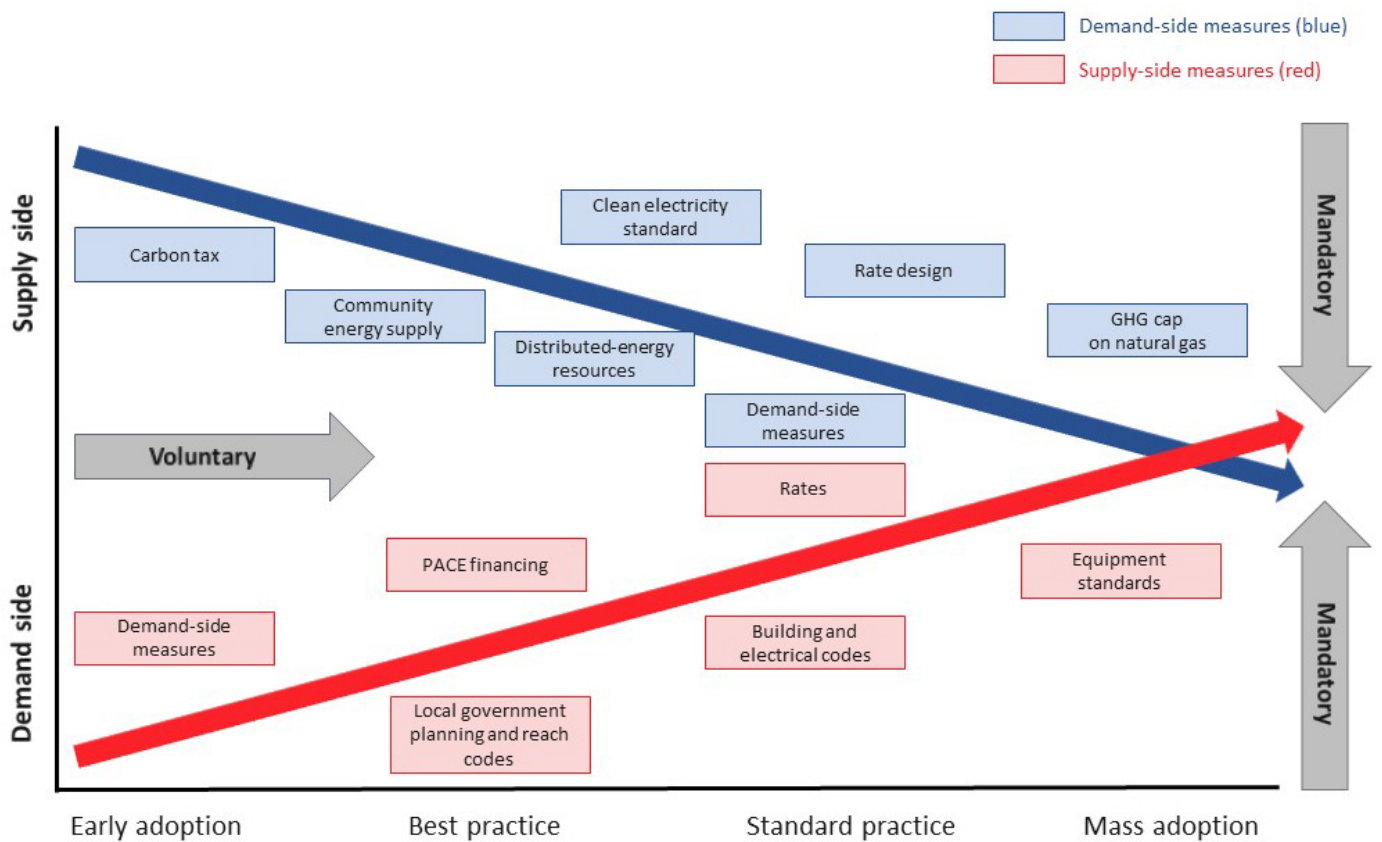


Figure 25: Market transformation approach between supply-side and demand-side measures.

Principle #4: Leverage Existing Investment Triggers in the Building Life Cycle

This principle pertains to the common triggers for investment in new and existing buildings and the associated objectives of government policy that are applied at the time of investment. The outcomes sought from this roadmap include energy efficiency, decarbonization, flexibility of energy systems, and resiliency. These are a subset of the overall objectives of building codes highlighted under Principle #2.

Principle #4 supports an alignment between the timing of building improvements to achieve the most cost-effective construction and renewal over the long-term life cycle of the building. It seeks to achieve economies of scale for professional services, construction, commissioning, and financing; to co-optimize design solutions that deliver multiple objectives; and to minimize disruption to building occupants and functions, in particular those with cost implications.

For new buildings, this practice is standard—the objectives of building codes are all achieved simultaneously. What is missing are objectives not included in codes that have long-term economic value, such as resilience against natural disasters or building durability. Building codes have life-safety objectives but do not generally have economic objectives, such as mitigating damage costs from extreme weather events, as outlined in Principle #2.

The renewal of existing buildings is more complicated, as investment triggers are often voluntary, with the exception of equipment or system replacement following failure or end of life.

Many building owners develop a capital asset management plan, depreciation report, or reserve fund study in concert with technical studies that consider the condition of capital assets, including roofing, windows, cladding, and mechanical and electrical equipment. These studies are mandated in several provinces for stratified housing or condominiums. For example, the BC *Strata Property Act* requires depreciation reports to be completed every three years, with a planning duration of 30 years.¹⁶¹ This creates an ideal opportunity to consider the timing of building renewals that address multiple objectives in an orderly fashion.

The result of capital asset management planning is that some building improvements occur earlier than needed to achieve economies of scale in design and construction, and others may be delayed, with temporary life-extension measures. Many building owners do the latter (i.e., deferred maintenance) as a natural course of cost minimization, but in some instances, the cost of replacement skyrockets with excessive delays.

The approach taken for stratified housing could be extended to all building types. Other sectors do so voluntarily, including commercial real estate.

Figure 26 illustrates natural triggers for investment in buildings. These include:

- Careful land-use planning to consider community objectives, the orientation of buildings for daylighting and access to on-site renewable resources, interconnections with utilities, the use of topography and landscaping for energy conservation and resilience (e.g., shading to reduce vulnerability to extreme heat events), and other objectives.
- For new construction, an integrated design process to co-optimize objectives mandated in building and safety codes and objectives of an economic nature, such as risk mitigation and building durability. A key aspect is commissioning to ensure design performance objectives are implemented.
- Building operations can include continuous optimization practices to maintain ongoing energy performance or explicit recommissioning or retro-commissioning efforts and real-time energy management.¹⁶² Collectively, these can result in a 5% to 25% energy improvement relative to no action.¹⁶³
- Development of a capital asset management plan to comply with legislation (e.g., for stratified housing), pursue the objectives in this roadmap, upgrade buildings to current standards, and future-proof buildings to prevent obsolescence.
- Implementation of a capital asset management plan for individual components within a budget, with timing to optimize economies of scale.
- A decision to either undertake a comprehensive building renewal or pursue demolition and building replacement.

¹⁶¹ Government of British Columbia. n.d. Strata Depreciation Report Requirements. Accessed 2022. <https://www2.gov.bc.ca/gov/content/housing-tenancy/strata-housing/operating-a-strata/repairs-and-maintenance/depreciation-reports/depreciation-report-requirements>.

¹⁶² BC Hydro. n.d. Continuous Optimization. Accessed 2022. <https://www.bchydro.com/powersmart/business/programs/continuous-optimization.html>.

¹⁶³ Natural Resources Canada. n.d. Recommissioning. Accessed 2022. <https://www.nrcan.gc.ca/energy-efficiency/data-research-insights-energy-ef/buildings-innovation/building-optimization/recommissioning/3793>.

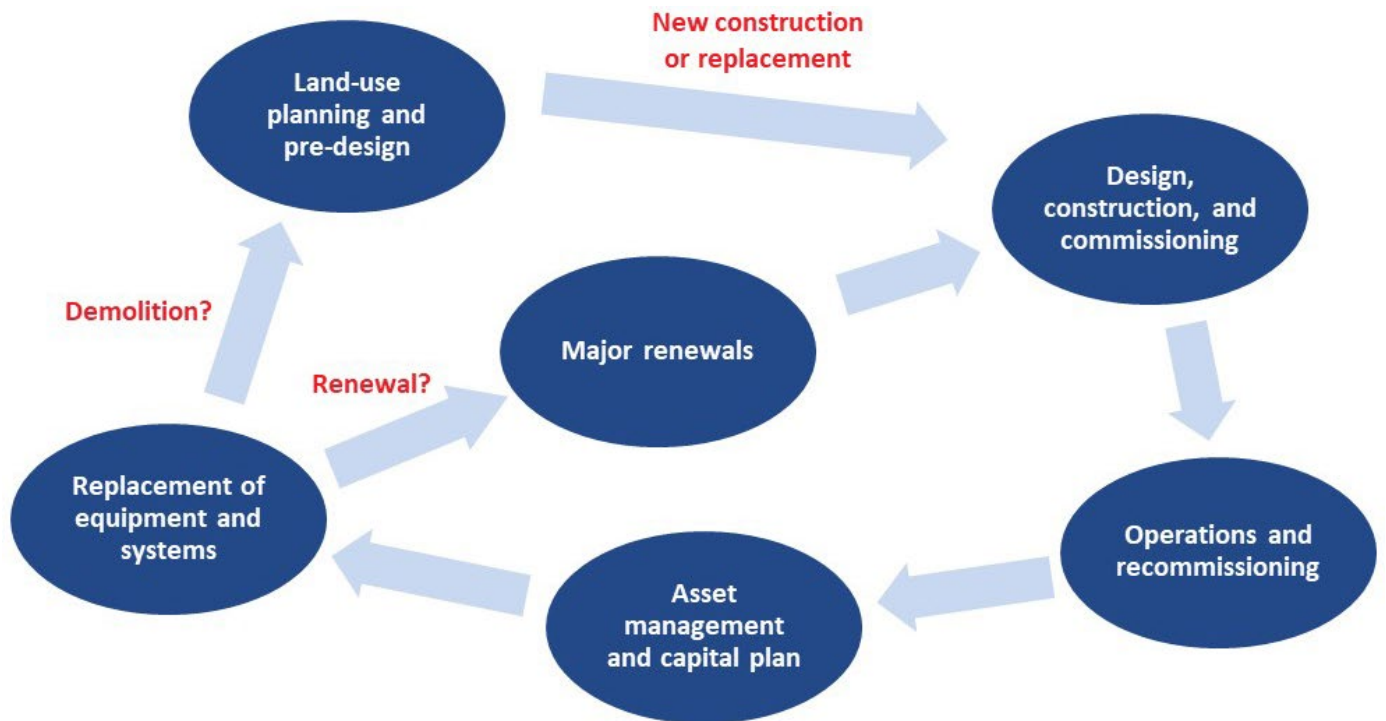


Figure 26: Investment triggers across the building life cycle

Principle #5: Facilitate Data-Driven, Outcomes-Based Codes and Standards

The premise of the roadmap is to promote outcomes-based policy-making and align government policy interventions with the vision set out in Section 2, using the goals and measurable outcomes from Section 3. The Government of BC’s *Policy Approaches Playbook* highlights “outcomes-based instruments” as a regulatory approach that is designed to focus on measurable outcomes rather than prescriptive processes, techniques, or procedures. This approach shifts the focus of regulation to the end results or outcomes, rather than inputs or theoretical outputs, although outputs may be used as proxy measurements. Outcomes-based regulations reduce the degree of government intervention by allowing businesses and individuals to choose how they will comply with legislated requirements.¹⁶⁴

To support this approach, the buildings sector would benefit from a significant increase in the use of data to drive performance-based standards and outcomes-based instruments. This could include data related to the desired outcomes at all stages of the building life cycle (see Figure 27). Given the importance of data in advancing outcomes-based instruments, its collection and reporting could justifiably be mandated by standards, along with appropriate protections for private information. The four stages of the building life cycle are outlined below, along with inherent data sets for each stage:

1. **New construction design** – Assumptions, parameters, and modelled performance. This is affected by land-use planning, including resource opportunities such as community energy systems that use waste heat and maximize efficiency of energy generation, distribution, and use.

¹⁶⁴ Government of British Columbia. 2020. *Policy Approaches Playbook: Considerations for Policy Development*. Accessed 2022. https://www2.gov.bc.ca/assets/gov/government/about-the-bc-government/regulatory-reform/pdfs/policy_approaches_playbook.pdf.

2. **Commissioning and validation at the time of occupancy** – Observed differences between design and construction, including aspects removed for value engineering.

Following this step, the data set from commissioning can be used to develop mitigation measures to address differences that could compromise building performance.

3. **Building operations** – Multiple data sets at various scales (e.g., whole building, individual systems, equipment, circuits), followed by verification of design against measured performance data, leading to a rejigging of continuous optimization operating strategies, including occupant engagement and building management priorities around energy use and GHG emissions.

Following this learning step, opportunities may be identified to adapt to changes in building occupancy and usage patterns for continuous optimization and to inform future retrofit priorities based on deficiencies or impact assessments.

4. **Building capital renewal** – Equipment condition assessments, capital asset management plans (with target replacement dates), energy audits, calibrated energy modelling based on measured data, and prospective building usage.

Following this learning step, guidance can be advanced to inform innovations in new construction design, codes, and standards, based on the performance of existing buildings, as verified by data sets.

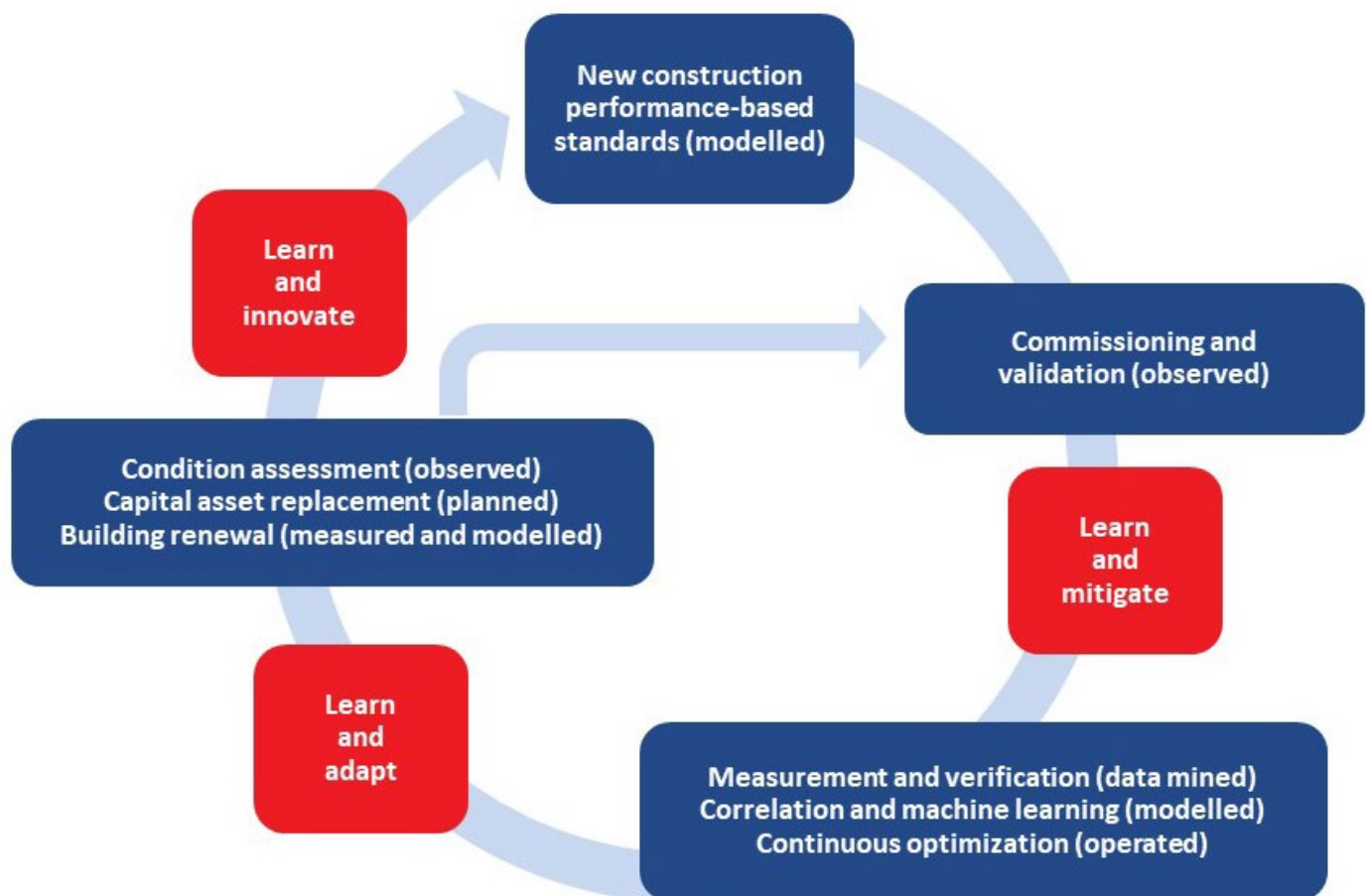


Figure 27: Collection of data related to desired outcomes at all stages of the building life cycle.

ASHRAE Standard 100, Energy and Emissions Building Performance Standard for Existing Buildings, is data-driven in that the energy use analysis and target requirements are based on measured data from thousands of buildings across North America.¹⁶⁵ Supplemental studies for British Columbia and Washington State have been completed from cohorts of building energy performance measurements and are summarized in the ASHRAE 100 Users' Guide.¹⁶⁶

With a data-driven, outcomes-based policy framework comes significant responsibility for market participants. A side effect is that the highest-performing buildings will command greater market value. With that comes an ethical responsibility among professionals to balance the protection of owners and public interests as manifested by government policy.

A data-driven policy framework also brings the burden of data collection, storage, analysis, and dissemination, which is increasingly common across all facets of Canadian society and the economy. There is a unique opportunity for the academic sector and other learning institutions to steward the emerging “big data” and analytical engines driving this transformation, under the privacy protection of government legislation. There are also complementary institutions such as statistics agencies, land title offices, and property assessors. In British Columbia, these include BC Stats (and Statistics Canada), the Land Title and Survey Authority, and BC Assessment.

Further, the data sets need to be used to inform codes and standards such as ASHRAE 100. To do this requires institutional capacity (e.g., academic learning organizations) and a strong liaison with codes and standards authorities (e.g., Codes Canada and ASHRAE).

Finally, with data collection and analysis emerges an opportunity for public education. For example, the City of Seattle has a long-standing data collection mandate on building energy benchmarking, and its ongoing data dissemination and specialized reporting provides significant value to multiple sectors. These include real estate, building management, energy utilities (resource planning and demand-side measures), and government (for strategy development and evaluation of policy impact).¹⁶⁷

¹⁶⁵ American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2024. ANSI/ASHRAE/IES Standard 100-2024: Energy And Emissions Building Performance Standard For Existing Buildings. Accessed 2022. <https://webstore.ansi.org/standards/ashrae/ansiashraeiesstandard1002024>.

¹⁶⁶ Government of British Columbia. n.d. ASHRAE Standard 100 Users' Guide. Accessed 2022. <https://www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/existing-buildings/ashrae-standard-100>.

¹⁶⁷ City of Seattle, Office of Sustainability and Environment. n.d. Energy Benchmarking. Accessed 2022. <https://www.seattle.gov/environment/climate-change/buildings-and-energy/energy-benchmarking>.

Policy Roadmap to Resilient, Ultra-Low-Energy Buildings

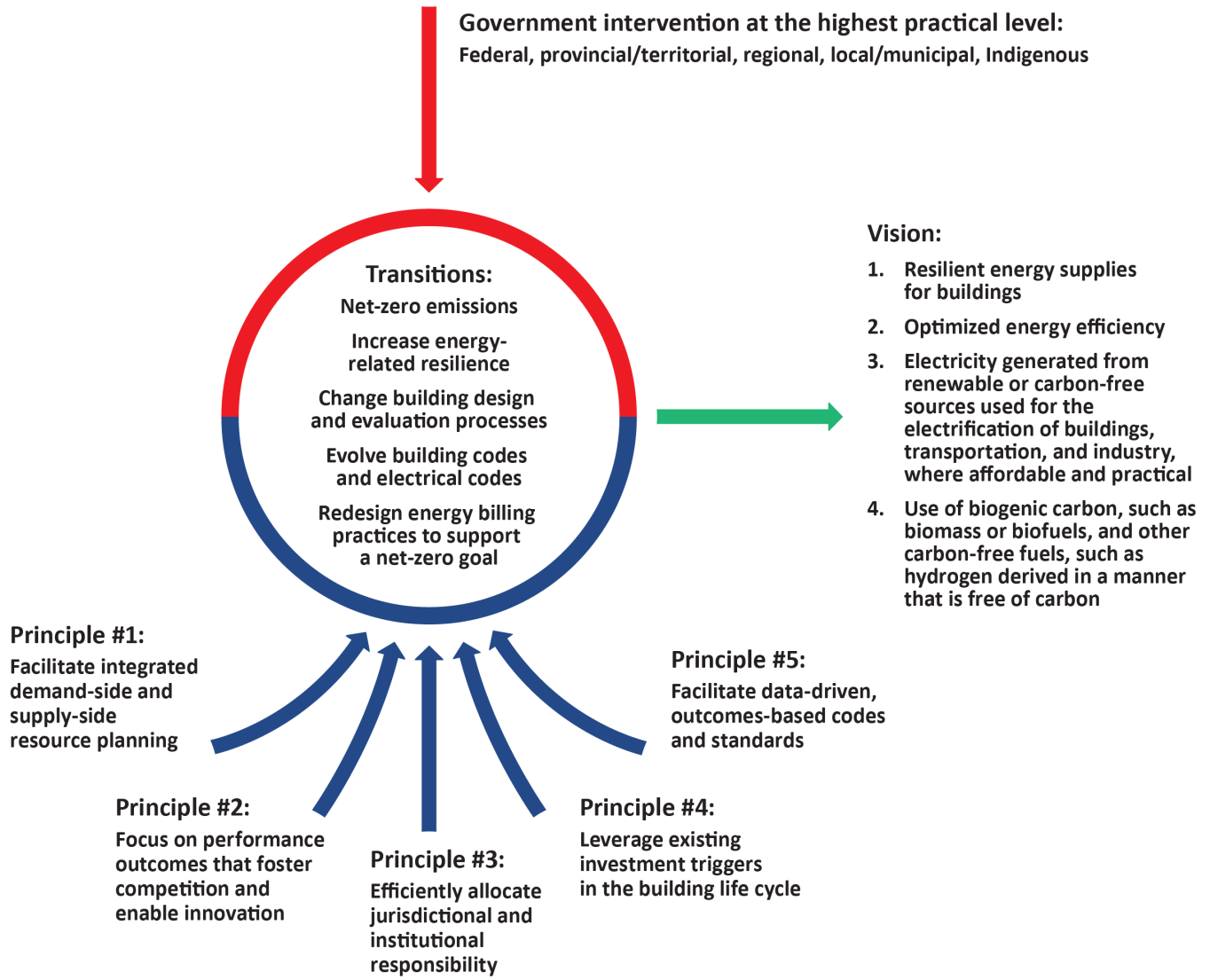


Figure 28: Government implementation of the principles to achieve the roadmap vision.

7. Call to Action and Roadmap for Engineers

Rosamund Hyde

This section proposes an expanded role for engineers to support an orderly, cost-effective, and resilient transition to ultra-low-energy buildings, distributed energy resources, and decarbonization. It also provides a call to action for engineering leadership, innovation, and active participation in informing policy-makers and policy-making.

The engineering profession is ideally suited to be a core partner of government, institutions, and buildings-sector associations, for the following reasons:

- The engineering profession interacts with all aspects of the topics covered in this roadmap and serves multiple buildings-sector stakeholders.
- Engineering practice collectively bridges government, institutional, and sectoral silos and provides service in a manner that addresses a diversity of drivers for building design and operations.
- Professional practice aligns with codes of ethics, which include an obligation to “hold paramount the safety, health, and welfare of the public, including the protection of the environment and the promotion of health and safety in the workplace.”¹⁶⁸
- Professional advice supports multiple objectives and goals in policy, regulation, codes, and standards.
- Engineers are in a unique position to catalyze meaningful action on policy goals while highlighting limitations of design solutions in the context of management practices, local context, and a changing climate.

This form of leadership was present under the former Bridging Government and Engineers Committee, an initiative of Engineers Canada that included an annual meeting with the federal government on Parliament Hill.¹⁶⁹ It also called upon participants to meet individually with federal government elected representatives¹⁷⁰ to discuss the issues statements of Engineers Canada.¹⁷¹ While Engineers Canada no longer sponsors the committee, the initiative could serve as a template for efforts with provincial and territorial governments, which hold significant influence on public policy in the domain of buildings.

The roadmap has presented a vision of a resilient, ultra-low-energy, and decarbonized building sector in Canada; metrics to track outcomes through the transition process; case studies of relevant innovations; and principles to guide a nationwide policy transition in the fluid context of a changing environment. This section identifies opportunities for and expectations of professional engineers to grow and exercise their skills in this process.

¹⁶⁸ Engineers and Geoscientists BC. n.d. Code of Ethics. Accessed 2022. <https://www.egbc.ca/Complaints-Discipline/Code-of-Ethics/Code-of-Ethics>.

¹⁶⁹ Engineers Canada. 2016. Engineers Canada’s Bridging Government and Engineers Committee on Parliament Hill. Accessed 2022. <https://engineerscanada.ca/news-and-events/news/engineers-canadas-bridging-government-and-engineers-committee-on-parliament-hill>.

¹⁷⁰ Engineers Canada. 2016. Bridging Government With Engineers Committee Members Meets With More Than a Dozen MPs. Accessed 2022. <https://engineerscanada.ca/news-and-events/news/bridging-government-with-engineers-committee-members-meets-with-more-than-a-dozen-mps>.

¹⁷¹ Engineers Canada. n.d. Issue Statements. Accessed 2022. <https://engineerscanada.ca/public-policy/issue-statements>.

Many engineers in Canada support the construction and renewal of buildings. This was recently amplified due to the housing shortage and pandemic renovation boom, both of which benefited from government investments. This call to action asks engineers to:

- Collectively establish a vision for professional practice to support future-proofing of buildings against various risk factors through ultra-low-energy design, energy resilience, and decarbonization.
- Individually evaluate risk factors and mitigation measures associated with building designs across the broad performance metrics highlighted in the roadmap. This is aligned with the risk management approach championed by engineering profession regulators in their practice guidance.¹⁷²
- Measure the performance of buildings and learn from the data, support property owners and managers in continuous optimization of the day-to-day management of building operations, and enable ongoing service contracts that pay for themselves through efficiencies.
- Bring their expertise and measured performance data to policy development processes and participate in the development of codes.
- Draw on the examples offered in the case studies to collaborate with academics in proposing demonstration projects for buildings that go beyond current standard practice and support research and innovation.
- Collaborate with the Canadian Academy of Engineering to establish an innovation ecosystem to explore potential new design strategies and business models.¹⁷³

Figure 29 summarizes an example of how professional practice can evolve to support one of the goals and measurable outcomes sought by the roadmap. This can serve as guidance for professional engineers, along with the other professions supporting the buildings sector, such as professional planners. The red boxes on the left depict individual actions that support the goal in the corresponding blue box on the right. The white boxes in the middle represent opportunities for continuous improvement.

¹⁷² Engineers and Geoscientists BC. 2021. Climate Change Action Plan. Accessed 2022.

<https://www.egbc.ca/getmedia/50e4e26b-30ad-46c8-8ca1-f06428af65dc/Engineers-and-Geoscientists-BC-Climate-Change-Action-Plan.pdf>.

¹⁷³ Asgarpour, S. 2021. PTAC Methane Detection and Mitigation Initiatives Report. Petroleum Technology Alliance Canada. Accessed 2022. <https://www.ptac.org/wp-content/uploads/2021/12/PTAC-Methane-Detection-Mitigation-Initiatives-Report-v2.pdf>.

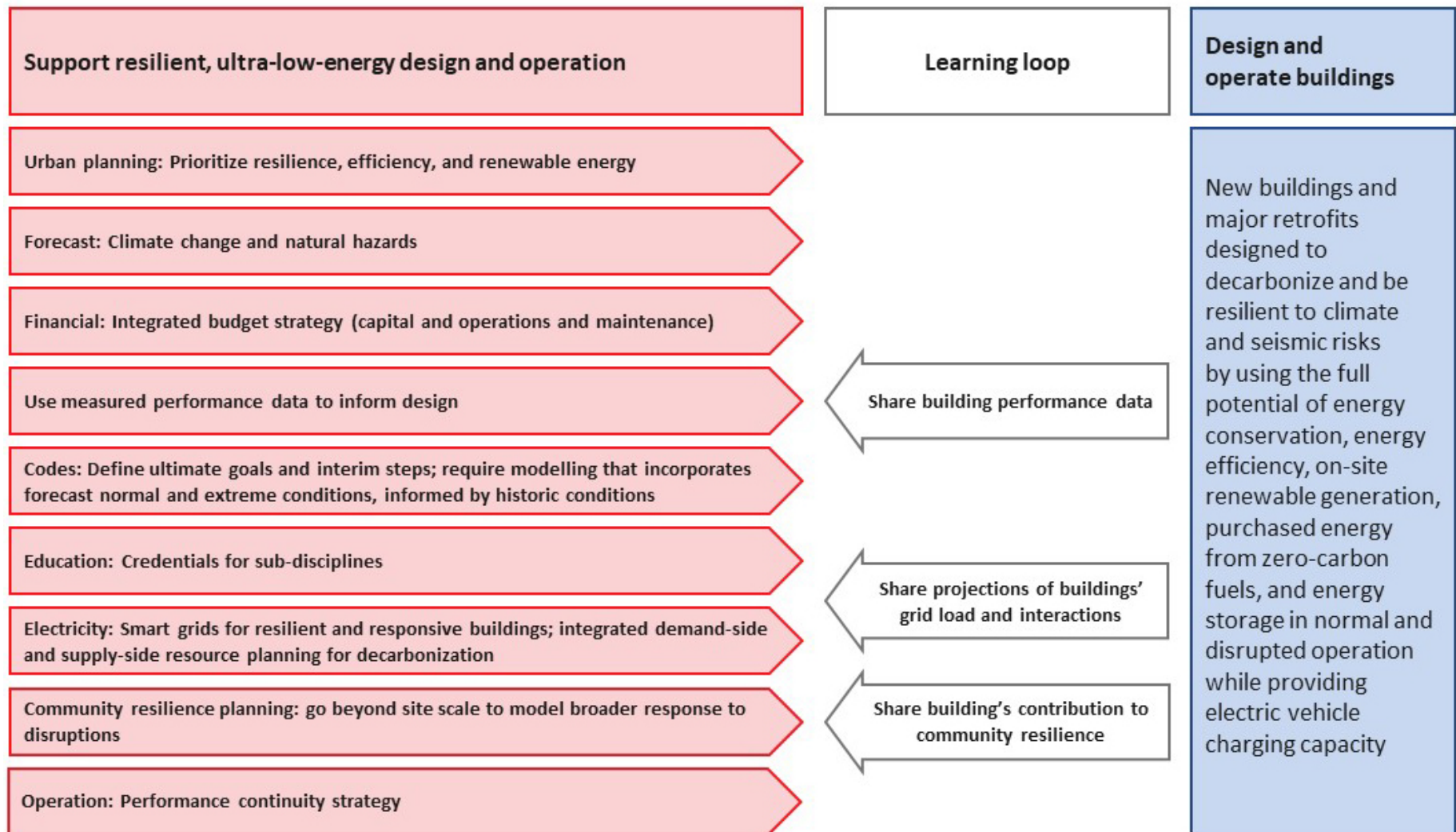


Figure 29: Roadmap for engineers and other professional practitioners.

This broadening of building design engineers' scope is not trivial. However, it offers many advantages. The changes can enable the industry:

- To serve clients better and strengthen competition between designers based on innovation and engineering evidence of superior performance, rather than on marketing claims of pre-eminence.
- To move toward a more harmonized and strategically structured system of codes that can make ultra-low-energy, resilient, and decarbonized Canadian building stock possible.
- To elevate building design to a more sophisticated level, with an increased dimension of stewardship throughout the service life of the building.
- To address the long-standing gap between building design practice and university research on building design, which has resulted from an academic focus on building simulation in the absence of available building performance data.
- For purposes of succession and renewal of the industry, to attract recruits who want to improve building design and address the gap between designed and actual energy performance by learning from building performance data.
- To engage with design professionals and engineers in other fields, bringing data that can help solve big-picture problems.
- To participate strategically in climate action.

The Canadian Academy of Engineering will be discussing the potential for its Fellowship of inducted professional leaders to disseminate the messages in this roadmap to the buildings sector and climate action departments of provincial and territorial governments through individual meetings.

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Appendix A

Roadmap Advisory Committee

Roadmap Advisory Committee

- Dr. Marianne Armstrong, National Research Council Canada
- Dr. David Bristow, University of Victoria
- Waleed Giratalla, Green Municipal Fund, Federation of Canadian Municipalities
- Roland Charneux, Pageau Morel
- Chantal Guay, Standards Council of Canada
- Dr. Caroline Hachem-Vermette, University of Calgary and Concordia University
- Julie Hewlett, Technical Safety BC
- William Larson, Pacific Northwest Building Resilience Coalition
- Dwayne Torrey, CSA Group
- Harshan Radhakrishnan, Engineers and Geoscientists BC

Appendix B

2019 Montreal Workshop Position Paper



Roadmap to Resilient Ultra-low Energy Built Environment with Deep Integration of Renewables in 2050 - Position Paper for Workshop

Background

Canada's long-term goal of reducing greenhouse gas (GHG) emissions by 80% by 2050, aligns with the global scientific consensus of stabilizing the atmospheric concentration of GHGs and limiting average temperature rise to less than 2°C. The goal is referenced (relative to the year 2005) in [Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy \(2016\)](#), and is legislated in British Columbia (relative to the year 2007). Many different pathways to achieve this goal are being debated in different contexts and from different perspectives. These discussions include the CCA "Expert Panel on Energy Use and Climate Change Report" [1], with recommendations related to buildings as well as the transportation, community infrastructure, and industry sectors¹, the CAE Trottier Energy Futures Project ([2]; e.g., scenario 8), and the [Pan Canadian Framework on Clean Growth and Climate Change \(2016\)](#) and aligned jurisdictional initiatives such as the [CleanBC Plan \(2018\)](#).

The feasibility of new net-zero energy buildings (NZEBs) that **integrate ultra-high energy efficiency with on-site renewable energy generation** to produce, in an average year, as much energy as they use, has been demonstrated both for detached houses and low- to mid-rise commercial and institutional buildings, both in Canada and other developed countries [3]. Many definitions exist for NZEBs, most recently documented and discussed under IEA SHC Task 40 / EBC Annex 52 [2] and new design approaches are being developed [4, 5]. It is currently recognized that the renewable energy technologies, such as photovoltaics, required to reach net-zero are limited by up-front costs, despite being cost-effective for standalone systems, along with **market and institutional barriers**, depending on the jurisdiction and local resource availability. Standalone PV is the lowest cost electricity resource in the world at roughly \$0.65/watt, but is limited by intermittency, associated grid issues, institutional barriers, lack of market capacity and other major barriers to integration in buildings and public spaces.

Driven by the need to make high performance housing affordable, governments have come up with less stringent short-term targets such as **net-zero ready** (no widely accepted definition) and **nearly zero** (China, APEC). Also, **carbon neutral** and **zero carbon** buildings are being advocated, which can be challenging to enforce when emissions due to manufacture and transportation of materials are considered, along with the upstream production and transmission of energy resources. For example, if transportation is through electric vehicles/trains 10 years from now, in theory there would be low or no emissions from transportation, providing that the electricity is generated from renewable energy sources.

¹ - Space and water heating account for most energy use and carbon dioxide emissions in the buildings sector. Buildings that incorporate features such as passive solar design; enhanced use of insulation; and air-, ground-, and water-source heat pumps can reduce heating and cooling demands by 60 to 90% over conventional construction.

- Dramatic efficiency gains can make it economically viable for buildings to convert to low-emission electricity to meet all remaining energy needs, resulting in substantial reduction of emissions in this sector.
- Low-emitting district energy systems powered through renewable energy and cogeneration can also reduce emissions.
- Governments can support emission reductions through building codes, energy efficiency standards, capacity development, and urban planning.

Aside from the **multitude of high-performance building targets**, there is broad agreement that three strategies need to be integrated in achieving the targets for new buildings/communities and for retrofits:

1. **Ultra-low Energy Design** (for buildings and communities, including public spaces and adjacent infrastructure) that enable buildings to meet most of their needs from on-site or community-based renewable energy supplies (e.g., net-zero energy ready).
2. **Deep integration of renewable energy** (BIPV, energy waste capture, geoexchange, air-source heat pumps, on-site hydrogen, storage, smart micro-grid) on the buildings or near the buildings and public spaces/local infrastructure. This will enable net-zero energy buildings/communities.
3. **Smart buildings and energy utility infrastructure** (smart buildings, smart grid, regional renewable energy centres, storage, interaction with electric vehicles, energy management information systems, biofuels including renewable natural gas, waste-to-energy, and district energy) to support efficient buildings and zero-carbon supplies and storage, load management (including demand response) and consumer engagement.

Another important aspect, increasingly being recognized to be of equal importance to the reduction of GHG emissions and “future-proofing” buildings is **resilience**. **Resilience** is defined by the 100 Resilient Cities network as, “the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience” [6], and for the purposes of this paper, may be broadly split into several categories:

1. **General resilience** against chronic stresses that are disruptive to the operations, maintenance and economic viability of buildings, including **health, indoor environmental quality** (e.g., criteria air contaminants), **comfort** (e.g., overheating), and long-term **durability** (e.g., avoiding structural damage from water ingress).
2. **Energy resilience**: for how many days/weeks can a community/building satisfy basic services (possibly with integrated electric vehicles) to occupants (minimum heating and electrical appliances) after energy supplies from utilities are cut under extreme weather conditions or other events?
3. **Structural resilience**: occupancy and function of buildings in a short timeframe following an acute shock (e.g., resistance to earthquakes and extreme weather events)?

Most suggested solutions to the NZEB target involve ultra-efficient building envelopes, solar energy and both electrical and thermal energy storage. One challenge with **solar energy systems** during the heating season (when Canada has the highest emissions) is that they usually produce power during off-peak periods when the **grid** may not need it. Hence **energy storage** is needed, which is also necessary for resilience. Thus, in addition to **energy efficiency measures and renewable energy, energy storage** is important to optimizing energy flows with building needs and smart grids, thus facilitating penetration and integration of intermittent renewable energy resources (wind, solar). This includes electrical and chemical storage, tanks of water or other fluids, building thermal mass and seasonal thermal storage. Thermal mass is present in different levels in all buildings and can be used to store passive solar gains in the heating season, while in other seasons this “mass” can reduce overheating and improve comfort. Increasingly, **buildings will be active prosumers** in the power system that can play the role of local energy storage and production, adjusting their behaviour to contribute positively to the operation of the grid, and hence contributing simultaneously to the resilience of the smart grid in an affordable and efficient manner.

Furthermore, the importance of system integration to achieve net-zero energy buildings and communities in an affordable way cannot be overemphasized: It is increasingly being recognized that buildings and their energy & HVAC systems need to be **designed and operated in an integrated manner** to be effective and affordable. Challenges include:

1. Current **building and electrical codes do not include resilience as an objective**. The health, safety, structural protection and energy efficiency objectives of the National Building Code (NBC)² and safety objective of the Canadian Electrical Code (CEC) support many aspects of resilience for new construction, particularly for acute shocks. However, chronic stresses are largely overlooked due to a lack of future-facing climate data, particularly as they relate to overheating and critical air quality events. Furthermore, long-term durability is not an objective of the NBC, potentially exacerbated by chronic stresses. Should resilience to probable shocks and stresses be considered in code design parameters?
2. The **existing building stock is largely overlooked by the NBC and CEC** due to a lack of guidance on suitable standards for existing buildings that may need to be less stringent than those for new construction due to the limited options for improving building performance, post occupancy. Furthermore, the NBC only applies during building alterations with a building permit, occurring on average once every ten years, with “energy related” permits occurring every thirty years, but in one jurisdiction there is inconsistent enforcement [7]. The CEC applies for equipment installation.
3. Current **building codes do not consider integration of renewables**. They are however covered by the CEC and equipment standards. Should they be included in the National Building Code? One example is BC’s “Solar Hot Water Ready Regulation” for municipal opt-in that requires conduit and structural support for solar water heaters to be installed at the time of construction, improving the economics for owners to install solar collectors in the future. There may be similar drivers for energy resilience, even installing back up power, with storage capability for a period of time. This will intersect with community-scale utility infrastructure planning with the potential for shared supply and storage, along with micro-grids.
4. New technologies such as BIPV and active solar systems, active building envelopes, do not have enough **standards** developed, hindering their adoption. What is the appropriate scope of a BIPV standard [8]?
5. **The role of architects and engineers** in the construction process could be enhanced, enabling greater emphasis on building performance. Options include innovation/performance based codes (including alternative solutions and “step” codes), certified professional designation for greater professional reliance under the building regulatory system, improvements in the procurement of design services (*e.g.*, need for [qualification-based selection](#)), project management (*e.g.*, construction management or integrated project delivery), and broadened requirements for system “commissioning” prior to occupancy permit. What are the gaps that hinder deep design integration and other opportunities?
6. Integration of **thermal with structural building design, durability**; Concrete or wood? Concrete production causes increased emissions compared to wood but has major structural and thermal advantages (*e.g.*, can store a lot of heat (**thermal mass**), reduce overheating through free night cooling/natural ventilation). What is the appropriate use of concrete in mass timber NZEBs?
7. Integral role of **urban, community and regional planning** to enable building and neighbourhood resilience and sustainability. Options include broadening the scope of urban planning departments to consider energy resilience and enable community-based, smart energy supply and storage, as well as the interactions of buildings and neighborhoods with the smart power grids of the future, and symbiotic sustainable transportation systems that could provide energy storage. **Should energy storage be mandated in codes, or at a community-based scale, or both?** Furthermore, community planning could advance other policy objectives such as complete communities and active transportation modes. Should resilience be a component of regional planning?

² Other NBC objectives include fire protection, accessibility for people with disabilities and water efficiency.

Workshop Scope

The topic under consideration, resilient, ultra-low energy buildings with integrated renewables, invites an impractical breadth of issues, and thus the precise definition of scope is critical. Of particular importance here is to identify “system boundaries”. For example:

- Balancing building design considerations between emphasis on building envelope, construction materials, mechanical and electrical systems, renewable energy system choices and smart grid integration of equipment. Presumably all in scope?
- Renewable energy systems can be integrated in the buildings themselves, and/or public spaces adjacent to buildings and infrastructure, connected with a smart utility infrastructure. For a community energy plan where is the boundary drawn?
- How do we balance access to daylight and other amenities of traditional urban form, versus densification and transportation advantages? What are the lessons learned from other countries about sustainable communities and urban planning [9]? Interaction with electric vehicles?

Target and Key Questions

In the context of the above discussion, the planning workshop will address the following key questions:

- How can Canada develop a bold but flexible plan (adaptable to different provincial energy contexts) to achieve the deep **80% reductions in GHG emissions** for new and existing buildings by designing for net-zero **resilient** communities for 2050? What are the pathways to achieve/approach this goal for existing communities?
- A key approach in market transformation programs and policy **roadmaps** is often to lock in energy savings through progressively stringent energy codes and standards (e.g., [BC Energy Step Code](#)). What are the key barriers and opportunities to achieve this approach? It is recognized that the context is different in different regions/provinces and different pathways may be followed.
- How can future-drivers be incorporated into building designs and retrofits today, thereby enhancing the **resilience** against acute shocks and chronic stresses in the built environment and the associated community energy infrastructure?
- What is the role of **innovation and performance-based design**, versus a conservative approach that emphasizes prescriptive standards based on historic evidence and postpones consideration of probable design drivers such as climate change and other resilience factors?
- What can we learn from **transformative technologies such as low-emissivity windows that took nearly 30 years** for full adoption [10] and how can the process of adoption be sped up for other transformative technologies such as building-integrated photovoltaics, cold-climate heat pumps, climate-responsive building materials (e.g., windows that can change solar heat gain depending on heating versus cooling loads), thermal and electrical storage, and smart predictive controls?
- What is the **optimal institutional framework** for advancing the aforementioned objectives, with respect to the national building and electrical code development system, provincial and territorial adoption in regulation, enforcement institutions (mainly local governments), professional reliance models, the “objective-based” premise of performance in building codes (despite continued adherence to prescriptive “acceptable-solutions”), and the opportunities for data-driven performance verification. What can we learn from other countries on innovation and resilience in building regulatory systems? What tweaks and comprehensive shifts could Canada benefit from?
- What is the audience for the output of the workshops? How should the results be communicated?
- Who should be invited to the two symposiums (tentatively the first technical symposium in 2020 and the second policy-focused symposium in 2021)?
- Further planning and communication of results?

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Appendix C

2019 Montreal Planning Workshop
Agenda and Communiqué



Program – Workshop on Roadmap to Resilient Ultra-low Energy Built Environment with Deep Integration of Renewables in 2050

Thursday, March 21st

19:30 Working dinner, [Concordia EV Building, Room EV 2.184 \(2nd floor\), 1515 Saint Catherine Street West](#)

- Icebreaker activity – Deep Green Vision for the Built Environment
 - What will your city look like in 2050 with 80% less emissions, while being resilient?
 - 30 sec elevator pitch to the Prime Minister of Canada or the CEO of the largest real estate investment trust or pension fund on how to achieve that big vision.

Friday, March 22nd

8:00 Breakfast, [Concordia EV Building, Room EV 2.260 \(2nd floor\), 1515 Saint Catherine Street West](#)

8:20 Opening remarks by Yves Beauchamp, CAE President-Elect

8:30 Framing the Resilient, Ultra-Low Energy Built Environment with Deep Integration of Renewables

- [Trottier Energy Futures Study](#) **Doug Ruth or Kevin Goheen** (TBC). Overview of Scenario 8. (20 min)
- [Current State of Play](#) – **Andreas Athienitis**. [Overview of Canadian Academy of Engineering Position Paper](#). Proposed NSERC Smart Solar Buildings and Communities Strategic Network. (25 min)
- [Proposed CAE Symposia](#) in 2020, 2021 – **Andreas Athienitis**. (10 min)
- Discussion. (20 min)

9:45 Break

10:15 Pervasive Challenges and Responses (6-10 min each + questions)

1. [Towards developing the technical basis for increased resiliency](#) Speaker: **Trevor Nightingale**
2. [Standards for existing buildings](#) Speaker: **Andrew Pape-Salmon**
3. [Integration of renewables \(standards, storage, grid optimization\)](#) Speakers: **Miguel Anjos and Andreas Athienitis**.
4. [Role of architects in integrating renewables and energy efficiency](#) Speaker: **Toon Dreesen**
5. [Integration of durability, thermal and structural design](#) Speaker: **Ted Stathopoulos**
6. [Urban, community and regional planning](#) Speaker: **Caroline Hachem-Vermette**
7. [Role of cities](#): **Diane Freeman**

12:00 Working Lunch

- Extra time to cover themes from the morning



12:45 Tying it together – Synthesis of problem statement

- First half of “Communiqué” – Andrew Pape-Salmon
- Discussion

13:15 “Roadmap” Development – key questions from the CAE Position Paper

Format: 1-5 slides introduction (target 2-5 min), followed by comments from participants.

- Deep Reductions in GHGs – Speaker: **Geneviève Gauthier**
 - Insights from energy utility demand-side measures (education, incentives, pricing, codes & standards). What are the pathways to achieve/approach deep 80% reductions in GHG emissions in 2050 for existing communities?
 - 15 min total (13:30 end)
- Technical Roadmaps – Speaker: **Andrew Pape-Salmon**
 - Case study of the BC Energy Step Code. What are the key barriers and opportunities to achieve this approach? It is recognized that the context is different in different regions/provinces and different pathways may be followed.
 - 15 min total (13:45 end)
- Resilience – Speaker: **Liam O’Brien**
 - Taking a long-term perspective on planning. How can we enhance the resilience of buildings against acute shocks and chronic stresses in the built environment and the associated community energy infrastructure?
 - 15 min (14:00 end)
- Innovation – Speaker: **Rosamund Hyde**
 - What is the role of innovation, and performance-based design versus a conservative approach that emphasizes prescriptive standards based on historic evidence and postpones consideration of probable design drivers such as climate change and other resilience factors?
 - 15 min (14:15 end)
- Transformative Technologies and Performance Based Design – Speakers: **Ian Beausoleil-Morrison and Michel Bernier**
 - What can we learn from transformative technologies such as low-emissivity windows and how can the process of adoption be sped up for other transformative technologies such as building-integrated photovoltaics, cold-climate heat pumps, climate-responsive building materials, thermal and electrical energy storage, and smart predictive controls? How can performance-based design be aided with building simulation tools?
 - 20 min (14:35 end)
- Affordability, and socioeconomic - housing industry perspectives – Speaker: **Kathleen Maynard**

Innovation, energy efficiency and the need for resilient housing through integration of renewable energy poses several challenges. How do we achieve the long-term objectives while reducing costs through integration and prefabrication?

 - 15 min (14:50 end)



- **Institutional Framework** – Speaker: **Andrew Pape-Salmon**
 - What is the optimal institutional framework for advancing the aforementioned objectives, with respect to the national building and electrical code development system, provincial and territorial adoption in regulation, enforcement institutions (mainly local governments), professional reliance models, the “objective-based” premise of performance in building codes (despite continued adherence to prescriptive “acceptable-solutions”), and the opportunities for data driven performance verification. What can we learn from other countries on innovation and resilience in building regulatory systems? What tweaks and comprehensive shifts could Canada benefit from?
 - 15 min (15:05 end)

15:10 Break

15:25 Communiqué Part 2 – the CAE Work Program

- **Summary of document** – **Andrew Pape-Salmon**
- Feedback

15:50 Planning (2020 and 2021 Chairs Andreas and Andrew)

- **Symposium Attendance**
 - Who should be invited to the two symposiums (tentatively the first technical symposium in 2020 and the second policy-focused symposium in 2021)?
 - (15 min)
- **Symposium Planning**
 - Further planning and communication of results?
 - (15 min)

16:20 Closing Remarks – Andreas

16:30 Adjourn



COMMUNIQUÉ – CANADIAN ROADMAP FOR RESILIENT BUILDINGS

April 23, 2019

Canadian Academy of Engineering: www.cae-acq.ca

The Canadian Academy of Engineering (CAE) assembled Thought Leaders from the professional community, construction industry, academia and three levels of government to begin to work on a national “Roadmap to Resilient, Ultra-Low Energy Built Environment with Deep Integration of Renewables in 2050”, with an aim to achieve at least an 80% reduction in greenhouse gas (GHG) emissions in new and existing buildings and associated community infrastructure.

The CAE's [Trottier Energy Futures Pathway project](#) described scenarios for reducing energy supply emissions by up to 70% below 1990 levels across all energy uses, requiring an investment of 20-30% of Canada's non-residential business capital up to 2050. This represents a significant opportunity for diversification and economic growth.

The CAE Roadmap will articulate resilient solutions for community planning, building form and design, existing building renewal, "smart" community energy infrastructure, and on-site renewable energy generation to provide a supplemental perspective on the Trottier project. These solutions could enable achievement of the 80% by 2050 goal, while simultaneously increasing the resilience of communities to acute shocks and chronic stresses that are anticipated this century.

In recent history, we have experienced such shocks as the 1998 central/eastern Canada ice storm that resulted in up to 5-week power cut, 4.7 million people displaced in Québec and Ontario and economic loss of over \$6 billion. This led to significant damages to buildings after their occupants evacuated them due to utility outages, resulting in extensive water damage from frozen water pipes and contributing to the economic loss. Such damage could be greatly reduced through resilient solutions that enable on-site electricity and heat production with building-integrated renewables. We anticipate that climate change will increase prevalence and intensity of chronic stresses as well as acute shocks. We need to increase our resilience to these and other acute shocks, such as a catastrophic earthquake in British Columbia or the Yukon where much of the older building stock could be destroyed in some cities, depending on the location and scale of the event. Solutions that address the three objectives of resilience, deep reductions in GHG emissions, and optimized energy efficiency plus on-site renewables can future-proof buildings and infrastructure and maximize long-term economic benefits for building owners, occupants and society.

At the March 22 Thought Leaders' Workshop, we discussed many technological and systems solutions already demonstrated by leaders across Canada, including the Varennes Library in Québec, Canada's first institutional solar net-zero energy building. Inaugurated in 2016, this building is designed to

produce approximately as much energy as it uses in an average year through a building-integrated photovoltaic system. In fact, the solar energy potential across most of the populated areas of Canada is significantly higher than most of northern Europe. Peak utility demand can be reduced through smart grids, with smart buildings being active participants to provide load flexibility and services to the grid, including short-term curtailment of water heaters, thermal storage on-site, and additional storage from electrical vehicles. Energy utility resource planning, consumption and production rate structures, and the development of building codes and standards will benefit from access to measured data from building operations, requiring information infrastructure aligned with privacy legislation.

The CAE and its partners have launched a major effort to consider many of the questions raised at the workshop, reflecting various constituencies represented, to identify practical technical, policy, standards development and institutional solutions, and to develop the Roadmap document by 2021. The Roadmap could be used by all levels of government, including Indigenous communities, the construction and real-estate industries, energy utilities, the associated professional communities, product manufacturers, academia, and other key influencers. The vision is for a resilient built environment that is economically optimized in design, operation, retrofit/renewal and energy over a long-term horizon equivalent to the lifetime of the building/infrastructure (at least 50 years).

Further research will build upon existing strong evidence that energy efficiency and on-site renewable energy generation are required for broader resilience of the building stock and associated community infrastructure. To accelerate the innovation cycle, we will look to reframe the problem statements, continue to learn from existing building operations, and enable “double-loop” learning. We will aim to integrate “silos” in the professional community (*i.e.*, engineering, planning, architecture, real estate, and the administration and management of construction, buildings, utilities, governments and others). Finally, we will develop win-win approaches and solutions adapted to the different regional contexts for new and existing buildings and community energy infrastructure by identifying the design solutions that optimize the multiple objectives of building code objectives, energy efficiency, GHG reductions, on-site renewable energy generation and durability.

The first order of business is to clarify the scope of the Roadmap. We will then define the range of questions that correspond with technical, market and human behavioural barriers. The Thought Leaders discussed concerns around the durability of modern construction, fuel and material choices, maintenance of existing affordable housing stock, procurement of professional services and “value engineering” (often cutting construction costs by installing lower performing components than envisioned in the design), market acceptance of innovative designs, management of risk and liability, and capacity of the industries to deliver solutions at scale. Consideration of key related barriers and research questions is being addressed through a network of leading Canadian researchers from about 15 universities across all major regions and over forty partners covering major stakeholders, including the built environment designers, energy utilities, municipalities, builders, and manufacturers.

The Roadmap will articulate existing and emerging societal goals, highlight all available government policy levers and market mechanisms, and provide at least three “pathways” to achieve the vision. Pathways are expected to include, but not limited to the following: evolving objectives for the national building code development system; adoption/ implementation of these codes by provinces, territories Indigenous communities and local governments; public/ industry awareness and education; opportunities through incentives/ insurance/ financing/ leadership investments; technical synergies of having buildings be active participants in the energy grids; energy pricing strategies for energy efficiency and models to facilitate integration of on-site renewable energy systems; qualification-based/ financial

outcome-based (best net-present value design) construction procurement; alternative institutional frameworks, and community planning.

In 2019 and 2020 the Thought Leaders' Workshop participants and associated partners will endeavour to develop the "near final" draft Roadmap in time for a symposium in Montreal in the fall of 2020, co-hosted by the CAE and the Concordia Centre for Zero Energy Building Studies. At the Montreal meeting, a broadened audience of all stakeholders and key influencers will be invited to submit papers and discuss the draft Roadmap in progress with a dual emphasis on technological win-win solutions and government policies.

In 2021 a symposium will be held in Victoria BC, focusing on policy solutions for all four levels of government (local/regional, Indigenous, provincial, federal) that are analyzed and vetted by the CAE and partners, along with options for the roles and responsibilities of the key institutions that develop, implement and support building codes and standards, community energy infrastructure, and construction and building management.

The resultant draft Roadmap will be posted by mid-2021 with an opportunity for public input to the Canadian Academy of Engineering. It will be practical and digestible by layperson audiences and decision makers alike. It will provide multiple pathways that will appeal to the diversity of Canadian jurisdictions.

For additional information or interviews, please contact:

Kevin Goheen, P.Eng., Ph.D. Executive Director

Tel: (613)235-4836

E-mail: kgoheen@cae-acg.ca

Appendix D

2021 Communities Workshop Agenda

CAE Roadmap to Resilient Ultra-Low Energy Built Environment with Deep Integration of Renewables in 2050 – Low-Carbon and Positive Energy Resilient Communities Webinar – October 12, 2021

All times displayed in EST. Register in advance for this meeting at the Zoom link below:

<https://concordia-ca.zoom.us/meeting/register/tZEpd--grjloGdRgyiMkqN74M2rVXIO3VIMj>

Scope: The webinar will focus on lessons learned and experiences from existing and ongoing developments in high profile low-carbon and positive energy communities in Canada and Europe, and informing the CAE Roadmap on current status and future opportunities and challenges

Online connection	10:55– 11:00
<p>Opening/Welcome Remarks Yves Beauchamp, FCAE/FACG, President CAE, VP Administration and Finance, McGill University Mourad Debbabi, Dean Gina Cody School of Engineering & Computer Science, Concordia University</p> <p>Setting the Framework for Zero Carbon Communities Andreas Athienitis, FCAE, Roadmap Co-Chair, Professor and NSERC/Hydro-Québec Industrial Research Chair & Concordia Chair, Concordia University Andrew Pape-Salmon, FCAE, Roadmap Co-Chair, Adjunct Professor, University of Victoria Ursula Eicker, Professor, Canada Excellence Research Chair and IEA Positive Energy Districts Subtask Leader, Concordia University Caroline Hachem-Vermette, Associate Professor and IEA SHC Solar Neighborhood Planning Subtask Leader, Environmental Design, University of Calgary</p>	11:00 – 11:30
CASE STUDIES - SESSION I	
Co-chairs: Leon Wang and Mohamed Ouf, Concordia University	
<p>Dirk Pietruschka, Stuttgart University, Germany: Low Depth Geothermal District Energy System in Wüstenrot</p>	11:30 – 11:45
<p>Silvia Croce, Eurac, Italy: Building and District Energy System Retrofit in Bolzano</p>	11:45 – 12:00
<p>Gilles Desthieux, HEPIA, Switzerland: Cité Carl Vogt Heritage Neighborhood Retrofit in Geneva</p>	12:00 – 12:15
<p>Rongling Li, Technical University of Denmark, Denmark: Energy Flexibility of a District Heating System in Copenhagen</p>	12:15 – 12:30
<p>David-Olivier Goulet, Hydro Quebec, QC, Canada and Stéphane Vachon, City of Lac Mégantic Lac-Mégantic Microgrid</p>	12:30 – 12:45

CASE STUDIES - SESSION II

Co-chairs: Hua Ge and Bruno Lee, Concordia University		
Walter Merida , University of British Columbia, BC, Canada: Feathers and Dinosaurs: A Living Laboratory for Smart Energy Districts		12:45 – 13:00
Bill Wong , NRCan, ON, Canada: Drake Landing Solar Community		13:00 – 13:15
Milfred Hammerbacher , S2e Technologies, ON, Canada: West 5 Smart Grid Project		13:15 – 13:30
Nayeem Ninad , NRCan, ON, Canada: PV-Storage-Diesel Hybrid Microgrid of Colville Lake		13:30 – 13:45
Travis Hickford-Kulak , Corix Utilities, BC, Canada: Burnaby Mountain District Energy Utility		13:45 – 14:00
BREAK		14:00 – 14:05
PANEL DISCUSSION: Co-Chairs: Ted Stathopoulos, FCAE and Andreas Athienitis, FCAE All presenters		14:05 – 14:25
Closing remarks	Webinar Chair and Roadmap Co-Chair: Andreas Athienitis	14:25 – 14:30

In collaboration with IEA Positive Energy Districts (Annex 83) and SHC Solar Neighborhood Planning (Task 63):



Appendix E

Examples of Government Policy Measures

Examples of Government Policy Measures

In the 1990s, the Government of Canada undertook planning and leadership for energy efficiency under Natural Resources Canada's Office of Energy Efficiency. This included substantial planning, programs, and regulations, including targets for new buildings (e.g., 25% better than the 1997 Model National Energy Code Canada for Buildings, EnerGuide 80 for new homes by 2010) and equipment standards (e.g., condensing furnaces). These efforts included significant collaboration with provinces and territories, such as harmonized equipment-efficiency standards^{174,175} and the creation of the Green Municipal Fund to support local governments.¹⁷⁶ BC's 2005 and 2008 *Energy Efficient Buildings Strategy*^{177,178} adopted national energy-efficiency targets for new buildings; coordinated with federal codes, standards, and incentive programs; and acknowledged the critical role of local and Indigenous governments, effectively advancing market transformation for buildings through measures at all levels of government.¹⁷⁹ Despite a shift in jurisdictional turf in the mid-2000s, the multipartite coordination continued into the late 2000s, culminating in the policy framework *Moving Forward on Energy Efficiency in Canada: A Foundation for Action*.¹⁸⁰ The provinces and territories asserted their jurisdiction via the Council of the Federation but generally aligned with previous Natural Resources Canada leadership.¹⁸¹ A tangible outcome of these efforts was changes to the National Building Code of Canada (NBC), including the National Energy Code of Canada for Buildings 2011 and the EnerGuide 80 standards in NBC 2012. What was not included in this coordinated planning was integrated demand-side and supply-side planning—only demand-side planning.

This coordinated planning with meaningful results was paused for a decade, but it restarted in the context of the Council of Energy and Mines Ministers, the *Pan-Canadian Framework on Clean Growth and Climate Change*, and *Build Smart: Canada's Buildings Strategy*, which was again focused on demand-side measures and energy efficiency.¹⁸²

An integrated approach was achieved in BC in 2021 under the *CleanBC Roadmap to 2030*. It optimized supply-side and demand-side measures and was premised on integrated analysis that sought the least-cost solutions to

¹⁷⁴ Natural Resources Canada. n.d. Guide to Canada's Energy Efficiency Regulations. Accessed 2022.

<https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-regulations/guide-canadas-energy-efficiency-regulations/6861>.

¹⁷⁵ Government of British Columbia. n.d. Energy Efficiency Standards. Accessed 2022.

<https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/energy-efficiency-conservation/policy-regulations/standards>.

¹⁷⁶ The Green Municipal Fund. n.d. Helping Municipalities Create a Sustainable and Prosperous Future. Accessed 2022.

<https://greenmunicipalfund.ca/>.

¹⁷⁷ Frappé-Sénéclauze, T.-P., and MacNab, J. 2015. Evolution of Energy Efficiency Requirements in the BC Building Code. Pembina Institute. Accessed 2022. <https://www.pembina.org/reports/pembina-evolution-of-energy-efficiency.pdf>.

¹⁷⁸ Government of British Columbia. 2008. Energy Efficient Buildings Strategy: More Action, Less Energy. Accessed 2022.

https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/energy_efficient_buildings_strategy.pdf.

¹⁷⁹ Pape-Salmon, A., Muncaster, K., and Kaye, E. 2011. British Columbia's Energy Efficient Buildings Strategy. ASHRAE Transactions 117(1):298–305. <https://link.gale.com/apps/doc/A257557810/AONE>.

¹⁸⁰ Natural Resources Canada. 2007. Moving Forward on Energy Efficiency in Canada: A Foundation for Action. Accessed 2022. <https://publications.gc.ca/site/eng/416349/publication.html>.

¹⁸¹ Council of the Federation. 2008. Climate Change: Fulfilling Council of the Federation Commitments. Accessed 2022.

https://canadaspremiers.ca/wp-content/uploads/2017/09/communiqu_e_en_climate_changejuly131clean.pdf.

¹⁸² Natural Resources Canada. 2017. Build Smart: Canada's Buildings Strategy. Energy and Mines Ministers' Conference, St. Andrews-by-the-Sea, New Brunswick, August 13–15, 2017. Accessed 2022.

https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/emmc/pdf/Building_Smart_en.pdf.

reduce emissions. It included a buildings pathway that aimed to address emissions and referenced climate adaptation, including:

- Reduction of building sector emissions by an additional 1.3 Mt by 2030, over and above the 2018 CleanBC plan, targeting total emission reductions of 59% to 64% from 2007 levels.¹⁸³
- Economy-wide input/output modelling to demonstrate least-cost technology solutions and policy measures.
- Zero-carbon new construction by 2030.
- A diversity of fuel choices, including renewable natural gas and green/blue hydrogen.
- Highest efficiency standards (100%+) for new space-heating and water-heating equipment by 2030.
- Enhancement of utilities' energy-efficiency programs and energy supply decarbonization, including a cap on natural gas emissions.
- Supportive carbon pricing and the introduction of property-assessed clean energy (PACE) financing.
- Home energy labelling.
- Low-carbon building materials and circular economy initiatives for materials.
- Government leadership in climate preparedness and adaptation and community land-use planning.

A subsequent 2022 budget announcement provided a further boost for the retrofit of existing buildings with a 5% tax credit for building renovations that achieve ASHRAE Standard 100 and match the energy-use intensity of the top 40% most efficient buildings in BC.^{184,185}

This a model integrated plan that could be replicated in all other provincial/territorial jurisdictions. In March 2022, the federal government released *Canada's 2030 Emissions Reduction Plan: Clean Air, Strong Economy*. It could provide the impetus for additional provincial/territorial plans, as it lays out an integrated demand-side and supply-side approach in areas of federal government jurisdiction.¹⁸⁶ It is anticipated that future provincial/territorial plans will reference measures within this federal plan, such as:

- Increasingly stringent performance-based model building codes, including the introduction of net-zero-energy-ready model codes for new construction and a code for retrofits to existing buildings.¹⁸⁷
- A low-carbon building materials innovation hub to drive further research, building code reform, and demonstration activities, all promoting the use of lower-carbon construction materials (e.g., wood, steel, concrete) in the built environment.
- Regulatory standards and an incentive framework to support the transition away from fossil fuels for heating systems.

¹⁸³ Government of British Columbia. 2021. 2021 Climate Change Accountability Report. Accessed 2022. https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/2021_climate_change_accountability_report.pdf.

¹⁸⁴ Government of British Columbia. n.d. Clean Buildings Tax Credit. Accessed 2022. <https://www2.gov.bc.ca/gov/content/taxes/income-taxes/corporate/credits/clean-buildings>.

¹⁸⁵ Government of British Columbia. n.d. ASHRAE Standard 100 Users' Guide. Accessed 2022. <https://www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/existing-buildings/ashrae-standard-100>.

¹⁸⁶ Environment and Climate Change Canada. 2022. 2030 Emissions Reduction Plan: Canada's Next Steps for Clean Air and a Strong Economy. Accessed November 2022. https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf.

¹⁸⁷ Environment and Climate Change Canada. 2022. 2030 Emissions Reduction Plan: Canada's Next Steps for Clean Air and a Strong Economy. Accessed November 2022. https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf.

- An approach to require EnerGuide labelling of homes at the time of sale and to design a complementary Climate Adaptation Home Rating Program.
- A new Net Zero Building Code Acceleration Fund to accelerate adoption and implementation of the highest-performance tiers of the national model energy codes, incentivizing stakeholder participation while addressing persistent challenges in Canada’s codes system and paving the way to a code for alterations for existing buildings.
- Federal capacity and technical support to provinces, territories, and key stakeholders for the development and adoption of net-zero-emission codes and alteration to existing building codes.
- An approach to increase the climate resilience of the built environment.¹⁸⁸

¹⁸⁸ Environment and Climate Change Canada. 2022. 2030 Emissions Reduction Plan: Canada’s Next Steps for Clean Air and a Strong Economy. Accessed November 2022. https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf.

Appendix F

Key Influencers

Key Influencers

- Agencies, tribunals, and Crown corporations empowered by legislation, including those delegated by legislation to implement mandates/regulations:
 - Building codes and standards:
 - Local governments
 - Régie du bâtiment du Québec
 - Equipment and safety standards:
 - Technical Safety BC
 - Public energy utility regulators:
 - Alberta Market Surveillance Administrator
 - Alberta Utilities Commission
 - British Columbia Utilities Commission
 - Canada Energy Regulator
 - Manitoba Public Utilities Board
 - New Brunswick Energy and Utilities Board
 - Newfoundland and Labrador Board of Commissioners of Public Utilities
 - Northwest Territories Public Utilities Board
 - Nova Scotia Utility and Review Board
 - Nunavut Utility Rates Review Council
 - Ontario Energy Board
 - Prince Edward Island Regulatory and Appeals Commission
 - Régie de l'énergie du Québec
 - Saskatchewan Rate Review Panel
 - Yukon Utilities Board
 - Real estate regulators:
 - Land Title and Survey Authority of British Columbia
- Professional regulators that oversee the work of registered professionals and universities:
 - Engineers and Geoscientists BC, under the Professional Governance Act
 - Engineers Canada, which accredits engineering schools, among other functions
- Standards development organizations that establish model technical standards that can be referenced by legislation and/or used as best practices for professional practice:
 - CSA Group (e.g., Canadian Electrical Code)
 - Codes Canada (e.g., National Building Code of Canada, National Energy Code of Canada for Buildings)

- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) (e.g., ASHRAE Standard 100, Energy and Emissions Building Performance Standard for Existing Buildings)
- Research and education institutions, including academia:
 - Concordia University’s Centre for Zero Energy Building Studies (e.g. NSERC Smart Net-Zero Energy Buildings Strategic Research Network)
 - University of Victoria civil engineering department (e.g., Net-Zero Navigator, ReBuild Initiative)
 - Pacific Institute for Climate Solutions
 - Petroleum Technology Alliance Canada
 - Natural Sciences and Engineering Research Council of Canada (NSERC)
 - Mitacs
 - Sustainable Development Technology Canada
 - BC Hydrogen Office
 - FPInnovations
 - Zero Emissions Innovation Centre
 - Canadian Centre for Mineral and Energy Technology (CANMET)
 - National Research Council Canada
 - US Department of Energy National Laboratories
 - Northwest Energy Efficiency Alliance
- Investment governance and institutional investors that apply environment, social, and governance criteria:
 - Canada Infrastructure Bank (e.g., \$2 billion in building retrofits)
 - Canada Mortgage and Housing Corporation (e.g., criteria for mortgage insurance)
 - BC Housing HousingHub (e.g., \$2.8 billion in affordable housing partnerships)
 - The Atmospheric Fund (Toronto/Hamilton) and Efficiency Capital Corporation
 - Green Municipal Fund
- Government-owned energy utilities with demand-side measures that enable or promote energy conservation, energy efficiency, load management, zero-emission vehicle fuels, on-site generation, microgrids, biofuels, green hydrogen, and other initiatives:
 - Provincial/territorial electric utilities (Crown corporations):
 - BC Hydro
 - Hydro-Québec
 - Manitoba Hydro
 - Newfoundland and Labrador Hydro
 - Northwest Territories Power Corporation
 - SaskPower
 - Yukon Energy Corporation
 - Provincial/territorial methane utilities (Crown corporations):
 - Manitoba Hydro

- Municipal utilities:
 - Lonsdale Energy Corporation (North Vancouver)
 - Toronto Hydro
- Programs agencies (energy-efficiency and clean energy offices that administer programs):
 - Energy efficiency (e.g., Efficiency Manitoba, Efficiency Nova Scotia)
 - Local government sustainability (e.g., Federation of Canadian Municipalities)
 - Technical support (e.g., Zero Emissions Innovation Centre)
 - Financing (e.g., Clean Foundation, Nova Scotia PACE)
 - Zero-carbon energy (e.g., BC Hydrogen Office, QUEST Canada)

Appendix G

**2022 Pacific NorthWest Economic Region
Annual Summit Panel Discussion**

2022 Pacific NorthWest Economic Region Annual Summit Panel Discussion¹⁸⁹

Bridging Silos to Catalyze Decarbonization and Resilience of Buildings

Description

Increasing the resilience of buildings against natural disasters, coupled with decarbonization, is a daunting challenge for the market and institutions that govern building codes and standards, registered professionals, community planning, and the energy sector. Current jurisdictional, institutional, and professional silos are fragmenting the market and creating unnecessary conflict that threatens public confidence. Sub-national governments and the engineering profession are positioned to drive the evolution of the real estate, property management, and energy sectors to catalyze investment toward optimal levels of building performance. This includes a principled approach to mitigate risks, maximize public benefits, and minimize costs, while allocating responsibilities to the key influencers.

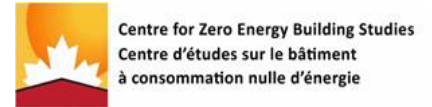
Speakers (underlined names are linked to presentations on the CAE website)

- [Andrew Pape-Salmon](#) (moderator). University of Victoria, Adjunct Professor.
- [Harshan Radhakrishnan](#) (speaker). Engineers and Geoscientists BC, Manager, Climate Change and Sustainability Initiatives.
- **Soheil Asgarpour** (speaker). Petroleum Technology Alliance Canada, President and CEO, and Canadian Academy of Engineering, President.
- [Evan Reis](#) (speaker). US Resiliency Council, Executive Director.
- [Paul Chang](#) (speaker). Government of Alberta, Municipal Affairs, Community and Technical Support, Codes and Standards Development, Provincial Building Administrator.

¹⁸⁹ Canadian Academy of Engineering. 2022. Bridging Silos to Catalyze Decarbonization and Resilience of Buildings. Accessed 2022. <https://www.cae-acg.ca/bridging-silos-to-catalyze-decarbonization-and-resilience-of-buildings/>.

Appendix H

2020 Montreal Symposium Proceedings



Roadmap to Resilient Ultra-Low Energy Built Environment with Deep Integration of Renewables in 2050:

**Proceedings, Montreal Symposium
October 16, 2020**

ISBN 978-0-9690101-1-1

**Editor: Andreas Athienitis, FCAE, Director CZEBS
Centre for Zero Energy Building Studies and
Canadian Academy of Engineering**

Table of Contents

Introduction.....	1
Program.....	4
Papers.....	6
Technical Review Committee.....	94
Biographies of Presenters.....	95

Introduction

The Canadian Academy of Engineering (CAE) in collaboration with Concordia's Centre for Zero Energy Building Studies (CZEBS) hosted a **planning workshop on March 22, 2019 for a "Roadmap to Resilient Ultra-low Energy Built Environment with Deep Integration of Renewables in 2050"**. The workshop was co-chaired by the **Roadmap Co-Chairs and Fellows of CAE Andreas Athienitis and Andrew Pape-Salmon**. Following the workshop attended by about 25 thought leaders, a communique was published, summarized and updated below, followed by an overview of the Montreal 2020 meeting.

The Canadian Academy of Engineering (CAE) assembled Thought Leaders from the professional community, construction industry, academia and three levels of government to begin to work on a national "Roadmap to Resilient, Ultra-Low Energy Built Environment with Deep Integration of Renewables in 2050", with an aim to achieve at least an 80% reduction in greenhouse gas (GHG) emissions in new and existing buildings and associated community infrastructure. The CAE's Trottier Energy Futures Pathway project described scenarios for reducing energy supply emissions by up to 70% below 1990 levels across all energy uses, requiring an investment of 20-30% of Canada's non-residential business capital up to 2050. This represents a significant opportunity for diversification and economic growth. The CAE Roadmap will articulate resilient solutions for community planning, building form and design, existing building renewal, "smart" community energy infrastructure, and on-site renewable energy generation to provide a supplemental perspective on the Trottier project. These solutions could enable achievement of the 80% by 2050 goal, while simultaneously increasing the resilience of communities to acute shocks such as the **COVID19 pandemic**.

In recent history, we have experienced such shocks as the 1998 central/eastern Canada ice storm that resulted in up to a 5-week power cut, 4.7 million people displaced in Québec and Ontario and economic loss of over \$6 billion. This led to significant damages to buildings after their occupants evacuated them due to utility outages, resulting in extensive water damage from frozen water pipes and contributing to the economic loss. Such damage could be greatly reduced through resilient solutions that enable on-site electricity and heat production with building-integrated renewables. We anticipate that climate change will increase prevalence and intensity of chronic stresses as well as acute shocks. We need to increase our resilience to these and other acute shocks, such as a catastrophic earthquake in British Columbia or the Yukon where much of the older building stock could be destroyed in some cities, depending on the location and scale of the event. Solutions that address the three objectives of resilience, deep reductions in GHG emissions, and optimized energy efficiency plus on-site renewables can future-proof buildings and infrastructure and maximize long-term economic benefits for building owners, occupants and society.

At the March 22 Thought Leaders' Workshop, we discussed many technological and systems solutions already demonstrated by leaders across Canada, including the Varennes Library in Québec, Canada's first institutional solar net-zero energy building. Inaugurated in 2016, this building is designed to produce approximately as much energy as it uses in an average year through a building-integrated photovoltaic system. In fact, the solar energy potential across most of the populated areas of Canada is significantly higher than most of northern Europe. Peak utility demand can be reduced through smart grids, with smart buildings being active participants to provide load flexibility and services to the grid, including short-term curtailment of water heaters, thermal storage on-site, and additional storage from electrical vehicles. Energy utility resource planning, consumption and production rate structures, and the development of building codes and standards will benefit from access to measured data from building operations, requiring information infrastructure aligned with privacy legislation.

The CAE and its partners have launched a major effort to consider many of the questions raised at the workshop, reflecting various constituencies represented, to identify practical technical, policy, standards development and institutional solutions, and to develop the Roadmap document by early 2022. The

Roadmap could be used by all levels of government, including Indigenous communities, the construction and real-estate industries, energy utilities, the associated professional communities, product manufacturers, academia, and other key influencers. The vision is for a resilient built environment that is economically optimized in design, operation, retrofit/renewal and energy over a long-term horizon equivalent to the lifetime of the building/infrastructure (at least 50 years).

Further research will build upon existing strong evidence that energy efficiency and on-site renewable energy generation are required for broader resilience of the building stock and associated community infrastructure. To accelerate the innovation cycle, we will look to reframe the problem statements, continue to learn from existing building operations, and enable “double-loop” learning. We will aim to integrate “silos” in the professional community (i.e., engineering, planning, architecture, real estate, and the administration and management of construction, buildings, utilities, governments and others). Finally, we will propose win-win approaches and solutions adapted to the different regional contexts for new and existing buildings and community energy infrastructure by identifying the design solutions that optimize the multiple objectives of building code objectives, energy efficiency, GHG reductions, on-site renewable energy generation and durability.

The Thought Leaders discussed concerns around the durability of modern construction, fuel and material choices, maintenance of existing affordable housing stock, procurement of professional services and “value engineering” (often cutting construction costs by installing lower performing components than envisioned in the design), market acceptance of innovative designs, management of risk and liability, and capacity of the industries to deliver solutions at scale. Consideration of key related barriers and research questions is being addressed through a network of leading Canadian researchers from about 15 universities across all major regions and over forty partners covering major stakeholders, including the built environment designers, energy utilities, municipalities, builders, and manufacturers.

The Roadmap will articulate existing and emerging societal goals, highlight all available government policy levers and market mechanisms, and provide at least three “pathways” to achieve the vision. Pathways are expected to include, but not limited to the following: evolving objectives for the national building code development system; adoption/ implementation of these codes by provinces, territories Indigenous communities and local governments; public/ industry awareness and education; opportunities through incentives/ insurance/ financing/ leadership investments; technical synergies of having buildings be active participants in the energy grids; energy pricing strategies for energy efficiency and models to facilitate integration of on-site renewable energy systems; qualification-based/ financial outcome-based (best net-present value design) construction procurement; alternative institutional frameworks, and community planning.

The Roadmap includes two major symposia – a mainly technically focused Symposium in Montreal in 2020 with papers from experts published as proceedings, followed by a policy focused Symposium in Victoria in 2021. The proceedings and discussions at the Montreal Symposium provide input to an Interim Roadmap Report to be completed by early 2021. In 2021, a symposium will be held in Victoria BC, focusing on policy solutions for all levels of government (local/regional, Indigenous, provincial, federal) that are analyzed and vetted by the CAE and partners, along with options for the roles and responsibilities of the key institutions that develop, implement and support building codes and standards, community energy infrastructure, and construction and building management. The resultant draft Roadmap will be posted by early 2022 with an opportunity for public input to the Canadian Academy of Engineering. It will be practical and digestible by layperson audiences and decision makers alike. It will provide multiple pathways that will appeal to the diversity of Canadian jurisdictions.

The Montreal Symposium and Proceedings

This Symposium was held via webinar because of the COVID19 pandemic on October 16, 2020.

A technical committee was formed to organize the Symposium that will provide major input to the Roadmap through papers from experts and short presentations from key stakeholders, as well as discussion with the participants during the nearly 25 paper and panel presentations. The technical committee reviewed the papers, and the authors then implemented the comments of the reviewers in the final form included in these proceedings. The proceedings partly address the following **targets and key questions** identified in a position paper in the planning workshop of March 22, 2019, updated with the resilience challenges for the built environment to fight pandemics such as COVID19.

- How can Canada develop a bold but flexible plan (adaptable to different provincial energy contexts) to achieve the deep **80% reductions in GHG emissions** for new and existing buildings by designing for net-zero **resilient** communities for 2050? What are the pathways to achieve/approach this goal for existing communities? Some important solutions are discussed in the proceedings.
- A key approach in market transformation programs and policy **roadmaps** is often to lock in energy savings through progressively stringent energy codes and standards. What are the key barriers and opportunities to achieve this approach? It is recognized that the context is different in different regions/provinces and different pathways may be followed.
- How can future-drivers be incorporated into building designs and retrofits today, thereby enhancing the **resilience** against acute shocks and chronic stresses in the built environment and the associated community energy infrastructure?
- The **COVID19 pandemic** has further revealed the need for **resilient buildings** and their **ventilation systems** to be designed to limit the spread of viruses such as COVID19, which has been shown to be significantly spread as aerosols. This can be done by reducing recirculation of HVAC air and bringing in more fresh air to dilute pathogen concentration, thus limiting the spread of infections, in addition to use of special filters and UV disinfection measures. Canadian buildings need to be able to face crises such as ice-storms and pandemics simultaneously since both typically happen in winter; if they do, physically distancing with millions of people displaced from their homes and relocated in confined places/shelters will be very difficult, if not impossible, possibly resulting in many more deaths than what we experience with the COVID19 pandemic, particularly among vulnerable people.
- What is the role of **innovation and performance-based design**, versus a conservative approach that emphasizes prescriptive standards based on historic evidence and postpones consideration of probable design drivers such as climate change and other resilience factors?
- What can we learn from **transformative technologies such as low-emissivity windows that took nearly 30 years** for full adoption and how can the process of adoption be sped up for other transformative technologies such as building-integrated photovoltaics, cold-climate heat pumps, climate-responsive building materials (e.g., windows that can change solar heat gain depending on heating versus cooling loads), thermal and electrical storage, and smart predictive controls?
- What is the **optimal institutional framework** for advancing the aforementioned objectives, with respect to the national building and electrical code development system, provincial and territorial adoption in regulation, enforcement institutions (mainly local governments), professional reliance models, the “objective-based” premise of performance in building codes (despite continued adherence to prescriptive “acceptable-solutions”), and the opportunities for data-driven performance verification. What can we learn from other countries on innovation and resilience in building regulatory systems? What tweaks and comprehensive shifts could Canada benefit from?
- How can **integrated approaches for building design and operation, integration of on-site renewable energy generation, optimized interaction with smart grids, healthy and comfortable indoor environment** be developed and followed? This is a major challenge that cuts across major engineering disciplines and architecture/urban planning, as well as traditionally separate government departments.

Roadmap to Resilient Ultra-Low Energy Built Environment with Deep Integration of Renewables in 2050: Symposium Program

Click on the paper title to open the selected paper and the presenter's name to open the biography.

Online connection		10:30 – 11:00
Graham Carr , President and Vice-Chancellor of Concordia University	Opening Remarks	11:00 – 11:05
Gina Cody, FCAE , Gina Cody School of Engineering & Computer Science, Concordia University	Welcoming Remarks	11:05 – 11:10
Andreas Athienitis, FCAE, Symposium Chair & Roadmap Co-Chair , Director, Concordia Centre for Zero Energy Building Studies, Concordia University	Introduction	11:10 - 11:20
Yves Beauchamp, FCAE/FACG, President CAE , VP Administration and Finance, McGill University	Background	11:20 - 11:30
PAPER SESSION I		
PRESENTER	TITLE	
Miguel Anjos, FCAE , Professor and Chair of Operational Research, School of Mathematics, University of Edinburgh, U.K.	Integration of Smart Buildings into the Electric Energy Grid	11:35 - 11:40
Andreas Athienitis, FCAE , Professor and NSERC/Hydro-Québec Industrial Research Chair & Concordia Chair, Concordia University, QC	Design and Operation of Resilient and Flexible Buildings	11:40 - 11:45
Andrew Pape-Salmon, FCAE, Roadmap Co-Chair Executive Director, Building and Safety Standards Branch, Ministry of Municipal Affairs and Housing, BC	Net-Zero Ready Building Codes	11:45 - 11:50
Christopher Kennedy, FCAE , Professor and Chair, Civil Engineering, University of Victoria, BC	Jurisdictional Responsibility for Improving the Resilience of Buildings to Climate-related Power Outages	11:50 - 11:55
QUESTIONS		11:55 - 12:10
Ursula Eicker , Professor and Canada Excellence Research Chair, Building, Civil and Environmental Engineering, Concordia University, QC	Planning and Simulation of Net-Zero, Carbon Neutral and Resilient Communities	12:10 - 12:15
Remi Charron , Associate Professor, Energy Management, New York Institute of Technology, BC	Expanding Performance-Based Step-Codes Beyond Energy Efficiency using A Forward-Looking Reference Building	12:15 – 12:20
Caroline Hachem-Vermette , Associate Professor, Environmental Design, University of Calgary, AB	Design Strategies for Climate Resilient Neighborhoods	12:20 – 12:25
Theodore Stathopoulos, FCAE , Professor, Building, Civil, and Environmental Engineering, Concordia University, QC	Wind Resilience: Proceeding from Wind Codes and Standards of Building Design Practice	12:25 - 12:30
QUESTIONS		12:30 – 12:45

BREAK		12:45 – 13:05
PAPER SESSION II		
PRESENTER	TITLE	
Rosamund Hyde , Manager of Research and Innovation Services, Stantec, ON	Building Operation and Occupant Behavior	13:05 - 13:10
Ted Kesik , Professor, Architecture, University of Toronto, ON	The Challenges of Developing Thermal Resilience Policies, Protocols and Procedures for Buildings	13:10 – 13:15
Iain MacDonald , Senior Research Officer, National Research Council Canada, ON	Supporting the Development of Net Zero Energy Ready Building Codes	13:15 – 13:20
Liam O’Brien , Associate Professor, Architectural Conservation and Sustainability Engineering, Carleton University, ON	A New Housing Stress Test: Codifying Thermal Resilience of Buildings	13:20 - 13:25
Louis Gosselin , Professor, Mechanical Engineering, Laval University, QC	Lessons Learned with Respect to the CAE Roadmap from the Monitoring of a High-Performance Social Housing Building in Quebec City	13:25 – 13:30
QUESTIONS		13:30 - 13:45
Chang-Seo Lee , Research Associate, Building, Civil and Environmental Engineering, Concordia University, QC	Air Purification Technologies for Resilient Buildings: Abilities and Limitations	13:45 – 13:50
Meli Stylianou , Manager, Housing and Buildings R&D, CANMET Energy, Natural Resources Canada, ON	Pathways for Net Zero Energy Buildings and Communities Research Activities at Canmet Energy-Ottawa	13:50 – 13:55
Marianne Touchie , Assisant Professor, Civil Engineering and Mechanical & Industrial Engineering, University of Toronto, ON	Passive Strategies to Improve Multi-unit Residential Building Thermal Comfort Resilience in Future Climate Scenarios	13:55 – 14:00
Costa Kapsis , Assisant Professor, Civil and Environmental Engineering, University of Waterloo, ON	Building-Integrated Photovoltaic Systems: Enabling Energy-Resilient High-Performance Buildings	14:00 – 14:05
Ian Beausoleil-Morrison , Professor, Mechanical and Aerospace Engineering, Carleton University, ON	Providing the Majority of the Energy Needs of Canadian Housing by Solar: The Need for Seasonal Storage	14:05 – 14:10
QUESTIONS		14:10 – 14:25
BREAK		14:25 – 14:30
PANEL DISCUSSION: Designing a Resilient Ultra-Low Energy Built Environment with Deep Integration of Renewables: additional perspectives Co-chairs: Andreas Athienitis and Andrew Pape-Salmon Marianne Armstrong , Principal Research Officer, NRCC: <i>Resilience in building codes</i> Christian Bélanger , Director Strategic and Transversal Projects, IREQ, Hydro-Québec: <i>Buildings and Electric power system of the future - A new partnership to define</i> Bryan Purcell , Vice President of Policy and Programs, Atmospheric Fund & Federation of Canadian Municipalities: <i>Planning municipalities for sustainability and resilience</i> Sophie Hosatte – Ducassy , Director- Buildings Group, CanmetENERGY, NRCAN: <i>Building energy efficiency, advanced heat pumps, thermal storage and optimal control of high performance buildings</i>		14:30 – 15:30
ALL	CLOSING DISCUSSION	15:30 – 16:00



INTEGRATION OF SMART BUILDINGS INTO THE ELECTRIC ENERGY GRID

Miguel F. Anjos, Ph.D., P.Eng., SMIEEE, FEUROPT, FCAE

Chair of Operational Research, School of Mathematics, University of Edinburgh, Scotland, UK

Inria International Chair on Power Peak Minimization for the Smart Grid

GERAD and Polytechnique Montréal, Montréal, Québec, Canada

anjos@stanfordalumni.org

ABSTRACT

This paper considers the present and future roles of the built environment towards attaining the ultimate objective of an energy system that is zero-carbon and resilient under extreme weather conditions or other disruptive events. Smart buildings in particular will be key players by becoming prosumers. This raises the policy challenge for Canada of how best to integrate them within the existing energy system so as to maximize their positive impacts.

INTRODUCTION

The operator of an electric energy network must meet user demand while ensuring the stability of the electricity grid. This is particularly challenging during periods of peak demand because the system is then operating near its limits of both generation and transmission. This often requires bringing online the most expensive generating units, thus increasing the total cost of meeting demand.

At the same time, the electricity grid is aging and is thus more susceptible to weather events, human error, malicious attacks, and equipment failure. This increased susceptibility has led to an increase in the number and severity of utilities' operational problems. When these problems propagate in the power system they can lead to massive blackouts (NASME, 2017).

Moreover, there is a global drive to integrate increasing quantities of renewable energy generation into the electricity grid. In Canada, solar and wind power capacity together represented 9% of the total power capacity in 2015 (NEB, 2016), and this proportion is expected to more than double by 2040 (NEB, 2017).

When large-scale renewable energy providers such as wind farms are connected to the grid, a further complication is added because of the fluctuating nature of this generation. These fluctuations require the network operator to keep in reserve, and to more frequently use, more of the most expensive generating units. Because these reserve units are almost always fuelled by natural

gas, this leads to increased greenhouse gas emissions that cancel out some of the benefit from the integration of renewable energy.

This situation has created a great need for flexibility on the demand side of the electricity equation. In this paper we consider the opportunities for the smart buildings of the (near) future to provide such flexibility, the risks involved, and the policy challenges that arise. While the discussion is framed in general terms, the relevance to the Canadian situation is highlighted throughout.

SMART BUILDINGS AS THERMAL ENERGY STORAGE UNITS

We start from the perspective that a building can be viewed as a means to store heat. In other words, from the perspective of the grid operator, a building is able to store thermal energy by virtue of its use of electricity to operate heating/cooling devices. This includes not only space heaters and air conditioners but also appliances such as refrigerators, freezers, and hot water heaters. This means that buildings can provide flexibility to the grid to the extent that the operation of these devices can be shifted in time, and specifically out of peak demand periods and into periods of the day with lower demand.

The potential for flexibility provision by buildings in Canada is significant. Space heating is responsible for more than 60% of the total residential energy consumption (Stats Can 2013), and electric baseboards account for 27% of heating equipment nationally, and for 66% of it in Québec, a winter-peaking jurisdiction. Ontario is typically a summer-peaking jurisdiction due to the high penetration of air conditioning systems (OEB 2015, NRCan 2011).

Load shifting by users is generally referred to as demand-response (DR) or demand-side management (DSM). This is a well-known paradigm that has contributed to the operation of electric grids for many years. While DR programs have traditionally focused on taking advantage of the response capabilities of large industrial consumers, the advent of time-of-use pricing

for electricity has partially tapped the DR potential of commercial and residential customers.

Smart buildings offer the prospect of maximum utilisation of the thermal storage potential of the built environment to provide DR services to the grid. From a practical perspective, individual buildings are unlikely to participate directly in providing DR because, differently from large industrial customers, their numbers are much larger and their DR capacities much smaller. The pooling and coordination of their capacities is done via a DR aggregator, or more generally, a virtual power plant. These are commercial entities that deploy their portfolio of commercial and residential DR providers to perform near real-time load shifting, and more generally to provide new ancillary services to the grid. (Ancillary services are all the functions required to maintain grid stability.) For example, customers in California can already choose to participate in such DR problems (CPUC, 2020).

In Canada, much of the leadership in this area has taken place in the Maritime provinces. The demonstration project *PowerShift Atlantic* (PowerShift Atlantic, 2015) aggregated around 17 MW of load from more than 1400 residential and commercial customers based on directly controlling their electric water heaters and electric heating. The *smartDESC* R&D project (Malandra et al, 2020) provided a proof of concept for the possibility to use a decentralized control architecture to provide DR. These projects demonstrated that commercial and residential DR is both technically possible and economically promising. Going beyond R&D, Saint John Energy is deploying a commercial energy management system to manage commercial and residential energy consumption at peak times (NRCan, 2019).

The provision of DR via the thermal storage capabilities of buildings is thus already becoming a reality in Canada, and is poised to grow in the future. In the rest of this paper, we glimpse into the future of the interaction of smart buildings with the electricity grid.

SMART BUILDINGS AS PROSUMERS

The technological advances and decreasing costs of PV panels, batteries, and electric vehicles have led to an increasing integration of these technologies into the built environment. By taking the storage capacity of buildings and pairing it with these technologies, smart buildings become prosumers.

A *prosumer* both produces and consumes electricity and is hence able to manage its own electricity usage and supply. The advent of prosumers will be another major development in the current evolution of the electricity grid. Prosumers will directly contribute to the distributed integration of renewable energy in a pervasive manner,

and hence will support the development of net-zero buildings and communities.

Prosumers have the potential to provide benefits to the grid as a whole through the provision of ancillary services. Furthermore, the distribution of generation throughout the grid may help to defer, or even avoid, the need for investment in new grid infrastructure to address congestion, reliability, or resilience issues. The value of their contribution will however depend on their attributes, including their location within the network and their availability when needed (NASEM, 2017).

The conditions for prosumers to blossom are becoming a reality. A recent study of residential prosumers in Europe reported that PV adoption is expected to reach 39.5% of the total potential residential solar PV capacity in Germany by 2030, 29.0% in Belgium, 26.4% in the Netherlands, 18.7% in Denmark, and even 13.1% in the UK (EC, 2017). This is without taking into account the synergies with battery storage, electric vehicles, and other prosumer technologies. In the Canadian context, Ontario and the Maritime provinces are promising jurisdictions for prosumers due to the combination of high penetration of renewables and relatively low hydro-electric generation, both of which lead to higher electricity prices thus making the economic case for prosumers more attractive.

The impact of prosumers on the grid will initially be difficult to detect within the total consumption of residential and commercial customers. However, there will be a critical threshold on prosumers penetration beyond which the ability of prosumers to adjust their consumption, possibly even by temporarily choosing operate in a stand-alone manner, will lead to increased uncertainty in load forecasting, and make it more expensive to maintain grid stability. We discuss this further in the next section.

An unexpected aspect of the nature of prosumers is that they have high expectations for acknowledgement of their contribution. A recent study in Finland that directly interacted with private solar panel owners and energy company representatives via interviews and observations concluded that prosumers are a new group of stakeholders in the grid who expect a relationship of reciprocity with the grid on the basis of co-production of energy (Olkonen et al, 2017). This will clearly require adjustments on the part of many electricity providers.

POLICY CHALLENGE FOR CANADA

The emergence of prosumers will follow one of two possible scenarios. In the first scenario, prosumers will focus on reducing their consumption from the grid, operating in a standalone mode (temporarily disconnected) or possibly even in disconnected mode (physically disconnected). The second scenario is that prosumers will remain connected and provide ancillary

services, including flexibility, thus becoming active stakeholders of the electricity grid. These two scenarios are discussed in detail in Kuznetsova and Anjos (2019). We briefly summarize here the key points of their analysis and its implications for Canada.

One of the key motivators for grid disconnection is an electricity pricing structure that penalizes prosumers. For example, in Ontario in 2016 the cost of energy and power represented less than 9% of the typical electricity bill, with the remainder covering grid fees and various subsidies, environmental initiatives, fixed costs, and taxes (Kuznetsova and Anjos, 2019). Feed-in tariffs provided some compensation for this, but this economic incentive to remain connected has now been removed. By disconnecting from the grid, a prosumer could use the savings towards the setup equipment cost, and thus be protected from possible increases in the non-energy and power components of the electricity bill.

In Ontario, disconnection is particularly attractive for prosumers in low-density regions. Not only are their grid charges the highest in the province, but moreover they usually can more easily and cheaply accommodate the physical space needed for PV panels, storage, and other equipment required.

One of the consequences of the physical disconnection of large numbers of prosumers would be an increase in the economic pressure on the remaining connected customers who are faced with increased fees to maintain the network.

Furthermore, the economic viability of the electricity grid itself could be threatened. In Australia, the grid operators have been lobbying for compulsory connection fees in the residential and commercial sectors, regardless of whether the building in question is connected to the grid or not, or alternatively, for customers disconnecting from the grid to pay a penalty (Parkinson, 2015).

While it is in principle possible for all customers to become prosumers, if this were to happen, it would likely be in the form of local micro-grids within which participants can exchange energy according to availability and needs. This reflects in a smaller scale the main benefit of the electricity grid: the increased reliability provided by interconnections between buildings, communities, and provinces. The intent is that a microgrid should be able to function for more than a few minutes as a controlled electrical island (CIGRE, 2015).

It is therefore important to support and promote the rise of prosumers while proving incentives for them to remain connected to the grid. The objective should be to strike a satisfactory tradeoff between the interests of prosumers and the needs of the network operators.

One possibility is to encourage high levels of energy exchange between all stakeholders via the grid. This will

require a large amount of investment in the grid infrastructure for it to be able to support *bi-directional flows of electricity*. This is because the current (local, low voltage) distribution systems are typically designed for the electricity to flow in only one direction, namely from the grid to the consumer. Significant modifications to existing distribution systems will be required to support the injection of electricity into the grid by prosumers while supporting the continuing use of existing infrastructure (CCA, 2015). A large-scale energy exchange mechanism would also be required, likely in the form of a market.

An alternative option is to encourage local energy generation and consumption within a micro-grid, as mentioned earlier, while keeping the connectivity to the electricity grid to be able to carry out a certain amount of energy exchange, and to benefit from the greater reliability of large-scale generation whenever the local energy balance is problematic due to seasonal, social, or other factors. This option would likely require less investment in infrastructure but would depend on having a suitable energy pricing structure that is attractive for both local communities of prosumers and the grid operator.

One proposal to reconcile their interests is *time-and-level-of-use pricing (TLOU)* (Gómez-Herrera and Anjos, 2018, 2019). This is an extension of the time-of-use (TOU) pricing that is widely used, for example in Ontario. TLOU extends TOU by having the electricity price vary not only according to the time of day but also according to the total amount of power used at the same time. The idea is that the customer (prosumer, micro-grid) and the grid agree in advance on a maximum power capacity for each period of the day, for example every hour. TLOU then charges a lower price for the energy consumed up to the power capacity limit, and a higher price for energy exceeding the limit. The original motivation for TLOU is to encourage consumers to even out their consumption throughout the day, but it equally benefits prosumers who can negotiate the individual power capacity limits, and hence the cost of energy from the grid, according to their capabilities and needs.

In closing, it is important to remember that the successful nurturing and integration of prosumers into the Canadian electricity grid will support the integration of renewable generation in the energy system, and hence reduce the use of fossil fuels in meeting Canada's energy needs.

CONCLUSION

This paper provided an overview of the present and future roles of the built environment in an electricity grid with increasing integration of renewables, with the ultimate objective of achieving an energy system that is zero-carbon and resilient under extreme weather conditions or other disruptive events. Smart buildings in

particular will become key players with the advent of prosumers. This raises the policy challenge for Canada of how best to integrate them within the existing energy system so as to maximize their positive impacts. Key policy issues to incentivize prosumers to remain grid-connected include:

- Acknowledging the role of prosumers within the electricity system as co-producers of energy.
- Supporting local energy management within grid-connected micro-grids via suitable pricing schemes.
- Establishing a large-scale energy exchange mechanism.

The Montreal symposium will be a welcome opportunity to discuss these issues and propose ways to address them in the Canadian context.

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DESIGN AND OPERATION OF RESILIENT AND FLEXIBLE BUILDINGS

Andreas Athienitis, Liangzhu Wang, Hua Ge, James Bambara
Centre for Zero Energy Building Studies, Concordia University, Montreal, QC

ABSTRACT

This paper reviews some of the key technological developments that led to modern buildings – their building envelopes and their heating and cooling systems and the more recent energy generating systems from renewable on-site energy sources. Current challenges to achieve energy resilience to extreme weather events and other disasters are discussed. Flexibility in building design to facilitate adaptation to evolving needs and operational flexibility in the interaction with smart grids are discussed. Efficient integration of HVAC and building-integrated solar technologies, along with energy storage are discussed as a means of achieving energy resilience, including designing buildings to resist the spread of viruses such as COVID19.

INTRODUCTION

Buildings have evolved over the centuries from the traditional mud-brick and stone structures, or timber houses, into the complex structures that define our built environment today¹. To provide structural strength we now typically design steel structures, concrete structures or wood structures or increasingly hybrid structures. The building envelope that separates the indoor from the outdoor environment consists of two main parts – an opaque part and the fenestration; the opaque envelope typically includes several layers that have different functions – the inner layer hides many of the services (e.g. wiring and piping) but also has a protective function from moisture exfiltration in the indoor environment. Insulation is typically placed between and behind structural members and then there are the outer layers that have traditionally been passive and have a weather barrier /weather protection function.

The fenestration has evolved from single glazing² to the sealed double glazed units (with air in the cavity) that became widespread in the last decades of the 20th Century. A major advance in fenestration was the adoption of a low-emissivity coating on one of the two

surfaces in the cavity that reduces radiation heat transfer between the two surfaces by about 90%; the convection heat transfer between the two surfaces is also reduced by about 20-40% by using inert gases such as Argon and Krypton in double-glazed units and further through insulated framing systems. In colder climates, triple-glazed units also started becoming common. The adoption of low-e windows started becoming widespread in North America during the period 2005-2010, although low emissivity coatings were developed since the 1980's (Rissman and Kennan, 2013). This adoption of low-e windows enabled designers to adopt increasingly larger window areas so as to have more daylight and better views to the outdoors, but heating and cooling loads started to rise as a result of this new trend.

BUILDINGS AND ADOPTION OF HVAC & ENERGY SYSTEMS

In much of the world, buildings until the beginning of the 20th century were **passive structures** with manually operable windows, relying on natural ventilation for cooling and combustion of fossil fuels for space heating.

A major development in the modern industrial era was the adoption of **electricity** with the development of alternating current motors that made possible the invention of oscillating fans in the early 20th century and artificial lighting with incandescent lamps. In the early 20th century, Willis Carrier invented the first modern **air-conditioning** (AC) system; its initial purpose was dehumidification. In 1922, Carrier invented the centrifugal chiller, which added a central compressor to reduce the unit's size. The widespread adoption of AC units in US homes took about 40-50 years. By the late 1960s, most new homes had AC, fueling population growth in hot-weather states like Florida. AC is now in 87% of all US households³. In Canada, the adoption of AC was slower in homes until **heat pumps** became widely available at a relatively low cost, with the capability to do both heating and cooling. The rate of adoption of heat pumps is increasing and this trend will

¹ <https://www.buildingscience.com/documents/digests/bsd-007-historical-development-of-the-building-enclosure>

² The Romans were the first known to use glass for windows, a technology likely first produced in Roman Egypt, in Alexandria ca.

100 AD (Wikipedia) but it started being widely used only in the 17th Century in England.

³ <https://www.energy.gov/articles/history-air-conditioning>

continue with higher efficiency modulating units available at lower cost.

Solar technologies – mainly solar thermal and photovoltaic (PV) panels have been developed in the last 60-70 years. Solar thermal collectors are mainly used for water heating and, while PV produces electricity, PV/thermal collectors have also started being developed in the last 20 years to produce both electricity and heat. Standalone PV is the lowest cost electricity resource in the world at roughly \$0.65/watt⁴, but is limited by intermittency, associated grid issues, institutional barriers, lack of market capacity and other major barriers to integration in buildings and public spaces. Steps are being taken around the world on the production of Building-integrated photovoltaics (BIPV) and more recently BIPV/thermal systems (BIPV/T). With BIPV/T systems, the building skin becomes essentially a solar collector that produces electricity and useful heat.

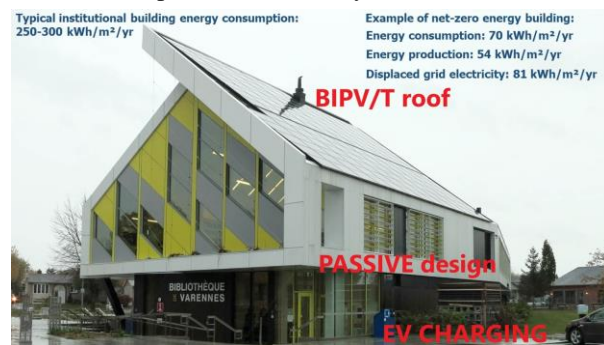


Figure 1. Varennes Library – Canada's first institutional NZEB with a building integrated photovoltaic/thermal system, passive solar design, EV charging, a geothermal heat pump system and radiant slabs.

NET ZERO ENERGY BUILDINGS

The feasibility of new **net-zero energy buildings** (NZEBs) that integrate ultra-high energy efficiency with on-site renewable energy generation to produce, in an average year, as much energy as they use, has been recently demonstrated both for detached houses and low-to mid-rise commercial and institutional buildings, both in Canada and other developed countries (Athienitis and O'Brien, 2015). Many definitions exist for NZEBs, most recently documented and discussed under IEA SHC Task 40 / EBC Annex 52 (Voss, 2011) and new integrated design approaches are being developed. NZEBs need energy storage to achieve energy resilience in the event of power outages and also to provide flexibility to smart grids. This storage could be thermal or battery (or both) and an EV/PHEV could possibly be used to trade energy with a smart grid and provide backup power. In Canada, the first institutional solar NZEB, the Varennes Library, was inaugurated in 2016

(Dermardiros et al., 2019). A similar archetype building could be designed to generate twice as much electricity and heat, possibly powering and heating adjacent buildings and providing resilience through adequate energy storage and micro-grids.

Design of buildings and groups of buildings (communities, clusters) for resilience creates new challenges. A major challenge is setting the **goals for energy resilience: for how long should a community be able to generate its own power and heat** in natural disasters such as Ice-storm 98 (Lecomte, 1999) that resulted in up to 5-week power cut, 4.7 million people displaced in Québec and Ontario and economic loss of over \$6 billion. This led to significant damage to buildings after their occupants evacuated them due to utility outages, resulting in extensive water damage from frozen water pipes and contributing to the economic loss. Such damage could be greatly reduced through resilient solutions that enable on-site electricity and heat production with building-integrated renewables.

A simulation study (Bambara et al., 2020) was conducted to evaluate the impact of replacing aging detached houses in Montreal with two houses of equivalent living areas on the same land lot. The new high efficiency houses can reduce energy consumption by 67% (22,600 versus 7,300 kWh/year) and a photovoltaic roof can generate nearly 3 times more energy than the house consumes (43,300 kWh/year). In addition to the advantage of doubling the number of inhabitants on the same land area, densification has the potential to transform the current status of people consuming 5,640 kWh/year to becoming net producers of 3,580 kWh/year. The excess solar electricity generated by the new houses could be instrumental in decarbonizing the transportation sector by providing clean power for electric vehicles, which in-turn can provide bi-directional energy flow from/to buildings as needed.

BUILDING ENVELOPE, DURABILITY

The building envelope is critical in achieving high performance resilient and flexible buildings. Its performance directly affects the energy efficiency, indoor environmental quality, and durability. The role of building envelope has evolved from a conventional environmental separator to an important element in moderating indoor environment and contributing to the energy generation and resilience. Energy efficiency and durability of the building envelope are two cornerstones of sustainable building design. Building envelope is intended to have a long service life and is costly to maintain and repair if failures occur. The **durability of the building envelope** is influenced by the combination of the environmental loads, namely, temperature,

⁴ https://iea-pvps.org/wp-content/uploads/2020/01/2019-223_RP-ANU_DER-PVNORD_CBaldus-Jeursen_YPoissant_EN.pdf

moisture and UV radiation. The presence of moisture is a key element associated with most degradation mechanisms. In areas with higher amount of wind-driven rain, rain penetration is the main source of moisture, such as Southern British Columbia. The systematic building envelope failure due to rain penetration cost \$2 billion for repairs (Barrett, 2000). For cold climate, moisture due to air leakage and vapour diffusion are the main sources. There are numerous cases of failure of building envelopes, often due to a mis-understanding of the environmental loads and the performance of these building envelope systems to specific microclimates (Lstiburek, 2006). Unless properly designed, particularly during retrofits, highly insulated building envelope may have reduced drying capacity and increased risks for moisture damage.

The mean global temperature has increased by 0.85°C compared to the pre-industrial period (1850-1900). For Canada, the temperature rise was double and in the arctic latitudes the increase was triple (Pachauri et al., 2014). Higher precipitation totals have been projected for all parts of Canada with the highest increases projected for the northernmost regions. For certain locations, it is projected that increases in the frequency, intensity and duration of precipitation as well as increase in peak wind loads and the frequency of occurrence of extreme winds (Lacasse et al., 2020) with associated wind driven rain.

Buildings built today are optimized based on historical climatic conditions. With a warming climate, more frequent extreme weather events are anticipated and these buildings will be exposed to a climate that is significantly different than that observed historically during their service life. Therefore, they need to be able to adapt to future climatic conditions, as well as to function as intended during extreme weather events such as heat waves, ice storms and wind storms with heavy rain. Under the projected future climates, the heating energy demand would be reduced, while the cooling energy demand would significantly increase. The overheating risk during summertime would be significantly increased in the future (Baba and Ge, 2019). Therefore, buildings typically designed to reduce heating energy consumption need to be optimized based on projected future climates. Buildings also need to be able to maintain acceptable indoor thermal conditions during **extreme weather events** such as heat waves or ice storms with low requirement of power. The integration of renewables such as photovoltaics (BIPV, BIPV/T, semi-transparent PV windows) can serve the conventional building envelope function as well as generating electricity and thermal energy. To function as a Building Envelope system, it needs to fulfill the function of controlling heat, air and moisture, fire, noise transmission, and provide structural resistance to earthquakes and wind. The electricity generated from

BIPV systems may provide energy needed during these extreme weather events and power outage. Currently there is no standard for evaluating the performance of BIPV and BIPV/T as building envelope systems and this is a major barrier to their adoption. Inclusion of BIPV in building codes is also an urgent need.

HYBRID AND NATURAL VENTILATION

The **COVID19 pandemic** has further revealed the need for buildings and their ventilation systems to be designed to limit the spread of pathogens, such as COVID19, which has been shown to be spread as aerosols (Li et al., 2020). This can be done by reducing recirculation of HVAC air and bringing in more fresh air to dilute pathogen concentration, thus limiting the spread of infections (ASHRAE, 2020), in addition to use of special filters and UV disinfection measures. Canadian buildings need to be able to face crises such as ice-storms and pandemics simultaneously since **both typically happen in winter**; if they do, physically distancing with millions of people displaced from their homes and relocated in confined places/shelters will be very difficult, if not impossible, possibly resulting in many more deaths than what we experience with the COVID19 pandemic, currently in its second wave.

Natural ventilation (NV), is the process of replacing stale or noxious indoor air with fresh air without using mechanical means. NV was used since ancient times; for example, Persians and Egyptians used curved-roof vents to control the level of indoor dust so as to reduce the risk of getting respiratory diseases by enhancing ventilation (Allard and Santamouris, 1998). NV is also widely applied in both residential and commercial buildings to reduce indoor CO₂ concentrations (Stabile et al., 2017), lower the risk of sick building syndrome (Seppänen and Fisk, 2002), provide acceptable thermal comfort, and achieve energy savings when the quality of the outdoor air is suitable for NV. It was reported that by replacing the mechanical ventilation system with a NV system, annual energy consumption was reduced by 18-33% while maintaining acceptable classroom comfort levels (Gil-Baez et al., 2017). According to opening locations, there exist two main types of NV: single-sided ventilation and cross-ventilation. In single-sided ventilation, only one façade is designed to have openings, whereas cross-ventilation is enabled by two or more openings on adjacent or opposite façades.

NV is well suited to Canadian climates that are characterized by long seasons of cool-mild outdoor environments from May to October (ECCC, 2014). Figure 2 shows the maximum annual total NV potential hours for a 70 W/m² cooling load across North America with the arrows indicating the best window-facing directions. For example, the study showed that Toronto has a NV potential of 1,600 hours/year of southwest facing single-sided NV compared to the 1,500

hours/year with northeast-facing windows in Vancouver. The difference is because Toronto has a higher average daily temperature and more suitable for the rated cooling load of 70 W/m^2 (Cheng et al., 2018)

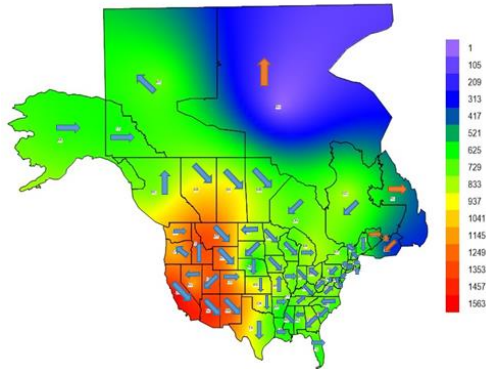


Figure 2. Natural ventilation potential in North America.

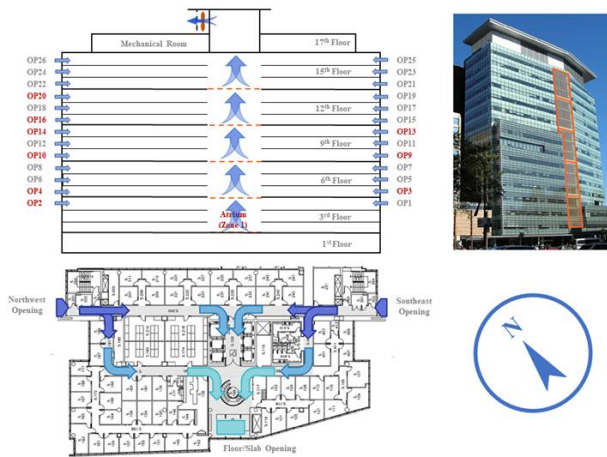


Figure 3. An institutional high-rise building with HV.

When NV alone cannot satisfy the needs of air exchange or space cooling, mechanical fans and artificial cooling are added, so hybrid ventilation (HV) applies. Previous studies found that HV could save 90% of cooling system energy when proper control strategies were in place (Ezzeldin and Rees, 2013). The study applied hybrid ventilation to space cooling in a desert area with diurnal temperature variation. A climate-responsive operation strategy was designed that incorporated several technologies (i.e., direct evaporative cooling, borehole heat exchanger, night convective cooling strategy, and radiant cooling elements coupled to a cooling tower). HV was found to contribute to more than 40% of the total energy savings while at the same time providing satisfactory thermal comfort. A higher temperature set point with a higher thermal mass used in the design reduced temperature fluctuations and improved thermal comfort in the building. A whole-building study that integrated HV and building thermal mass was conducted in an institutional high-rise building (Yuan et al., 2018) (Figure 3) at Concordia University; it showed that 180

Whr/m² of cooling energy could be saved in the daytime after the corridor concrete floors had been chilled by HV for four hours during the night. Nagano et al. (2006) applied a phase-change material (PCM) to the floor in a air-PCM ventilation system and showed that the PCM increased the thermal storage to 1.79 MJ/m^2 . Zhang (2019) studied the building in Figure 3 with the integrated HV and PCM systems and found that the PCMs could double the stored heat.

The design and operation of NV and HV systems for resilient and flexible buildings need to address the following major challenges:

- The design of a NV/HV system must be based on a systematic and integrated approach, starting at the conceptual design stage due to many interacting parameters involved: outdoor and indoor conditions, many building parameters (site, shape, orientation, window-to-wall ratio, internal layouts), thermal comfort and ventilation requirements. Many major decisions have to be made at the initial stage as the modification of an existing system is difficult and more expensive.

- The NV/HV system design must also address important issues such as fire protection, because the same system, which is designed for energy saving, may facilitate a quicker fire smoke spread during a fire, and thus may create a fire risk. A typical NV/HV system must be designed to accommodate both fire-protection and non-fire-protection modes, such as through automatic fire-proofing dampers aided by advanced sensor systems for fire smoke zoning and separations. The NV/HV system must also be controlled as a function of the variable ambient weather and air quality through sensor systems both indoors and outdoors. It should also adaptively increase the amounts of fresh air (possibly solar heated) **to remove viruses such as COVID19** while recovering energy from the exhaust air.

- For regions with significant diurnal temperature variations, there often exists a mismatch between demand and response for a NV/HV system. The peak cooling load may occur in the middle of the day, whereas the outdoor temperatures are unsuitable for NV/HV; when the outdoor air temperature is low at night, the indoor cooling load may become so low that natural ventilation becomes unnecessary. This problem can be solved by the use of load-shifting techniques. The thermal mass can be cooled at night so that it cools down the indoor environment during the daytime. The thermal mass also helps to stabilize the variation of indoor temperature for better thermal comfort when the outdoor temperature fluctuates. The operation of a NV/HV system should be in a proactive manner. It can be based on model-predictive controls with future weather forecasts as inputs, so that the system reacts early enough before an extreme weather event occurs or when there is a foreseeable need for flexible building operations.

CONCLUSION

This paper considered the historical evolution of buildings to controlled indoor environments protected by a resilient and durable building envelope that can now integrate renewable energy sources. It is now possible for buildings to generate as much energy from renewable sources as they consume while supporting smart grids, and even to generate electricity for electric vehicles, thus further contributing to reducing GHG emissions. As the current COVID19 crisis shows, it is increasingly important to design resilient buildings that also have flexible ventilation systems that eliminate contaminants and viruses. The CAE Roadmap will need to address the challenges of resilience, decarbonization and a healthy indoor environment in an integrated manner.

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NET-ZERO READY BUILDING CODES

Andrew Pape-Salmon^{1,2} and Toby Lau³

¹BC Ministry of Municipal Affairs and Housing, Building and Safety Standards Branch, BC

²University of Victoria, Civil Engineering, BC

³BC Hydro, Advanced DSM Strategies, Conservation and Energy Management, BC

ABSTRACT

This paper provides an overview of current legislation and regulatory frameworks or proposals of three levels of government to achieve “net-zero energy ready” new construction over the next decade. The paper defines the performance standard, highlights policy drivers, and compares and contrasts the approach of three levels of government from the perspectives of technical performance of buildings, consistency, compliance and enforcement, and opportunities for transformative market change. While the scope of the paper is limited to current building code objectives, namely energy efficiency, it provides a foundation for future research on decarbonization and resiliency of buildings.

INTRODUCTION

This paper provides an overview of current legislation and regulatory frameworks or proposals of three levels of government to achieve “net-zero energy ready” new construction over the next decade. The three levels of government include the federal government publishing of the National Building Code of Canada (NBC), the Province of BC’s Energy Step Code within the BC Building Code (BCBC) and the City of Vancouver’s Building Bylaw and rezoning policy.

Codes Canada publishes the NBC and the National Energy Code for Buildings (NECB) approximately every five years, with the 2020 edition anticipated by the end of 2021. While the federal government publishes the NBC, it is the provinces, territories and charter cities such as Vancouver that adopt it in regulation, along with its various performance standards.

A key federal policy driver is the Pan Canadian Framework on Clean Growth and Climate Change. It states, “The Government of Canada will work with the provinces and territories to ... develop a “net-zero energy ready” model building code, with the goal that provinces and territories adopt it by 2030” [ECCC 2016]. This precipitated amendments to the NBC and NECB that were posted for public review in early 2020.

The BCBC is adopted in regulation under the *Building Act*, applying to owners and developers of buildings. The *Local Government Act* and *Community Charter* enable local governments to implement the BCBC and enforce it through local government bylaws and building permits. Local governments are unable to enforce technical standards that are “matters” referenced in the BCBC unless the Building Act General Regulation [Queen Printer 2020-1] explicitly makes a matter “unrestricted” such as the form, exterior design, or finish of buildings relating to wildfire hazard (a topic of resiliency). In the case of the conservation of energy and the resultant reduction of greenhouse gas emissions, a local government can reference any step of the BC Energy Step Code in policy or bylaw.

A key policy driver is the 2018 CleanBC Plan that includes a commitment to “Improve the BC Building Code in phases leading up to ‘net-zero energy ready’ by 2032”. This includes making homes and buildings 20 per cent more energy efficient by 2022, 40 per cent more energy efficient by 2027, and 80 per cent more energy efficient by 2032 – the net-zero energy ready standard” [BCECCS 2018].

The BCBC objectives include “Energy Efficiency and Water Use” to “limit the probability that, as a result of the design, construction or renovation of the building, the use of energy will be inefficient or the use of water will be excessive.” [Queens Printer 2020-2]. Energy security, carbon intensity and resiliency are beyond the scope of this paper, but conclusions are drawn to inform future research on those topics.

The regulatory jurisdiction of the City of Vancouver is governed by the *Vancouver Charter*, and that includes authority to publish its own building bylaw with unique technical standards, including regulations for the reductions of greenhouse gas emissions [Queens Printer 2020-3]. In practice, the Vancouver Building Bylaw standards are harmonized with the BCBC, but in some areas adopt different standards. Vancouver’s “rezoning policy” has very stringent energy efficiency and

emission management standards which is only triggered when changes in density, height or use is sought.

Definition of Net-Zero Energy Ready

There are several definitions on ‘Net-Zero Energy’ (NZE) vs. ‘Net-Zero Energy Ready’ (NZER) buildings/houses. The following established definitions are frequently referenced:

- The Canada Mortgage and Housing Corporation [CMHC 2018] defines a NZE house as:

A house that is designed and built to reduce household energy needs to a minimum and includes on-site renewable energy systems, so that the house may produce as much energy as it consumes on a yearly basis.

- Natural Resources Canada [NRCan 2020] defines:

A Net-Zero Energy (NZE) house is a house that produces as much energy from on-site renewable energy sources as it consumes each year, and

A Net-Zero Energy Ready (NZER) house is a variant of the NZE house in which the builders have not installed the renewable energy generation system.

- BC Energy Step Council [ESC 2020] defines:

Net-zero energy buildings produce as much clean energy as they consume. They are up to 80 percent more energy efficient than a typical new building, and use on-site (or near-site) renewable energy systems to produce the remaining energy they need, and

A net-zero energy ready building is one that has been designed and built to a level of performance such that it could, with the addition of solar panels or other renewable energy technologies, achieve net-zero energy performance.

DISCUSSION AND RESULT ANALYSIS

The current and proposed codes and standards to achieve net-zero energy ready construction are highlighted below.

BC Energy Step Code

The BC Energy Step Code (ESC) was included as an optional compliance path into the BC Building Code (BCBC) in April 2017. The fourth and most recent amendment was included in the BCBC 2018 mid-cycle revision that took effect on December 12, 2019 [MAH 2019]. The BC ESC provides a technical “roadmap” to net-zero energy ready construction. It includes between three and five tiers for the following building types in all climate zones within the province:

- Part 9 residential;
- Part 3 hotels and motels;
- Part 3 residential;
- Part 3 office; and,
- Part 3 business and personal services or mercantile.

The tiers have increasingly stringent energy efficiency requirements for whole-building or mechanical end-use intensity, building envelope thermal performance, and in some cases airtightness. The BC ESC does not include prescriptive solutions; rather is exclusively a performance-based code. All buildings are required to undertake energy modelling and conduct a whole building airtightness test.

Tier 1 is always equivalent to the performance of the BCBC Division B acceptable solutions set out in section 9.36 or section 10.2. The BCBC s9.36 is based substantially on the NBC 2015 and s10.2 references both ASHRAE 90.1 2016 and NECB 2015 as acceptable solutions. The BC ESC energy modelling is primarily based on the performance paths of BCBC/NBC s.9.36.5 or NECB 2015 Part 8. It also references the City of Vancouver Energy Modelling Guidelines.

The most recent amendment to the BC ESC included a first tier (with no performance requirements) for Part 3 public sector archetypes, including schools, libraries, colleges, recreation centres, hospitals and care centres, effectively requiring energy modelling and air tightness testing for those buildings [MAH 2019].

The BC ESC top tier is designed to be equivalent to “net-zero energy ready” construction. For houses, Step 5 requires a mechanical end-use intensity (MEUI) as low as 25 kWh/m²/yr, excluding plug load and lighting, a thermal energy demand intensity (TEDI) of 15 kWh/m²/yr, and an airtightness of 1 air change per hour at 50Pa pressure differential (ACH₅₀). Passive House certified houses are deemed compliant with Step 5. An alternative Step 5 compliance path for TEDI includes a 50% improvement compared to an EnerGuide Rating system reference house. Alternative compliance paths for both TEDI and MEUI apply to Steps 2 through 4 based on EnerGuide; up to 40% for MEUI and 20% for TEDI, aligned with the NBC 2020. MEUI for all steps depend on climate zone, size of house, and use of cooling energy. TEDI requirements can be adjusted to reflect the specific heating degree days in the community where the house is located.

For multi-family residential buildings, Step 4 is the highest tier, with total energy use intensity (TEUI) as low as 100 kWh/m²/yr in Climate Zone 4, including plug load and lighting, and a TEDI of 15 kWh/m²/yr. These figures increase to TEUI ≤ 140 and TEDI ≤ 60 in Climate Zone 8.

For hotels and motels Step 4 is the highest tier, with TEUI as low as 120 kWh/m²/yr and TEDI ≤ 15 in Climate Zone 4.

For other Part 3 buildings, the top tier is Step 3, with TEUI as low as 100 kWh/m²/yr and TEDI ≤ 20 in Climate Zone 4 for offices, and TEUI as low as 120 for

business and personal service and mercantile occupancies with TEDI ≤ 20 .

National Building Code 2020

Codes Canada conducted the final public review of the next edition of the national codes from January to March 2020. Two proposed tiered performance requirements were introduced: one for the NBC Section 9.36. (Part 9 Residential Buildings) and one for the NECB (Part 3 Buildings). The tiers represent voluntary standards that have been codified. This provides increased flexibility to authorities having jurisdiction (AHJ). It is up to the AHJ to decide whether to adopt a tier or not, and at which level. The publication of these voluntary tiers in the code should help industry and the public prepare for potential upcoming code changes, essentially ‘priming’ the market for upcoming code cycles.

Tiered Performance (NBC Section 9.36.)

The Proposed Code Change Form (PCF) 1617 [Codes Canada 2020-1] introduces a new Subsection that establishes tiered performance requirements by defining five tiers in terms of overall energy performance improvement, improvement in building envelope performance, and airtightness level. The tiers are based on a reference case of the 2015 NBC and represent percentage improvements in energy performance of 10%, 20%, 40% and 70% for Tiers 2 through 5 respectively. For the envelope, the improvements are 5%, 10%, 20% and 50% compared to the reference case.

For airtightness, there are two target levels, albeit the PCF 1610 [Codes Canada 2020-2] includes 6 possible levels that span from 3 air changes per hour (at 50Pa) to 0.6 ACH₅₀. Two additional airtightness methodologies using the Normalized Leakage Area (NLA) or the Normalized Leakage Rate (NLR) approach are included – the NLA@10 and the NLR@50.

To supplement this tiered approach, it adds a new Subsection on prescriptive requirements for compliance with Tier 2 above (i.e., 10% improvement compared to reference case, 5% improvement in building envelope, level 1 airtightness) based on a points system that links to dozens of performance improvement technologies and designs. This is documented in PCF 1611 [Codes Canada 2020-3].

Tiered Performance Requirements (NECB)

Similar tiered performance requirements were introduced for the NECB through PCF 1527 [Codes Canada 2020-4].

As Tier 1 requirements are the same as the balance of the NECB there is no cost impact or energy savings attributed to this Tier.

Table 1. NBC 2020 Tiered Performance.

Tier	Performance vs. Target	% Improvement of Envelope	Airtightness Level ¹
1	$\geq 0\%$	n/a	Test only
2	$\geq 10\%$	$\geq 5\%$	1
3	$\geq 20\%$	$\geq 10\%$	1
4	$\geq 40\%$	$\geq 20\%$	3
5	$\geq 70\%$	$\geq 50\%$	3

Note (1): Airtightness Levels are defined in Table 3.

Table 2. NBC 2020 Airtightness.

Airtightness Level	ACH ₅₀	NLA ₁₀		NLR ₅₀	
		cm ²	in ² /100ft ²	L/s/m ²	cfm ₅₀ /ft ²
1	3.0	1.92	2.76	1.17	0.23
2	2.5	1.60	2.3	0.98	0.19
3	2.0	1.28	1.84	0.78	0.15
4	1.5	0.96	1.38	0.59	0.12
5	1.0	0.64	0.92	0.39	0.077
6	0.6	0.38	0.55	0.23	0.046

Table 3. NECB 2020 Tiered Performance.

Energy Performance Tier	Performance of Proposed Building Relative to Performance of Reference Building (% building energy target)
1	$\leq 100\%$
2	$\leq 75\%$
3	$\leq 50\%$
4	$\leq 40\%$

Progressive Tiers were selected to improve efficiency levels, leading to a fourth tier which is equivalent to net zero energy ready performance. Based on Codes Canada committee work Tier 4 was originally set at 25% of the reference building energy target, or a 75% reduction in energy use, the modelling rules, non-regulated loads, and fixed loads, made this target near impossible to achieve for several building typologies [Personal communications between author and committee]. As a result, the Tier was increased to 40%, for the proposed NECB-2020, to enable progressive designs to achieve Tier 4 irrespective of building type.

The four tiers for the NECB are shown in Table 3.

Vancouver Building Bylaw (VBBL)

In July 2016, Vancouver City Council approved the Zero Emissions Building Plan, aimed at reducing emissions from new buildings by 90% in 2025 [Vancouver 2016]. The Plan also adopted a target of reducing emissions from all newly permitted building to zero by 2030. To

achieve this, the City is setting limits on emissions and energy use in new buildings through several policy levers. As noted earlier, the Vancouver Building Bylaw closely matches the BC Building Code, with the exception of significantly more stringent standards for one- and two-family houses, not documented in this paper.

The Green Building Policy for Rezoning applies when a development falls outside of the “Community Plan” for the particular neighborhood with respect to height, density, occupancy and other factors. This represents a sizable proportion of construction activity in the city [Personal communication with City of Vancouver]. It includes two alternative compliance paths based on the carbon intensity of the fuels used for the building. Table 4 illustrates that energy efficiency requirements are less stringent for buildings with lower carbon fuels, resulting in an equivalent greenhouse gas intensity (GHGI) under both compliance paths.

Table 4. VBBL Rezoning Requirements.

Performance Limits Buildings Not Connected to a City-recognized Low Carbon Energy System			
Building Type	TEUI (kWh/m ²)	TEDI (kWh/m ²)	GHGI (kgCO ₂ /m ²)
Residential Low-Rise (< 7 storeys)	100	15	5
Residential High-Rise (7+ storeys)	120	30	6
Office	100	27	3
Retail	170	21	3
Hotel	170	25	8
All Other Buildings	EUI 35% better than Building By-law energy efficiency requirements, Section 10.2, in effect at the time of rezoning application		

Performance Limits Buildings Connected to a City-recognized Low Carbon Energy System			
Building Type	TEUI (kWh/m ²)	TEDI (kWh/m ²)	GHGI (kgCO ₂ /m ²)
Residential Low-Rise (< 7 storeys)	110	25	5
Residential High-Rise (7+ storeys)	130	40	6
Office	110	27	3
Retail	170	21	3
Hotel	170	25	8
All Other Buildings	EUI 35% better than Building By-law energy efficiency requirements, Section 10.2, in effect at the time of rezoning application		

TEUI: Total Energy Use Intensity
TEDI: Thermal Energy Demand Intensity
GHGI: Greenhouse Gas Intensity

Comparison and Analysis

The following highlight the differences between the four profiled “net-zero energy ready” codes – the BC Energy Step Code (BC ESC), the proposed National Building Code (NBC) 2020, National Energy Code for Buildings (NECB) 2020, and the City of Vancouver Green Buildings Policy for Re-zoning (COV).

All four codes include a performance path, leaving it to the developer/builder to ensure the building meets targeted performance outcomes. Up to four specific performance outcomes are required: (i) airtightness; (ii) energy use intensity (EUI), (iii) thermal energy demand intensity (TEDI), and (iv) greenhouse gas intensity (GHGI). Only the first requirement is measured, whereas the remaining three are modelled. The modelled values can be later verified through measured energy consumption and sub-metering; however, this falls outside of the timeframe that a building permit applies.

The primary driver for the BC ESC, NBC and NECB is energy efficiency. Up to three energy performance indicators are included – whole-building, building-envelope and airtightness. The NECB does not include TEDI. By having airtightness, TEDI, and/or a percentage envelope improvement to the reference building, the codes adopt an “building envelope first” framework, which prevents a designer from meeting the whole-building efficiency with mechanical solutions alone.

The COV drivers include both energy efficiency and greenhouse gas reductions, adding a limit to modelled emissions from the building, both direct from the combustion of fuels and indirect from the production of electricity. However, the approach allows for reduced energy efficiency for lower carbon fuels. This is misaligned with economic optimization given that low-carbon fuels are often higher cost to consumers and therefore there is rationale for increased levels of energy efficiency. This could compromise consumer affordability due to both lower energy efficiency and higher cost fuels. It would be appropriate to retain the TEDI between the two fuel choices for residential, as Vancouver has done for office, retail and hotel (albeit not for residential), thereby reducing heat loss and protecting affordability.

Based on the author’s experience the performance tiers of the BC ESC and COV are based on best practices of previously constructed buildings within generalized archetypes that represent a large proportion of construction. The reference case is based on a fixed EUI, TEDI and (for Part 9 Buildings only) airtightness level. In contrast the NBC and NECB are based on the building-specific reference case, a hypothetical building that aligns with the design and meets the prescriptive requirements of NBC and NECB. In all four codes, the design must have an energy performance that is better than the reference building.

In three of the codes (excluding COV), the lower tiers are aligned with financially optimized design solutions with a positive net-present value (NPV) of energy bill reductions versus incremental capital costs based on [BC Housing 2018]. The upper tiers are based on technical best practices and best-available technologies, which in some cases have a positive NPV and in other cases are

not strictly “cost-effective”, depending on the architectural design of the building. However, the financial assessment overlooks the fact that current carbon pricing is unlikely to address the necessary costs to mitigate emissions, and henceforth market failures exist, a topic for future research.

With their fixed reference cases, the BC ESC and COV approaches allow for greater consistency, verifiability and enforcement. In contrast, the NBC and NECB with hypothetical reference cases can vary for each individual designer and energy modeller, thereby reducing consistency across the marketplace. The local authorities having jurisdiction will be unlikely able to verify the reference case due to the complexity of modelling. Several BC urban municipalities have concerns with the reference case for thermal performance in lieu of TEDI, suggesting this will undermine the “building envelope first” design approach. Absent a formal evaluation, measurement and verification system with calibrated energy modelling, it will be difficult to identify the differences between designers. Furthermore, the BC ESC and COV use energy modelling guidelines to enhance consistency, and the Engineers and Geoscientists of BC and Architectural Institute of BC have published professional practice guidelines for energy modelling services.

There are some differences in the number of tiers and their stringency, depending on the particular code. For Part 9 Buildings, both the BC ESC and NBC have the same number of steps and similar expectations of performance improvements of 10%, 20%, 40% and 50+% based on BC Housing [2018]. However, the airtightness requirements for the equivalent tier of the NBC are less stringent. For example, the Step/Tier 3 airtightness is 3ACH50 and 2.5ACH50 for NBC and BC ESC respectively. For Step/Tier 5, those compare at 2ACH50 and 1ACH50.

For Part 3 buildings, the BC ESC and NECB have the same number of steps, but slightly different expectations of performance improvements based on BC Housing [2018]. BC ESC steps 2, 3 and 4 are estimated to achieve improvements up to 40%, 50% and 60% [BC Housing 2018]. The percentage improvements in NECB-2020 are 25%, 50%, and 60% for tiers 2,3,4 respectively, as compared the prescriptive standards in NECB. To allow for comparison, separate research pegs NECB-2017 as about 5-9% improvement compared to NECB-2015 in British Columbia [EnerSys 2018], similar to the anticipated performance of NECB-2020. Thus, expected BC ESC Step 4 savings are 51-55% compared to NECB-2020, potentially less stringent than the 60% improvement of Tier 4 in NECB-2020.

COV standards are comparable to BC ESC Step 3 for buildings over 7 storeys, and Step 4 for lower buildings.

The Higher Building Policy is aligned with BC ESC Step 4, the equivalent to net-zero energy ready construction.

CONCLUSION

This paper has summarized four alternative “technical roadmaps” to net-zero energy ready construction, including the BC Energy Step Code, the proposed changes to the National Building Code and National Energy Code for Buildings and the Vancouver Rezoning Policy. The two significant differences were:

- (1) The national codes are based on a hypothetical reference building of the same configuration being designed with prescriptive standards. Whereas, the BC ESC and COV have fixed energy performance references associated with a generic archetype building.
- (2) The COV policy emphasizes greenhouse gas reduction, whereas the national codes and BC ESC emphasize energy efficiency.

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JURISDICTIONAL RESPONSIBILITY FOR IMPROVING THE RESILIENCE OF BUILDINGS TO CLIMATE-RELATED POWER OUTAGES

Christopher Kennedy and Andrew Pape-Salmon
University of Victoria, BC

ABSTRACT

This paper reviews the role of building codes, local municipalities and utilities regulators in achieving zero-carbon, climate resilient buildings, primarily drawing upon codes and regulations from British Columbia.

INTRODUCTION

The costs of catastrophic losses – due to climate change and other factors – is increasing in Canada. In 2016, the insured catastrophic losses were over \$5 billion, with the Northern Alberta wildfire causing insured losses estimated at \$3.58 billion (Insurance Bureau of Canada, 2017). With global concentrations of greenhouse gases (GHGs) in the atmosphere continuing to rise, and increases in global average temperatures of 0.3 to 0.7°C expected for 2016–2035 (relative to 1986–2005; Kirtman et al. 2013), the need to make Canadian households and communities more resilient to climate-related acute shocks will continue to grow.

This paper is particularly concerned with the need to make Canadian buildings more resilient to disruptions in electrical power provision, whether arising from climate change related events, or other shocks such as earthquakes. The reason for focusing on electrical power is that use of electricity for an increasing amount of human energy needs is an essential strategy for reducing global GHGs and mitigating climate change. Provision of energy services causes the majority of global emissions, and the essential interlinked strategies for deep decarbonization of energy supplies are (IPCC, 2014; IEA 2014; Kennedy et al. 2018):

1. Decarbonize power supply (i.e., eliminate the use of fossil fuels in electricity generation).
2. Increase energy conservation and efficiency (i.e., reduce energy demand).
3. Fuel switching, either through electrification (i.e., substitute carbon-free electricity for fossil fuel use in engines, furnaces, among others) or use of other zero-carbon fuels (e.g., renewable natural gas, synthetic natural gas or hydrogen from zero carbon sources) for

major end-uses. For the purposes of this paper, we will only focus on electricity, despite the potential climate and resiliency advantages of zero- or net-zero-carbon producing thermal energy resources.

Currently, Canadian provinces use electricity to meet between 10% and 40% of end-use energy needs. To reduce GHG emissions, provinces such as Alberta, Saskatchewan and Nova Scotia need to reduce the carbon intensity of their electricity supplies; and all provinces need to increase the percentage of electricity in end-use energy, beyond the 40% in Québec. This will require: increased use of electric vehicles for transportation; use of heat pumps for heating and cooling of buildings; greater use of electricity by industry.

From building science and energy end-use perspectives, the design of thermally efficient and air-tight building enclosures with heat-recovery ventilation, thermal-mass and “passive” cooling, heating and ventilation features, can help to cost-effectively minimize the demand for purchased energy and/or on-site generation.

From electrical and mechanical system perspectives, the use of “smart” appliances and controls to track electricity supply availability and pricing, along with high-efficiency HVAC equipment to minimize demand that is coincident with the utility peak, will further increase the cost-efficiency of electrification.

From a climate change adaptation perspective, however, increasing electrification is challenging, because it reduces the diversity of energy sources used in communities. Replacing fossil fuels with electricity – as is necessary – will decrease the variety of types of energy sources that households and businesses use, putting greater reliance on electricity and thereby making them more vulnerable to acute shocks. Moreover, as well as the diversity of energy sources being important, the ability to store energy in communities also makes them resilient (Bristow & Kennedy, 2013). Currently there is relatively little storage of electricity at the building scale, but this expected to change as costs continue to fall (Schmidt, et al. 2017). These issues also apply to other zero-carbon energy sources.

The solution to the dual challenge of climate change adaptation and mitigation is electricity generation and storage at the building or community scale. Due to climate change, future low-carbon electric communities cannot be exclusively reliant on high capacity overhead power cables bringing in electricity from distant sources. These systems are vulnerable to windstorms, fires and ice storms of increasing frequency. Provincial and sub-national electric grids will still be essential, but they need to be supplemented with building scale storage; and/or community-scale micro-grids; including perhaps power generation, the scale of which would be defined by the resilience timeframe sought in the event of natural disasters.

The question that this paper asks is who will take responsibility for building scale electricity generation and storage? The paper imagines a future where most buildings in a community have photovoltaics on the roof and/or a stationary back-up electric battery (including those in electric vehicles) capable of providing for basic building functionality over a few days following a shock event. The paper examines the possible role of building codes, local municipalities and utilities regulators in achieving this vision of a zero-carbon, climate resilient building stock. Much of the analysis of codes and regulations draws upon examples from British Columbia, though similarities with other provinces are expected.

BUILDING CODES

Building codes are one potential means by which widespread building scale electricity generation and storage could be achieved. Current building codes in Canada and British Columbia do not explicitly consider building ‘resilience,’ albeit indirectly cover it through objectives of health, life-safety and fire and structural protection of buildings. They do not include electricity supply resilience. They do indirectly cover climate mitigation via energy efficiency, but not fuel switching.

The National Energy Code of Canada for Buildings (NECB), produced by the Canadian Commission on Building and Fire Codes with support from Natural Resources Canada (NRCan) is a starting point to consider. The current NECB (2017) describes technical specifications for achieving energy efficiency in new buildings, including control of air leakage, thermal transfer and limiting unnecessary consumption of energy for lighting, heating & cooling, water heating, and electrical equipment and devices.

The NECB includes functional statements of intent (National Research Council of Canada, 2017):

“F99. To limit the inefficiency of systems”; and

“F100. To limit the unnecessary rejection of reusable waste energy”,

which could be possible opportunities to incorporate thermal energy or electricity storage into building codes.

A challenge with the NECB is that it tends to be conservative – providing a ‘middle of the road’ model for energy efficiency in new buildings, rather than tackling the leading edge. Some provinces go beyond the NECB in encouraging higher levels of energy efficiency. An example of this is the Energy Step Code in British Columbia (Government of British Columbia, 2019), which pushes towards net-zero energy ready buildings that use 50-80% less energy than the 2018 BC Building Code and include specific design guidance on resilience related to overheating and air quality.

Further work may be needed to introduce climate change mitigation and resilience as objectives of the National Building Code, substantially informing the content of provincial codes.

MUNICIPAL GOVERNMENTS

Building owners are responsible for compliance with building codes. Local governments are delegated authority to elect to enforce building codes, and most require building permits for construction via local bylaws. Yet, even if resilience of buildings to power outages and other shocks is not considered part of the building code, there may still be some responsibility shouldered by municipal governments. This can be seen at a high level by examining the BC Local Government Act (Government of British Columbia, 2015).

Amongst the purposes of the BC Local Government Act (Part 1) is:

“(c) to provide local governments with the flexibility to respond to the different needs and changing circumstances of their communities.”

This broad statement alone is arguably a starting point for local governments in BC to increase the resilience of communities to climate change.

Looking further through the Act, the purpose of regional districts in BC (Part 5, 185) includes:

“(b) providing the services and other things that the board considers are necessary or desirable for all or part of its community,

(c) providing for stewardship of the public assets of its community, and

(d) fostering the current and future economic, social and environmental well-being of its community.”

Items (c) and (d) here, give a mandate to local governments to consider the resilience of buildings

within the community, and (b) points to the potential for municipalities to provide electrical power services (as is the case with New Westminster, Kelowna, Penticton, and a few other municipalities in BC).

Part 9 (section 298) of the BC Local Government Act provides further details of building regulation bylaws, the purpose of which are:

- “(b) the conservation of energy or water;
- (c) the reduction of greenhouse gas emissions;
- (d) the health, safety or protection of persons or property.”

These regulations provide further motivation for local governments to be more fully involved in building-scale electricity generation and storage. Furthermore, matters related to energy or water conservation or the reduction of greenhouse gas emissions are deemed “unrestricted matters” under the auspices of the Building Act, along with matters related to district energy systems (i.e., that could include zero-carbon supplies and micro-grids).

UTILITIES REGULATORS

The generation of electricity in British Columbia, at any scale, generally falls under the authority of a utilities regulator. As in many Canadian provinces, British Columbia has a publically owned electrical utility, BC Hydro, which is the dominant distributor of electricity in the province, established by the Hydro Power and Authority Act. The only areas not served by BC Hydro are the City of New Westminster, and several municipalities in the central and south Okanagan, and the west Kootenay regions, along with the electrical service area of an investor-owned utility (IOU) FortisBC. Public utilities include electricity, natural gas, propane and district energy providers, but exclude municipally-owned utilities. Public utilities are regulated by the British Columbia Utilities Commission (BCUC). Currently several aspects of BC Hydro oversight are regulated directly by the BC Ministry of Energy, Mines and Petroleum Resources under the Clean Energy Act (CEA), but these aspects are being returned to BCUC oversight on March 1, 2021.

The BC Utilities Commission Act (UCA) (Government of British Columbia, 1996) stipulates the duties of the BCUC. At the highest level, these include (Section 5):

“On the request of the Lieutenant Governor in Council, it is the duty of the commission to advise the Lieutenant Governor in Council on any matter, whether or not it is a matter in respect of which the commission otherwise has jurisdiction.”

This provision provides the Lieutenant Governor of BC with an entry point for transforming the utilities sector towards a low-carbon electric future.

More specifically, the BCUC provides oversight for:

- Long-term Resource Plans (LTRP) of public utilities (UCA section 44.1), generally for a 20-year timeframe, including “conservation” plans to reduce the demand for energy, load forecasting, and an assessment of supply needs. Since 2010, BC Hydro submitted its “Integrated Resource Plan” (IRP) to the government for approval, not under BCUC oversight.
- Expenditure plans (UCA section 44.2), generally for a 2-4-year timeframe, including forecasted capital spending for achieving LTRP conservation targets, building new LTRP supplies, or purchasing supplies from third parties. This includes BC Hydro capital spending but is subject to the requirements and exemptions of the CEA noted below.
- Certificates of Public Convenience and Necessity for the construction of public utility plants and systems. Several BC Hydro capital expenditures in their 2013 IRP are exempt from this requirement, including several clean energy plants (hydro, bio-energy, building-scale renewables, and smart meters) and strategic transmission lines.

The Clean Energy Act (CEA) (Government of British Columbia, 2010) establishes a path toward a low-carbon energy system with an emphasis on “BC Energy Objectives”, “demand-side measures” (DSM) and “clean or renewable resources”.

BC Energy Objectives of relevance to this paper include:

- To achieve “electricity self-sufficiency” – ensuring rights to electricity supplies to meet demands, assuming “mid-level forecasts”, or average water conditions in hydroelectric supplies (Government of BC, Electricity Self-Sufficiency Regulation, 2012);
- To take DSM, including a target for BC hydro (see below);
- To generate at least 93% of electricity from clean or renewable energy resources, including biomass, biogas, geothermal heat, hydro, solar, ocean, wind, and additional technologies within the Clean or Renewable Resource Regulation (2011), including biogenic waste, waste heat, and waste hydrogen;
- To use and foster the development of innovative technologies;
- To ensure BC Hydro’s rates remain among the most competitive of rates charged by public utilities across North America, thereby dispelling the myth that zero-carbon energy supplies are misaligned with economic efficiency;
- To reducing BC GHG emissions by 33% by 2020 and 80% by 2050 (note: this differs from the targets in the 2019 Climate Change Accountability Act of 40% by 2030, 60% by 2040, and 80% by 2050); and,
- To encourage fuel switching to lower carbon fuels.

The definition of DSM includes utility tariffs such as the “residential inclining block rate”, programs such as Power Smart and FortisBC Energy Efficiency and Conservation, and support for government codes and standards to conserve energy or promote energy efficiency. DSM can also shift the use of energy to periods of lower demand. It explicitly prevents DSM that increases greenhouse gas emissions. BC Hydro is required to reduce its expected increase in demand for electricity (GWh) by 66% through DSM.

Shifting to the topic of resilience for buildings, there a number of drivers for BCUC jurisdictional oversight toward decarbonization and resiliency of the energy system as it relates to buildings.

First, the operation of buildings on zero-carbon energy supplies will benefit from technically achievable and economically optimized DSM. The 2013 BC Hydro IRP targets 78% of demand-growth through DSM, and BC Hydro (2019) documents that the recent cost of DSM is \$0.019/kWh, well below the cost of new power supplies and rates (see below). Over 48% of the savings during the three-year period from 2017 to 2019 are from “codes and standards” in the provincial building code and provincial and federal government equipment standards. Benefit-cost ratios such as the “Utility Cost Test” documents DSM delivering benefits that are 3.6 times the cost of avoided supply, “Total Resource Cost” delivering consumer benefits that exceed costs by a factor of 2.4 to 2.7, and zero rate impacts of DSM, despite lowering demand.

Second, achieving GHG goals requires access to zero-carbon energy supplies. The BC Energy Objectives target 93% clean and renewable energy for all electrical utilities, focused primarily on utility-scale generation by BC Hydro and independent power producers. In 2018/19 BC Hydro electricity generation was 97.8% clean energy (BC Hydro, 2019-2). The subsequent Clean BC Plan (2018) includes a commitment to work with natural gas providers to put in place a minimum requirement for 15 per cent renewable content in natural gas by 2030. In 2019, FortisBC announced a goal to reduce its customers’ emissions by 30% by 2030, noting that the cost of renewable natural gas is \$0.06/kWh, compared with BC Hydro electricity at \$0.09 and \$0.14/kWh for step 1 and step 2 respectively (FortisBC, 2018).

Third, achieving “resilience” for the provincial energy systems to withstand acute shocks such as earthquakes and chronic stresses from climate change requires further consideration around response times for power outages such as the December 20, 2018 windstorm that left 730,000 customers without power, the most damaging in BC Hydro’s history. Furthermore, climate change affects water resource availability which was 98% and 87% of

average in 2018 and 2019 respectively (BC Hydro, 2019-2).

Fourth, achieving resilience at the building scale in light of more frequent power outages may justify on-site electricity storage, supplemental generation and sophisticated energy use controls to ensure that buildings are efficient and manage loads appropriately. The legislation and BCUC tariffs permit on-site renewable energy such as photovoltaics, enabled through the “net-metering” programs of electric utilities. In BC Hydro’s case, this includes electricity billing that reflects the net consumption, “banking” for 12 months, and a payment for excess production at the end of the 12-month period, thereby serving as a “non-dispatchable” electricity resource for use by other customers. By extension, this could benefit from establishing micro-grids and the potential for shared storage and generation at a neighbourhood level, not currently promoted, but aligned with the “innovation” objective in the CEA. Part 3 of the UCA, on Regulation of Public Utilities, provides further provisions that are relevant to building-scale generation and storage of electricity. These include: a definition of a “person generating electricity for own use...; exemptions that the minister may make with regard to the production, sale, or purchase of power...; orders that the Commission may give to improve service...; and standards that the Commission may set”.

As a final point, municipal utilities are exempt from the UCA. However, part 3 describes the important relationship with the Local Government Act, noting (in Section 121):

“Nothing in or done under the Community Charter or the Local Government Act

(a) supersedes or impairs a power conferred on the commission or a public utility, or

(b) relieves a person of an obligation imposed by or under this Act or the Gas Utility Act.”

CONCLUSION

Optimized energy efficiency, on-site zero-carbon energy generation, electricity storage and/or micro-grids need to be incorporated into buildings to both mitigate and adapt to climate change, but which jurisdiction should have responsibility for this transformation? Three were highlighted – provincial building codes, municipal governments, and utility regulators. There are key inter-dependencies that need to be unravelled to expose the optimal jurisdiction.

First, the question of provincial energy system resilience needs to be confirmed by the utility regulatory in order to determine the need for building and community-scale energy independence, despite the extensive efforts to decarbonize electricity and natural gas systems. Recent

evidence of power outages highlights rationale for on-site generation and storage.

Second, given the inter-dependence between energy efficiency/load management and on-site generation, a question is raised whether these devices should be considered part of the building system, or not. If the answer is ‘yes’ then they should be included in the building code, supplemented with new National Building Code objectives for climate adaptation and mitigation and enforcement activities of municipalities; if the answer is ‘no’ then utilities regulators need to lead. In either case, the potential need for micro-grids and value of shared storage and generation necessitate a role for the utility regulator and by extension, municipalities given their mandate to own or host community energy systems.

Transformation of the utilities sector to address this challenge has many barriers, amongst them being the difficulty of finding business models that support distributed electricity generation (Kennedy et al. 2017). Solving this challenge is necessary for making our households and communities resilient to climate change. The BC Step Code for buildings is preparing the way for new buildings to be net-zero ready by 2032, but will municipalities, energy utilities and utility regulators be ready?

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PLANNING AND SIMULATION OF NET-ZERO, CARBON NEUTRAL AND RESILIENT COMMUNITIES

Ursula Eicker, Jürgen Schumacher, Sanam Dabirian, Navid Shirzadi, Soroush Samareh Abolhassani, Rabeeh Hosseinihaghighi, Sahar Javadian, Karthik Panchabikesan
Concordia University, Canada Excellence Research Chair Next Generation Cities, Montréal, QC

ABSTRACT

An integrated urban platform is the essential software infrastructure for smart, sustainable and resilient city planning, operation and maintenance. Today such platforms are mostly designed to handle and analyze large and heterogeneous urban data sets from very different domains. Energy modeling and optimization functionalities are usually not part of the software concepts. However, such functionalities are considered crucial to develop zero carbon urban transformation scenarios and to optimize smart city operation.

In this study, we propose to develop a software architecture concept for an integrated urban data and modeling platform, which allows to analyze and optimize the urban infrastructure with their energy, water and further resource streams such as food or goods consumption. A methodology for extracting building geometry information at urban scale from CityGML and a framework for integrating building geometry with energy attribute data for urban energy modelling are proposed and discussed in detail. A first case study application is shown for renewable energy system design by considering two different scenarios using the Concordia University Campus, Montréal, and the obtained results are reported.

INTRODUCTION

Supporting the planning and operation of smart and sustainable cities with a minimized CO₂ footprint is a huge challenge, as very different domain knowledge needs to be combined in an urban platform. Urban platforms mostly consist of data collection and analysis from very diverse sources such as sensors, municipal data records, knowledge repositories or social media streams (Celani et al. 2015). They make efficient use of the rapidly growing information and communication (ICT) infrastructure for collecting, processing, and sharing information (Yin et al. 2015). A reliable communication and networking infrastructure and big data handling can be considered as the backbone of smart cities (Rana 2018). At the same time, e-participation and

smart technology applications offer new possibilities for citizen engagement and smart governance (Qing 2019), (S 2016). Smart city services rely on such urban ICT platforms, which offer seamless interconnection with monitoring systems at the infrastructure level. On top, storing and analyzing the generated information can eventually be offered to third parties through standardized interfaces as open data (Vilajosana et al. 2013). Urban data can then be used to validate physical or data driven models based on 3D geometry, which allow to develop ambitious zero carbon transformation strategies for a city.

PROCESSING OF URBAN GEOMETRY DATA

Extracting geometry information from CityGML

In this study, a fully automated python-based data pre-processing engine is designed to (i) extract the building geometry data from CityGML, (ii) query the data, and (iii) organize the data based on the input requirements of a building energy simulation engine such as EnergyPlus. The aim is to provide a user-friendly platform to integrate urban scale geometry information efficiently with other energy data and modeling tools. The exchange format CityGML represents the 3-D geometry and semantics of the buildings, transportation infrastructure, water bodies, and city furniture. The first step in the geometry extraction from CityGML includes collecting, analyzing, and restoring data. To map the footprint of buildings, at first, all polygons that belong to the respective building are merged. Besides, to create the 3-D model, the unified polygon of the buildings is extruded considering its average height. To reduce the computational runtime of the process, the 3-D geometry model is simplified (Figure 1). Subsequently, the extracted geometry data is enriched by other building characteristics such as year of construction and building type. One exclusive index is considered based on the central coordinate for each building to be easily recognized by the user. The building characteristics are assigned using this defined index. In the next step, building physics attributes are assigned to the buildings.

Finally, the enriched buildings' 3-D model with the attributes from other datasets along with the details on the occupancy model (based on the building typology classification) are created as an XML-based dataset.

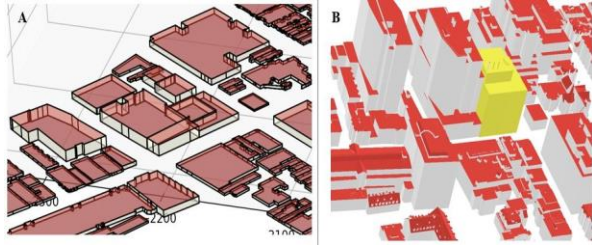


Figure 1. Visualization of the Energy Plus input simplified 3D city model (left), city 3D model (right).

Generating input data file for energy simulation

To develop zero carbon strategies through improving the building stock energy performance needs a systematic evaluation of buildings individually over the temporal and spatial scale. The energy simulation of buildings on a large scale is done using a bottom-up engineering approach using archetype building modeling. Archetype modeling abstracts the building stock to a set of prototypes with detailed attributes for building physics, occupants and system operation. Each prototype is a representative model of buildings with similar characteristics, such as building activity, shape, and age located in the same climate zone. The US building archetypes (DOE, Commercial Reference Building Modeling) (DOE, Commercial Prototype Building Modeling) is a notable open data source provided on the national scale with in-depth details for EnergyPlus building simulation. The US Department of Energy (DOE) in collaboration with further national laboratories have developed 16 residential and non-residential building models covering 16 ASHRAE climate zones based on the commercial building energy consumption survey (CBECS) and supporting ASHRAE 90.1 (Deru et al. 2011). Since the properties of buildings are not widely available as open source data/public domain data, in this study, we leveraged on the US building archetypes to associate buildings with the appropriate archetypes carrying energy attributes.

Figure 2 shows the developed framework for integrating the building geometry with designed archetypes in the urban building energy modeling (UBEM) workflow. The input data to the procedure consists of the following,

- The geometric data with level of detail (LoD) LoD1 or LoD2 on CityGML format containing the spatial information.
- The building related data that includes building age, size, and activity type. Such details will be acquired from the Municipality or Governmental data sources.

The matching of CityGML and building data provides the condition for connecting the archetype attributes.

- The designed building physics library covers the reference building archetypes, i.e., the archetypes with various refurbishment scenarios, and building components with regular ASHRAE 90.1 and advanced standards (ASHRAE 189.1-2009 and AEDG) for making new archetypes.

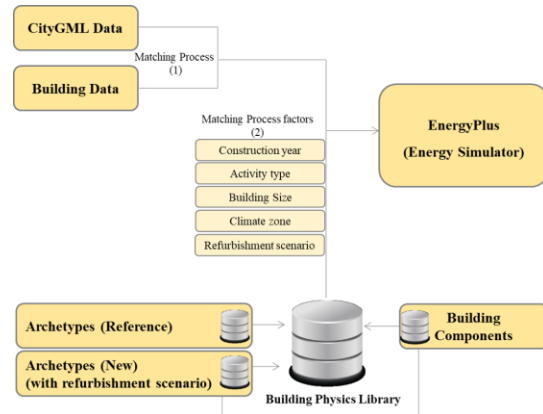


Figure 2. Framework for integrating building geometry with energy attribute data.

In order to simulate the heating and cooling loads, building models are necessary (Chen et al. 2019). The requirements of the building energy simulation are building geometry, internal gains (e.g., occupancy schedule, plug load and lighting energy consumption), and the climatic boundary conditions (Schiefelbein et al. 2019). Four datasets organize the structure of archetype models in terms of serving the dynamic energy simulation. The program category provides the required data to arrange plug and process loads, ventilation requirements, occupancy, and operating schedule. The form parameters identify the required geometric data coming from measured input geometry data (CityGML). The fabric property covers the constructional components and attributes plus the equipment category that supports the HVAC system, lighting, and control setting. Note that, in this study, we will use EnergyPlus to simulate the building energy loads. The enriched building with energy attributes or archetypes is connected to EnergyPlus using a geomeppy library in Python. Inputs regarding the occupant schedules for different building typologies are generated and the number of occupants is determined based on the buildings type. The output of the simulation including heating and cooling loads are visualized which could be used as a decision-making tool.

Renewable energy system modeling

To implement an integrated renewable energy system at urban scale, there are several possible solutions, such as integrating different renewable technologies like wind turbines, PV or biomass. To compare solutions, the objective function can be varied and depends on the goal of the specific project. In most cases, minimizing the net present cost (NPC) of the system or cost of energy (COE) are used as the objective function.

CONCORDIA UNIVERSITY CASE STUDY

Downtown campus as a case study

Concordia University in Montreal has two campuses; Sir George Williams (SGW) and Loyola Campus, where the buildings of SGW campus are located in downtown Montreal. The main buildings of SGW campus are called EV, GM, MB, LB, FB and FG building. Although in this study the monthly cooling and heating demand of the buildings of the SGW campus is simulated (Figure 3, 4), considering the limited availability of measured energy consumption data, the EV building is chosen as the case study building and subsequently, the potential of renewable energy system implementation in EV under two scenarios were analyzed and the respective results are reported.

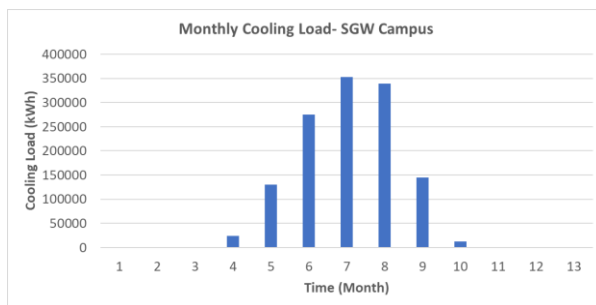


Figure 3. Simulation result of monthly Cooling demand of the buildings of SGW campus, Concordia University, Montreal.

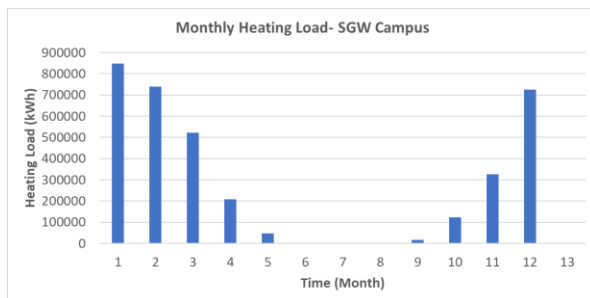


Figure 4. Simulation result of monthly heating demand of the buildings of SGW campus, Concordia University, Montreal.

Case study building (EV) description

With a gross area of 69,204 m², the EV building consists of Engineering Computers Science building (ENCS),

and Visual Art and Science (VA) building, which are connected at different heights. The ENCS tower has 17 floors above the ground surface which includes office spaces, conference rooms, mechanical and chemical laboratories which are located in the 12th to 16th floor. On the 17th floor there is the mechanical room. Every three floors from 2nd to 16th has an individual atrium. There are two underground levels that have a connection to the MB building, metro station, underground restaurants and a tunnel connecting to the Library building and Hall building. The VA tower has 12 floors above the ground including offices and workshops. The mechanical room is on the 12th floor. Note that the GM and MB building have gross floor areas of 22,663 m² and 37,935 m², respectively. Figure 5 and Figure 6 show the simulation result of the monthly cooling and heating demand of EV building that is calculated using the developed framework. In addition to geometry and construction material, occupancy and lighting are considered as the input to enrich the baseline model. For future work, the framework result needs to be validated by comparing the simulated result and actual energy data of the building.

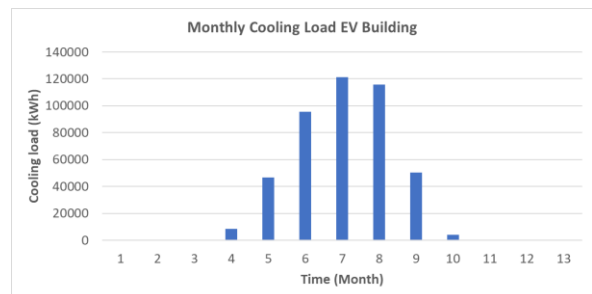


Figure 5. Monthly cooling demand of EV building, Concordia University located in downtown, Montreal.

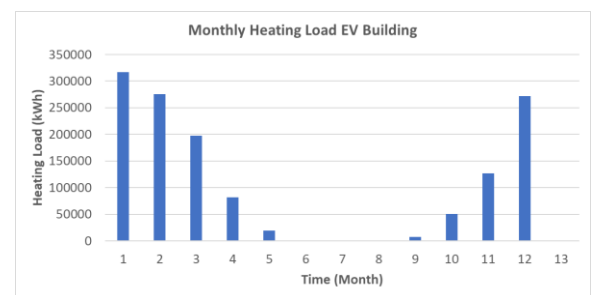


Figure 6. Monthly heating demand of EV building, Concordia University located in downtown, Montreal.

Renewable energy system concept for Concordia University EV building

In this section, EV building consumption is used to investigate the options for integrated renewable systems with two scenarios; (i) grid connected system and (ii)

100% renewable standalone system. In this research, the HOMER software is used as the optimization tool.

Grid connected system: Grid connection can solve the problem of the intermittent nature of renewable technologies and more importantly the challenge of storage since the high price of storage such as batteries could hinder its application in optimal energy systems. A complete grid rate schedule is used to consider different prices of purchasing and selling back to the grid in various times of the day and was applied for all weeks including weekends. Note that there is no interconnection charge as the Concordia University is already connected to the grid.

Stand-alone system: In this study, the stand-alone system includes PV, wind turbine, DC/AC converter and batteries. The wind turbine type considered was chosen based on low urban wind speed in Montreal. There are small 10kW wind turbines on the market with good power curves for low wind speeds that could be utilized for the location of Concordia University.

The comparison of both scenarios shows promising economic results. Three best cases were identified for scenario 1 (grid connected systems) and scenario 2 (standalone system) and the obtained results are presented in Table 1 and Table 2, respectively. The results show that grid connected systems are an even better economic alternative compared to the current energy system (purchasing from the grid) in case of net present cost (NPC) and cost of energy (COE)). In the grid connected system, the fraction of solar PV (solar fraction) is high at 79% of annual consumption of 37.4 GWh as shown in Figure 7. Considering the average price of 8-10 Cent/ kWh of electricity in Quebec (see Table 1), the cost of energy could be decreased around 40 -50% with grid connected systems and even less with considering solar tracker for PV systems. Table 2 shows that, for the second scenario, i.e., considering a 100% standalone renewable system with storage (Li-Ion Battery), the NPC and COE are relatively high and not cost efficient today. The main reason for the higher NPC for scenario 2 is because of the investment cost of the batteries.

Although the grid-connected scenario could bring down the cost of electricity significantly, lack of resilience and possible stress on the grid could be mentioned as one of the crucial challenges of using this scenario practically. Using batteries in a grid-connected scenario could solve the deficiency of resilience by increasing the reliability of the system for power supply in case of grid failure and power outage acting as a backup. Also, batteries could be charged in off-peak hours (in case of limitation for selling to the grid for bringing down the stress) when the availability of the renewable resources (solar irradiance in this research) is high and be discharged in peak hours in the time of electricity overpricing. An energy management system is mandatory for reducing the

operational cost and proper management schedule based on the number of batteries and grid limitations.

Table 1. Considered cases for grid connected system.

CASE	PV (KW)	WIND TURBINE (10 KW) NO.	DC/AC CONVERTER (KW)	NPC (10 ⁶ USD)	COE (USD/ KWH)
Case 1	19,635	0	12,123	30.7	0.052
Case 2	20,617	1	12,533	30.8	0.051
Case 3 (Grid only)	0	0	0	36.4	0.111

Table 2. Considered cases for standalone system.

CASE	PV (KW)	WIND TURBINE (10 KW) NO.	BATTERY (1KWH LI-ION)	DC/AC CONVERTER (KW)	NPC (10 ⁶ USD)	COE (USD/ KWH)
Case 1	111,630	0	151,754	4,735	166	0.506
Case 2	20,336	708	103,020	4,948	102	0.311
Case 3	0	2,021	253,396	13,269	224	0.683

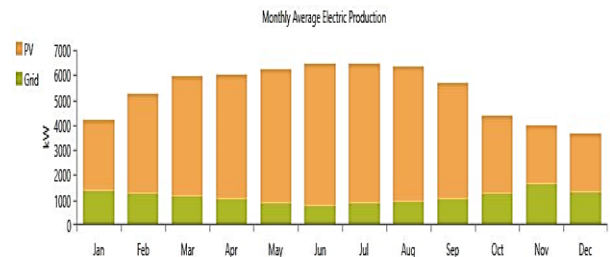


Figure 7. Monthly average electrical generation by PV and grid in scenario 1 (grid connected system).

CONCLUSION

At urban scale, buildings, commerce and industry as well as the transport sector are in the focus of the decarbonization strategy. To develop such zero carbon transformation strategies for complex urban systems, we propose to model the buildings, energy supply and distribution systems of a city, calibrate the model with urban monitoring data and then to simulate transformation scenarios towards zero carbon cities. In this regard, a systematic procedure for extracting the building geometry data from CityGML and integrating building geometry with energy attribute data for energy simulation are proposed. The integration of renewable energy systems for a case study building of the Concordia University under two scenarios are investigated and the respective economical results are presented. The results show that the scenario 1 (grid

connected system) is economically best suited for the implementation of renewable energy systems even when compared to today's electricity purchase from the grid and even more when compared to scenario 2 (standalone systems). The proposed methodologies could be used for optimizing today's infrastructure performance. A well-designed user interface and diverse 3D visualization features including virtual and augmented reality should enable access and involve citizens and local stakeholders interacting both in operation and strategic planning for sustainable cities.

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EXPANDING PERFORMANCE-BASED STEP-CODES BEYOND ENERGY EFFICIENCY USING A FORWARD-LOOKING REFERENCE BUILDING

Remi Charron

New York Institute of Technology – Vancouver Campus, Vancouver, BC
rcharron@nyit.edu

ABSTRACT

Performance based codes often rely on energy modelling to demonstrate equal or better performance than previously established codes or standards. This paper proposes to flip the concept to a forward-looking approach where the reference building would represent a future high performance standard. This shifts the focus to a common future targeted performance level providing more guidance to all stakeholders of where the Code will transition to in the coming years. This paper discusses how this approach can also expand “performance-based” codes to areas beyond energy efficiency, to other performance attributes.

INTRODUCTION

Governments around the world are continuously increasing the minimum energy performance of buildings as a way to help mitigate climate change. There are a number of challenges associated with having minimum performance requirements changing at every code cycle. It is difficult to provide training and education to industry stakeholders, developers planning a community do not know what performance will be required for different project phases, the supply chain needs to rapidly change, etc.

In an effort to help address these issues, the BC government introduced its Energy Step Code that sets out how the BC Building Code (BCBC) will transition from its current energy requirements to near net-zero energy requirements by 2032 in a series of stepped increments in minimum energy requirements (British Columbia, 2018). The idea is to advise all stakeholders how the BCBC will transition in the next 15 years so that stakeholders have ample time to prepare.

The BC approach is consistent with the Canadian government plans to develop a Step Code to help all jurisdictions transition from current energy requirements to a “net-zero energy ready” model building code by 2030 (Canada, 2016). The proposed change to the 2020 National Energy Building Code (NECB) has for four

steps starting with matching performance to prescriptive code equivalent to requiring a 60% reduction in energy use in its last step (NRC, 2019).

There are two main categories of energy codes for buildings: prescriptive approaches that dictate the minimum performance of different building elements, and performance based approaches that rely on energy modelling to show that the building met a certain performance criteria. Performance based approaches can have absolute performance metrics (e.g. thermal energy demand, total energy use intensity, etc.) or they can rely on a differential predictive approach, which compares the performance of the proposed building to that of a baseline reference building (Rosenberg, et al., 2015).

Energy performance codes that use a reference building are easier to implement than setting absolute performance targets (e.g. energy intensity targets). Establishing absolute targets requires careful consideration of targets for different archetypes, and can be more sensitive to differences in energy modelling approach or software.

A reference building approach compares the modelled performance of the proposed building to that of a reference building with design parameters are set by the energy codes. The baseline has characteristics in three dimensions (Rosenberg, et al., 2015):

1. design parameters: prescriptive performance and design elements of reference,
2. time reference: year that baseline reference is established, and,
3. test criteria: relative performance difference that proposed building needs to achieve.

The architectural design of the reference building can either be dependent on the proposed building design or it can follow an independent rule-set. In a dependent design, the proposed building has the same form and shape as the proposed building but its efficiency is adjusted to meet prescriptive code values. The architecture of the reference house using an independent baseline is developed following a rule-set, developed

based on floor area and building type (e.g. a set form factor, window-to-wall ratio, window distribution, HVAC system, etc.). There can be some combination, where some parameters are dependent on the proposed design (e.g. building shape), whereas others are independent (e.g. window area and distribution).

The time reference can either be fixed, where the reference code is established at a certain point in time and is not updated with code changes, or it can be set to the current prescriptive code requirements, which are updated at each code cycle. A stable or fixed baseline allows for easier tracking of code improvements, as the only thing that needs to change when increasing performance requirements is the relative difference in performance (e.g. requiring 40% energy savings instead of 30%). The fixed baseline also makes it easier to develop and maintain software that automate the generation of the reference building.

Test criteria indicates if the proposed building must be equivalent to the baseline (same energy use or cost than code minimum) or differential, meaning it must beat the reference by a set amount. When Rosenberg, et. al (2015) developed a roadmap for the U.S. Department of Energy for the future of energy codes for commercial buildings, they concluded that a differential predictive approach with a stable and independent baseline showed the best promise. It allows for a reliable comparison to a known baseline, normalizes the performance target to each specific building, enhances the ability to track improvement over time, paves the way for automated performance modeling, and markedly improves predictive accuracy.

Given the intention of a Step Code to transition building codes to a future energy performance standard, it would be more insightful to develop a reference building that represents the targeted future performance level. Instead of looking at a 10 to 20 year old energy code to set a minimum performance level that needs to be beat by 60% to 80%, the reference building could represent the desired future performance level that we are moving towards. This paper presents how this forward looking reference building approach could be implemented.

FORWARD LOOKING REFERENCE BUILDING

This section describes how the baseline reference building could be defined using a future desired performance level. It is proposed that the reference baseline could use the following characteristics:

Design parameters: Quasi-independent design parameters that represent a desired outcome of the Step Code process.

Time reference: Static time reference set at the target date to reach high performance building standard.

Test criteria: for energy, develop targets of percent more energy than reference building, that would reduce for each step of the Step Code. Other test criteria could be developed to establish minimum performance levels beyond operating energy consumption.

In order to implement this approach, the building code committees would need to develop design elements that represents this future performance level. As part of the European Energy Performance of Buildings Directive (EPBD), Member States need to define minimum requirements of energy performance of buildings and building components with a view to achieving cost-optimal levels (Corgnati, et al., 2013). One approach used is to define reference buildings is to set prescriptive requirements to measures that lead to the lowest lifecycle cost. A similar approach could be applied to define the forward-looking reference building by setting it to the design that achieves the desired performance target at the lowest life-cycle cost.

Architectural Design Elements

Architectural form can have a significant impact on energy consumption. There are a number of tools and methodologies that have been developed to maximize the performance of the form (Touloupakia, Theodosioua, 2017). A sophisticated methodology could be employed to find the site-specific optimal architectural form for the reference building. Alternatively, a more simplified method could be used that would simply use a form that minimizes the exterior envelope area to volume ratio (A_e/V) given the desired building footprint and floor area. Window areas and distribution could be based on standard window-to-wall ratios (WWR) with even window distribution by orientation or it could involve optimisation of the WWR by orientation to maximize performance.

It is proposed that the reference building utilize quasi-independent design parameters to account for specific site and/or project constraints that would prevent the proposed building from utilizing idealized design choices. The reference building definitions could allow for fixing certain design elements based on specific site and/or project constraints.

Potential site constraints could include adjacent structures or street orientations that may limit the allowable building and fenestration orientation. Geological and/or climate features could limit the type of foundation that is allowed. Bylaws may limit the total height of a structure. High wind areas may restrict the use of certain types of overhangs above windows. Project specific constraints could include things like a homebuyer requiring a single storey wheelchair accessible house. What is proposed is that if one of these constraints is present in a project, the reference building would implement the specific constraint in its modelling;

otherwise the standardized high performance design options would be selected.

Building Envelope Performance Levels

There could be a variety of approaches used to set the building envelope performance levels. Loukaidou, et al., 2017, assessed the lowest life-cycle cost performance levels for Cypress to meet the EPBD requirements. They found that the performance levels would vary based on the A_e/V ratio where they found a linear correlation between optimal mean R-values and the A_e/V ratio. However, the variation in optimal performance was not great, with the wall R-values increasing by a range of 5% to 11% when the A_e/V ratio changed from 0.2 to 1.2. The reference building could have envelope performance levels that only vary based on climate zone, or they could also vary by architectural form and building type.

If the objective is to find building envelope performance levels for a reference building that achieves a net-zero energy target, the most cost effective performance levels will depend on mechanical system selection where heat pumps operating at a higher COP could lead to lower optimal envelope performance levels.

Mechanical System Selection

As mentioned, the choice of mechanical systems to use for the reference building will have an impact on setting other building parameters. If provincial or federal governments are going to achieve their 2030 and 2050 GHG reduction targets, there should likely be little to no natural gas used in new homes by 2030, and the electricity should all be coming from low to no carbon sources. A number of decisions would need to be made in order to define the mechanical systems for the reference building, including:

- Should it be limited to all-electric options?
- Should the default system be heat-pumps, and if so, what performance levels?
- When should cold-climate air-source heat pumps be specified?

Renewable Energy Generation

The federal and BC governments both aim to bring building energy performance levels to net-zero energy ready levels by 2030 and 2032, respectively. Neither code is currently being developed with the intention that onsite renewables could offset consumption. Whether a building can actually offset its energy consumption with on-site renewable energy to achieve net-zero energy consumption will depend on a number of factors such as solar access, roof size, climate, etc., with larger mid- to high-rise buildings typically not having enough surface area for renewable energy technologies to offset all of the energy consumption.

The forward looking reference building could model a solar photovoltaic system to meet a certain size (either in power [kW] or in area), completely fill roof surfaces that have favourable solar orientation, and/or achieve a desired performance level (net-zero energy or carbon, lowest NPV, etc.). In addition, the renewable energy systems could also be integrated into the building with battery storage to achieve resiliency targets such as a set amount of hours of back-up power.

The decisions around what to include in the reference building, whether for renewable energy, insulation levels or mechanical systems, would depend on the selected performance metrics to be used for the test criteria.

ESTABLISHING NEW PERFORMANCE METRICS

If the broad objective for jurisdictions to implement energy efficiency requirements is to address climate change, energy-related metrics alone might not be enough. This section discusses how other performance parameters could be implemented within a future reference building approach.

Greenhouse Gas Intensity

Although reducing energy intensity is good, jurisdictions need to reduce their overall greenhouse gas (GHG) emissions. In the City of Vancouver, this was partially addressed by including a greenhouse gas intensity metric to their requirements, as well as capping the total emissions for large homes over 325 m² (3,500 ft²), which must demonstrate a GHG footprint at or below that of a 325 m² (3,500 ft²) home (VBBL, 2017).

Net-Zero and Net-Zero Ready – Energy and/or Carbon

As discussed, the federal government and the BC government both aim to bring building energy performance levels to net-zero energy ready performance levels by 2030 and 2032, respectively. Both have very broad definitions of what net-zero energy ready actually means, where neither code is currently being developed with the intention that onsite renewables could offset consumption. Net-zero energy performance levels are difficult to mandate as not all sites have a ready access to the sun, and larger mid- to high-rise buildings typically do not have enough surface area for renewable energy technologies to be able to offset energy consumption onsite. Net-zero carbon performance levels can be more feasibly achieved by different size buildings provided that a source of low-carbon electricity is available. If the intention is to get to net-zero energy ready, there needs to be a clear definition of what that means in order to be able to establish a reference building that achieves that performance level.

Lifecycle Energy and/or Carbon

Other metrics could be used to compare the performance of a proposed building to a reference building to help inform design decisions. For example, is it better to build using concrete, which may be more resilient in the face of the increasing intensity of storms, tornados and hurricanes (Khanduri & Morrow, 2003), or out of wood to reduce the carbon footprint of our buildings (Gustavsson, Pingoud, & Sathre, 2006). Lifecycle energy and/or carbon estimates of the proposed and reference buildings could provide some guidance.

Allowable Thermal Comfort

Looking beyond energy and greenhouse gas emissions at resilience, performance metrics could be used to compare the performance of a proposed building to that of the reference building to encourage more resilient design practices. During normal operation of the building, the number of hours that the reference building exceeds comfortable design conditions could be used as a limit for the proposed building. Similarly, during power outages, the interior temperature reached in modelling of the reference house after a set period (e.g. 72 hours) during both an extended cold period (minimum allowable temperatures) and an extreme heat events (maximum allowable temperatures), could be used to set the performance targets for the proposed building.

MODELLING GUIDELINES

The required capabilities of energy modelling tools used to support the forward-looking reference building approach would depend on the selected performance metrics. Depending on the metrics, the tools and associated modelling guidelines, would need to be able to model the comfort requirements, life-cycle costing, embodied carbon, etc. In addition, current modelling tools rely on historical climate data for their calculations. Given the potential influence that energy modelling can have on building design, it would be best to model buildings with expected instead of historical climate.

CONCLUSION

Instead of designing a building to beat an old standard by a certain amount, targets can be set as a percentage more consumption than the reference building or simply matching the performance of the high performance reference. This approach could have a number of benefits:

- Shifting the focus to a common future targeted performance level.
- Having a time independent baseline makes it easier to implement a number of future step improvements to the code.
- Could make selling minimum efficiency houses harder, given that it would be rated as a home that

consumes ~400% more energy than the reference house, compared to current approach saying that it is 20% better than our current reference building.

- Opportunity to include other metrics to performance based codes.
- Provides a clear defensible methodology in developing high performance building metrics.

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DESIGN STRATEGIES FOR CLIMATE RESILIENT NEIGHBORHOODS

Caroline Hachem-Vermette, PhD

Associate Professor, University of Calgary, Calgary, AB

caroline.hachem@ucalgary.ca

ABSTRACT

This paper presents a holistic approach to the design of climate resilient neighborhoods. Strategies discussed span from building level to neighborhood design level, encompassing elements such as building envelope design, integration of solar technologies in buildings and neighborhood surface areas, and integrated neighborhood energy systems. The paper highlights the role that interaction between various design factors play in achieving resilient communities, and the need of holistic design approach for successful design of resilient neighborhoods.

INTRODUCTION

A climate resilient neighborhood is defined by its ability to rebound from climate-related shocks. Designing climate resilient neighborhoods is becoming increasingly urgent due to the frequency and severity of climate events, worldwide. The overall design of communities affects significantly their ability to resist disruptions, and their ability to continue functioning through extreme events. Mitigation and adaptation are the two main approaches that are employed in planning for resilience. Mitigation has been extensively studied, and is progressively implemented, primarily in relation to reducing energy consumption and associated GHG emissions of the built environment. Investigation of adaptation to climate change is still lagging, especially as related to the development and application of design strategies at urban level.

This paper presents some fundamental strategies in the design of neighborhood resilience, not just in mitigation of the effects of climate change, but also in adapting to this change and associated disruptions, such as risks of large-scale dysfunction. These strategies relate primarily to building design, to neighborhood characteristics and spatial design, and to urban and building energy systems. Discussion presented in this paper is based on extensive research on methods to enhance resilience of buildings and communities.

BUILDING DESIGN

Building design plays an important role in overall energy performance and potential resilience. Design parameters including building type, building shape and layout, and

building envelope, affect the energy consumption of the building as well as its potential to integrate solar technologies for renewable energy generation. Architectural design decisions including efficient building envelope with adequate insulation level, air tightness, window to wall ratio ((WWR) up to 40% on south facades, minimal on other facades) and high-performance window systems can reduce the energy demand for heating, cooling and daylighting, and thus the size of mechanical equipment. Design of various other features such as shading devices, light shelves, solar chimneys, and others can assist in optimal utilization of solar energy, reducing dependence on local energy grids.

Building envelope design for energy generation. Building envelope can be exploited to integrate solar technologies, such as PV and PV/thermal systems for the generation of electric and thermal energy. The shapes of the building and of the envelope affect the available surface area for PV and PV/T integration, as well as their exposure to solar radiation. While in low-rise buildings (≤ 3 floors) PV integration in roofs is dominant, in a multistory building integration of PV systems in facades offers advantage, due to the increased available surface area of facades, relative to roofs. Building shapes and

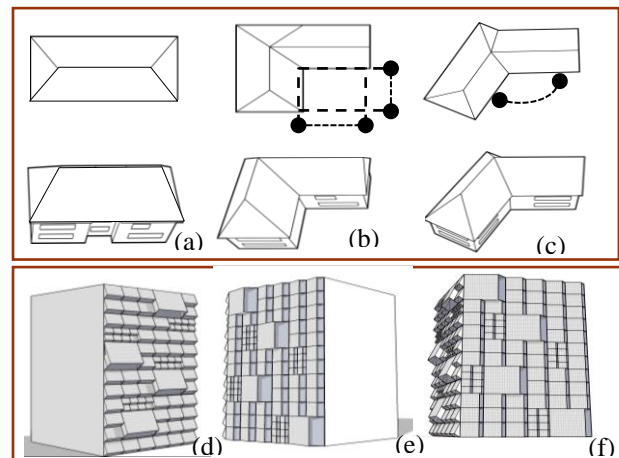


Figure 1. Manipulation in geometry of buildings for increased solar capture, (a-c) building layout, (d-f) building facades.

their orientations, and manipulation of self-shading building shapes (Fig 1b, c), affect solar accessibility of roof and facade surfaces, and their suitability for integration of PV systems (Hachem et al, 2011).

The geometry of building envelope can be manipulated to improve the electric and thermal output of the solar collectors. Modifying the tilt and orientation angles of some surfaces, independently of the shape and orientation of the building itself, can result in higher PV electricity yield. For example, a folded geometry of the can increase significantly the energy generation potential of roofs and particularly facades (Hachem-Vermette, 2018) (see Fig 1d-f). Such manipulations can provide creative architectural integration of PV systems.

Passive design in buildings. Passive design can be implemented in office and commercial buildings, as well as in residential buildings. For example, daylighting, passive heating of perimeter zones, passive and hybrid ventilation, coupling ventilation with solar chimneys, are design features that can significantly affect energy demand, reducing the buildings' dependence on the local grid.

Energy efficiency measures. Energy efficient lighting and equipment, including efficient mechanical systems are essential part of energy efficient buildings, which should be designed to complement the passive design. Efficient energy systems are discussed, below.

NEIGHBORHOOD DESIGN

Neighborhood design plays an important role in improving its environmental impact in terms of net energy consumption and GHG emissions, and in enhancing the resilience of a community and its potential to adapt to various stresses. Some of the main factors that need to be considered are summarized in the following.

Type of neighborhood. A mixed-use neighborhood that includes various amenities within walking distance reduces the distance traveled per day, and therefore transport related energy use and associated GHG emissions. Such neighborhood presents a number of opportunities that can increase the energy resilience of the neighborhood. These include potential application of urban energy systems such as district energy, large-scale application of renewable energy, seasonal thermal storage and sharing energy potential between buildings, facilitating net-zero or even energy positive status.

Impact of building mix. The composition of building types within a neighborhood can significantly influence the amount of energy consumption by the neighborhood, as well as its potential to generate renewable energy from buildings and neighborhood integrated solar technologies. Research on the environmental and energy impact of building mix indicates that an optimal ratio of commercial land area to overall built land area lies in the range of 23% to 32 % (Hachem-Vermette and Singh 2019a). Residential buildings constitute the remaining

part of the built area. This optimal range allows reducing the energy consumption and GHG emissions, while increasing the neighborhood's potential to generate non-fossil fuel based energy, to fulfill a significant part of its energy demand.

Orientation of streets. Street layout can affect the potential to capture and utilize passive solar energy, as well as the energy output of various solar technologies. Buildings should be designed to properly interact with street layout (e.g. orientation of main façade with respect to the street) without negatively affecting their energy performance. An example is shown in Fig. 2, where the design and orientations of buildings in various street layouts result in less than 3% difference in solar radiation incident on the main building surfaces (Hachem-Vermette and Singh 2019b).

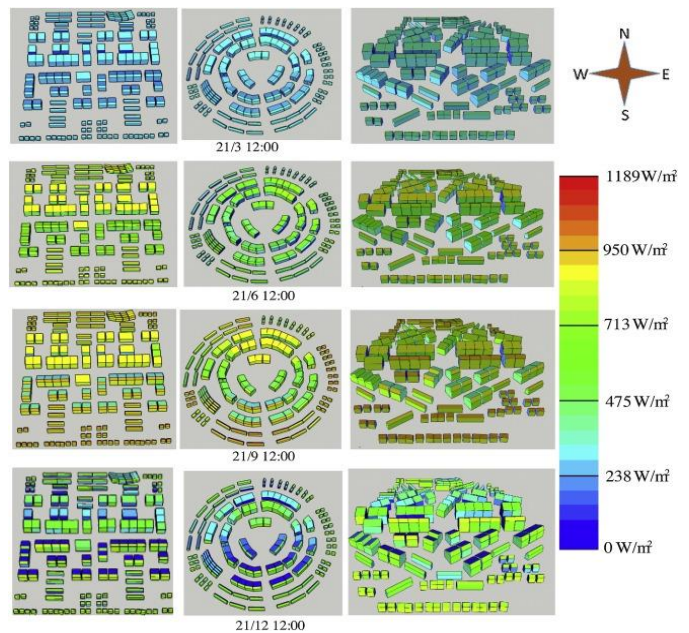


Figure 2. Solar radiation for 3 neighborhood layouts, during 4 representative days of the year.

Density. Large number of studies associates an increased built density with urban environmental sustainability, especially at the city scale (Jabareen, 2006). In temperate and cold climates, where enhancing solar availability is a high priority, the negative impact of increased density can be counterbalanced through the deliberate manipulation of urban layout. For a given density, the level of solar radiation can be manipulated through combinations of site coverage and building heights (Lee et al, 2016). Increasing spacing between buildings allows better solar access to buildings, and thus increases their potential to utilize solar radiation for passive heating and daylighting, while also increasing solar availability at ground level. The impact of density as an isolated factor should be distinguished from the cumulative effects of various additional factors of a compact development,

such as land use, transit accessibility, job availability, walkability and others (Hachem, 2016).

Green and spatial areas. Landscape can offer solutions for the integration of PV and solar thermal collectors in high performance resilient neighborhoods. New issues and opportunities arise in designing public open areas and landscape within the built environment for the integration of solar technologies (Fig.3a). Significant challenges are posed by the selection of public areas that offer an adequate solar potential, while avoiding shade from surrounding buildings. On the other hand, integration of solar collector structures in the public landscape provides the opportunity to improve the outdoor thermal comfort of the built environment. For example, PV structures can be employed as shading structures in urban landscape. They can be designed as charging stations for electrical vehicles, or as integral part of public parks to provide shading or rain protection (Fig. 3b, d). In addition, PV systems can be integrated along streets, fulfilling some functions such as noise barriers, while benefiting from high solar exposure (Fig. 3c).

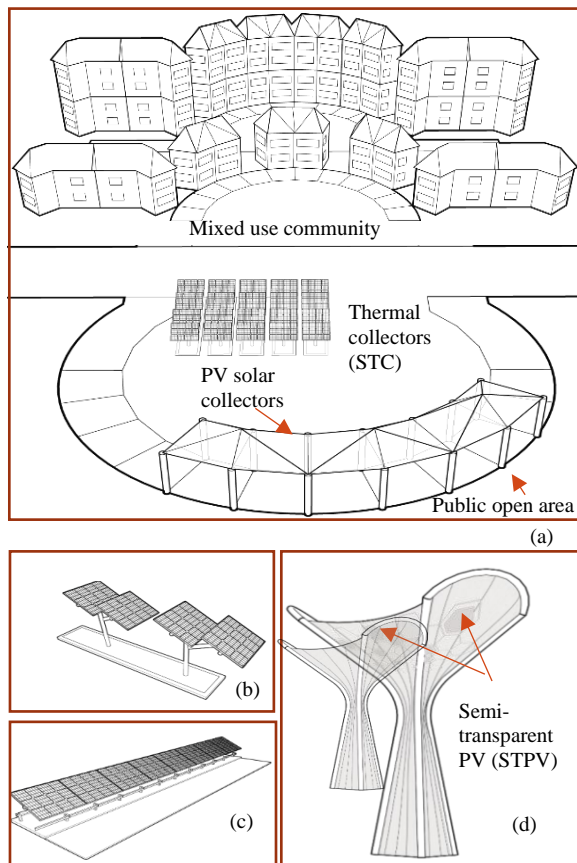


Figure 3. (a) Mixed use community with PV and STC integration in public areas, (b) PV as parking structure, (c) PV on street borders, (d) STPV in sculptural elements.

Street design. Street design can affect transport mode and associated energy and GHG emissions. The availability of biking lanes can decrease the number of trips per vehicles and associated GHG emissions. Studies shows that the use of individual private cars can be reduced when designing streets with increased number of intersections (Hachem, 2016). Street design, including connection nodes and number of available routes, has significant impact on resilience of the neighborhood and potential evacuation during emergencies. Reducing the dependency on major streets constitutes a major criterion in the design of resilient neighborhood layouts, by avoiding the destabilization of the whole street network system when some of the central nodes are disabled. For instance, research shows that while a hexagonal street layout offers numerous advantages, some nodes of the street network are highly dominant, which may lead to disabling the neighborhood if such nodes are deactivated. The rectilinear street network, based on the fused grid design, is associated with a number of issues including longer distance between some nodes, and low overall efficiency, as well as restricted number of paths between some locations of the neighborhood. Such issues need to be addressed in the early design stage of a neighborhood (Hachem-Vermette, C. and Singh, K., 2019b).

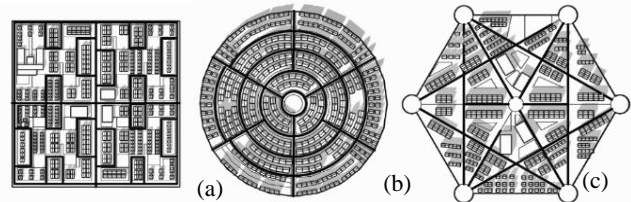


Figure 4. Three different street network designs, rectilinear (based on fused grid), radial and hexagonal.

ENERGY SYSTEMS

Resilient neighbourhood design should consider, in addition to the energy demand side, local and distributed energy generation strategies. A multiplicity of energy systems can assist significantly in avoiding functional disruption of the neighbourhood, during emergencies. Urban energy systems, both on the demand and supply sides, and their impact on neighbourhood resilience are briefly discussed below.

Energy demand. The architectural design of buildings, coupled with spatial neighbourhood design, can assist in reducing energy demand and in allowing buildings to exploit passive solar energy, increasing thus the capability of the neighbourhood as a whole to withstand chronic stresses and acute shocks. Energy consumption of buildings can be further reduced by employing high-energy performance mechanical systems. Methods employed to increase the efficiency of mechanical systems are in continuous development including heat

pump technologies, heat recovery systems, different methods of ventilation (e.g. displacement ventilation), effective distribution and controls, and others. For instance, electrical air source heat pump (ASHP) powered by PV in combination with the local electric grid presents a viable, highly efficient solution for multi-storey buildings (Singh and Hachem-Vermette, 2020). Ground source heat pumps (GSHPs) can supply heat of up to quadruple the energy of the electricity they consume, by using ground-extracted heat. Smart control management systems enable preheating or precooling buildings before the peak hours. Preheating and precooling can be readily applied through strategic exploitation of thermal mass, highly efficient building envelope and controllable mechanical ventilation. Geothermal energy can be implemented on a large scale for energy production through a geothermal power plant. For buildings with heating-dominated energy consumption, the combination of a ground coupled heat pump (GCHP) system with a solar thermal system offers a high potential for energy conservation (Zhai et al, 2011).

Energy supply. Solar PV technologies, integrated in buildings and in various public open areas, form an important layer of resilience in case of utility energy disruption. Other energy systems can be exploited to increase the diversity of energy sources and provide additional layer of energy production for neighborhood resilience. For example, waste to energy (WtE) and small wind turbines can be exploited in mixed-use neighborhoods, alongside solar technologies (PV and STC) and borehole seasonal thermal storage. An optimization study of the mix of these energy sources, conducted for two concepts of a sample mixed-use community with the same composition and layout – a stand-alone community and a grid-tied community – indicates that a grid tied community is capable of achieving a net-zero energy status with a moderate size of renewable energy systems. Such self-sufficient neighborhood requires a thermal energy storage, coupled with solar collectors, together with PV installed in available south-facing roof areas (Hachem-Vermette et al, 2019). WtE and wind turbines, can be employed to supplement other renewable energy systems (e.g. PV and STC), especially when available surfaces for installing these systems are restricted. It should be taken into account that energy balancing and congestion issues may occur with the integration of increased levels of distributed energy resources. Integrated urban energy system should be designed to address potential congestion issues, allowing to manage energy generation, consumption, control and storage components.

CONCLUSION

Planning climate resilient neighborhoods relies on a number of considerations, which need to be part of a holistic and integrated design approach, spanning from the building components level to the urban level, focusing on the interaction between these design considerations. Such approach should consider buildings and surrounding open public spaces as active elements of the energy network, consuming, producing, storing and supplying energy, rather than stand-alone energy consuming components of the grid. Consequently, all neighborhood components need to be designed to ensure continuous operation, energy efficiency and potential contribution to the urban energy system. For instance, street layouts can be designed to function in case of interruptions, while allowing near optimal orientations to enable passive and active solar design, enhancing thus the overall efficiency of the neighborhood. Additionally, building density can be determined to achieve various economic, social and environmental objectives, while not compromising the potential of open public spaces and building surfaces for integration of solar technologies.

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WIND RESILIENCE: PROCEEDING FROM WIND CODES AND STANDARDS OF BUILDING DESIGN PRACTICE

Ted Stathopoulos, and Hatem Alrawashdeh
 Concordia University, Montreal, QC
 statho@bcee.concordia.ca; hatemalrawashdeh@yahoo.com

ABSTRACT

The central pillar of this paper revolves about how to employ resilience concepts in providing solutions for wind-related issues with emphasis placed on building issues. The regulatory provisions of the current wind codes and standards are addressed from resilience perspectives to identify their deficiencies. It is our belief that concentrating the efforts on these wind codes and standards could enhance the building resilience against wind.

FUNDAMENTALS

Structures on earth exist within the lowest portion of the atmospheric boundary layer (ABL), which in itself is a major difficulty in wind engineering. Wind flow within this range is characterized as complex, wherein the turbulence level (I_u) is very high and the wind speed (V) is very responsive to earth surface topography and terrains. As shown in Figure 1, which provides a simple illustration for ABL over different terrain exposures, the wind speed within the ABL decreases as coming down to the earth's surface, but the turbulence increases.

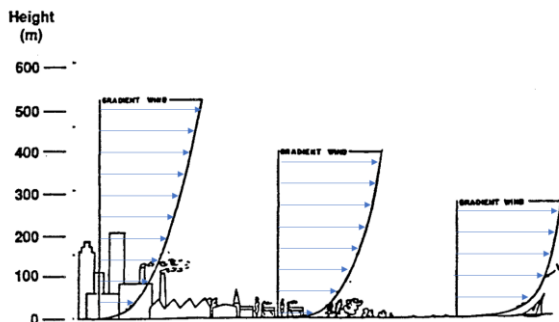


Figure 1. Illustration of mean wind velocity profile for sites of different terrain-exposures (Stathopoulos, 2007).

Wind flow characteristics in strong-wind events (i.e., hurricanes, tornadoes, or downbursts) differ considerably from those of ABL. Examining the tornado flow interaction with buildings is even more marred by difficulties owing to the complexities of the tornado flows as compared with straight ABL winds. Tornado

flows are characterized by swirling effects such as vortices with high tangential and vertical velocity components. Moreover, the structure of the entire tornado may consist of single-spiral, double-spiral or multiple-spirals (Davies-Jones, 2015 and Karami et al, 2019) with low-pressure zone (high suction) at the center of the spiral (Haan et al, 2008 and Karami et al, 2019) – see Figure 2.

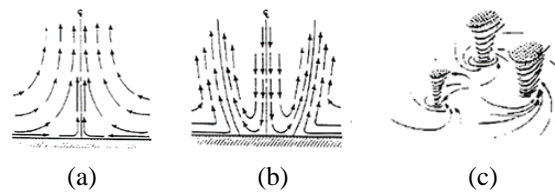


Figure 2. Schematic illustration of (a) one-spiral vortex, (b) two-spirals, and (c) multiple-spirals (Davies-Jones, 2015).

Building resilience is a forked concept encompassing numerous areas and aspects, including but not limited to energy and structural resilience. According to the resilience definition by 100 Resilient Cities Network (Pape-Salmon et al, 2017), these two aspects could be regarded as the core of the general building resilience since they are more directly involved with life permanence in the wake of acute shock occurrences like strong-wind events. Specifically, energy resilience concerns with promoting the energy self-efficiency of the building/community, while structural resilience concerns with occupation, serviceability, and functionality of the building itself and other renewables integrated or attached into the building.

The occurrence of strong-wind events is limited, but when they strike enormous loss of life, socio-economic, infrastructure and environmental damages might be left in their wake. Therefore, structural resilience against such events is a desirable goal to be promoted in order to maintain the three above mentioned characteristics of the structural resilience. Against this background, this paper discusses several points around the following questions: Where are the wind codes and standards with structural resilience? and shall we need to re-assess the current wind codes and standards? – with placing the National

Building Code of Canada (NBCC, 2015) at the center of debate as Canada is considered one of the countries exposed to tornados and other extreme winds.

WIND CODES/STANDARDS

Wind codes and standards are fundamental reference sources for providing wind design provisions and regulations for structural engineers and practitioners.

Indeed, the current Canadian wind load provisions for buildings have undergone major developments and have been consolidated with extensive efforts devoted to the design pressure coefficients during the past 60 years. Canadian provisions are perceived to be innovative and ground-breaking by researchers and practitioners across the globe, thereby they have earned wide international recognition and reputation. Indeed, these provisions have contributed significantly to the development and evolution of various national and international wind load standards, namely: the American Society of Civil Engineers Standard (ASCE 7), the ISO wind load standard, the European Standard (EN 1991-1-4) and the China standard for Wind Loads on Roof Structures (JGJ/T, 2018) among others.

The NBCC provisions, as is the case with other international wind codes and standards, were formulated for normal wind conditions, i.e. straight ABL winds. Such presumption was not certainly intended to embrace a simplified or idealized approach but to provide a more appropriate framework for design purposes satisfying the safety and the economy of the design. The North American wind codes and standards (ASCE and NBCC) have generally been proven adequate, especially when treating low-rise buildings. Bearing in mind that low-rise buildings, mostly residential, industrial or institutional, comprise the majority of the structures on earth.

The interaction of ABL with structures is extremely complex, resulting in wind pressures on surfaces of the exposed structure spatially heterogeneous from point to point. The national wind codes/standards are based on the shape and size of the building, building openings, wind characteristics, surrounding environment such as nearby obstacles, and upstream terrain exposure.

Buildings with height less than 20 m and less than half of the smaller plane dimension are classified as low-rise buildings according to NBCC (2015). The wind-induced pressure (p) on external surfaces of such structures is defined as

$$P = I_w q_h C_e C_t (C_g C_p) \quad (1)$$

in which I_w is the building importance factor, q_h is the reference wind pressure given as $0.5\rho V_h^2$, V_h is the basic wind speed at reference height (h), C_e is the terrain factor, C_t is topography factor and $C_p C_g$ is the peak pressure coefficient. These factors among other wind

codes and standards are discussed at great length by Stathopoulos and Alrawashdeh (2019).

The evaluation of the wind actions and effects on structures depends to a large extent on the estimation of wind speed at the concerned site. Together with wind engineering and structural researchers, meteorologists are also involved in this particular issue. The Canadian code (NBCC, 2015) demonstrates a sensible approach for describing the site. As indicated by Equation 1, the design pressure is derived using a variety of factors, most of which pertain to the site of the concerned structures. Both C_e and C_t are respectively accounted for adjusting the wind profile to be consistent with terrain exposure of the site and to speed-up the velocity due to the existence of escarpments or hills. Also, NBCC (2015) specifies values for the reference wind pressure (q) for several geographic locations across the country.

The code adopts the power-law, a model highly recommended for engineering application, to describe the ABL wind. Two surrounding terrain exposures are assessed on that basis, namely: Open exposure like a building situated on the periphery of open sea or lake, smooth land (without any noticeable obstacles, low vegetation) and open-land (isolated obstacles, low crops or plant covers); and rough exposure like a building situated in built-up areas such as areas with crops, plant covers, occasional obstacles, such as isolated low buildings or trees.

For cases involving sites of complex-terrain (e.g., buildings surrounded by urban or suburban areas of dense tall-buildings) and extreme climates, the Canadian code recommends wind tunnel testing – the same situation shared by other national wind codes and standards.

The peak pressure coefficients ($C_g C_p$), referred to in Equation 1, are related to the shape and size of the structures. Through the past five decades, a lot of research studies conducted to measure wind pressure coefficients on a variety of low-rise buildings, mainly utilizing the atmosphere boundary layer wind tunnels. The current pressure coefficients of North America wind codes/standards (NBCC, 2015 and ASCE 7, 2016) are virtually inclusive for most geometries and configurations of low-rise buildings (flat, gable, hip, multi-span, and saw-tooth, etc). It has been recognized that hip roofs are given advantages over gable roofs for mitigating the exposure to high wind effects (Sandink et al, 2019).

TORNADOS IN NBCC (2015)

In the past, assessing near-ground wind speeds of tornados commonly made through an indirect approach depending on the observed damages following the storm. Fujita Scale (F-Scale) is a case in point for that practice, which grades tornadoes on the basis of the intensity of

wind damage – see Table 1. Mainly, difficulties of installing near-ground instrumentation in the path of a tornado were the reason for limiting the field measurements. Recent efforts aimed at further understanding the tornado and the surrounding environments through collecting data during tornadoes using mobile weather stations and radars (Bluestein et al, 2004; Blair et al, 2008; and Kosiba and Wurman, 2013). However, measurements at levels below 10-15 m are comparatively still scarce (Karen et al, 2014).

Table 1. Enhanced Fujita Scale (EF-Scale) and Fujita Scale (F-Scale) Wind Speeds (Information from Environment Canada’s Weather Service).

Rating	Wind Speed (km/h)		Damage Description
	F	EF	
0	60-110	90-130	Light
1	120-170	135-175	Moderate
2	180-240	180-220	Considerable
3	250-320	225-265	Severe
4	330-410	270-310	Devastating
5	420-510	> 315	Massive devastation

Tornadoes vary in the degree of intensity and severity. Canada adopts the Enhanced Fujita Scale (EF-Scale), which has been introduced by Environment Canada’s Weather Service as an upgraded version of the Fujita Scale (F-Scale) – as compared in Table 1. Canadian tornadoes often occur in the season extending from April to September, although they could really strike any time of the year. They frequently develop in mid-afternoon to early evening.

Figure 3, which is included in the Commentary of NBCC (2015), shows the Canadian regions of vulnerability to tornadoes with the Fujita Scale (F-Scale) (Environment Canada: Sills et al, 2012). Clearly, large portions of the country are tornado-prone areas. According to Environment Canada’s Weather Service, most of the Canadian tornadoes are F-0 by an estimated 45%; whereas, the rest tornadoes of scale F-1, F-2, F-3, and F-4 are estimated by 29%, 21%, 4%, and 1%, respectively.

As shown in Figure 3, three thresholds are established by NBCC (2015) to categorize the Canadian regions according to their vulnerability to tornadoes, defined by the probability of occurrence (PO) and intensity (F-scale), specifically: “prone to significant tornados”, “prone to tornados” and “tornadoes are possible” for regions with F2-F5 ($PO > 10^{-5}$ km²/yr), F0-F2 ($PO > 10^{-5}$ km²/yr) and tornado observed ($PO \leq 10^{-5}$ km²/yr), respectively. Notwithstanding the above, the probability of a building being struck by a tornado is very low, estimated at 10^{-5} /year.

Concerning low-rise buildings, the computational study of Lewellen et al (1997) and site measurements of Bluestein and Pazmany (2000) brought to light the fact that the strongest winds exist within heights of 10-20 m above the ground with significant ramifications in evaluating wind loads produced by tornadoes, as that elevation range represents the height of most low rise-buildings (Haan et al, 2008).

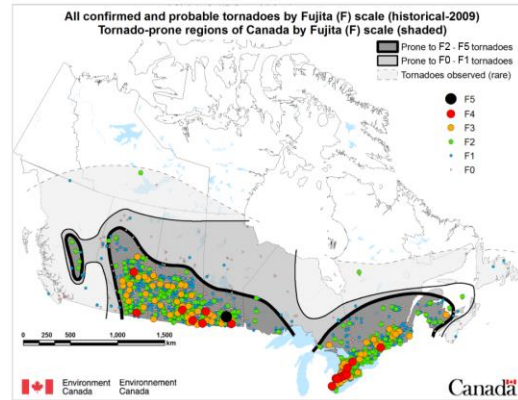


Figure 3. Map of all reported tornadoes in Canada between 1980 and 2009, identified by colored F-scale (Environment Canada: Sills et al, 2012).

As indicated previously, developing the wind codes and standards for extreme wind conditions may be inefficient practice from building construction cost perspectives because of the “low risk of loss to individual owners” (NBCC, 2015). The Commentary of NBCC (2015) has recently included a basic set of measures in response to reducing tornado effects:

“The first detail – the anchorage of the house floors – is essentially covered by NBC Article 9.23.6.1. for typical housing with permanent foundations. CSA Z240.10.1, “Site preparation, Foundation, and Anchorage of Manufactured Homes,” contains anchorage recommendations for protecting mobile homes against the effects of tornadoes. The second detail – roof anchorage in block walls – is essentially covered in CSA S305, “Design of Masonry Structures,” through limit states requirements for wind uplift and, for the empirical method of masonry design, by Clause F.1.4 of the standard. Deficiency of this construction detail is especially serious for open assembly occupancies because there is nothing inside, such as stored goods, to protect the occupants from wall collapse. For such buildings in tornado-prone areas, it is recommended that the block walls contain vertical reinforcing linking the roof to the foundation. Key details such as those indicated above should be designed on the basis of a factored uplift wind suction of 2 kPa on the roof, a factored lateral wind pressure of 1 kPa on the windward wall, and a suction of 2 kPa on the leeward wall. ”

THE POSITION ON THE QUESTION OF WIND CODES AND STANDARDS RE-ASSESSMENT

It has been demonstrated that the engineered buildings are less affected by extreme winds. Tornado damage to a tightly connected building typically begins at roofs, façades and components and develops towards the interior walls, floors, and foundation. As illustrated in Figure 4, which schematically shows building components and supporting system in a vertical section, more attention is necessary for building integrity through preserving the wind pressure induced transferring along its path safely and smoothly, i.e., “continuous vertical load path” (Sandink et al, 2019). It is widely recognized that the loosening parts become more vulnerable to wind dynamics as the wind loads magnified due to their vibration. As a precautionary measure, periodic maintenance and check for inherent deficiencies in the building construction should be undertaken particularly for roof to wall connections. Also, further construction detailing measures may be undertaken. A case in point, a change in the spacing of roof sheathing fasteners of intermediate supports from 300 mm to 150 mm, driven by increasing the resistance for high wind like tornadoes, was made into the Ontario Building Code (OBC, 2010).

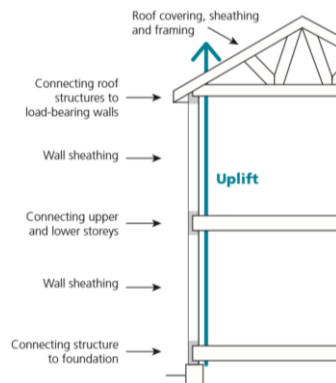


Figure 4. Building vertical section showing the components and load path (Sandink et al, 2019).

Recently, some structural and wind engineering researchers have embraced the strategy of applying resilience for buildings of public service facilities, such as hospitals, educational institutions, airports, and power plants. In this regard, the buildings of such facilities shall be designed for severe tornados (i.e., F-3 intensity of mean wind speed 250-320 km/hr) or higher (Haan et al 2008).

Finally, more action and measures on the reference design basic wind pressure (q_h as referred in Equation 1) may be taken to further raise the wind resilience through wind codes and standards. The maximum q_h value to be found in Appendix C of the NBCC (2015) is 1.23 kPa (at Resolution Island, Nunavut for a return period of 50 years); whereas, the vast majority of the values found to be ranging from 0.30 - 0.70 kPa. It could be suggested

that these values of q_h may be revised and magnified to accommodate the risk of F-2 tornado pressure forces (which covers the occurrence of 75% of the Canadian tornadoes), particularly in dense population regions. In these cases, wind measurements at meteorological stations and special wind tunnel simulations must certainly play their part.

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BUILDING OPERATION AND OCCUPANT BEHAVIOR

Rosamund Hyde

Stantec, 1331 Clyde Avenue, Ottawa, ON

Rosamund.Hyde@stantec.com

ABSTRACT

This paper discusses “building operation and occupant behavior” in the context of developing a Canadian roadmap for resilient buildings. Two questions are explored: 1) what is the role of building operators and 2) what tools can help with the process of learning from buildings over their lifecycle? These questions were chosen because they are real-world questions that emerged from a series of post-occupancy evaluations, they are under-studied or newly studied in the scholarly literature, and they appear to converge upon an important component for the roadmap for resilient buildings.

INTRODUCTION

The 2019-2021 “Canadian Roadmap for Resilient Buildings” process of three symposia has taken on the task of finding solutions that address the three objectives of resilience, deep reductions in GHG emissions, and optimized energy efficiency plus on-site renewables. This paper, prepared as a contribution to the second symposium, addresses the topic of “building operation and occupant behavior”, specifically focusing on the building operator as building occupant. The paper enlarges on two questions that emerged in the course of a series of post-occupancy evaluations of green buildings carried out between 2002 and 2014: 1) what is the role of building operators and 2) what tools can help with the process of learning from buildings over their lifecycle?

FOCUS ON BUILDING OPERATORS

The title of this paper references “occupant behaviour”. Building occupants include those few whose core role is managing the building and its systems, and those in a larger group whose primary reasons for being in the building are other than assisting in its operation. The behaviour of the latter is being studied by other contributors to this symposium. The behavior of the former will be described and discussed here.

Interviews with building operators during post-occupancy evaluations prompted this exploration. Many buildings have building operators, and operation and maintenance activities have a strong influence on energy

use in buildings (Gazman 2012), but the role of building operator is not consistently defined or frequently studied. In Canada, there is no unique National Occupation Classification (NOC) code for “building operator”, due to the diversity of related roles. The number of actual building operators in Canada was recorded as “unknown” in a 2011 study (EcoCanada 2011). The same study defined a building operator as “a person who has the appropriate skills needed for the day-to-day maintenance and operation of large facilities that have complex heating, mechanical, and electrical systems along with specific knowledge of how to operate the facility in a way that takes into consideration the interplay of building systems to maximize energy and resource efficiency, reduce waste, provide superior indoor air qualities, and the requirements of building tenants” (EcoCanada 2011). For comparison, “Facility Manager” can include building, facility and maintenance managers (Hughes 2017). Some sources do not distinguish between “building operator” and “facility manager” (for example, Bernardo 2019).

In the United States, a federal level process has examined the requirements for every job classification in the building design and operation field (37 by their count) through the lens of competence in building science and have identified “Buildings Operations Professional” as the one who “manages the maintenance and operation of building systems and installed equipment, and performs general maintenance to maintain the building’s operability, optimize building performance, and ensure the comfort, productivity, and safety of the building occupants”. The process aims to develop voluntary national guidelines to improve the quality and consistency of commercial building workforce credentials, and to clarify pathways for workers to strengthen their credentials through accredited training, including for example the Building Operator Certification (BOC®) program delivered in many states (Metzger 2017). Those advocating for the improved process note that many building operators simply learned from the previous person in their role, some had not taken an exam for twenty years, and that utility subsidies

were important in making training financially accessible (Gazman 2012).

Despite increasing automation and availability of data for training machine learning systems, many buildings continue to rely upon human operators; in 2017, only 14% of buildings in the United States (43% of conditioned space) had any kind of building automation system (Katipumala 2019). Even enthusiastic promoters of digital transformation of buildings recognize that “we still need experienced and knowledgeable staff” (Woodhead 2017).

Labour market research indicates that human operators can be hard to find. For example, the real estate industry provides many jobs in building operator roles, to manage commercial buildings. However, recruitment and retention are challenging and urgent given the aging workforce. A recent BC study indicated that the industry perceived itself as underserved and not well understood by post-secondary institutions in terms of its needs for qualified workers; at the same time, its practices around credentialing have been inconsistent and may not have established clear standards for candidates, while the candidates may be seeking careers that are more technology-driven and that offer “work-anywhere” conditions. The top ten skills identified as lacking among the talent pool included smart building technical knowledge, energy conservation knowledge and leadership skills (BOMA-BC 2017). As reported in the US process mentioned above, challenges facing the US building energy efficiency workforce include lack of early career interest, lack of diversity, fragmented preparatory programs, and difficulty recruiting. In Canada, difficulty in getting leave for training has also been identified as a problem (EcoCanada 2011).

OPERATING RESILIENT BUILDINGS

This section reviews expectations that are placed on building operators under conditions that require resilience, i.e., “the ability to prepare and plan for, absorb, recover from and more successfully adapt to actual or potential adverse events” (GAO 2015).

A building placed in service today will be cared for by building operators until it is taken out of service, possibly as far out as the next century, through all the changes and adverse events anticipated in these coming years.

Upon handover, the design team and construction team normally exit, leaving a set of documents or a digital dataset with the building operator to support building operation and maintenance; this can be the first involvement that the operator has with the building, though it is recognized that including the operator in the design process can improve outcomes in building performance. In some cases, the building is commissioned, typically by a third-party agent who ensures that the building is functioning properly when

started up and who may carry out some training with the operator. After the commissioning work is completed, the building operator and their reporting hierarchy carry forward the responsibility for ensuring regular recommissioning, recommended at 3 to 5-year intervals. Recommissioning can pay for itself by reducing wasted energy, but like commissioning, it is not well understood by decision-makers among the building owner groups.

Both commissioning and recommissioning, while rewarded within resilient building rating systems, may need to be advocated to building leadership by building operators (Min 2016). In cases where buildings have not received commissioning prior to occupancy, the building operator may need to recommend retro-commissioning to management.

During the building’s service life, it is likely that its operators will need to respond to conditions that test resilience. According to Hewitt *et al.* (2019), “Buildings exist primarily to shelter vulnerable people from the external environment”. However, in some cases, buildings may not be able to fully withstand shocks that they receive, resulting in three end-user experiences of building condition: typical building operations, atypical building operations (in adverse circumstances) or building failure. For example, during Hurricane Sandy, the well-known Battery Park building was able to continue operating because its substation (located in a rebuilt section of the World Trade Centre) was not flooded, and the building’s electrical equipment was on a high enough building level to escape water incursion. Its stormwater reservoir and wastewater treatment plants were shut down as had been planned in advance, so it was operating in an atypical condition, but it did not go into building failure. Because of highly effective work by building operators, residents were able to return to the undamaged building in a short time, hastening their recovery from the extreme weather event (Hewitt 2019).

To continue to “shelter vulnerable people”, even if in atypical building operations, buildings need to be resilient. Also, the buildings’ operators need to have skills for resiliency. Phillips *et al.* (2017) recently reviewed four resilience rating frameworks and grouped into themes the 88 strategies that they developed. The themes are Risk Avoidance, Passive Survivability, Durability and Longevity, Redundant Systems, and Response and Recovery. At least three of these themes directly recruit the competencies and leadership skills of those in charge of operating the building.

For Passive Survivability, renewable energy systems require skills in operating, maintaining and integrating the energy system in normal operation and possibly in different modes in atypical operation. For example, the presence of PV systems complicates the challenges for building operators to avert demand charges related to building electrical load peaks (Zhang 2018).

For Redundant Systems, the operation of back-up generators and water supply systems requires specific skills. For Response and Recovery, the ability to resume operation quickly post-hazard requires leadership ability and competence in connecting with local networks.

In general, decision-making at the building operation level during or after an adverse event is a challenging task that may require time-sensitive discernment about whether the building will be able to resume operation.

The US federal process mentioned above recognizes building operators' growing scope, and explicitly names, among core competencies, the need to understand building resilience, natural or man-made disasters, and onsite energy generation. Considering the level of responsibility for building operators in all buildings and especially in sustainable and resilient buildings, the proposed roadmap to resilient buildings for Canada needs to include, similarly, provision for support to this group in terms of recruitment, training, certification, and visibility of their role. Consistent certification of building operators in specific roles (categorized by size of building, complexity of systems, scope of duties, responsibilities in adverse events) could strengthen public recognition of these career paths and promote appropriate compensation as well as inclusion in design processes. As the built environment changes through pressure to be more sustainable and resilient, buildings may require much more sophisticated skills than at present to operate optimally; professional engineers may take to specializing in building operation in their undergraduate programs and beyond. Canada cannot have real resilience in the built environment if the building systems are not understood, maintained and implemented correctly by skilled building operators.

FOCUS ON LEARNING FROM BUILDINGS

The second question being considered in this paper is, what tools can help with the process of learning from buildings over their lifecycle? This question moves the discourse from human solutions (building operator) to technological solutions (software tools for sharing information). Over the past half century, techniques for evaluating building performance have been developed and applied, including many called in general "post-occupancy evaluations" (POE). These techniques have been used to study the occupancy phase of the building lifecycle, including "assessment of building performance, exploration of relationships between inhabitant behavior and building resource use, optimization of the indoor environment for inhabitants, more informed decisions about future building design, and opportunities to enhance the dialogue within design teams and their partners" (Li 2018).

A frustration for post-occupancy evaluators is what has been called the "3-ring folder POE" – the document that

gathers dust when a study's results have not been integrated into architectural practice or building operators' methods (Goçer 2015). To date there have been few ways that designers could conveniently integrate the findings from POEs with their own experience – for example, they could read reports, attend presentations about completed studies, or explore the results of occupant satisfaction surveys in comparison with reference datasets (Huizenga 2006). Only a small minority of buildings receive evaluation, so the random chance of a designer having the opportunity to learn from an evaluation of a building they have worked on is small.

However, increasing digitalization of the construction industry may address the problem of unused POE reports as Building Information Modelling (BIM) features become fully implemented and as advances in Internet of Things (IoT) provide more opportunities for data to be gathered, either from occupant feedback or from onsite sensors. According to Tang et al., (2019):

By incorporating geometry, spatial location and a scalable set of metadata properties, BIM models provide a high-fidelity operable dataset capturing the as-designed building objects, properties and spatial organization as a set of virtual assets. IoT data enhances this information set by providing real-time and recordable status from the actual operations in construction and operations.

With the continuing development of the full functionality of Building Information Modelling (BIM), emerging information can be associated with every aspect of the as-built computer models of the building. This can include: all information learned about the building from inception to end of life; all model and IoT sensor data throughout the building life as well as virtual reality systems and automation systems; all data from other aspects of the construction industry, integrated through the development of interoperability standards, and used for shared purposes such as facility management; all information needed to operate the building with minimum energy and emissions. From the perspective of the building operator, an enhanced resource for guiding operation is created by feeding all this information into the as-built model, and the information can be displayed in a three-dimensional form (either using BIM or alternative software as described in (Motawa 2013) or (Lee 2019)) to help clarify where salient features are located in the building.

The information can "flow forward or back", that is, it can be used by design teams to learn (through post-occupancy evaluation results) from the outcome of their past design decisions, or can be used as a reference for future operation of the building. Appropriately curated, the information can theoretically "flow sideways" to other building operators and other design teams in the same company or (in a spirit of collaboration) other

companies. From a knowledge management perspective, the arrangement of relevant information into the three-dimensional representation of a real project, as explored by (Jaffery 2016), can potentially engage and inform all those who are concerned with the project. The diverse professional dialects and file formats (as outlined in Dibley 2012) that may have impeded interdisciplinary relationships in the past can be circumvented so that information is able to flow into understanding and knowledge for all participants. This kind of construction industry collaboration is classified as “BIM Level 2”.

A higher level, BIM Level 3 (also referred to as iBIM or “integrated BIM”), is foreseen that would open possibilities for interacting and collaborating through distributed ledger technologies (DLT, i.e., blockchain). According to Li et al. (2019):

The integration of BIM, DLT, smart contracts and the IoT can have a significant impact on construction activities and facilities management, especially where tracking of components proves useful and where there is duplication of work; IoT tracking devices will automatically collect data regarding an item or a process and update the ledger accordingly.

Arup (2017) suggested that Level 3 BIM capability may be still “a few years away”. In 2018, the Hackitt report on the Grenfell Towers fire in Britain recommended that a controlled digital record such as would be made possible by distributed ledger technologies should be required at handover in a building design and construction process (Li 2019). By 2020, a Canadian/Australian research collaboration produced a proposed modular information management framework that could form the basis for a blockchain-enabled system to improve construction processes (Succar 2020). On the other hand, a different 2020 Canadian-authored paper outlined the existing barriers to streamlined construction processes: “outdated BIM, disconnected trades, lack of terminology, insufficient documentation, inefficient transitions across views and artifacts, unavailability of design information, information discrepancy, unfit navigation tools, and office–site disconnect” (Mehrbood et al. 2020). ARUP (2019) estimates commercialization of BIM blockchain technologies to start around 2027, and adoption to occur around 2035, but recognizes that these predictions may be inaccurate. In summary, despite significant pressure and rapid disruptive technological development, the goal of automatically integrating post-occupancy evaluation results into single shared DLT-based building models may still be remote. However, as off-site modular prefabricated construction becomes more widely implemented, the design cycle for buildings may be expected to be more like automobiles, with user results from present models feeding into design for future models through the iBIM route.

CONCLUSION

This paper has addressed areas of inquiry that emerged through a series of post-occupancy evaluations. The role of building operators in resilient buildings was explored, with the recommendation that a stronger system for building operator certification in Canada is needed to make buildings more resilient in use. The challenge of learning from the full life-cycle of buildings was described, and possible technological solutions were proposed. Of these two action areas, the building operator training opportunity may be faster to implement. If training includes BIM and iBIM skills, the renewed role of building operator can include using these technologies to channel findings about building performance to designers, as an integral part of Canada’s roadmap to resilient ultra-low energy built environment.

Further research and reflection are needed on the implications of the problems and solutions proposed above, in particular the extensive use of building information modeling as a way to learn from buildings in use. At present the building design and construction industry is unevenly mediated by technology. Using advanced data management and visualization techniques to collate post-occupancy research findings may lead to rapid steps into machine learning, that may outpace the capacity of humans to become better building operators. Computers may make decisions about building operation that would differ from those that humans would make. In parallel with national public sector leadership needed for improved building operator certification, governments at all levels may need to provide improved regulation for decision-making for human health in buildings.

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THE CHALLENGES OF DEVELOPING THERMAL RESILIENCE POLICIES, PROTOCOLS AND PROCEDURES FOR BUILDINGS

Ted Kesik¹, Daniel Pearl², Liam O'Brien³, Amy Oliver², Yan Ferron⁴, William Harvey⁴

¹University of Toronto, Toronto, ON

²L'OEUF, Montreal, QC

³Carleton University, Ottawa, ON

⁴Pageau Morel and Associates Inc., Montreal, QC

ABSTRACT

The recent recognition of the need for greater resilience of our built environment in the face of climate change and other natural and anthropogenic disasters has spurred numerous research efforts around the world. As a growing proportion of the global population lives in cities, and the frequency and severity of extreme weather events escalates, it is important to put research findings into practice. This paper presents an example of translating thermal resilience research into public policies, protocols and procedures that can be adopted presently and then implemented strategically over time.

INTRODUCTION

Resilience of our built environment hinges on a large number of interrelated factors that differ across geographic and climatic regions, as well as between cities, towns and rural communities. One critical determinant of resilience is *passive survivability* - a building's ability to maintain critical life-support conditions in the event of extended loss of power, heating fuel, or water. Passive survivability involves a number of aspects including thermal moderation, water, food and emergency medical supplies - it speaks to a prolonged power outage resulting from an extreme condition which could be related to a severe climate event, infrastructure crisis or conflict situation (Wilson, 2005). Examples of outcomes stemming from inadequate passive survivability include hypothermia, heat stroke, water shortage, food spoilage, freezing/bursting of water pipes, computer system meltdowns/flooding, etc. It is an extreme condition with serious negative consequences for the occupants, the building, its equipment and contents.

Thermal resilience is an aspect of passive survivability in buildings that is commonly assessed using two metrics: *thermal autonomy* (TA) is a measure of the fraction of time a building can passively maintain

comfort conditions without active system energy inputs; and *passive habitability* (PH) is a measure of the duration of time that an indoor space remains habitable following a prolonged power outage over an extended period of extreme weather, hot or cold.

This paper focuses on policies, protocols and procedures needed to enhance the passive habitability of social housing recognizing that such measures must be nested within a broader framework of resilience planning that itself must respond to the particular context of the community it wishes to shelter and protect when extreme weather events and/or disasters strike.

CONTEXT

Service de l'Habitation, Ville de Montréal engaged Danny Pearl and Amy Oliver of the local architecture practice L'OEUF to explore the potential for enhancing the resilience of its existing and future social housing projects. Ice storms and heat waves over the past several decades have revealed the vulnerability of this housing stock for a population that is economically challenged to fend for itself under crisis conditions. In turn, engineers Yan Ferron and William Harvey were retained to provide technical assistance under a framework developed by Professors Ted Kesik and Liam O'Brien. The purpose of the study was to develop a report containing recommendations for how to enhance the thermal resilience of Montreal's social housing, both short-term measures and long-term strategies.

PROCESS

The process began with a review of the principles and concepts advanced in two publications: 1) the *Resilience Planning Guide* (Kesik, 2017); and 2) the *Thermal Resilience Design Guide* (Kesik et al., 2019). The first publication provides a broader framework for resilience planning and risk management. The second publication provides for technical design and analysis of thermal

resilience measures in buildings based on previous research (Ozkan et al., 2019).

Then, using existing social housing projects constructed in Montreal that had been designed by the architects undertaking the study, the engineers that were retained conducted thermal resilience analyses, in particular, assessments of the passive habitability of the buildings under both extreme cold and hot weather scenarios.

The information gained through the analyses could then be input to a framework of thermal resilience protocols and procedures as outlined in Figure 1. It could also be used to assess the current thermal performance of social housing technical standards to determine if these are adequate.

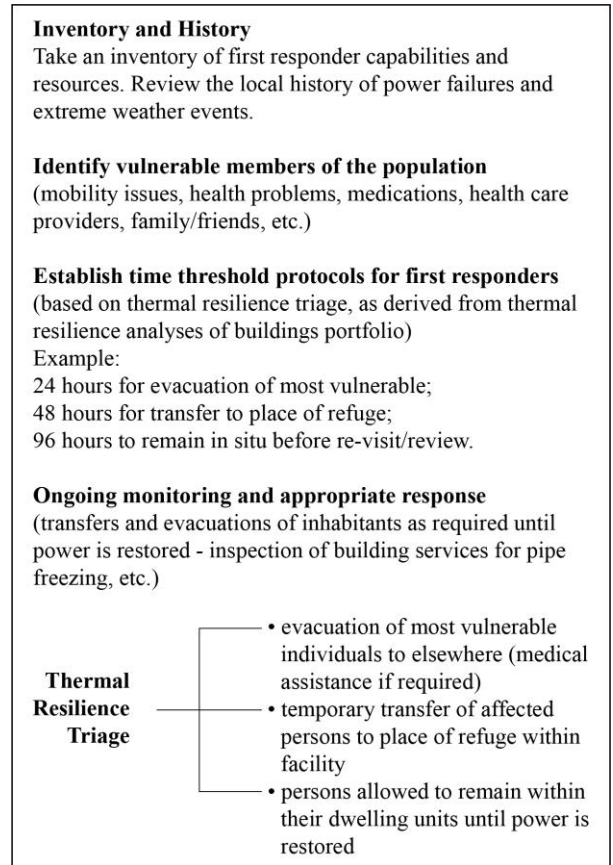


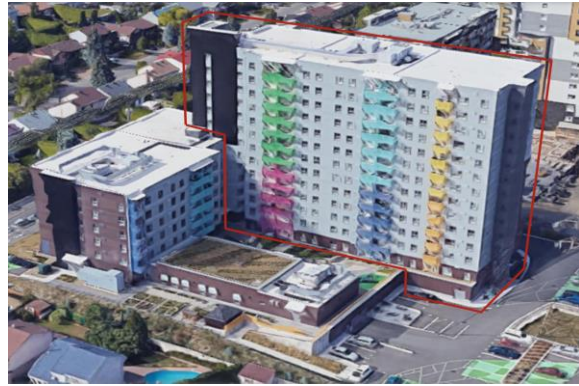
Figure 1. Framework of thermal resilience protocols and procedures.

RESULTS

All simulation results cannot be conveyed in this paper. However, an example of the work is presented in order to highlight some of the issues and challenges. Existing buildings may be most challenging because an often overwhelming number of issues need to be resolved to achieve an acceptable level of thermal resilience.

The Bois Ellen housing project in Montreal was selected among others to assess its thermal resilience. Figure 2 depicts Building A of the development and lists the

relevant simulation parameters. It is important to note this building is more energy efficient than much of the older social housing stock in Montreal, but not as advanced as possible by implementing best practices.



- 13 storey building constructed to Novoclimat + standard
- Exterior walls RSI 2.9 (R-16.6)
- Roof RSI 4.3 (R-24.6)
- Windows USI 1.6 (U-0.28), SHGC 0.6
- Infiltration 0.45 ach @50 Pa
- Thermal mass 200 mm (8 inches) concrete between floors
- No solar shading devices
- No natural ventilation

Figure 2. Bois Ellen Building A and simulation parameters.

Beginning with cold weather passive habitability, Figure 3 indicates that approximately 45 hours after a power failure in winter, the temperature in north-facing suites falls below the lower passive habitability threshold of 15 °C. Based on the thermal resilience triage in Figure 1, this time represents the period during which the most vulnerable occupants need to be evacuated, followed by the transfer of other affected persons to a place of refuge within the building. It will be much longer before periodic inspections of the building services are necessary (e.g., freezing of pipes, etc.).

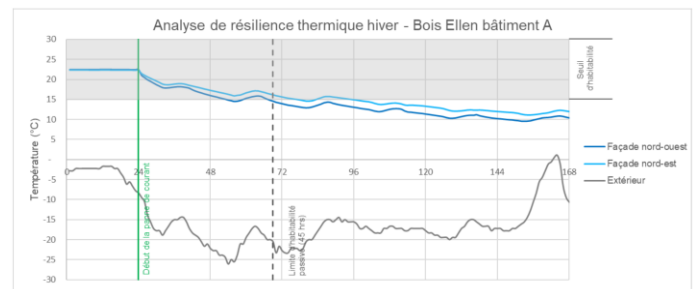


Figure 3. Bois Ellen cold weather passive habitability.

One issue is whether or not most power outages will not exceed approximately 2 days duration. Another issue is providing a warming centre as a place of refuge within the building. Almost all older buildings were not designed with his consideration in mind and it may be both costly and difficult to incorporate such a facility within existing buildings. A combined heat and power

plant running on a non-electricity energy source may be a feasible alternative, but not always possible.

Looking at the hot weather passive habitability in Figure 4, after about 10 hours the upper threshold of 30 °C is exceeded for south-facing suites. Evidence indicates that more deaths and medical episodes are caused by over-exposure to heat than to cold, hence it is critical that much less time is afforded to first responders for evacuating the most vulnerable occupants during extreme hot weather power failures than cold weather events.

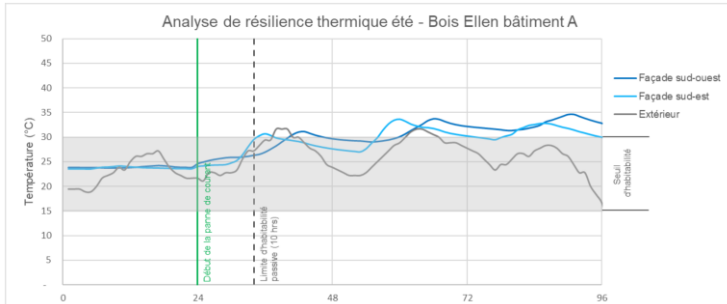


Figure 4. Bois Ellen hot weather passive habitability.

Passive strategies for enhancing hot weather thermal resilience in buildings include:

- Control of heat conduction through opaque enclosure elements with higher effective levels of insulation;
- Control of infiltration through an effective air barrier;
- Control of solar gains through fenestration by selecting higher thermal efficiency glazing with a lower solar heat gain coefficient, and providing shading devices to block the sunlight; and
- Control of indoor temperatures by provision of thermal mass and natural ventilation.

Such passive strategies may be deployed in new buildings, but are often difficult to implement in existing buildings. The specific attributes of a particular jurisdiction’s social housing stock must be considered when formulating policies, plans and protocols for enhanced thermal resilience. An inventory of first responder capabilities and the history of extended power outages for the locale must be examined. Feasible options are not always clear. For example, should a renewable energy system be provided to run fans for better air movement and ventilation in all suites? Should a back-up emergency generator be provided to operate a place of refuge (cooling centre)? Should there be one central place of refuge for the building or one per floor? It soon becomes obvious that solutions must respond to the particular context of the building and its microclimate. In some cases, no amount of passive measures will provide adequate cooling and it must be recognized that active cooling and uninterrupted power supply are essential services.

RECOMMENDATIONS

The recommendations pertaining to new buildings are presented in Table 1 below. The process for dealing with existing buildings is still evolving and requires a great deal of measurement and verification to correlate simulation predictions with actual indoor conditions.

Table 1. Summary of recommendations to guide new social housing projects.

WHAT TO DO
<p>Minimal and Affordable Measures</p> <ul style="list-style-type: none"> • Minimize thermal bridging • Increase effective levels of thermal insulation • Manage increased potential for interstitial condensation • Enhance envelope airtightness • Assess the performance of each façade according to its solar orientation and construction typology (i.e., wood versus concrete) • Provide clearer guidelines for indoor air quality and reduce/eliminate off-gassing due to interior materials, finishes, adhesives, sealants, paints, etc. • Require energy simulations of thermal resilience starting at early stage of design • Simplify mechanical systems – reallocate savings to enhanced building envelope • Allocate funds for future measures to improve performance
<p>Towards Passivhaus Measures</p> <ul style="list-style-type: none"> • Install sensors/probes in 10% of the suites to monitor performance/behaviour and inform post-occupancy evaluations • Adopt airtightness standard of 0.6 ach @ 50 Pa (Passivhaus) • Establish a minimum threshold of thermal autonomy • Provide refuge areas for 10% of the area of each floor in the building • Provide 50% of the energy supply from renewable sources on large scale projects • Institute measures to conserve thermal mass to enhance passive habitability.
<p>HOW TO DO IT</p> <ul style="list-style-type: none"> • Incorporate clear commitments from the general contractor in the contract estimate • Require general contractors to satisfy a prequalification system during the tender stage • Develop a Novoclimat training program for general contractors and their trades • Require air tightness testing in a number of units, early in the construction • Establish a commissioning period of 2-3 years; hire a third party; provide an appropriate budget • Allocate a budget for the education and awareness of the inhabitants • Ensure fees for professionals are adequate and reflect the level of effort needed for Novoclimat certification • Provide post-construction energy performance monitoring and evaluation

Within the context of Montreal's climate and the ambitions of Service de l'Habitation, Ville de Montréal, enhancing the thermal resilience of new building projects is straightforward and feasible to implement over time. Two big strategies emerge: 1) high-performance passive measures; and 2) better airtightness plus commissioning to realize the full potential of what has been designed and constructed.

DISCUSSION

There remain a great many unknowns pertaining to thermal resilience design of buildings. They are always a function of the condition, attributes and occupancy of the building. For example, tall buildings housing very ill persons, without emergency power supplies for elevators, make it difficult to reach and evacuate mobility-challenged occupants on higher floors. In practical terms, this means more time must be allowed to evacuate the most vulnerable, and subsequently to move those adversely affected to places of refuge within the building. Establishing acceptable habitability time thresholds must account for the availability of first responder personnel and resources. Scenarios must also account for coincident crises, such as pandemics or fires, that reduce their availability.

It is also recognized that thermal resilience planning and design has not been formalized (Porritt et al., 2012). There is not yet a consensus about best simulation practices and procedures in terms of risk analysis (Sailor, 2014), and extreme weather data for simulation (Pernigotto et al., 2020 and Laouadi et al., 2020). A great deal of field work is still needed to correlate predictions with actual outcomes.

Organizations that aspire to enhancing the thermal resilience of their building portfolios continue to lack formal methodologies of risk assessment and for the development of policies, protocols and procedures. Climate change has spurred interest in adaptation strategies to improve resilience but it is taking time for professional disciplines to craft appropriate responses.

It is hoped that advances in this field will come from proactive research and development reinforced by pilot demonstration programs rather than learning from losses and mistakes incurred while facing disasters.

CONCLUSIONS

The process presented in this paper embodies a number of practical considerations and admittedly is neither technically comprehensive nor scientifically rigorous. The general approach to taking inventory, examining history, identifying risks and predicting habitability time thresholds accordingly, as advanced in this paper, has yielded helpful information and provided a way forward.

The resilient building design field requires further empirical study and practical application before it can reliably deliver acceptable health and safety through a suite of suitable passive measures and essential active back-up systems. It is also important to appreciate the roles and capabilities of social agencies and first responders as they relate to vulnerable populations.

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SUPPORTING THE DEVELOPMENT OF NET-ZERO ENERGY READY BUILDING CODES

Mariana Barssoum¹, Heather Knudsen¹, Iain Macdonald¹, Ghassan Marjaba²,
Edward Vuong¹ and Adam Wills¹

¹National Research Council Canada, Ottawa, ON

²Engineers in Motion Inc, Ottawa, ON

ABSTRACT

The Construction Research Centre of the National Research Council of Canada (NRC) is conducting research in support of the development of updated National Model Construction Codes. The research is directed at informing decision making for the National Energy Code for Buildings of Canada (NECB), and Section 9.36 of the National Building Code (NBC).

A review of international codes is presented, and the technical goal of 'net-zero energy ready' framed. Results of a simulation/cost study are presented to demonstrate that the goal is achievable. Remaining challenges are presented.

INTRODUCTION

Globally there is a push towards improving energy performance of new buildings and existing building stocks. Examples include EPBD (Energy Performance of Buildings Directive) in Europe (BUILD UP, 2020) and in the US various versions of the IECC and ASHRAE 90.1 (US Department of Energy, 2020).

In the Canadian context the Federal, Provincial and Territorial governments' collective plan to address climate change is outlined in the Pan-Canadian Framework on Clean Growth and Climate Change (Canada 2016). The specific goals for the built environment are:

1. Making new buildings more energy efficient;
2. Retrofitting existing buildings, as well as fuel switching;
3. Improving energy efficiency for appliances and equipment;
4. Supporting building codes and energy efficiency in Indigenous communities.

Items one and two are being addressed via the national building codes and item one is the focus of this paper. National codes in Canada are developed by the Canadian Commission for Building and Fire Codes (CCBFC).

Since 1937 the NRC has been developing and maintaining Canada's building codes and the CCBFC approves all changes proposed by any stakeholder. In 2016, the CCBFC published a position paper on the long-term development for energy codes (CCBFC 2016). This document outlines the policy positions on energy code development and introduces the concept of a Tiered-code approach to permit a flexible framework for adopting jurisdictions while also defining an 'ultimate performance target'. This is a significant change from current codes, where only minimum acceptable performance is defined. For new buildings the 'ultimate performance target' is defined as 'net-zero energy ready'. In addition to new buildings, CCBFC also recognises that the energy performance of existing buildings is a critical component to achieving national energy demand reductions; therefore, there is a need to develop technical guidance for improvements during alterations and renovations.

Energy provisions in Canadian codes are divided between the NECB and the NBC. The Standing Committee on Energy Efficiency (SC-EE) under the CCBFC is responsible for developing code change proposals for the NECB and NBC (specifically Division B, Section 9:36). The provisions in NBC 9:36 are only for housing and small buildings – essentially buildings types that are considered simple enough to not require professionals in their design (the technical definition is in Division A 1.3.3.3 (NRC 2015)). Every code change proposal is subject to a comprehensive review process including public review and final approval by CCBFC.

This paper highlights some of the technical challenges and achievements in converting policy directions into code language/technical requirements.

REGULATORY CONTEXT

While the NECB and NBC are developed at the national level, they are modified and adopted by the Provinces and Territories, and then enforced (and sometimes further modified) by local authorities having jurisdictions, usually municipalities. This provides a

challenge in developing harmonized codes, as individual jurisdictions can have vastly different drivers (environmental, economic, land availability etc.). This is particularly true in Canada, where energy resources vary across the country, and thus demands on energy efficient building codes differ. This is compounded by carbon accounting and general societal perspectives.

International overview

A review had been completed of approaches taken in other jurisdictions (Bourgeois, 2018). This review identified that energy code solutions were driven by the energy supply context of the adopting jurisdictions. In particular, the EPBD has many different implementations by EU member states.

The approach taken in France is notably different from other countries. Absolute targets for maximum energy consumption are defined as opposed to the more conventional reference vs proposed methodology, e.g., ASHRAE Standard 90.1 (ANSI/ASHRAE/IES 2019). Proponents of absolute targets argue that the method delivers real energy savings since the required performance is defined, as opposed to the conventional reference vs. proposed method where the target performance is defined relative to a notional reference building modelled using prescriptive rules. However, enforcement of a code with absolute targets requires a fully defined calculation procedure; in the reference vs. proposed method, identical assumptions made in both models can cancel out. For instance, infiltration rates in energy codes are often assumed; this is neutralized in the reference vs proposed method, as both buildings will be equally impacted. In the absolute method, the assumed rate will contribute directly to a pass/fail (note this is a separate issue from requiring airtightness testing and using a measured value). Likewise, assumptions related to occupancy, space use, etc. all directly affect the predicted performance. The solution in France was to develop a set of ‘factors’ that relax the headline energy performance target depending on space use, climate and altitude, essentially defining a reference building. The compliance target then ranges from 50 kWh/m² to over 600 kWh/m². This is particularly relevant for Canada due to the variations in climate across the country and the variations in building use/type covered by the NECB. Therefore, the current approach of reference vs. proposed is likely to be the most suitable method for performance assessment.

The review also highlighted the variation in scope and metrics used to assess energy performance. In some cases site energy is used (i.e., at the meter), in other cases source energy (i.e., at the power station) and in some cases energy is converted into equivalent carbon dioxide emissions. In the NECB and NBC, energy is regulated at the building, i.e., site energy. This is different from the

goals of the Pan Canadian Framework, where carbon dioxide (and equivalent) reductions are the goal.

Net-zero energy ready

In their position paper, the CCBFC identified that Tiers of energy performance should be developed and that the top Tier should be ‘net-zero energy ready’. The definition in the position paper is:

A net-zero energy building is defined as a high-performance building that combines superior standards in energy efficiency with renewable energy production to offset all of the building’s annual energy consumption. A net-zero energy ready building is defined as a high-performance building that is built to the same level of energy efficiency as a net-zero energy building but does not include renewable energy production.

It should be noted that the annual energy equation fails to identify peak load issues and potential temporal mismatches between renewable generation and demand (for example, see Clarke, Hensen, Johnstone and Macdonald (1999). Wide-scale deployment of renewables without concern of temporal effects has resulted in grid issues characterized by the ‘duck’ curve (Lazar 2016); essentially the rate at which utilities have to adjust their generation increases as PV goes offline in the evening while residential loads are increasing. This has results in a need for increased peak load capacity and grid stability management.

Recalling the definition of a net-zero energy building there is considerable latitude in defining the performance associated with a ‘high performance building’ and ‘superior standards in energy efficiency’. Two studies were conducted to frame the ultimate performance goal:

1. How close are current code minimum buildings to net-zero energy ready performance levels?
2. What performance level are current net-zero energy buildings achieving?

To address the first question, existing building archetypes with renewable systems were simulated in several Canadian locations (Beausoleil-Morrison, Meister and Brown 2018). The work showed that single family housing in some locations could be considered net-zero energy ready when built to current codes. However, this required installing the maximum possible number of PV panels and thus would be cost prohibitive (cost is one of several considerations in determining code changes). For buildings the results were clear: additional energy efficiency measures are required. Therefore, for all building types, further improvements in energy efficiency are required before a building can be determined to be net-zero energy ready.

The second question was addressed by reviewing existing performance data. This data is sensitive to building type and limited information is available

(ASHRAE, AIA, IES, USGBC, & US-DOE, 2018, 2019). For small to medium offices and K-12 schools, the absolute energy performance varies by building type and location (see Table 1). It should be noted that these figures are for all energy consumed in a building – the NECB and NBC only regulate some energy uses, e.g., heating and cooling are regulated, but residential lighting is not. Thus, direct comparison is not possible, rather the figures should be used as a guideline.

Table 1. ASHRAE Design Guide Site Energy Targets (kWh/m^2).

ASHRAE Climate Zone	Small to Medium Offices EUI	K-12 School EUI
4A	69	60
4B	65	58
4C	55	56
5A	73	60
5B	72	60
5C	55	56
6A	87	65
6B	78	62
7	96	68
8	114	75

TIER DEVELOPMENT

Based on the constraints of current energy code as a minimum acceptable performance level and net-zero energy ready as highest performance level, the SC-EE proposed an additional two Tiers between these performance levels (i.e. four Tiers in total):

- Tier-1 is the enforced edition of the NECB;
- Tier-2 at least a 25% energy reduction from Tier-1;
- Tier-3 at least a 50% energy reduction from Tier-1;
- Tier-4 at least a 60% energy reduction from Tier-1.

To validate if the Tiers were technically possible and to determine cost impacts, a simulation study was undertaken on the following six archetypes:

- Secondary School (2 storeys, 19,600 m²);
- Medium (3 storeys, 5,000 m²) and Large (12 storeys, 46,300 m²) Offices;
- Warehouse (1 storey, 4,800 m²);
- Retail Strip Mall (1 storey, 2,100 m²); and
- Highrise Apartment (10 storeys, 7,800 m²).

Annual simulations of these archetypes were conducted for five locations: Victoria BC, Windsor ON, Montreal QC, Edmonton AB, and Yellowknife, NT, representing climate zones (CZ) 4 to 8. Both the base (NECB 2017) and Tier-compliant set of archetypes were simulated and the differences costed, totaling 120 simulations.

Simulation Method

An engineering approach was applied to the simulations: the models were analyzed and the least performing aspect improved iteratively until Tier 4 performance was achieved. The solution arrived at via this ‘hill climbing’

approach demonstrates that the technical goal can be achieved (the primary objective of the analysis), but does not necessarily represent the cost-optimal solution.

Key energy performance areas examined include: additional insulation in opaque assemblies; reduced glazing area; increased window performance; alternative HVAC systems and heat recovery. Internal gains were also examined. Lighting technology can already deliver substantial savings over current code maximums and are expected to further improve (the expected high end value was used for Tier 4). Although plug loads are not currently regulated expectations are that office equipment will become more energy efficient, therefore reduced load assumptions were examined.

Some options available to practitioners were not examined: window distribution (all facades had equal glazing areas), orientation and form remained static for each archetype.

To manage the simulations the BTAP environment (authored by NRCan) for OpenStudio was used. This enables a consistent application of energy efficiency measures to the archetype models using EnergyPlus as the calculation engine.

Tier-4 Sample Design Solution Set

All six archetypes in all five locations can achieve the Tier-4 target (and by extension the lower Tiers). Each solution was unique, and Table 2 presents an overview of the initial NECB 2017 and Tier 4 archetype descriptions for the Secondary School, Warehouse, Highrise Apt, and Retail Strip Mall. Complete results and data for Offices are available (Vuong, Barssoum, Macdonald and Wills 2019).

Incremental costs for the Tiers were estimated by a cost consultant. Note that these costs represent only the elements of the building that effect energy performance – for example it was assumed that structural costs would be identical in all cases for a specific archetype. Table 3 summarizes the incremental costs for Tier 4. In some cases the cost to build to the higher performance level is less than current code. This is primarily due to smaller window areas and smaller HVAC equipment resulting in cost savings offsetting increased insulation costs.

This analysis was cross-referenced with other studies. Simulated data showed little correlation between overall performance and cost. Therefore, these costs are subject to considerable variation depending on myriad design decisions.

Table 2. Tier-4 Description of Secondary School, Warehouse, Highrise Apt, and Retail Strip Mall in CZ-4 to CZ-8.

Component	NECB 2017	Tier-4
Wall R-value [(°F·ft ² ·h)/BTU]	R18 – R31	R36 – R57
Roof R-value [(°F·ft ² ·h)/BTU]	R30 – R47	R40 – R57
Window U-value [W/(m ² K)]	2.1 – 1.4	1.2 – 0.7
Window-Wall Ratio	0.4 – 0.2	0.26 – 0.08
Air Leakage [L/(sm ²) @ 75 Pa]	1.45	0.2 – 0.8
Shading	N/A	Horizontal (30% window length)
Air Handling Unit	MAU, RTU	Through Wall DOAS+ERV, VAV
Heating/Cooling	Baseboard, Boiler, DX Cooling	Baseboard (only in some), Condensing Boiler, DX Cooling
Service Hot Water	Electric/Gas Water Tank	Air Source Heat Pump (ASHPH)
Lighting	NECB Table 4.2.1.6	70%-85% reduction
Electrical Equipment	NECB Table A-8.4.3.2.(1) and (2)	70%-85% reduction

Table 3. Tier-4 Archetype Incremental per Area Cost (\$/m²) for 5 Locations in Canada (CZ-4 to CZ-8).

Archetype	Victoria BC (CZ 4)	Windsor ON (CZ 5)	Montreal QC (CZ 6)	Edmonton AB (CZ 7a)	Yellowknife NT (CZ 8)
Secondary School	\$44	\$59	\$58	\$58	\$32
Medium Office	-\$102	-\$150	-\$162	-\$174	-\$55
Large Office	-\$97	-\$91	-\$29	-\$52	-\$65
Warehouse	\$50	\$111	\$36	\$53	\$48
Retail Strip Mall	\$78	\$4	\$60	\$70	-\$7
Highrise Apt	\$57	\$37	\$11	\$36	-\$37

DISCUSSION

For all Tiers increasing the insulation level for opaque assemblies proved less effective than reducing fenestration transmittance and area (higher performing windows can help offset the lower fenestration and door to wall ratios used). Increasing the insulation level for opaque assemblies results in diminishing rates of return on energy use reduction; although heat losses are reduced, additional cooling energy (fan, water pump) is

required in many cases (typically those with large internal gains). It should be noted that thermal bridging in the envelope remains a concern and that improving airtightness was identified as the most cost effective route to achieving energy performance gains.

Although reduced lighting results in increased heating, for the majority of the locations this additional energy consumption is negligible when compared to the direct energy saved. As a result, for Tier-4, more efficient lighting technology must be used to deliver reductions in the range of 70% to 85% compared to current code. This will be a challenge for the lighting industry; indications from SC-EE members are that 50-60% are achievable with current technology.

It was found that HVAC changes, e.g., replacing constant volume (CAV) with variable volume (VAV) systems, adding dedicated outdoor air system (DOAS) and other HVAC changes greatly reduces the energy consumption of the archetypes. This is attributed to the inefficient CAV rooftop units and make-up air units currently prescribed in the baseline ('reference') NECB 2017 archetypes.

CONCLUSIONS

Developing technically sound code requirements to deliver net-zero energy ready building performance requires a nuanced understanding of the drivers and goals. Reviews have shown that other jurisdictions have tailored their codes to their contexts. This presents challenges for a national code in a diverse country.

Work to frame the target has shown that a single EUI is not the most appropriate and that further improvements in energy efficiency are required to deliver 'net-zero energy ready' buildings. It has been demonstrated via simulation that these goals are achievable with minimal cost implications.

Future work is required to ensure the availability of solutions that deliver the assumed performance levels in the simulation study. In addition, the solution sets identified in the initial study should be expanded and there is growing need to validate that the predicted savings at design are being achieved once the building is operating.

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A NEW HOUSING STRESS TEST: CODIFYING THERMAL RESILIENCE OF BUILDINGS

Liam O'Brien¹ and Ted Kesik²

¹Department of Civil and Environmental Engineering, Carleton University, Ottawa, ON

²Daniels Faculty of Architecture, Landscape and Design, University of Toronto, ON

ABSTRACT

With increasing frequency and severity of natural disasters and other events that cause power outages, combined with increasing reliance on building automation systems, incorporating thermal resilience into buildings is of critical concern. Given building codes often drive new building design, they should incorporate the best practices for resilient design. This paper describes a brief building simulation study with a house to demonstrate the effectiveness of various categories of resilience upgrades. Following that, possible pathways for incorporating thermal resilience into building codes are discussed.

INTRODUCTION

With the progression of climate change, natural disaster-induced power outages are becoming more frequent and longer duration (Konisky, Hughes and Kaylor, 2016, Government of Canada, 2019). In the past several decades, Canada has experienced numerous widespread multi-day outages, such as those caused by ice storms in 1998 and 2013 (see **Figure 1**) and the power outage in summer 2003. To make matters worse, such outages are more likely to occur in periods of extreme cold (e.g. from ice storms) or extreme warmth (e.g., grid overload from air-conditioning) (Spengler, 2012). Given the reliance of heating and cooling to maintain acceptable indoor conditions in our buildings, power outages can pose a serious risk to buildings and their occupants. Accordingly, resilience to such outages is becoming recognized as a priority. While resilience is broad and can cover access to water, food, light, and clean air, this paper is focused on the thermal domain – including both the comfort and health of occupants and the temperature of buildings to avoid damage (e.g., frozen pipes).

In the past decade, several papers have begun to quantify thermal resilience of buildings using simulation to both quantify it and improve it. For example, Levitt, Ubbelohde, Loisos and Brown (2013) introduced the notion of thermal autonomy, which is defined as the

fraction of the year that a building is comfortable for occupants without heating or cooling. O'Brien and Bennet (2016) applied passive survivability as a metric to quantify the time before a building becomes unlivable (considering elderly occupants, for example) and set 15 and 30°C as lower and upper limits. Since then, the metric was renamed passive habitability Ozkan, Kesik, Yilmaz and O'Brien (2019). Baniassadi and Sailor (2018) used a similar approach with small variations, such as using a discomfort index (mean of dry and wet-bulb temperature) at 28°C. More recently, Laouadi, Gaur, Lacasse, Bartko and Armstrong (2020) adapted the standard effective temperature (SET) to be more suitable for assessing comfort during heat waves: transient-SET (t-SET). A critical observation they made is that the appropriate upper threshold (for which they proposed 30°C) depends on whether occupants are acclimatized to warm conditions that occur during heatwaves.



Figure 1. Example of a weather event that caused widespread long-term power outages (Toronto, 2013).

In 2017, the USGBC introduced RELi Rating Guidelines for Resilience Design and Construction for assessing the resilience of buildings “against weather extremes, economic disruption and resource depletion” (United States Green Building Council, 2018). For residential buildings, it requires the indoor air temperature to remain above 10°C in the winter. In the summer, it must be

demonstrated through models that the heat index never exceeds 32°C or that the wet-bulb globe temperature (WBGT) does not exceed 28°C. Heat index is a measure of air temperature that accounts for the fact that the human body's ability reject heat via evaporation is a function of relative humidity. WBGT is a weighted average of wet-bulb temperature (0.7) and globe thermometer temperature (0.3). RELi also prescribes availability of natural ventilation such that 2.36 L/s of outdoor air is provided per occupant with a windspeed of 0.5 m/s (specified as 118 cm² of opening for single-sided ventilation). In addition to passive survivability, RELi requires a source of back-up electricity (e.g., PV and battery storage) for at least four consecutive days.

While most reviewed studies have focused on using entire or parts of the typical meteorological year (TMY), e.g. (EPW, CWEC), Laouadi, Gaur, Lacasse, Bartko and Armstrong (2020) developed reference summer weather years (RSWY), which are built to represent more extreme heat waves from the past 31 years.

Ozkan, Kesik, Yilmaz and O'Brien (2019) assessed numerous MURB designs for three different climates and found a strong correlation between energy performance and resilience; many of the design qualities that benefit energy also benefit thermal resilience. O'Brien and Bennet (2016) quantified resilience for four different MURB designs (code-compliant and high-performance; with and without a balcony) and occupant types (passive and active). They found that both design and occupant behaviour can profoundly affect passive survivability in the winter by an order of magnitude from the worst to best case.

The existing literature is largely preliminary and with great diversity in methods to quantify and limit comfort, use of weather files, and discussion on possible methods to incorporate thermal resilience into the building code. Therefore, the objective of this paper is to provide possible methods to incorporate thermal resilience into the building code. The paper starts by presenting a brief simulation case study. Following the results of the case study, the paper discusses potential prescriptive and performance-based methods to codify thermal resilience of buildings.

METHODOLOGY

To demonstrate the quantification of thermal resilience, a two-storey 10 by 10 by 5-meter detached house in Ottawa was modelled using EnergyPlus V9.0. The nominal design and variants are summarized in **Table 2**. **Error! Reference source not found.** The window to wall area ratio is assumed to be 20% on all sides of the house. The enclosure's effective thermal resistance values are outlined in the table. For modelling simplicity, the house is assumed to be raised above ground (i.e., floor is exposed to air). The combined mechanical

ventilation and infiltration rate are assumed to be 0.5 ach in the base case. The nominal thermal mass is the inherent thermal mass in a light-framed home with an assumed effective thermal mass of furnishings, etc. The high thermal mass case includes a 15 cm masonry floor that is 10 by 10 meters (i.e., the entire floor)

Two types of occupants are considered: passive and active. The passive occupants do not actively attempt to adapt the house to improve thermal performance, whereas the active occupants adjust operable windows and window shades. When windows are open, the natural ventilation rate is assumed to be 10 m³/s based on engineering approximations considering the opening area and average wind speed.

A warm and cold week were selected from the 2016 EPW file for Ottawa, using the peak temperatures encountered in the house without heating or cooling, to assess resilience when the power is cut. These are summarized in **Table 1**.

Two types of resilience metrics were evaluated: time after power failure until the house reaches 5, 15 and 30°C and emergency energy supply required to maintain 21°C in the winter. The latter metric is the electric energy during the winter week required to provide lighting and operate a furnace fan (assuming a 90% efficient natural gas-fired furnace with an intact gas supply) or wood for a woodstove (assumed thermal efficiency of 80%). For the natural gas case, the PV area (assuming 18% efficiency, 45° slope) to supply electrical needs is calculated assuming a battery has at most a two-day capacity and it is fully charged at the time of power failure.

Table 1. Summary of weather data for resilience analysis periods in the Ottawa CWEC file.

	WINTER	SUMMER
Date range	Jan. 12-18	Aug. 27-Sept. 2
Mean temperature	-12.4°C	21.3°C
Mean of daily horizontal solar radiation peaks	273 W/m ²	760 W/m ²

RESULTS

The results, summarized in **Table 2**, show that both building design and adaptive opportunities are critical to improving thermal resilience. The code minimum house performs particularly poorly and reached uninhabitable conditions (below 15°C) within three hours. The high mass case does not perform significantly better with regards to passive habitability (five hours). Deeper investigation revealed that, during the period without active heating, the heat transfer between the massive floor and indoor air and surfaces for small temperature differences is insufficient to adequately offset heat losses to the outdoors. Considering the significant thermal mass

considered (15 cm concrete on floor), a possible approach to enhance thermal mass effectiveness is through active heat exchange (e.g., a fan or embedded pipe network).

The thermal mass, however, does significantly increase the amount of time before the house drops below 5°C – to over three days. The well-insulated house performed somewhat better regarding time till 15°C than the code minimum case, but not profoundly – in part because the code-minimum envelope is relatively good and because the overall heat loss remains quite high relative to the thermal energy storage. Notably, the combination of high mass and insulation allows the house to stay above 5°C – barely – for the entire winter week.

The active occupants effectively maintain the temperature below 30°C during the entire analysis period by using at least one of shading and operable windows. However, the thermally massive case also achieves this level of performance without requiring active participation of occupants. This result is important considering buildings that house occupants with

disabilities or limited mobility. Overheating does not appear to be a serious concern in this case. A home with more south-facing windows would also be susceptible to overheating in the shoulder seasons when solar altitudes are low but temperatures are mild.

Unsurprisingly, the results showed that the high insulation case significantly reduced heating energy. This is particularly important for the back-up energy systems, which will be discussed next. The required PV array size to run lights and a furnace fan is between 1.0 and 1.6 kW (approximately 5 to 8 m² assuming 20% efficiency), with the high insulation cases yielding the lower end of the range. Alternatively, the amount of firewood (e.g. logs or pellets) required to maintain the house at 21°C was estimated considering the heating energy consumption during the winter week. As shown in **Table 2**, the values range between 193 and 324 kg of wood for the week. The calculations are based on Red oak – a hardwood with a heating value of approximately 15 MJ/kg.

Table 2. Model parameters and resilience performance.

	CODE-MINIMUM (NBC-2015)	HIGH INSULATION	HIGH MASS	ACTIVE OCCUPANTS	ALL UPGRADES
Resilience parameters					
Wall R-value (m ² K/W)	3.08 (R-17.5)	5.0 (R-28.4)	3.08	3.08	5.0
Roof R-value (m ² K/W)	8.67 (R-49.1)	8.67	8.67	8.67	8.67
Floor R-value (m ² K/W)	4.67 (R-26.5)	6 (R-34.0)	4.67	4.67	6
Windows U-value (W/m ² K); SHGC	1.60; 0.55	1.0; 0.4	1.60; 0.55	1.60; 0.55	1.0; 0.4
Total effective ventilation + infiltration (ach)	0.5	0.25	0.5	0.5	0.25
Total UA-value (W/K)	244	187	244	244	187
Equivalent envelope R-value (m ² K/W)	2.69	3.99	2.69	2.69	3.99
Thermal mass	Nominal	Nominal	High	Nominal	High
Occupants	Passive	Passive	Passive	Active	Active
Resilience performance					
Winter: hours till 15°C	3	8	5	3	19
Winter: hours till 5°C	34	80	78	34	*
Summer: hours till 30°C	63	65	*	*	*
Electric energy for fan and lights (kWh)	36.5	22	36.1	36.5	21.5
PV array capacity (kW) for above electricity	1.6	1.0	1.6	1.6	1.0
Wood (kg) energy for heating to 21°C for winter week	324	193	320	324	188

* Condition not reached during week

DISCUSSION AND CONCLUSION

The results of this study show that thermal mass, a high-performance envelope, adaptive opportunities for occupants, a wood stove, and back-up power supply using PV can all increase the resilience of homes (and other buildings, by extension). In many cases, mutualistic relationships arise; for example, the well-insulated thermally massive house performed much better than the house with the individual upgrades.

Most building energy codes, including those in Canada, have a prescriptive and a performance path. For energy considerations, the prescriptive path sets building specifications (e.g. R-values, infiltration, HVAC) and the performance path specifies that the proposed design must use no more energy than a code-minimum reference building. The performance path necessarily requires simulation – usually on an annual basis.

In contrast to energy code requirements for which the relative annual energy performance is the focus, the absolute performance of homes under power outage scenarios is critical. While we cannot be sure about the trajectory of weather following a power outage event or the vulnerability of a home's occupants, the code should necessitate a degree of certainty that it can protect those occupants. Economics and environmental impacts aside, the consequences of a building using more energy than planned are relatively less critical than endangering the wellbeing of occupants – and in some cases the building (e.g., widespread flooding from frozen pipes). Accordingly, we recommend a simulation-based approach to the code but with absolute limits in temperature or overheating/underheating duration.

The selected requirements must incorporate typical extreme power outage durations, safety, and practicality (i.e., risk and rewards). In the case of building envelope, improved energy efficiency generally means improved thermal resilience. However, the other explored aspects are not yet requirements of Canadian building codes. As for all building code amendments, all aspects must be considered, including practicality, economics, enforceability, ease of implementation, etc. These aspects are beyond the scope of this paper.

It is notable that NECB specifies that occupants cannot be relied upon to improve energy performance. If such language were applied for resilience-related requirements, it would effectively not credit measures for adaptive opportunities (e.g., operable windows, shading). In contrast, the current study and literature (e.g., O'Brien and Bennet, 2016) demonstrates the value of adaptive opportunities. Moreover, NECB primarily credits energy savings from automated systems (e.g., occupancy-based lighting), whereas such systems may not function at all (and may be detrimental to performance) under power outage scenarios. We believe,

in contrast, that adaptive opportunities should be rewarded and that manual overrides for systems (e.g. lighting, blinds, operable windows) should be mandated. RELi only covers one adaptive opportunity explicitly – operable windows— and does not thoroughly explain how they are used in simulation. RELi specifies that window openings must be large enough to provide 2.36 L/s of outdoor air (approximately that required by ASHRAE Standard 62) for windspeed of 0.5 m/s. However, this is wholly inadequate for natural ventilation for cooling effects. For example, if conditions are 5°C cooler outdoors than in, this ventilation rate only removes an order of magnitude less heat than is generated by occupants, let alone solar gains and other internal gains.

For the prescriptive path, the code should require a suite of passive and active measures. As shown in this paper, to a large extent the passive measures are consistent with improvements in energy efficiency (e.g., insulation, airtightness, window performance). Thermal resilience in the winter season can generally be considered the most challenging in most Canadian climates. A back-up heat source (e.g., wood stove) combined with a high-performance envelope are critical. As demonstrated by the current case study, a high-performance envelope is not sufficient for multi-day power outages.

In the future and particularly in urban environments, a growing threat to thermal resilience in the summer is that overnight temperatures can remain warm. In the current case study, the summer week that was used to evaluate resilience had temperatures that dropped to 15 to 20°C at night. Such conditions, coupled with strategic night-time ventilation and structural thermal mass can greatly reduce daytime overheating. However, if temperatures remain warm (e.g. mid-20s °C) at night, there is significantly greater risk of overheating.

A design feature that was not explored in the current simulation study is inclusion of a “safe room” that can be conditioned with relatively less energy to comfortable temperatures using back-up energy sources even if the main energy supply is cut. To some extent, even a basement could serve this purpose to escape summer heat. The current study did not involve a basement.

Beyond architectural design features, a valuable feature to improve thermal resilience is a manual drain valve that allows supply (i.e., pressurized) pipes to all be drained in the event that the home needs to be evacuated in the winter.

A gap in knowledge in the literature is a consistent metric for assessing thermal comfort and survivability – both in terms of the formulation of the metric and the threshold value. As noted by Laouadi, Gaur, Lacasse, Bartko and Armstrong (2020) occupants who are acclimatized to warm conditions are more likely to cope during a power failure. Accordingly, perhaps codes should mandate that

air-conditioned buildings should use lower thresholds than their naturally-ventilated counterparts. Homes without air-conditioning are more likely to have ceiling fans, cross-ventilation, etc.

An area requiring future work is to systematically identify the periods of the year that are used to assess resilience. Two main complications arise: 1) the typical meteorological year (TMY) data is specifically designed to be average and not extreme or based on climate change, and 2) the pain point of buildings (e.g., high solar intensity, solar geometry, wind, extreme temperatures) and building design-dependent and cannot necessarily be generalized. In the example above, the house was very vulnerable to intense solar radiation and low solar altitudes – until shading was deployed. In contrast RELi specifies the extreme weeks by dry-bulb outdoor air temperature only.

Two further areas for future fundamental research include: 1) quantifying the ability of occupants to adapt and optimally use adaptive opportunities (e.g., predictively with nighttime ventilation), 2) quantifying reasonable comfort limits as a function of history and acclimatization. Both could be incorporated into simulation-based code requirements for resilience.

ACKNOWLEDGMENT

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LESSONS LEARNED WITH RESPECT TO THE CAE ROADMAP FROM THE MONITORING OF A HIGH-PERFORMANCE SOCIAL HOUSING BUILDING IN QUEBEC CITY

Jean Rouleau¹, Louis Gosselin¹, Pierre Blanchet²

¹Department of Mechanical Engineering, Université Laval, Quebec City, QC

²Department of Wood and Forest Sciences, Université Laval, Quebec City, QC

Jean.Rouleau.1@ulaval.ca; Louis.Gosselin@gmc.ulaval.ca; Pierre.Blanchet@sbf.ulaval.ca

ABSTRACT

A prototype was built in Quebec City to demonstrate the feasibility of low-energy social housing buildings. The case study building was heavily monitored to follow its energy performance. This paper presents observations that emerged from this project regarding the design and operation of this social housing building. It shows the energy consumption of each individual dwelling, the indoor temperature in summer and heat fluxes flowing through the envelope. Lessons learned regarding low-energy residential buildings that are resilient and powered by renewable energy are discussed.

INTRODUCTION

The residential sector consumes ~20 % of the energy in Quebec and is largely responsible for electricity peak demands. Improving the design and operation of dwellings can offer opportunities for reducing the energy demand and providing flexibility in terms of load management. There are currently more than 3.5 million households in Quebec, 38.6% of which are tenants. Of this number, more than 225,000 households have benefited from at least one of the programs of the *Société d'habitation du Québec* (SHQ), the governmental organization supporting access to affordable dwellings. The social housing building stock is thus quite large and plays a critical role for many low-income families. Improving the energy performance in social housing buildings can reduce their operational costs and environmental impact. It can also increase the well-being of vulnerable populations (Vellei et al., 2017).

Recent studies on energy-related aspects of Canadian social housing have focused on indoor air quality (Akom et al., 2018), retrofitting (Tsenkova, 2018), energy monitoring (Rouleau et al., 2018) and policies. In the context of the CAE roadmap, many questions and challenges remain for achieving low-energy social housing, that is highly resilient and powered by renewable

energy. With the emergence of the concept of energy justice (Jenkins et al., 2016), these challenges are becoming more and more acute.

In 2015, a new social housing building was erected in Quebec City. The stakeholders decided to aim for a low energy building. Additionally, this project was used to test and document different options (with the idea to replicate successful elements in future projects) and more generally, to study the energy performance in this kind of building. In the next sections, we present the main features of the building. Then, we share some of the main takeaways of our study regarding the building energy performance, its resiliency to heat waves and the performance of its low-carbon envelope.

PRESENTATION OF THE CASE STUDY BUILDING

Architectural features

The building has four storeys and a total of 40 dwellings (Figure 1). The floor surface area of each unit varies from 70 to 80 m². The building is oriented in the 49° direction and the window to wall ratio (WWR) is 16.0%. Achieving a low-carbon design motivated the use of wood for the structure and envelope of the building. An interesting feature of the building is that one side was constructed with a cross-laminated timber (CLT) system, and the other side, with a light-frame system. This allowed for a direct comparison of the costs, construction processes, and heat and mass transfer features of both constructive systems. The RSI value of the opaque portion of the envelope is 6.32 for both construction systems. The tightness of the envelope was measured to be 0.6 ACPH at 50 Pa.

HVAC&R features

The building is part of a “green neighborhood” equipped with a district heating system. Centralized wood pellet boilers deliver water around 80°C to the neighborhood,

including to the case study building. Wood pellets can be seen as an alternative renewable energy source and offer an outlet for the byproducts of the wood industry (Padilla-Rivera et al., 2017). Within the building, each apartment is equipped with 3 to 4 hot water radiators.



Figure 1. Picture of the case study building.

The building has no mechanical cooling. Therefore, occupants rely on window opening to control the indoor temperature in the summer. Although some windows are shaded by the balconies of the upper dwelling, most windows have no shading systems, except for interior blinds. The southwest façade is also partially shaded in summer by trees. A 100% centralized fresh air ventilation strategy is used, with a heat recovery system. Each household has access to an on/off switch to control the mechanical ventilation in its dwelling. A solar wall allows to preheat makeup air when it is advantageous. Domestic hot water is heated by the district heating network. A recirculation loop within the building ensures a fast DHW delivery to occupants.

Monitoring

Temperature and humidity, consumption of domestic hot water, space-heating and electricity, window opening, and use of mechanical ventilation were measured in different dwellings every 10 minutes. Additionally, temperature, humidity and heat flux sensors were installed in the envelope. More than 350 sensors have been used. Data has been collected since October 2015.

ENERGY PERFORMANCE

Figure 2 presents a summary of the energy consumption in 2018 for each dwelling and per energy budget items. An interesting conclusion that arose from the study is the importance of the domestic hot water (DHW) load in the building energy balance. As efforts are devoted to improving building envelopes, the space-heating demand can be significantly cut down. In the present building, space-heating requires 33.3 kWh/m²y on average, which is significantly lower than the average value of the residential sector. As a result, the share of energy required for the other loads become dominant and the “next” critical load to focus on to reduce energy consumption is DHW. Note however that because of the recirculation loop, a part of the energy used for DHW contributes to the heating of the building. We estimated

that 10 to 15 kWh/m² of the energy consumed by the DHW system could contribute to space heating. By predicting in advance the DHW demand, it is possible to adjust some features of the system in order to minimize energy consumption or move DHW production to off-peak periods (Maltais LG and Gosselin, 2019).

One of the most striking take-aways from Fig. 2 is the large variability of energy consumption between the different dwellings. Only a very weak correlation of the DHW consumption with the number of occupants in the dwellings and of the space-heating demand with respect to the floor level were noted, but other factors such as orientation, constructive system, etc., were not able to explain the variance of the energy intensity. Most of the observed variance was due to the occupants themselves. In other words, buildings can only be as energy efficient as the people that use them. This emphasizes the need for building designs to be as robust as possible in front of the wide variations of possible occupant behaviors, as far as a low energy intensity is desired.

The so-called “energy performance gap” was also investigated, i.e. the difference between the preconstruction energy simulations and the actual energy consumption. The prior-to-construction estimation of the energy consumption is shown in Fig. 2 (PHPP). The difference between this prediction and the actual consumption is significant, but in line with those reported in literature. Rouleau et al. (2018) identified the assumptions of the original model that did not concur with actual observations. Among the most influential factors that were not well captured by preconstruction models are the set-point temperature, the use of windows, which were assumed constantly closed for preconstruction forecasts, but in reality were open on average 9.4% of the time (more than two hours per day) during winter.

RESILIENCY TO HEAT WAVES

As mentioned above, there is no mechanical cooling in the building. Different studies have pointed out the threat posed by heat waves, in particular for vulnerable populations, a problem that becomes more acute as climate changes increase their occurrence.

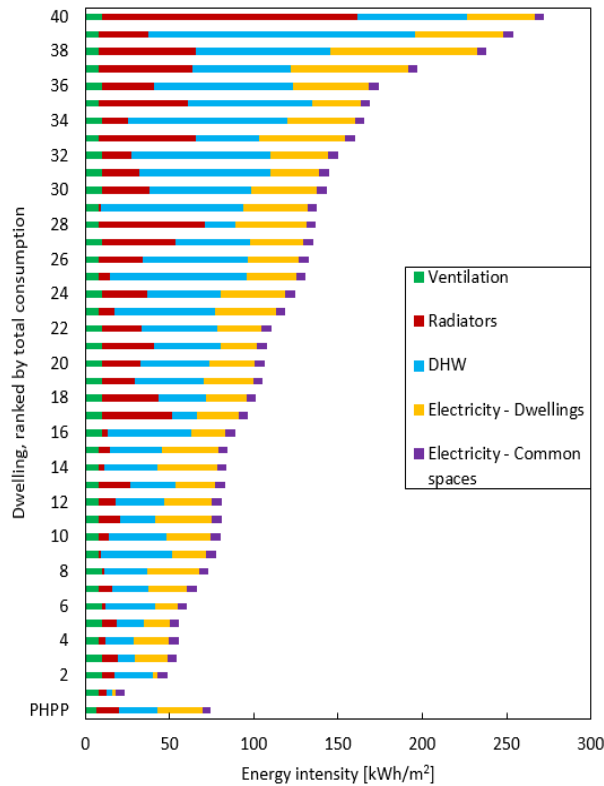


Figure 2. Specific annual energy intensity of all dwellings in 2018.

Based on temperature measurements and adaptive comfort model, it was determined that several dwellings experienced overheating during summer. From June to September 2018, the time spent outside the comfort zone varied between 5.0% and 70.9% depending on the unit. The large difference between these values shows that occupants not only have a large impact on energy consumption, but also on thermal comfort. Fig. 3 shows the indoor temperature for the coldest and warmest dwellings during the summer. Black lines represent the limit of acceptable thermal comfort according to ASHRAE 55. The prevailing mean outdoor temperature is the exponentially-weighted running mean temperature of the last month.

The data seemed to indicate that the dwellings in the CLT portion of the building were more prone to overheating than those in the light-frame portion. However, our study showed that overheating was due to a good extent to occupant behaviors (e.g., actions on windows, blinds, mechanical ventilation, etc.) which vary greatly from one dwelling to another. Statistical tests and simulations were not able to confirm the impact of the wall assembly on overheating.

From the beginning of June to the end of August, it was warmer inside the dwellings than outside 90.2% of the time. This figure combined with the high frequency of

overheating suggests that heat generated by passive solar gains and electrical appliances is trapped in the building. The high level of insulation of the envelope is unhelpful from that standpoint. It appears necessary to develop heat extraction strategies (increasing mechanical ventilation rates, ensuring that ventilation on the dwelling scale is activated and that radiators are turned off...) to mitigate overheating risks in summer in low-energy social housing buildings. Preventing non-necessary heat gains by adding exterior shading devices

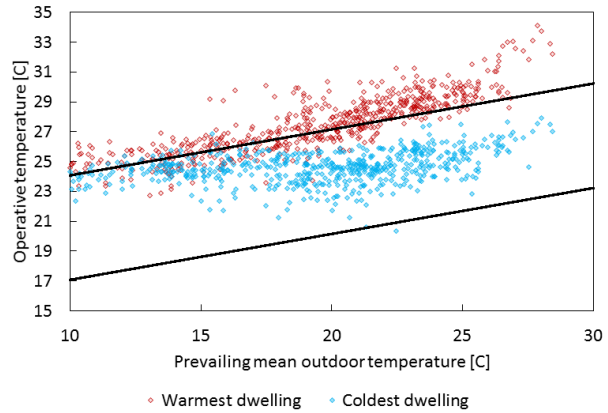


Figure 3. Comparison between the indoor temperature and the acceptable range prescribed by ASHRAE Standard 55 for the coldest and warmest dwelling.

or minimizing heat losses from the recirculation loop would also be beneficial.

LOW CARBON ENVELOPE

As building designs are more and more energy efficient and as renewable energy sources are more deeply integrated at the building scale, embodied carbon related to building materials is gaining importance in the consideration of buildings’ global warming potential (GWP) from a life-cycle perspective.

Different life cycle analyses were performed to analyze the case study building. Even if the building was to be heated with natural gas, it was found that the impact of materials on the GWP of the building would still be slightly above 10% of the total GWP (Breton, 2019). Using greener energy sources (e.g., solar, geothermal, biomass, etc.) will only increase this percentage and put more emphasize on the impact of materials.

As mentioned above, the temperature, heat fluxes and humidity in the building envelope were monitored over an extended period of time. This allowed the hygrothermal transfers in the two envelope systems (CLT vs. light-frame) to be studied. Although the two types of envelope have the same R-value, they have

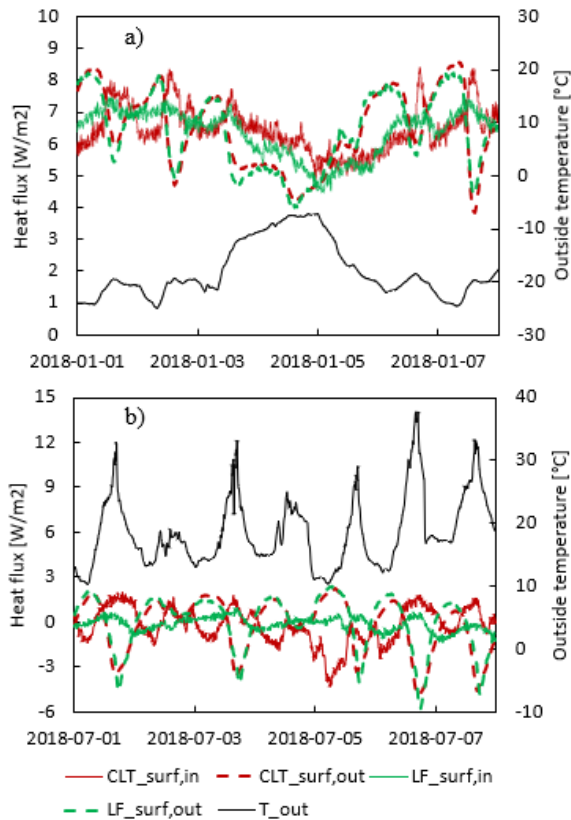


Figure 4. a) Winter and b) Summer comparison of the heat fluxes through the CLT and light frame envelope.

significantly different thermal mass. Fig. 4 presents the heat fluxes flowing through the northeast façade of both types of envelope for one week in winter and one week in summer. The “outside” heat flux sensor is installed behind the brick façade whereas the “inside” sensor is behind the gypsum surface. The outdoor temperature is also shown. We observe that even during extreme weather conditions (-20 or 35°C), there were no large spikes of heat leaving (or entering) the building – heat losses remain relatively constant throughout the week. In Fig. 4b, when the outdoor temperature briefly reaches a maximal value of 37°C, the heat flux through the outside surface of both envelope systems was approximately -6 W/m². The negative value conveys that the heat is flowing towards the indoor environment, which is undesired in summer. However, at the same time, the heat flux on the inside surface of the same envelopes are 1.2 W/m² for the CLT system and 0.1 W/m² for the light frame wall, meaning that the dwellings are actually losing heat.

Sensors in the two envelope systems exhibit similar behavior, suggesting that the increased thermal inertia of the CLT system had no tangible effect on the thermal behavior of the envelope.

CONCLUSION

This paper presented some key lessons learned from the monitoring of a Canadian social housing building that was designed to energy efficient. Heating for space heating and domestic hot water comes from wood pellet boilers and Hydro-Quebec provides electricity. Therefore, all the energy consumption of the case study building comes from renewables. The monitoring highlighted that the feasibility of reaching low-energy targets greatly depends on occupant behavior. There was a high variability of energy consumption between all dwellings, primarily caused by the actions of the occupants (window openings, use of DHW, set point temperatures...). The first lessons would thus be to aim for robust energy designs that work well with a wide variety of occupant behaviors. The second lesson learned is that as building professionals find solutions to reduce space-heating in dwellings, the share of energy required for DHW drastically increases. Research should attempt to identify strategies or technologies that cut down the energy required for DHW.

Variations among dwellings are also observed for overheating in summer. High insulation levels needed to achieve low-energy buildings are disadvantageous in summer since they prevent heat from escaping the indoor environment. The third main lesson of the paper is to keep in mind the required resiliency of low-energy building to heat waves.

The final lesson learned is that intrinsic energy of material is becoming more important. With that respect, different wood envelope systems can offer both a low embodied energy and a high operational performance.

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AIR PURIFICATION TECHNOLOGIES FOR RESILIENT BUILDINGS: ABILITIES AND LIMITATIONS

Fariborz Haghighat and Chang-Seo Lee
Concordia University, Montreal, QC

ABSTRACT

Various air cleaning technologies are applied for chemical contaminants (CCs) removal in commercial air cleaners. These devices, if they work properly, can play a significant role in reducing building energy consumption, and removing CCs, hence improving the well-being of occupants and building energy efficiency. For removing CCs, the use of traditional adsorption-based air cleaning systems such as activated carbon requires quality maintenance and regular media changes. New electronic air cleaning technologies, such as photocatalytic oxidation and non-thermal plasma, are now available for general ventilation systems. Such technologies can be more energy efficient and may require less maintenance; however, their performance is less studied and less documented. This paper discusses the potential and the limitations of air cleaning technologies for the improvement of indoor air quality in resilient buildings.

INTRODUCTION

Many of the materials used in construction and production of buildings material and buildings maintenance and operation as well as occupants' metabolism and use of consumer products can be sources of Volatile Organic Compounds (VOCs) in built environment. More than 300 VOCs have been identified in indoor air environment (ASHRAE, 2017). Even though VOC concentrations are relatively low in non-industrial environments, the high potential for many VOCs' presence in indoor air to cause symptoms is a result of both additive and synergistic effects. Due to the high volatility, VOC can easily vaporize under ambient conditions and inhalation is a major route of exposure. The potential harmful health effects of VOCs are irritations of upper respiratory system, eye and skin, sinus infection, allergic reaction, asthma, headache, fatigue, poor concentration, nausea, dizziness, and cancer. The indoor VOC concentrations are mostly higher than the ambient outdoors (ASHRAE, 2017). A field study of VOC levels in both indoor and outdoor air of office buildings in Montreal has shown that

indoor total VOC (TVOC) levels are 2 to 4 times higher than outdoor, and according to LEED BD+C V4.1, TVOC limit is 500 ug/m³ (Lee et al., 2009).

Ventilation is the generally adopted engineered solution to control the concentrations of chemicals in the air. The quantity of the outdoor air brought into the building can have a direct effect on the energy cost of building operations. There is a cost to heat, cool, humidify or dehumidify the outdoor air depending on the location and the season. This leads to a balancing act between occupants' health and ventilation cost. In the past decades, energy efficient building design and operation as well as the applications of renewable energy sources have been the prime objectives in building industry.

AIR CLEANING TECHNOLOGIES FOR VOC REMOVAL

Adsorption-Based Technologies

The traditional systems for filtering gases and vapors are based on adsorption process, i.e., activated carbon and/or potassium permanganate alumina pellets in trays or deep beds, particulate filters incorporating very thin beds of activated carbon or alumina pellets, and carbon cloth (Bastani et al., 2010, Haghighat et al., 2008). These adsorption-based technologies have long been used in wide ranges of applications, so their mechanisms and factors affecting the performance are relatively well understood. Properly designed adsorption-based air cleaning systems can have high efficiency. Currently available standards for the evaluation of gas-phase air cleaning devices were developed based on the behaviour of adsorption-based technologies (ASHRAE 2015 and 2016).

Main challenges in successful applications of adsorption-based air cleaning for IAQ improvement arise from the fact that hundreds of air pollutants exist in indoor air environment at various levels. The removal efficiency highly depends on the physicochemical properties of air pollutants and the media type (Khazraei et al., 2014). When activated carbons, which are most commonly used adsorption

media for IAQ applications, are challenged with a mixture of different VOCs, weakly adsorbed compounds get displaced by those with stonger affinity, as shown in Figure 1 (Kholafaei et al., 2010). However, only single challenge gas testing is generally required in current standards (ASHRAE, 2015 & 2016).

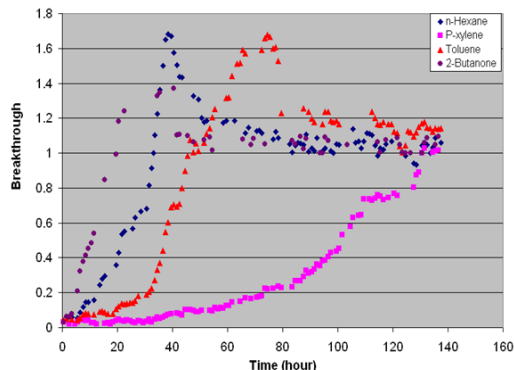


Figure 1. Displacement phenomena: 4 VOC mixture (5 ppm each) testing using 5cm bed of coal-based AC at 0.5 m/s air velocity (from Kholafaei et al., 2010).

Since adsorbent media have limited capacity, regular media replacement is necessary. Therefore, predicting the service life of adsorbent-based air cleaner is important. Existing empirical or theoretical models have been developed and validated for industrial process applications or cartridges used in personal protection, where the number of challenge compounds is limited to a few and the challenge concentrations are relatively constant. Modeling IAQ application conditions is cumbersome considering the presence of numerous air pollutants and temporal changes of their levels, which resulted in limited researches.

With the fast advance of low-cost sensor technologies, air cleaning industry starts adopting gas sensors to indicate the time to change adsorbent media. However, the main concern is the lack of information on low-cost sensors' performance and limitations. Studies showed that these sensors are generally vulnerable to the changes in environmental conditions, chemical interferences and aging (McKercher et al., 2017). The validity of these sensor applications needs further investigation.

Electronic Air Cleaning Technologies

There are newer technologies so called electronic air cleaning (EAC) technologies such as ultraviolet irradiation (UV), UV with photocatalysts, plasma, plasma with catalysts, and ozone generators. The EAC technologies generate oxidizing agents like radicals and ozone, and removing the gases and vapors through oxidation process (Lee et al., 2017 & 2020; Zhong et al., 2013). Compared to the adsorption-based air cleaning systems, EAC systems are generally easier to maintain and have lower flow resistance resulting in the

savings from the reduced fan sizes in air-handling systems. With these merits, EAC devices are quickly penetrating the market. Many studies have been conducted to develop better EAC systems, especially for photocatalysts (Mamaghani, et al., 2020; Shayegan et al., 2019), and demonstrated high removal efficiencies.

Air cleaners using EAC are often advertised that they can convert gaseous pollutants into carbon dioxide and water. This can be true if the challenge VOCs are hydrocarbons and completely oxidized. However, these results were often obtained under ideal oxidation conditions (e.g., long residence time under extremely high oxidizing agent output). Also, many studies used static batch test methods of which results are difficult to translate into dynamic performance of the in-duct systems that can be used in combination with ventilation.

For successful applications of these EAC technologies, air cleaning system should be designed and operated to ensure sufficient reaction. The performance of EAC significantly affected by air velocity, challenge VOC type and concentration and environmental conditions like humidity. Compared to adsorption-based technologies, the single-pass efficiency of EAC is generally lower and significant reduction is observed at higher challenge concentration as shown in Figure 2. The tested compounds are common VOCs found in indoor air so these are listed compounds in ASHRAE Std. 145.2 testing for gas-phase air cleaners.

Adsorbents, as shown in Fig. 1, in initial phase can have high efficiencies. Of course some thin bed of adsorbent or combination type filters can have lower efficiencies.

Complete oxidation is hard to achieve in actual EAC applications. In such cases, EAC can generate various intermediates including CO, formaldehyde, acetaldehyde, acetone and acetic acid along with some pollutants like ozone and nitrogen oxides inherently generated depending on the technology used (Mamaghani, et al., 2018; Shayegan, et al., 2017; Bahri and Haghghat, 2014). Due to the potential for the generation of these highly toxic by-products, the use of oxidation-based air cleaning devices needs to be carefully examined to prevent unexpected exposure. To address the by-product issue of EAC, some manufacturers include adsorbent media at the downstream of EAC unit; however, there is still lack of study on the performance of these scrubbers.

As more air cleaning devices using EAC technologies enter the market, it would be essential to develop a proper evaluation method for comparing their effectiveness and overall performances. However, there is no standard test method that can properly evaluate EAC technologies. Using the standards developed for

adsorption-based technologies may cause problems as they accelerate testing by increasing the challenge concentrations and do not require any by-product measurements. Table 1 summarizes the air cleaning technologies discussed above.

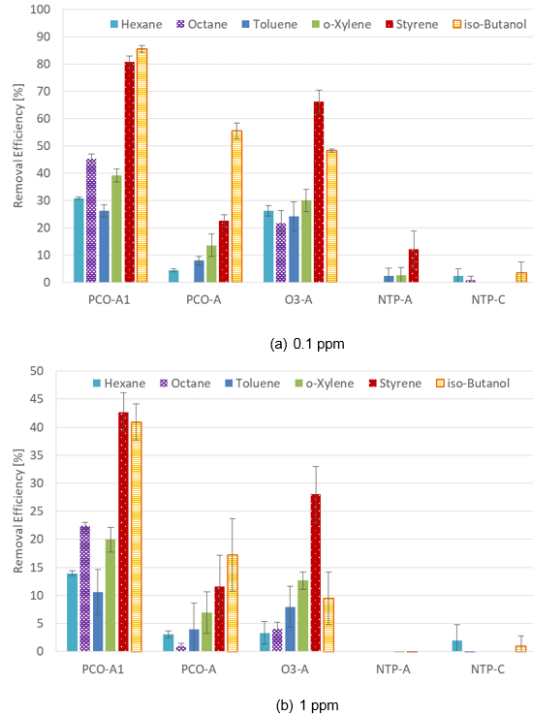


Figure 2. VOC removal single-pass efficiency of EAC at 0.5 m/s air velocity (Lee et al., 2020).

Table 1. Summary of air cleaning technologies.

Adsorption-based technologies	Electronic air cleaning technologies
<ul style="list-style-type: none"> Activated carbons Impregnated activated carbons Permanganate alumina Zeolites 	<ul style="list-style-type: none"> UV-PCO (Photocatalytic Oxidation) Plasma/Ion generators Plasma-Catalysts Ozone generators
<ul style="list-style-type: none"> Higher pressure drop Regular media change-out Standard test methods exist Well-documented performances 	<ul style="list-style-type: none"> Compact / Lower pressure drop Easier maintenance No/limited standard test methods exist Uncertainty in performances Byproduct generation

Standards relevant to the applications of air cleaning systems

ASHRAE Standard 62.1 (2019) specifies the requirements of ventilation system design and there are three design approaches: ventilation rate procedure (VRP), indoor air quality procedure (IAQP) and natural ventilation procedure. The mechanical ventilation system should be designed through the VRP and/or the IAQP.

The VRP is a prescriptive ventilation design approach that sets the minimum requirement for outdoor air ventilation rate for various space types. In the VRP, the outdoor air ventilation rate of a space is generally determined by simply adding the occupant-related demand and the building-related demand from the tabulated data. In VRP, improving IAQ is achieved by only dilution ventilation; therefore, having good outdoor air quality is necessary. Where poor air quality is expected, air cleaning has to be applied; however it specifies only ozone removal with minimum 40% efficiency among gaseous air contaminants. This may pose challenges in ensuring acceptable IAQ in the era of climate crisis, since climate change is expected to cause deterioration of ambient air quality due to increased frequency and severity of air pollution episodes as well wild land fires.

The IAQP is a performance-based ventilation design procedure requiring explicit contaminant load calculation and engineering analysis to meet the contaminant limits. While the VRP accounts for only dilution ventilation for indoor air quality control, the IAQP allows implementing all contaminant control methods: source control, dilution ventilation and air cleaning. Use of proper air cleaning systems can reduce the required outdoor air ventilation rate. In spite of great potential for improved indoor air quality and energy saving (Johnson, 2005), the IAQP has not been widely applied. Lack of proper standards to evaluate the effectiveness of air cleaning systems, especially for gaseous contaminants, may be part of the reason, along with the lack of IAQ regulations and the significantly more decision-making required for the engineers when using IAQP (Stanke, 2012).

The need for the development of standard testing method for gas-phase air cleaning systems has long been discussed. ASHRAE has developed two laboratory test standards:

ANSI/ASHRAE Standard 145.1-2015 Laboratory Test Method for Assessing the Performance of Gas-Phase Air Cleaning Systems: Loose Granular Media; and

ANSI/ASHRAE Standard 145.2-2016 Laboratory Test Method for Assessing the Performance of Gas-Phase Air Cleaning Systems: Air Cleaning Devices.

These standards, however, clearly limited to traditional air cleaning systems using sorptive media. Standard development to include EAC technologies is under progress by ASHRAE Standard Committee, SSPC 145.

CONCLUSION

A resilient building should be able to provide at least acceptable indoor air quality even under extreme situations. Relying on conventional dilution ventilation combined with particulate filtration may not be sufficient, Gas-phase air cleaning needs to be considered. Among gas-phase air cleaning technologies, the performances of traditional adsorption-based technologies are well studied and documented; however, newer EAC technologies have not been sufficiently investigated. This lack of thorough understanding of the performances of new technologies hinders the development of proper test procedures. At present, there are no test standards that can be applied for in-duct air cleaning systems using EAC technologies. As a result, design engineers only have data from testing done by manufacturers. Since each manufacturer develops its own test procedures, it is not possible to compare the performances of air cleaning products by different manufacturers. Also essential information like by-product generation is not reported. This lack of standards and convincing proof of actual performance greatly limits the proper use of EAC air cleaning systems.

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PATHWAYS FOR NET ZERO ENERGY BUILDINGS AND COMMUNITIES RESEARCH ACTIVITIES AT CANMETENERGY-OTTAWA

Meli Stylianou and Bill Wong
CanmetENERGY – Ottawa, Natural Resources Canada, Ottawa, ON
meli.stylianou@canada.ca

ABSTRACT

CanmetENERGY-Ottawa is developing a suite of projects whose objective is the improvements in retrofitting existing buildings, the design for new ones and their integration into communities that are able to deliver impacts on emission reduction targets. This paper provides the motivation for the work, outlines the activities and provides references for those interested in having more detailed information.

INTRODUCTION

The primary motivation for research in buildings and communities at CanmetENERGY-Ottawa (CE-O) stems from the commitment of the Federal Government to reduce Green House Gases (GHG) to 30% by 2030 (Environment and Climate Change Canada, 2016). In order to reach this target, residential and commercial building contributions will need to come from changes in the way these buildings provide the services Canadians rely on. These changes have implications on how we heat, cool and manage the electricity necessary for lighting and appliances, as well as how energy required for these services is managed at the community level.

The possible interventions in the building sector are constrained by a number of pre-existing conditions:

- Existing housing and buildings will make up ~75% of the 2050 building stock (Senate Canada, 2018).
- Today, natural gas, supplies ~75% of space & water heating for both housing and commercial buildings.
- Renewable electricity is generally not available when heating loads peak — cold winter nights.

CanmetENERGY-Ottawa, a research centre of Natural Resources Canada, is addressing the above challenges by strategically focussing research in:

- Improving the performance of existing buildings

- Designing and constructing new buildings that consistently perform at net-zero levels of performance
- Supporting the development and adoption of progressively higher performing building energy codes, and
- Planning new and existing communities so that the built environment as a whole operates as a seamless system

All four research areas rely on computational tools and field validations that allow the identification of cost effective solutions for the retrofit of existing buildings, the design of new and the targetted interventions in the broader community.

DECISION SUPPORT COMPUTATIONAL TOOLS

CE-O developed two computational tools to help with identification of optimised technoeconomically feasible approaches for building design and retrofit: the **Housing Technology Assessment Platform (HTAP)** addressing low rise construction (as per Part 9, NBC) and the **Building Technology Assessment Platform (BTAP)** addressing commercial and institutional buildings. The two tools use different simulation engines: HTAP uses HOT2000 (NRCan, 2008), while BTAP uses OpenStudio/Energy Plus (DOE, 2019) for energy simulation engines. However both tools use a similar structure to accomplish their objectives (Figure1).

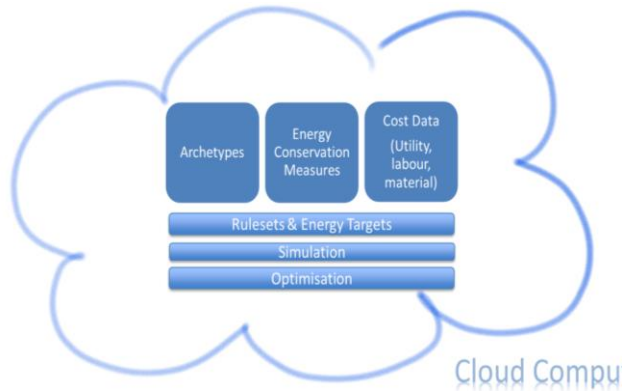


Figure 1. HTAP/BTAP Structure.

The purpose of the tools is to examine energy, GHG and cost implications of design and retrofit options for housing and commercial buildings. In order to achieve these objectives, models (archetypes) that represent building typologies and vintages are used. The tools allow the users to substitute the energy impacting characteristics of the archetypes (envelope characteristics, mechanical systems, plugloads) in a programmatic sequential manner, providing the user the possibility of modeling thousands of houses/buildings in a relatively straightforward manner. Each model thus developed is coupled with the utility and capital costs of the jurisdiction for which they are formulated. Depending on the objective of the analysis, rulesets representing, for example, a code-compliant archetype, are applied and the differential cost, energy and GHG implications are generated for the baseline (the code-compliant archetype) and the optimised archetype.

Large-scale fast cloud computing facilitates large number of simulations required to arrive at the combination of energy impacting features that optimize the cost-benefit for the building in question. The resulting large amount of data is displayed in easily interpretable visualizations tools.

IMPROVING THE PERFORMANCE OF EXISTING BUILDINGS

Envelope retrofits

When considering existing buildings deep retrofits are of particular interest, and more specifically the renovation to the building envelope. Heat loss through the envelope represents 2/3 of the energy use in a typical Canadian old home. Despite this, only 4% of retrofits conducted through NRCan incentive programs consisted of comprehensive building envelope performance improvements. The primary barriers to deep-energy enclosure retrofits include the high cost associated with the work, and the disruption that the work involves.

CE-O launched a project to directly deal with these barriers based on the use industrialized approaches to

achieve net-zero energy (NZE) retrofits. The principles of Prefabricated Exterior Energy Retrofit (PEER) have been applied in an initial pilot (Figure 2) that achieved post retrofit airtightness of 0.89 ACH50Pa, and modelled heating consumption reduction of 64%.

The next stage in the development of the PEER concept is the application of the developed building capture and prefabrication technologies to a full scale pilot. The building in question is a row housing unit (Figure 3) owned and operated by the Ottawa Community Housing (OCH) (Carver et al, 2019), and the objective of the retrofit is to take this 1950's building to net zero energy performance level.



Figure 2. Pilot Retrofit at Bells Corners.



Figure 3. OCH Full Scale Pilot in 2020.

The first step in the development of the retrofit approach dealt with the evaluation of the available options: insulation levels for the foundation, walls and roof, airtightness levels, window and door characteristics as well as domestic hot water and heating system performance levels. HTAP has been used to identify the most cost-effective combination of measures to reach the net zero level of performance and construction is slated to begin in the spring 2020.

Retrofit optimization for the north

Retrofitting housing in the North deals with similar issues as anywhere else: improving home airtightness, increasing insulation levels, and replacing mechanical systems etc. The challenges however are significantly more complex: availability of materials, cost of labour, remoteness of location.

In order to develop a plan that addresses northern communities, HTAP was used to develop the options for the Yukon and North West Territories. The resulting selected options were then developed as an illustrated guide by RDH with the support of CMHC (RDH, 2017).

DESIGNING AND CONSTRUCTING NEW HIGH PERFORMANCE BUILDINGS

In principle, designing and constructing high performing buildings, should not be a challenge given the studies demonstrating that such buildings can be built with little or no additional costs to the owners. However, a number of barriers appear when closer examination is applied. The first barrier is a result of the market competitiveness, resulting in limited time for engineers and architects to evaluate options that could meet high performance targets, and the lack of information on the performance and reliability of high performing equipment and systems and of their integration into high performing buildings.

Cost-effective high-performing design options

Evaluating the design options is a time-consuming, labour intensive activity that few owners are willing to pay for and few design studios are equipped to carry out. In order to deal with this first market shortcoming, CE-O uses HTAP and BTAP to deal with the large number of simulations required to arrive at high performance solutions that are cost competitive.

The complexity of the issue of finding the options for a certain level of investment, is best illustrated by considering a relatively simple design problem of a single family home. When one considers, the different options available for a net zero home: air-tightness levels, insulation levels for the different envelope components, electro-mechanical systems, the designer has almost 300,000 options to select from. A large commercial building is several orders of magnitude more complex.

Figure 4 demonstrates an example of the application of the computational tools to evaluate the cost/benefit ration of the options.

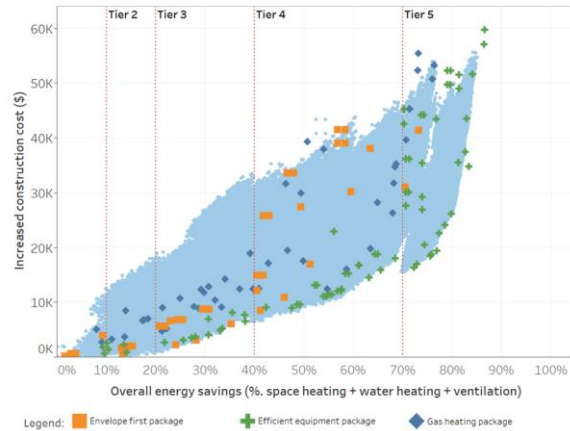


Figure 4. Cost implications of energy saving measures.

In the above figure, each dot is a complete model of the house. The designer can readily see the desirable options very fast and select those that meet their cost and performance targets.

De-risking innovative technologies

The second barrier to the design of high performing buildings is the lack of confidence in the performance of innovative technologies.

CE-O carries out laboratory and in-situ tests that lead to the development of guides for the industry (Sager, 2017) and that feed into the work that the LEEP team is doing to promote high performing housing (NRCan, 2019).

- Hybrid heating system: The majority of homes in Canada are heated using natural gas, consequently the transition to non-emitting sources of heating is an important component of the puzzle associated with reaching the GHG emission targets. To this end, CE-O has tested the performance of hybrid systems, systems that combine natural gas-burning furnaces with heat pumps with the switchover between the two occurring when the utility cost the climatic conditions and the unit's performance permit (Sager, 2020).
- In the commercial building sector, CE-O developed tools to facilitate the integration of passive technologies in the toolbox of designers. The earth tube tool, for example helps designers to select the characteristics of the tool for effective application in new construction (Brideau, 2018).

DEVELOPMENT AND ADOPTION OF BUILDING ENERGY CODES

According to the Pan-Canadian Framework on Clean Growth and Climate Change (PCF), “federal, provincial, and territorial governments will work to develop and adopt increasingly stringent model building codes,

starting in 2020, with the goal that provinces and territories adopt a net-zero energy ready model building code by 2030". To this end, CE-O applied the HTAP and BTAP tools to support Codes Canada in their efforts to develop the required justification and pathways to achieve net-zero energy ready level of performance in buildings and housing.

Housing analysis

HTAP has been applied to the development of the proposed housing tiered national building energy code. This activity applied the lessons learned from HTAP's application to the development of the British Columbia Step code (Province of British Columbia, 2017), and included considerations that are only possible due to the flexibility provided by the tool which was not available in previous code vintages.

As Proskiw (2011), there is a need to reflect regional weather, regional housing characteristics, costs and energy prices. In prior code development however, the use of HOT2000 limited the possible use of regionally representative archetypes, as the labour and computational costs would have been prohibitive. HTAP, as described above was developed to cope with the massive simulations required, and the first step in the analysis was the development of regionally representative archetypes.

CE-O developed a new set of 240 housing archetypes, representing detached and double/row new construction in major Canadian markets. The development relied on the approach developed as part of the Canadian Single Detached, Double and Row Database (CSDDRD) (Swan et al, 2009) development, and relied on data from the Energuide for Houses Database maintained by NRCan. The selection of the archetypes was informed by the Canada Mortgage and Housing Corporation's Housing Market Database and the Survey of Household Energy Use. The selected archetypes were sampled from actual homes built in Canada between 2015 and 2018 and have characteristics representative of the regional variations between major Canadian housing markets (Rasoul et al, 2019).

The archetypes formed the basis on which a variety of energy conservation measures were applied coupled with costing and utility data. The results of the simulations formed the basis for the new tiered approach to the building codes for housing.

Commercial building analysis

CE-O developed rulesets in BTAP for 16 building archetypes that are compliant with the NECB2011, NECB2015 and NECB 2017 codes.

The developed platform was used to evaluate the impact of updating the code for Prince Edward Island, Nova Scotia and Manitoba from NECB2011 to NECB2015 or

NECB2017. Based on the results of the analyses Nova Scotia adopted the NECB 2017 code.

CE-O guided National Research Council researchers on the use of BTAP in order to evaluate the impacts of moving NECB2017 to a tiered approach.

It should be noted that CE-O is closely collaborating with a number of academic and private organisations that use components and/or data generated by the Building Technology Assessment Platform in their research and development of related applications. These include the University of Victoria, Concordia University and Posterity.

PLANNING COMMUNITIES

Two projects deal with community-level activities.

The Canadian Energy End-use Mapping (CEE Map) Project aims to help governments and utilities see housing energy end-use and efficiency opportunities as an additional layer on a map of the community, province or the country.

The initial CEE Map prototype is being developed in collaboration with the City of Kelowna, BC, built on the ESRI-based Model City developed by city staff. NRCan's CanmetENERGY-Ottawa and GeoAnalytics divisions will create the CEE Map prototype by adding outputs from the HTAP and BTAP platforms to characterize the residential use and efficiency opportunities in Kelowna's housing stock.

The Low Carbon Communities Energy Systems project builds on the recent Canadian district energy survey, and from the learnings from the Drake Landing Solar Community project and a net-zero community energy feasibility study conducted by CE-O. It focuses on what is required to accelerate the uptake of low carbon energy technologies on a community-wide scale. This project is leveraging on CE-O's knowledge on a wide range of clean technologies and our partnership with stakeholders in the community energy market in delivering research outputs that will inform policy makers, planners and community energy managers. The project aims at lowering barriers and to increase the uptake of low carbon community energy technologies in our existing communities.

CONCLUSION

The paper addressed the research and development activities at CanmetENERGY Ottawa within the housing, buildings, and the community areas.

The teams at CE-O have developed a number of projects in close collaboration with academic and private organisations that expand the scope of the projects described in this paper to include issues related to electrification and embodied carbon considerations.

These projects, are at their initial stages of development and are closely linked with stakeholders that range from manufacturers, home builders, architectural and engineering firms, utilities and provincial and federal organisations.

The collaborative nature of the activities ensures that the developed technologies, tools and analyses significantly contribute to the broader Canadian efforts of improving the built environment and meeting the GHG emission reduction targets while maintaining and improving the competitiveness of Canadians.

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PASSIVE STRATEGIES TO IMPROVE MULTI-UNIT RESIDENTIAL BUILDINGS THERMAL COMFORT RESILIENCE IN FUTURE CLIMATE SCENARIOS

Jia Zhe Liu¹, Cheng Li¹, and Marianne Touchie^{1,2}

¹Department of Civil and Mineral Engineering, University of Toronto, Toronto, ON

²Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, ON

ABSTRACT

In Toronto, many of the thermally massive post-war multi-unit residential buildings (MURBs) do not have central cooling systems to mitigate overheating in summer weather. As the duration and severity of extreme heat events will increase in the future, these building occupants will be vulnerable to greater heat-related morbidity and mortality. Three passive strategies (overhangs, window films and interior roller shades) were simulated in an energy model of a 20-storey post-war MURB and compared against a base case model, to assess their impact on cooling energy consumption under current and future weather conditions. While the interior roller shades were found to be the single most effective measure at reducing cooling energy use, combining all three strategies yielded a 21.3% cooling energy reduction, as well as a 26.7% reduction in unmet cooling hours in the future weather scenario. In order to further reduce unmet cooling hours and address thermal comfort, active cooling systems are required.

INTRODUCTION

Multi-unit residential buildings are a significant source of housing in urban regions, such as Toronto. As of 2016, about 44.3% of the dwellings in the City of Toronto are in apartment buildings with five or more storeys (City of Toronto 2019). However, many of the high-rise apartment buildings were designed with electrical or hydronic baseboard heating systems and are not equipped with central cooling systems. Therefore, the suites can only rely on natural ventilation, fans or packaged terminal air conditioners (PTACs) for cooling (CMHC 2017). As a result of global warming, it is anticipated that the outdoor temperature in Ontario will experience an average annual temperature rise of 2.5°C to 3.7°C by 2050, compared with the baseline average of 1961 to 1990 (MECP 2014). Rinner and Hussain (2011) found that Toronto, the largest urban area in Ontario consisting of dense high-rise buildings, has experienced a 1.6°C to 4°C higher surface air temperature than the surrounding residential and open areas due to the

negative impacts of the urban heat island (UHI) effect. Thus, natural ventilation and air movement driven by fans, which some studies have already shown to be ineffective, will not be an acceptable solution to overheating any more. However, before considering the implementation of active cooling, thermal comfort should first be improved by optimizing the building's passive features in order to minimize energy use. Studies have shown that passive strategies can effectively reduce solar heat gain in high-rise residential buildings. For example, research in Seoul, South Korea shows that the introduction of horizontal overhangs and roller shades results in cooling energy saving potential of 19.7% and 17.7%, respectively (Cho et al. 2014, Oh et al. 2018). Although there has been extensive research of passive strategies under current weather conditions, less is known about how passive strategies can perform under future weather conditions. This study aims to address this gap. This paper examines the effectiveness of passive strategies reducing the cooling load and number of unmet cooling hours in MURBs during summer months, under current and future weather conditions.

METHODOLOGY

An archetypal post-war high-rise MURB was used as the subject of this study. The 20-storey rectangular building is a student family residence at the University of Toronto. It has a floor area of 28,730m² and is aligned along the east-west axis. The building has hydronic baseboard heaters and a pressurized corridor ventilation system. There is no central cooling but about one-third of the suites have PTAC units. Suite windows are double glazed with a low emissivity coating and thermally broken aluminium frames, and a window-to-wall area of 27%. Walls are made of concrete block with brick façade and drywall interior without insulation. The calibrated baseline model was generated in eQUEST (version 3.65.7173) by Touchie and Pressnail (2014), then each passive strategy was tested as part of the current study.

Baseline Model

To assess the impact of the passive strategies on cooling energy consumption, PTAC units were added in all suites, and the total cooling capacity of PTACs required to meet the current cooling loads was auto-sized by eQUEST. For all the subsequent models, PTAC capacity was kept the same as in the initial baseline model to assess the number of unmet hours of cooling in each zone.

Each floor of the building was modeled with three zones: a south-facing A/C conditioned suites zone, a north-facing A/C conditioned suites zone, and a non-A/C conditioned corridor zone. Corridors are pressurized with un-conditioned outdoor air supplied by the rooftop air handling unit to meet the minimum ventilation air requirement for suite zones, therefore the corridor zone can be excluded from this study as it does not contribute to the cooling load. The suite cooling setpoint is 26°C, a health-based maximum indoor temperature in apartment buildings during cooling season as specified in Toronto Municipal Code. In order to assess how the building responds to the projected future weather, the energy simulations were run with both current and future weather files, which were historical Canadian Weather Year for Energy Calculation (CWEC) from 1959 to 1989 and future weather generated for the decade of 2040 to 2049 (2040s) by SENES Consultants Limited in 2011. Next, the energy model was run three more times to determine the cooling energy consumption for each passive strategy, and unmet hours in the north and south zones. For each hour that a thermal zone fails to maintain the cooling setpoint, one unmet hour is counted.

Passive Strategies

Three passive strategies were selected for this analysis: overhangs, window films and interior roller shades. The overhang depth was obtained from an online tool developed by Sustainable by Design. Given the inputs of latitude (44°N), south-facing windows and window height of 2.0m (6.6ft), a chart of hourly heat gain from direct sunlight for any day during peak cooling month was generated. Overhangs with a depth of 0.76m (2.5ft) and an equal width to the windows where overhangs were installed right above, result in a minimal heat gain from direct sunlight at solar noon in July for south-facing windows. The adapted size of overhangs was also applied to north-facing windows to compare the change in unmet cooling hours between south- and north-facing zones. According to Ihm et al. (2012), it is beneficial to select glazing unit with low solar heat gain coefficient (SHGC) to reduce cooling energy load in MURB. But after-market window films can be an economical and feasible solution to reducing solar heat gain in a retrofit context. The commercially available interior films selected for this study can be directly applied to the interior side of the window to decrease SHGC from 0.67 to 0.44. Interior translucent roller shades were selected

to allow some daylight in but also reduce solar gain. For the purpose of this study, the roller shades were assumed to be closed 100% of the time to maximize solar gain reduction. The input parameters of the selected passive strategies in our study are summarized in Table 1.

Table 1. Input Parameters.

PARAMETERS	INPUT VALUE
Overhangs	Depth of 0.76m (2.5ft), full window width, installed right above windows
Window Films	Total Window SHGC: 0.44, VT: 0.38, U: 0.69 Btu/h·ft ² ·F
Roller Shades	Interior Translucent Roller Shades Openness: 3%, VT: 0.09

RESULTS AND DISCUSSION

Weather Comparison

Figure 1 compares the average monthly dry bulb temperature and relative humidity between the historical CWEC and 2040s Typical Meteorological Year (TMY) files. Figure 2 shows their corresponding monthly cooling degree days (CDD₁₈). As expected, the 2040s TMY features increased average dry bulb temperatures and thus increased cooling degree days.

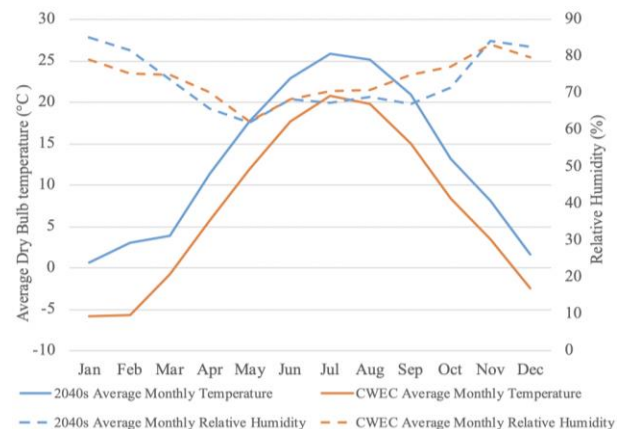


Figure 1. Average Monthly Dry Bulb Temperature and Relative Humidity.

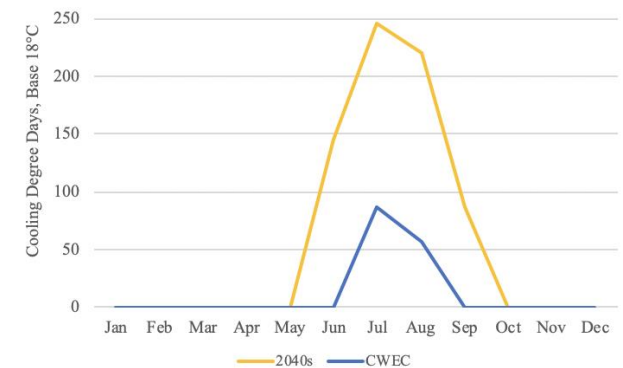


Figure 2. Monthly Cooling Degree Days.

Table 2 compares the results of the base case model with the two different weather files and shows an increase in total cooling energy use intensity (EUI) and unmet cooling hours, as expected.

Table 2. Total Cooling Energy Use.

Weather File	Cooling Energy Use Intensity (kWh/m ² /yr)	Total Electricity (MWh)	Unmet Cooling Hours
CWEC TMY	3.4	84.6	19
2040s TMY	14.3	355.3	937

Passive Strategy Comparison

Figures 3 and 4 summarize the monthly space cooling load of the baseline scenario and the passive strategies under current and future weather conditions.

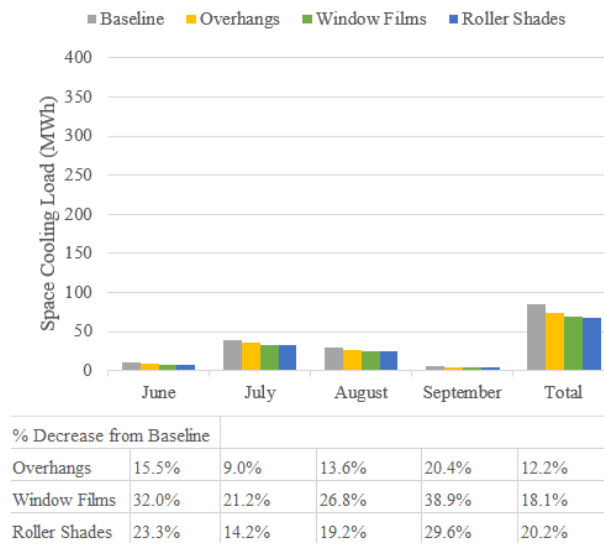


Figure 3. Monthly Space Cooling Load (CWEC).

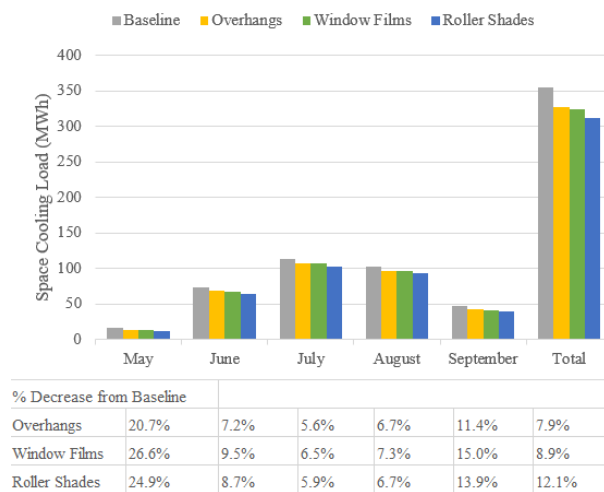


Figure 4. Monthly Space Cooling Load (2040s TMY).

Among the three passive strategies, the roller shades reduce the cooling load most significantly by up to 20.0%, compared with the baseline result under current weather conditions, whereas the overhangs are the least effective strategy. However, roller shades can only reduce the summer cooling by 12.1% under future weather conditions. The change in effectiveness is because the cooling load under future weather file is significantly larger than it is under current weather file.

Unmet Hour Comparison

For the future weather conditions of increased average dry bulb temperature, the auto-sized PTAC's cooling capacity in the current weather baseline model becomes inadequate to meet the cooling setpoint, which consequently, results in longer operation hours without mitigation of the overheating situation.

In the breakdown of the simulation results, the total number of unmet hours for each floor varies. It was found that Floor 19 has the highest number of unmet hours. Therefore, the 19th floor was further analyzed to illustrate the impact of each passive strategy on the total number of unmet cooling hours assuming future weather conditions. As shown in Figure 5, the unmet hours of the south-facing zones are greater than that of the north-facing zones. This is expected, as the south side of the building has a higher solar exposure.

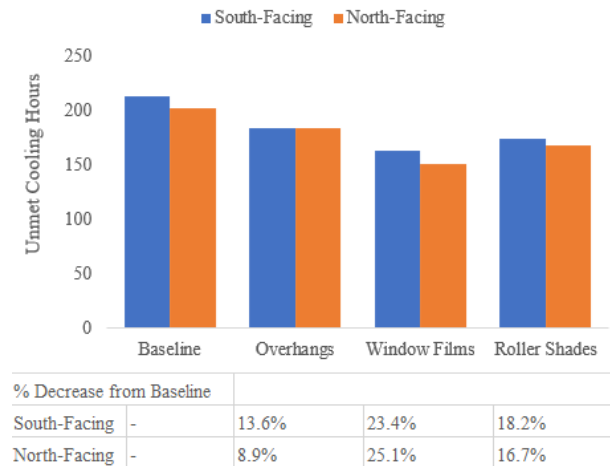


Figure 5. Floor 19 Unmet Hours versus Input Parameters under Future Weather Condition.

With the introduction of each passive strategy individually, unmet cooling hours for both south- and north-facing zones decrease; however, when comparing unmet hours between south- and north-facing zones, for example, adding overhangs to both zones result in a 13.6% decrease of unmet hours for the south-facing zone and a decrease of 8.9% for north-facing zone. Therefore, implementing passive strategies on the south side of the building is generally more effective to reduce overheating during summer, as expected.

Combination of Multiple Input Parameters

As seen in Figures 3 and 4, implementing a single passive strategy under current weather conditions can ease overheating and reduce the cooling load by 12.2%, 18.1% and 20.2% using overhangs, window films and roller shades, respectively. However, implementing a single passive strategy under future weather conditions is not as effective (a maximum of 12.1% energy saving for roller shades). In order to improve the effectiveness of the selected passive strategies in reducing the cooling energy consumption under future weather conditions, we input all three parameters in one model to simulate a combined scenario. The cooling energy savings for each passive strategy and the combination of all three strategies are summarized in Table 3 as well as their corresponding percentage reduction of unmet hours.

Table 3. Summary of Energy Savings and Unmet Hours Reduction under Future Weather Condition.

Input Parameters	Total Space Cooling [MWh]	Unmet Hours	% Energy Savings	% Unmet Cooling Hours Reduction
Baseline	355.3	937	-	-
Overhangs	327.1	874	7.9%	6.7%
Window Films	323.6	780	8.9%	16.8%
Roller Shades	312.2	833	12.1%	11.1%
Combine Three Input Parameters	279.5	687	21.3%	26.7%

As we can see from Table 3, combining all three input parameters results in a 21.3% cooling energy saving and a 26.7% unmet cooling hour reduction under future weather conditions. However, 687 unmet cooling hours indicates an unsatisfactory indoor environment and insufficient cooling capacity, therefore it is necessary to upgrade the existing PTAC system capacity or install other mechanical system such as heat pump to ensure indoor thermal comfort.

CONCLUSION

Passive features of buildings can significantly reduce cooling energy consumption in summer and mitigate overheating. Three strategies, overhangs, window films and interior roller shades, were studied by running energy simulations of a post-war MURB in Toronto. The effectiveness of each strategy is relatively high under current weather conditions but lower under future weather conditions because of the increase in cooling load. Although improving building resilience by implementing multiple passive strategies can reduce cooling energy consumption, active cooling systems are

still required to address thermal comfort in these buildings.

ACKNOWLEDGMENT

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BUILDING-INTEGRATED PHOTOVOLTAIC SYSTEMS: ENABLING ENERGY-RESILIENT HIGH-PERFORMANCE BUILDINGS

Konstantinos Kapsis

Department of Civil and Environmental Engineering, University of Waterloo, ON

ABSTRACT

As Canada rapidly transitions toward net-zero and carbon neutral building performance targets through building codes, roadmaps and building rating systems, the on-site electricity generation will become compulsory. Building integrated photovoltaic are expected to be one of the main technologies to generate on-site electricity since they can be designed to virtually cover any building surface that has access to sunlight. This paper provides a brief overview of barriers that still hinder BIPV adoption in Canada and proposes actions to overcome them thus, enabling energy-resilient high-performance buildings.

INTRODUCTION

While Canada is transitioning towards electrification and decarbonization of the building, energy and transportation sectors, its major cities struggle to mitigate and adapt to urban population surge and climate change. Currently, two thirds (27 million people) of the country's population live in census metropolitan areas. By 2050, it is projected that this number will rise to about 36 million people (Statistics Canada, 2019).

The urban population surge is expected to increase the net electricity and peak power demand in a somewhat predictable manner. On the other hand, the frequency, intensity and duration of extreme weather phenomena due to climate change creates a high uncertainty that extends beyond the increase of energy demand, to generation, operation and resilience of energy related infrastructure (Climate transparency, 2019; Perera et al., 2020).

Building-integrated photovoltaic (BIPV) are building envelope solutions that generate on-site electricity (and in some cases also thermal energy). BIPV can virtually cover any building surface (Table 1) turning buildings from energy consumers to energy prosumers. Considering that the major cities in Eastern Canada and the Prairies (e.g. Toronto, Montreal, Calgary, Edmonton, Ottawa, Winnipeg and Saskatoon) have solar potentials that are comparable to those of solar-leading countries (Figure 1), BIPV are expected to play a key role in the

transition towards decarbonization and energy resilience of the building sector. This paper provides a brief overview of the primary barriers identified for the widespread adoption of BIPV in Canada and proposes steps to effectively overcome them.

BIPV BARRIERS AND FACILITATORS

Barriers perceived by solar and building industry professionals

In 2016, an independent survey (n = 50) was conducted on behalf of the Refined Manufacturing Acceleration Process (ReMAP) network, funded by the Business-Led Networks of Centres of Excellence (BL-NCE) program (Forum Research inc, 2016). The purpose of the survey was to assess the receptivity of the building industry in North America to BIPV window products, specifically.

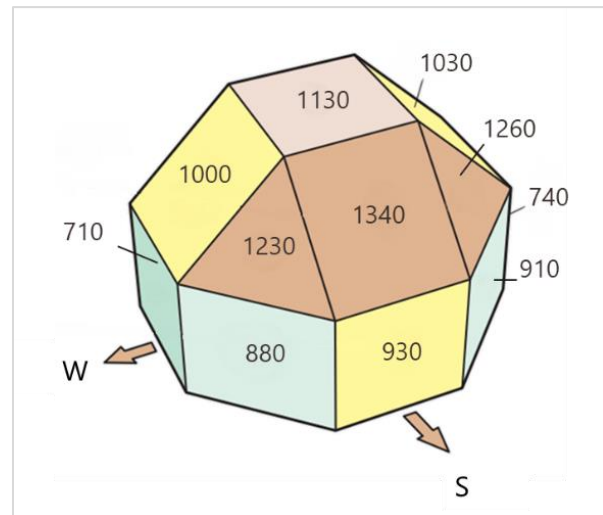


Figure 1. Potential annual electricity generation (kWh_{AC}/kW_{DC}) based on BIPV surface orientation and tilt angle, for Toronto (NREL, 2020). Routine or temporary shading is not considered.

The survey identified the following primary barriers for the facilitation and acceleration of BIPV windows:

- lack of product/system familiarity and what this entails in terms of building design and installation;

- upfront cost; and,
- return-on-investment (ROI), with ROI be of greater importance than upfront cost when it comes to new constructions as compared to retrofit ones.

Interestingly, 57% of the respondents were likely to use BIPV windows in future projects while more than three-quarters (78%) would be willing to pay more than \$21/ft² above that of energy efficient windows. Finally, most respondents reported that 10 to 15 years (70%) would be an acceptable time period for ROI.

In 2018, Natural Resources Canada conducted a consultation survey (n = 141) focusing on BIPV products at large, within the Canadian building and solar industry (Ebert and Kapsis, 2018). Like the ReMAP survey, the primary barriers identified for the widespread adoption of BIPV were:

- ROI;
- upfront cost; and,
- lack of design guidelines.

Overall, the optimism among respondents was strong with 98% of them being at least somewhat interested in using BIPV in future projects with the main motives being “green” (78%) and innovative (76%).

Similar studies have been conducted outside Canada indicating that some of the barriers hindering the uptake of BIPV are universal (Curtius, 2018; Heinstein et al., 2013; Lu et al., 2019; Shukla et al., 2018). The following section will try to address some of these barriers in Canada and when possible, propose actions to overcome them.

Codes, standards and regulations

The various organizations of international standards have recognized the multifunctional character of BIPV, the need to address both electrotechnical and building performance requirements and remove the risk from building owners and stakeholders. As a result, the first international BIPV standard is currently under publication, the IEC 63092. Modeled upon EN 50583 European standard (CENELEC, 2016a, 2016b), IEC 63092 is a two-part umbrella standard developed as a result of a liaison between Technical Committees (TC) IEC TC 82 and ISO TC 160. Part 1 of IEC 63092 describes BIPV module requirements while part 2 describes BIPV system requirements. Both parts address building and electrotechnical requirements, in general and specifically with respect to module assembly and application category (IEC, 2020a, 2020b). In addition, existing standards related to laminated glass in buildings are being revised to include BIPV.

The next necessary step to facilitate BIPV market acceptance is the Canadian adoption of the international standards. In addition, federal and provincial building,

energy and fire codes need to be updated to allow for standardization and consistency in BIPV practices and safety. An extensive report on the requirements, specifications and regulations relevant to the development of BIPV performance and safety standards can be found under IEA PVPS Task 15 (Inoue and Wilson, 2019).

Business models and policies

Since 2008, the price of a typical crystalline silicon module in Canada has declined by more than 83% (Baldus-Jeursen et al., 2019). The price reduction is attributed to global market factors such as increase of cell efficiency, public and private R&D and economies of scale (Kavlak et al., 2018). At the same time, the country’s installed capacity has increased from 32 MW_{DC} in 2008 to 3095 MW_{DC} in 2018, driven mainly by incentive programs in Ontario and Alberta. However, these factors had little impact on the price of BIPV and their widespread adoption in the building market.

While investment subsidies and feed-in tariffs related to BIPV can help and are welcome, Canadian BIPV industry needs to innovate by introducing new business models that:

- remove buildings owners’ upfront cost;
- allow service providers to cost-effectively capture new value streams through proven BIPV solutions; and,
- create high confidence in BIPV performance and its financial returns.

Such business paradigms exist in other markets from which BIPV industry can learn from and adopt.

In recent years, the PV and building industries have been fueled by business model innovations that provide services to end users, rather than selling them products. Also known as “Product-as-a-Service” (BaaS) business model, BaaS allows service providers to tap into these multibillion-dollar markets and create new revenue streams by effectively selling energy savings rather than the equipment that delivers these savings – through power purchase agreements (PPA) for the PV industry and energy service performance contracts (ESPC) for the building one.

Similarly, the convergence of technological developments in BIPV have created an untapped business opportunity in industrial, commercial, institutional and high-rise residential buildings. Appropriate for both new and retrofit buildings, BaaS business model can also be used by the BIPV industry to decouple energy saving investments in buildings from buildings owners’ upfront cost and ROI constrains. BaaS will be partly driven by the economies of scale (e.g. the added cost of BIPV is only 1-2 % of a commercial or institutional building cost), partly by the mandate to reduce energy consumption and peak power demand and

partly by carbon tax policies (Canadian Ministry of Justice, 2020). Other BIPV business models exist (Macé et al., 2018). In all cases though, robust business models must cope without investment subsidies and feed-in tariffs.

Research, development & technology demonstration (RD&D)

While BIPV have reached technological maturity, RD&D (both public and private) will remain key drivers of BIPV cost reduction. In addition to the latest developments on coloured BIPV (Figure 2), new optically-smart laminates, films and coatings promise increased conversion efficiencies by harvesting near-infrared (NIR) photons or by down-shifting high energy ultraviolet (UV) photons through active photon conversion and plasmonic scattering (Eder, 2019; Jelle, 2016).

Polymer and perovskite tandem solar thin films are emerging PV technologies suited for BIPV window and skylight applications. With tunable transparency and colour, these new PV technologies use low-cost raw materials and low-cost, low-temperature (<120°C) and scalable manufacturing processes. However, further RD&D is necessary to overcome their lack of long-term stability. In addition, advancements in the laminated

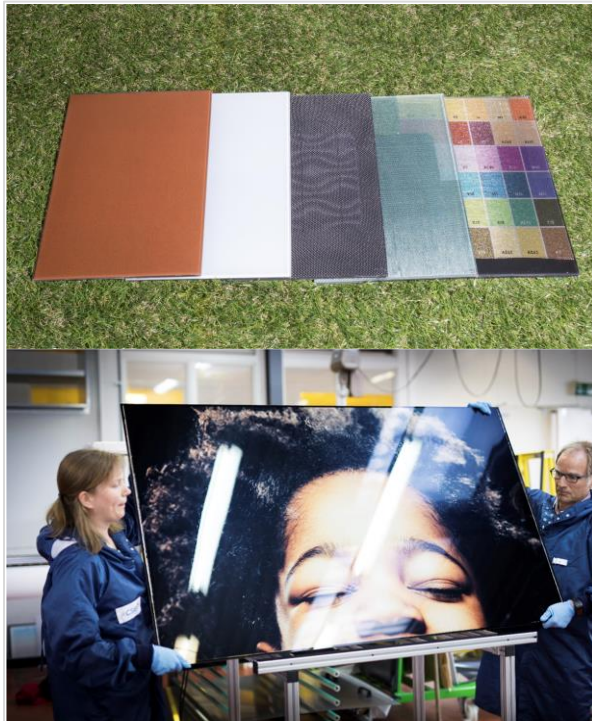


Figure 2. State-of-the-art coloured BIPV products redefine solar envelope aesthetics (Image credits – top to bottom: NRCan and Kaleo Solar, 2018).

glass industry have allowed the manufacturing of curved BIPV modules.

BIPV coupled with grid-interactive inverters and battery storage have enabled buildings to function in an isolated mode – when there is a power outage – or in a parallel-to-the-grid mode of operation (Figure 3). Treated as distributed energy resources (DER), these BIPV system configurations can also provide grid ancillary services at the request of the utility, thus, transforming buildings to an integral part of an energy-resilient, smart grid architecture (Kolokotsa, 2016).

Further RD&D is necessary to better understand the interactions of BIPV with the building HVAC, controls and operation (Kapsis et al., 2015; Kapsis and Athienitis, 2015), the energy storage, the power utility, and the transportation sector through electric vehicle (EV) energy transaction (Bhatti et al., 2016; Wu et al., 2016). It is only through interdisciplinary research collaborations, and integrated design and operation that the full potential of all these enabling technologies can be captured, providing safe, comfortable, efficient and affordable conditions in the built environment (Thomas et al., 2019). New advancements in the world of Building Information Modelling (BIM) and Internet-of-Things (IoT) also contribute to this direction (Gao et al., 2019; Mehmood et al., 2017; Minoli et al., 2017).

Education of the building professionals

While BIPV can benefit from the technological developments that take place in the solar industry, they are building products. As such, their price and market share are driven by building industry trends, and technological advancements specific to BIPV. However, it is a common mistake for BIPV to be compared (price- and performance-wise) with typical standard modules and systems used in PV farms, and building-added PV also known as BAPV (e.g. rooftop PV). The latter ones have a single function: to generate solar electricity. In the contrary, BIPV are multifunctional building envelope solutions that impact the building's:

- architectural aesthetics;
- mechanical resistance and durability;
- hygro-thermal and energy performance (heating, cooling and lighting); and,
- electricity consumption and its interaction with the power grid.

The BIPV multifunctionality (Table 1) and interoperability with the utility grid makes the realization of BIPV projects a challenging task. The current lack of technical knowledge between building professionals

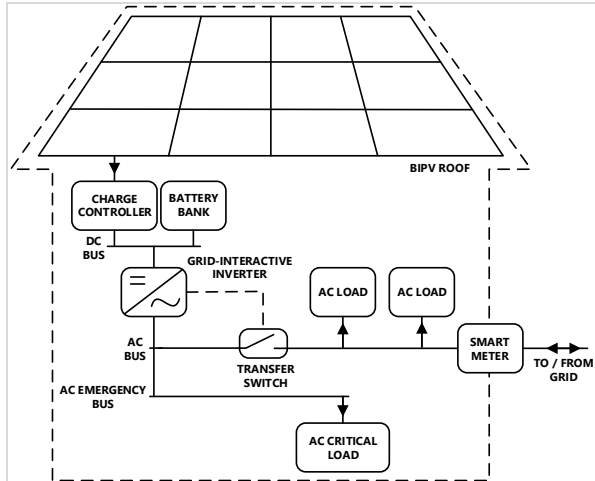


Figure 3. Grid-interactive BIPV application designed to continue operating during power outage (Credits: NRCan, 2018).

(architects, engineers and consultants) on how to design and carry out BIPV projects is an additional barrier to the adoption of BIPV that should not be overlooked. Currently, there are national and international efforts to consolidate existing BIPV knowledge and disseminate it through continuing education courses, technical seminars and BIPV-specific technical guides (Eisenlohr and Illich, 2019).

The intent of a BIPV technical guide is to support the implementation of best practices and drive the decision-making process that could lead to an effective BIPV design as well as a resilient and robust BIPV installation while maintaining good architecture. BIPV

shall be integrated into all phases of the construction process, from conceptual design stage, to construction, to operation and maintenance. Only this way, BIPV can evolve from a niche building technology to a mass market one.

CONCLUSIONS AND OUTLOOK

A climate-resilient built environment is inheritably an energy-resilient one, able to mitigate and adapt to critical short-and long-term impacts. BIPV are expected to play a key role to the transition from a centralized carbon-intensive power generation to a distributed, resilient and renewable generation.

Recent technological advancements on coloured BIPV and power electronics have created new architectural opportunities allowing BIPV to virtually cover any building surface with access to sunlight (e.g. from roofs and walls, to windows and balcony balustrade).

Further BIPV R&D is necessary to assess and optimize BIPV coupled with storage for demand response, grid ancillary services and supply of on-site electricity for critical loads during extreme weather phenomena (e.g. ice storms, heatwaves and floods).

Greater coordination among all stakeholders and members of the BIPV value chain presents business opportunities for new revenue streams. Flagship building projects across the country can also help accelerate the market deployment and acceptance of BIPV (Table 1).

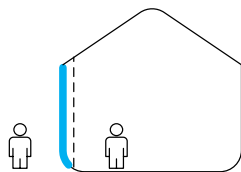
Finally, the Canadian regulatory framework and training of building professionals need to evolve accommodating BIPV envelope multifunctionality.

Table 1. BIPV application categories and performance requirements specific to each category, adapted from IEC 63092 standard.

BIPV Application Category	Pictogram of BIPV Application	Example of Canadian BIPV Application	Performance Requirements of BIPV Application
Category A Roof-integrated, not accessible to the user from within the building. e.g. gable roof, flat roof, shed roof			<ul style="list-style-type: none"> • Fire safety • Mechanical resistance and durability • Electrotechnical • Hygro-thermal performance
Category B Roof-integrated, accessible to the user from within the building. e.g. skylight, atrium, canopy			<ul style="list-style-type: none"> • Fire safety • Safety and accessibility in use • Mechanical resistance and durability • Electrotechnical • Hygro-thermal performance • Daylight and solar gains • Protection against noise (if applicable)

Category C

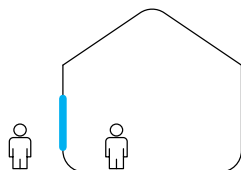
Façade-integrated,
not accessible to the user
from within the building.
e.g. wall, rainscreen,
curtain wall spandrel



- Fire safety
 - Mechanical resistance and durability
 - Electrotechnical
 - Hygro-thermal performance
-

Category D

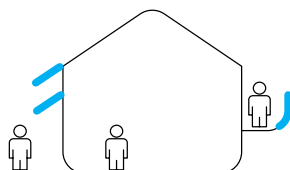
Façade-integrated,
accessible to the user
from within the building.
e.g. window, vision glass
curtain wall



- Fire safety
 - Safety and accessibility in use
 - Mechanical resistance and durability
 - Electrotechnical
 - Hygro-thermal performance
 - Daylight and solar gains
 - Protection against noise (if applicable)
-

Category E

Externally-integrated,
forming an additional
functional layer of the
building envelope.
e.g. balcony balustrade,
sunshade, louvers



- Fire safety
 - Safety and accessibility in use
 - Mechanical resistance and durability
 - Electrotechnical
 - Daylight and solar gains (if applicable)
-

Image credits (top to bottom): Maxime Gagné, Martin Tessler, Gordon Howell, One House Green and David Cigan

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PROVIDING THE MAJORITY OF THE ENERGY NEEDS OF CANADIAN HOUSING BY SOLAR: THE NEED FOR SEASONAL STORAGE

Ian Beausoleil-Morrison
Faculty of Engineering and Design
Carleton University, Ottawa, ON
Ian_Beausoleil-Morrison@carleton.ca

ABSTRACT

The majority of the space and water heating needs of housing in cold climates can be supplied by solar energy, but only if long-term (seasonal) storage is employed to enable solar energy captured during the summer and autumn to be used during winter. This paper explains the necessity of seasonal storage for achieving high solar fractions, reviews the applications to date, and presents an experimental study on seasonal storage that is currently underway at Carleton University's Urbandale Centre for Home Energy Research.

INTRODUCTION

Heating, cooling, and ventilating the places we live in, and providing the hot water, lighting, and appliance services we need, consumes tremendous amounts of energy. This contributes significantly to environmental and energy security issues. For example, housing accounts for 33% of all electricity and 24% of all natural gas consumed in Canada, and produces 13% of the country's greenhouse gas emissions (NRCan 2018).

In most cool and cold climates, space and water heating account for the majority of the energy demand in housing, and therefore offer the greatest potential for savings. If locally available solar energy could be exploited then the majority of these energy demands could be met in an environmentally benign manner. However, this is complicated by the strong seasonal mismatch between solar availability and space-heating needs. For example, in Ottawa approximately 85% of the solar energy resource is available outside the principle space-heating period (mid-November through mid-March).

NEED FOR SEASONAL STORAGE

The potential of solar energy for providing the energy needs of housing can be seen in Figure 1. The left side of the figure displays the total energy needs of three average-size detached houses over the year. The *average* house represents the average energy

consumption of the current Canadian stock of detached houses (NRCan 2018) while the *inefficient* house represents an older home that has not received substantial energy upgrades. The *efficient* house has insulation and airtightness levels beyond current code requirements and exceeds R-2000 levels of performance (NRCan 2012).

As can be seen, space and water heating demands dominate in all three cases. Even in the case of the efficient house, 44% of the total energy requirement is for space heating and 26% for hot water heating (70% of the total when combined). The remaining 30% of the energy needs are electrical and could be serviced by solar photovoltaics. However, solar thermal systems could more efficiently meet the 70% of the building's needs that are for low-grade heat.

The right side of Figure 1 illustrates the total amount of solar irradiance incident upon the opaque envelope of an average-size detached house (two-stories with a footprint of 75 m² and 30° roof pitch) over the year, assuming no shading by neighbouring buildings or objects. It can be seen that regardless of the building's orientation, the total solar energy incident upon the building greatly exceeds the energy requirements, even for the case of the inefficient house.

Contrasting the left and right sides of Figure 1 shows the potential for meeting the majority of a house's energy needs through solar energy, but the story is much more complicated due to intermittancy. This intermittancy issue is illustrated in Figures 2 and 3.

Figure 2 plots the solar irradiance to a 20 m² horizontal surface (size and orientation chosen for illustration purposes only) over two sunny winter days. It also plots the space heating demand of the average house for these days. As can be seen, the space heating demands are lowest around solar noon when passive solar gains are highest, and highest during the night. Conventional solar thermal systems employ diurnal storage—usually in the form of water tanks of a few hundred litres located in the

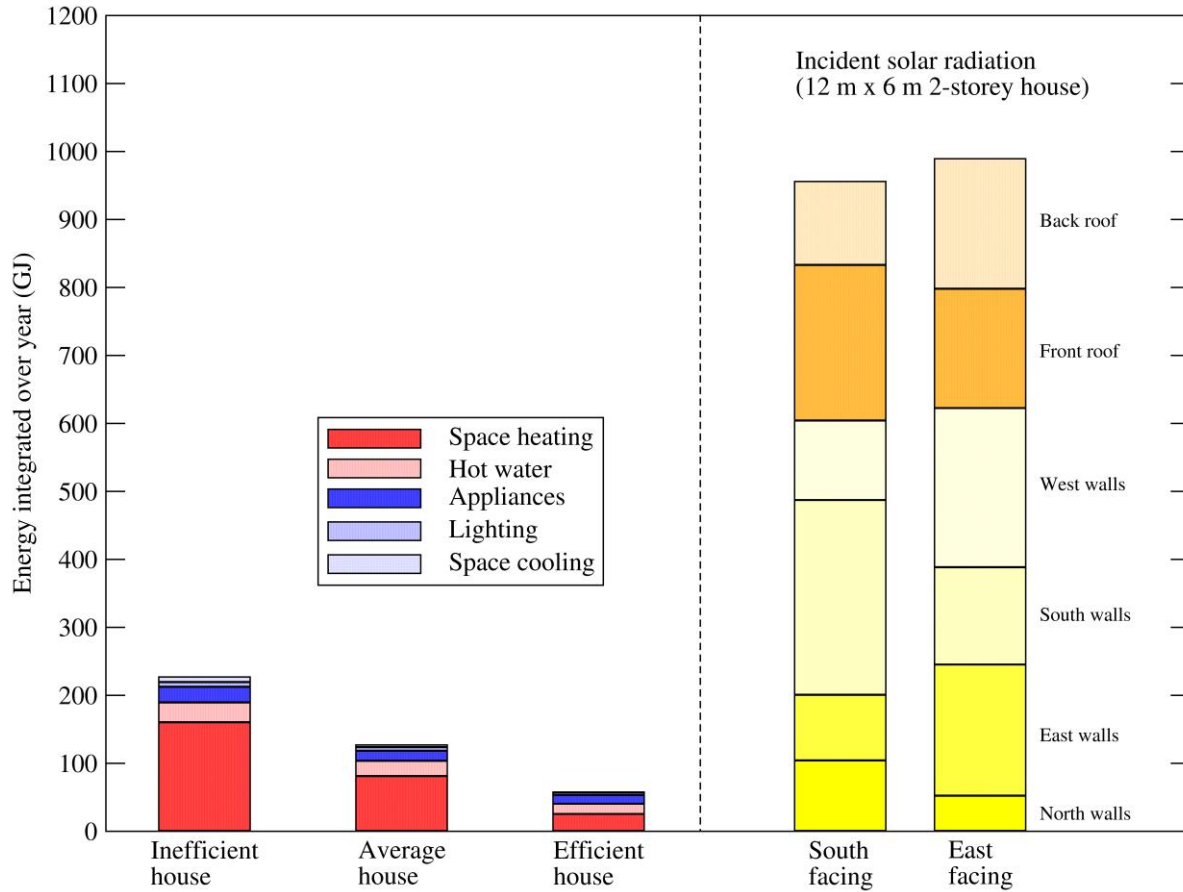


Figure 1. Annual energy demands vs solar resource.

basement—to buffer between this type of mismatch. Such systems can store energy from several hours to a couple of days. In practice they rarely achieve solar fractions greater than 50% (Edwards 2014).

The more significant mismatch between supply and demand is seasonal rather than diurnal. This is illustrated in Figure 3, which plots weekly integrated amounts of the same quantities. The preponderance of the solar resource during the summer period is clearly seen. The figure also shows that the vast majority of the space heating demand—which accounts for the majority of the building’s total energy demand—occurs from mid-November to mid-March. An integration of these two curves reveals that only 15% of the year’s solar resource is available at this time when the building’s needs are greatest.

For these reasons it is clear that high solar fractions can only be achieved if the solar resource from the summer can be captured and stored for use during the winter.

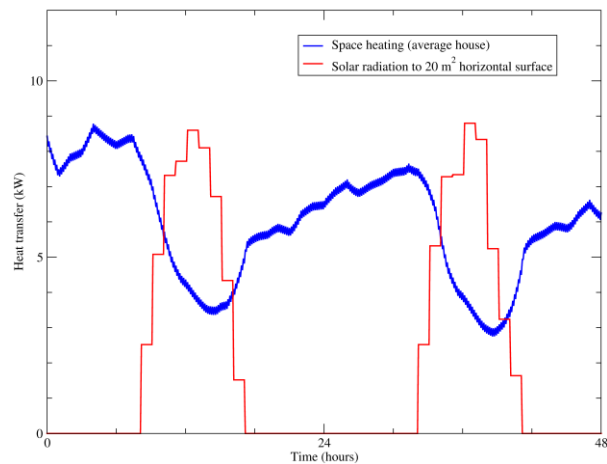


Figure 2. Diurnal mismatch between supply and demand.

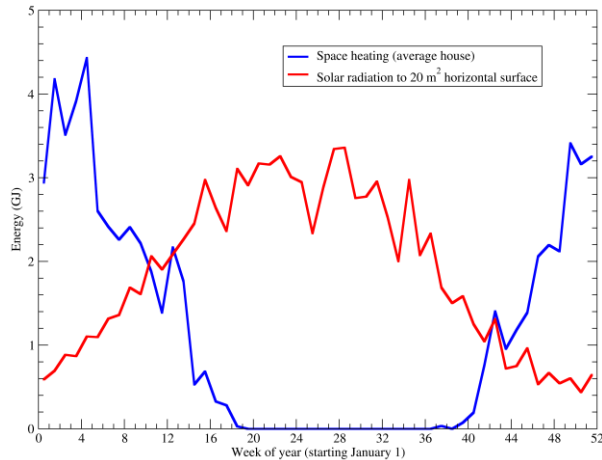


Figure 3. Seasonal mismatch between supply and demand.

SEASONAL STORAGE OPTIONS

Pinel et al. (2011) and Xu et al. (2014) performed extensive reviews of options for seasonal storage of solar thermal energy. The storage mechanisms can be broadly classified as sensible, latent, and chemical (reactions or sorption). Sensible storage relies upon the temperature rise of a medium; latent takes advantage of energy stored and released during a phase transition; and chemical methods make use of reversible endothermic/exothermic reactions.

Latent and chemical storage options offer considerable potential to reduce storage volumes and to reduce heat losses. Although some early applications of chemical storage have been reported (e.g. Köll et al, 2017), as stated by both Pinel et al. (2011) and Xu et al. (2014) these technologies are still in their infancy (at least from an economic perspective). For this reason, most of the seasonal storage applications to date have relied upon sensible storage.

Most applications of solar seasonal storage reported in the literature have been for district or community-scale systems. Ochs et al (2009) report on more than 30 such systems, with an emphasis on tank and pit sensible storage with volumes ranging between 300 and 12 000 m³. In an earlier study, Dalenbäck (1990) reviewed eleven district plants installed in Europe and Canada. These employed several different sensible storage methods, including earth (borehole) storage, insulated tanks, rockpits, and aquifers. Mesquita et al. (2017) report on a community-scale system that serves 52 single-family detached houses. The system is composed of flat-plate solar collectors with a 240 m³ short-term water-based sensible store and a large borehole field for seasonal sensible storage in the soil. According to Furbo et al (2018), as of 2016 there were 110 solar district systems operating in Denmark, with a combined collector (mostly flat plate) area of 1.3 million m².

Although heat losses from the seasonal stores have exceeded expectations in many cases, some of these community-scale systems have achieved high solar fractions for space heating, in some cases exceeding 80-90%.

Most applications of solar seasonal storage have been with community-scale systems because specific storage costs decrease with volume (Pfeil & Koch 2000). Notwithstanding, some authors (Kroll & Ziegler, 2011) have argued the benefits of building-scale systems based upon simulation studies and have shown that the prejudice against such small-scale systems is unfounded. The density of many residential neighbourhoods makes building-scale seasonal storage, despite its higher specific storage costs, an attractive alternative to community-scale systems because of reduced losses from transmission networks due to the proximity between building-mounted solar collectors and the seasonal store. Reduced capital costs for the transmission network and land demands for community-scale stores are other factors to consider.

In another recent simulation-based study, Hsieh et al (2017) examined possible storage options and found that decentralized building-scale systems could outperform centralized community-scale systems, at least for solar fractions in the range of 40% to 50%. Their findings also highlight the importance of having separate diurnal and long-term (seasonal) stores, and that the design and control of the system can have a significant impact upon performance. The development and testing of commercial building-scale seasonal storage tanks employing vacuum insulation is discussed in Fuchs & Hofbeck (2014).

A few experiments have also been conducted on solar seasonal storage at the scale of single-family detached houses. Köll et al (2017) examined the performance of an adsorption storage system in a scaled laboratory experiment in which building thermal loads were mimicked. Evacuated tube collectors were used to charge the seasonal adsorption store and a diurnal water store. They achieved a total solar fraction of 83.5% for the Austrian case they examined. Most other building-scale applications (Besant et al. 1979; Esbensen & Korsgaard 1977; Clarke et al 2014) have employed sensible storage using water.

DESIGN OPTIONS FOR CANADIAN HOUSES

A full-scale experiment of a solar thermal system with sensible seasonal storage has been designed, built, and commissioned at the Urbandale Centre for Home Energy Research located on the Carleton University campus to further the knowledge of seasonal storage at the single house scale for Canadian housing.

The system (see schematic in Figure 4) includes both diurnal and seasonal thermal stores, which can be charged independently or concurrently by the roof-mounted evacuated-tube solar thermal collectors. DHW loads are met by the diurnal store, while space-heating loads are met through a hydronic radiant floor distribution system by drawing hot water from either the diurnal or the seasonal store.

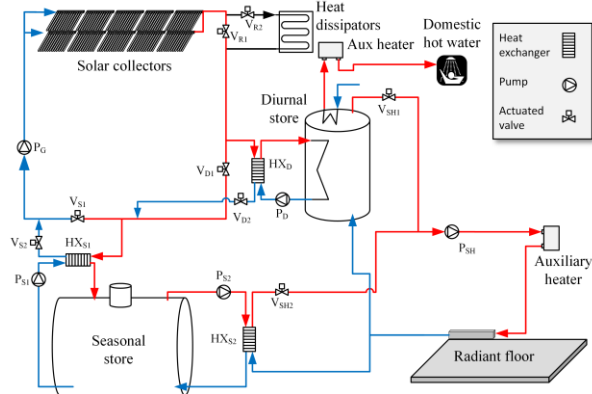


Figure 4. Configuration of solar thermal system with diurnal and seasonal storage.

The diurnal store is located within the house's basement while the seasonal store is buried next to the house. The seasonal tank is of cylindrical shape with rounded ends and has an interior diameter of 3 m. It is fabricated of a fibreglass reinforced plastic resin that has a long-term temperature tolerance of 93 °C. Spray-on polyurethane insulation was applied to the tank to a thickness of 30 cm, and this was protected with another layer of fibreglass reinforced plastic to prevent moisture and structural damage to the insulation. Figure 5 shows the tank located in the ground next to the house's basement, prior to its burial.



Figure 5. Seasonal store in ground next to basement of unfinished house.

The diffuser inlets and outlets—which are designed to encourage thermal stratification within the tank—as well as thermocouple monitoring ports can be seen on either side of the centrally located access hatch in the figure.

Based upon a detailed simulation study this system design is expected to achieve an overall solar fraction (space and hot water heating) over the year of 85-90%.

A second seasonal storage system composed of an insulated box of saturated sand has also been fabricated (Figure 6). This is under investigation as an alternative to the tank storage system. Future experiments may also investigate an adsorption based seasonal storage system.



Figure 6. Sand based seasonal storage system.

CONCLUSION

The majority of the energy needs of Canadian houses is for space and water heating. Although future building codes will require greater levels of envelope insulation and airtightness, the importance of these low-grade energy demands will continue. Therefore, solar thermal is an indispensable technology if we aim to deliver the majority of housing energy needs through solar energy. This paper shows that seasonal storage is a necessary component for a solar thermal system that achieves a high solar fraction. This paper outlines the possibilities for seasonal storage, and then describes ongoing experiments investigate sensible technologies at the single-house scale.

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Miguel F. Anjos, FCAE, holds the Chair of Operational Research at the School of Mathematics, University of Edinburgh, and an Inria International Chair. He is the Schöller Senior Fellow for 2020 at the University of Erlangen-Nuremberg. His research interests are in the theory, algorithms and applications of mathematical optimization. He is particularly interested in the application of optimization to problems in power systems management and smart grid design. He is the Founding Academic Director of the Trottier Institute for Energy at Polytechnique, and President-Elect of the INFORMS Section on Energy, Natural Resources, and the Environment. He served on the Mitacs Research Council since its creation in 2011 until 2017 and is now an Emeritus member. His accolades include IEEE Senior Membership, a Canada Research Chair, the NSERC-Hydro-Quebec-Schneider Electric Industrial Research Chair, the Méritas Teaching Award, a Humboldt Research Fellowship, the title of EUROPT Fellow, and the Queen Elizabeth II Diamond Jubilee Medal.



Dr. Andreas K. Athienitis, FCAE, is a Professor of Building Engineering and Director of the Centre for Zero Energy Building Studies at Concordia University. He holds the NSERC/Hydro Québec Industrial Research Chair “Optimized Operation and Energy Efficiency: Towards High Performance Buildings” and a Concordia University Research Chair. He is a Fellow of the Canadian Academy of Engineering, Fellow of IBPSA and Fellow of ASHRAE. He obtained a B.Sc. in Mechanical Engineering (1981) from the University of New Brunswick and a PhD in Mechanical Engineering from Waterloo (1985). He led as Principal Investigator the NSERC Smart Net-zero Energy Buildings Strategic Research Network and the NSERC Solar Buildings Research Network with over 30 researchers from 15 Canadian Universities and about 30 industry and public sector partners. He was profiled as one of 25 top innovators in Québec by Actualité Magazine. He has published over 300 refereed papers, including seven that received best paper awards, and several books. He played a leading role in the conception and realization of several award-winning innovative buildings such as the Varennes net-zero energy Library. He is currently co-chair of the Canadian Academy of Engineering Roadmap to Resilient, Ultra-Low Energy Built Environment with Deep Integration of Renewables in 2050.



Andrew Pape-Salmon, FCAE, is an adjunct professor with the University of Victoria. Over the past twenty years Andrew has worked with two provincial offices for building and safety standards and energy efficiency. He also worked as a consulting engineer with RDH Building Science, with the City of Vancouver and the Pembina Institute. He specializes in sustainable energy systems, conservation and efficiency, energy and building sector economics and policy, and most recently resilient communities with an interest in seismic risk mitigation.

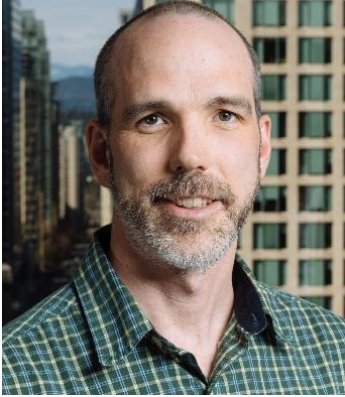


Dr. Chris Kennedy, P.Eng., FCAE, joined UVic in 2016, to chair a new ‘green’ Civil Engineering department, after 18 years at UofT. He conducts research on sustainable cities, biophysical economics and the industrial ecology of global infrastructure. Has been a visiting professor at Oxford University and ETH Zürich; and a seconded to the OECD. Chris is a former president of the International Society for Industrial Ecology; a member of the Global Cities Institute at UofT; and a member of UVic’s Institute for Integrated Energy Systems.



Professor **Ursula Eicker** is the new Canada Excellence Research Chair (CERC) for Next Generation Cities at Concordia University Montréal. A German physicist, Eicker has held leadership positions at the Stuttgart University of Applied Sciences and its Centre for Sustainable Energy Technologies. She coordinated many international research projects in the fields of energy efficiency in buildings and sustainable energy supply systems for more than two decades.

Since June 2019, she leads an ambitious research program to establish transformation strategies toward zero-carbon cities. The 7 year research program receives 10 million CAD government funding and is supported by a further 10 million Dollars by Concordia University, who invests in the city cluster research with five professor positions in buildings and electrical engineering, biodiversity, philosophy and design. The Concordia Next Generation Cities Cluster addresses the challenges of the urban transformation with a transdisciplinary approach and develops tools and strategies for a sustainable future. She has published 7 Books, 23 book contributions, 77 Peer Reviewed Papers and 317 Conference Papers.



Rémi Charron, Ph.D., P.Eng., has over 15 years of experience working to improve energy efficiency and integrate renewable energy on buildings in Canada. He has been working as a senior research and education consultant with BC Housing since 2012. In that role, he has been helping the building industry adapt to the continuously evolving building code requirements. He is also working as an Assistant Dean and Associate Professor for the Master of Science in Energy Management at NYIT-Vancouver.



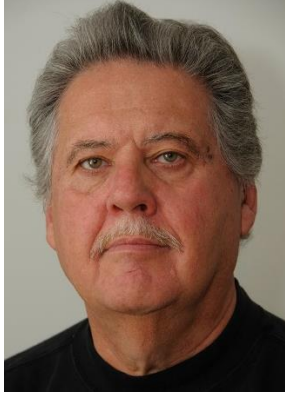
Dr. Caroline Hachem-Vermette is an associate professor at the University of Calgary, School of Architecture, Planning and Landscape. Her research area includes the investigations of multifunctional energy-efficient, resilient neighborhood patterns, solar potential and energy implications of building shapes, building envelope design, developing multifunctional facades for multistory buildings, and others. Her research is multidisciplinary, it plays a bridging role between building engineering and architectural and urban design. She is currently leading a subtask on developing strategies for net-zero energy solar communities, within the International Agency Energy Task (IEA) 63- Planning Solar Neighborhoods. She was also an expert on 2 others IEA tasks on solar energy in architecture and urban planning. She is widely published on the topic of energy efficiency and solar energy, including a book (with Springer) on designing solar buildings and neighborhoods. Dr. Hachem-Vermette is a recipient of a number of awards including the 2019 Peak Scholar Award, 2016 sustainability award, e-sim/ IBPSA award for innovation in modelling, and Hangai prize for young researchers.



Theodore (Ted) Stathopoulos, FCAE, is currently Professor at Concordia University, Montreal, Canada. His research in the area of wind effects on buildings and their codification has been influential in the development of codes and standards around the world. He has an extensive publication record with more than 500 articles in refereed journals and conference proceedings. He is a member of the ASCE 7 Committee on Minimum Wind Loads and the respective committee of the Canadian Code. He is a Fellow of the Canadian Academy of Engineering, the Institution of Civil Engineers and the American Society of Civil Engineers and its Structural Engineering Institute. He is the Editor of the Journal of Wind Engineering and Industrial Aerodynamics. He has been appointed Distinguished Professor in Building Physics, Urban Physics and Wind Engineering by the Technical University of Eindhoven, The Netherlands. He has received an Honorary Doctorate from the Aristotle University of Thessaloniki, Greece; and another one from the Technical University of Eindhoven, The Netherlands.



Dr. Rosamund Hyde is Stantec's Manager of Research and Innovation Services. She holds two degrees in Mechanical Engineering and a doctorate in Civil Engineering, and is licensed as a Professional Engineer in British Columbia and Ontario. After teaching in Canada and working in development in rural Nigeria for three years, she completed her advanced degrees and entered the consulting industry as a sustainable building researcher in 2001. For the past 14 years she has led the growth of research resources for Stantec consultants, managing internal research-related tax savings programs. She established and manages the Stantec R&D Resource eLibrary to make up-to-date technical literature available to Stantec employees worldwide in support of their evolving design work; in the past 10 years, downloads have grown to more than 30,000 articles per year. Dr. Hyde has been active in post-occupancy evaluation of green buildings in Canada, and served on the Canadian Engineering Accreditation Board for 6 years.



Ted Kesik is a professor of building science in the John H. Daniels Faculty of Architecture, Landscape and Design at the University of Toronto with a career focus on the integration of professional practice, research and teaching. His current research involves the development of design guidelines for low-carbon buildings that are resilient, sustainable and promote climate change adaptation. Dr. Kesik continues to practice as a consulting engineer to leading architectural offices, forward thinking enterprises and progressive government agencies.



Dr. Iain A. Macdonald is a senior researcher and team lead of the Integrated Building Performance group at the Construction Research Centre of the National Research Council (NRC), Canada. He is currently the technical lead for the Net Zero Energy Research project which is developing the supporting evidence to enable net-zero energy ready building codes for Canada.



Liam O'Brien, Ph.D., P.Eng., is an Associate Professor in Civil and Environmental Engineering at Carleton University. He is the principal investigator of the Human Building Interaction Lab, which consists of a team of 15 researchers with diverse backgrounds in engineering, architecture, and psychology. His team is developing occupant-centric design processes, building code, and controls for high-performance buildings. He has authored over 150 publications and two books on this topic. He is a co-Operating Agent of IEA EBC Annex 79: Occupant-Centric Building Design and Operation and the past president of the Canadian chapter of the International Building Performance Simulation Association.



Louis Gosselin is a full professor at the department of mechanical engineering at Université Laval. His work mainly focuses on energy efficiency in buildings and industries. He has supervised various research projects based on building monitoring and optimization. The work shown in this presentation consists in the PhD project of second author Jean Rouleau (now a research assistant for Prof. Louis Gosselin). It was part of the NSERC Industrial Research Chair on Eco-responsible Wood Construction (CIRCERB) and realized through a partnership with the Société d'habitation du Québec.



Dr. Chang-Seo Lee is a Research Associate and Part-time Faculty in the Department of Building, Civil and Environmental Engineering at Concordia University in Montreal, Canada. As a Professional Engineer in Ontario, she has an extensive experience in academic research and industrial projects in the areas of building environment, HVAC, air quality, air purification and odor control technologies, and environmental health and safety. Current areas of interest and activity include research and development of advanced air cleaning systems, modeling and development of photocatalysts, evaluation of ozone monitoring technologies and abatement systems. She is actively involved in ASHRAE Technical and Standard Committees including TC2.3, TC2.9 and SSPC145. At Concordia University, she teaches Building Science, and Indoor Air Quality & Ventilation.



As R&D Manager, **Meli Stylianou** is responsible for a team of researchers and engineers involved in research leading to the development of technologies as well as innovative tools that support the national energy codes as well as the implementation of these technologies for the design and retrofit of housing and buildings.

Prior to his current responsibilities, he was the Acting Director for the Renewables and Integrated Energy Systems, and as such was responsible for research programs in Wind, Marine and Solar Energy as well as in Integrated Energy Systems applied to housing and buildings.

He led the Canadian team in the International Energy Agency's Annex 25 developing the first diagnostic tools for high performance buildings and developed and presented material to the Canadian consulting engineering industry that led to the adoption of new ways of tuning commercial buildings.

He has been an invited speaker to a number of industry forums and is the recipient of ASHRAE's Willis H. Carrier as well as the AQME Energia awards.

He is currently the Canadian representative on the IEA Energy in Buildings and Communities Technology Collaboration Program.



Marianne Touchie is an Assistant Professor jointly appointed in the Departments of Civil & Mineral Engineering, and Mechanical & Industrial Engineering at the University of Toronto. In her Building Energy and Indoor Environment (BEIE) Lab, Dr. Touchie's research team focuses on improving the energy performance and indoor environmental quality of existing buildings to make them more comfortable, healthy and sustainable through comprehensive retrofits. This work includes field monitoring of building energy performance and indoor environmental parameters as well as occupant behaviours and perceptions through surveys. Much of her research has been in the high-rise residential sector and particularly social housing buildings. Dr. Touchie is also the President of the Building Science Specialist Board of Canada and the Chair of ASHRAE's Technical Committee 2.1 of Physiology and Human Environment.



Costa Kapsis is an Assistant Professor in the Department of Civil and Environmental Engineering at the University of Waterloo. His research is focused on questions of energy efficiency, solar energy generation and energy transaction in the built environment. These research efforts aim towards the evolution of (i) building envelope technologies, (ii) climate-resilient cities and communities and (iii) energy integration between the building and transportation sectors. Costa serves as an associated editor of the Architectural Engineering journal and co-leader of the IEA PVPS Task 15 Subtask C on the development of Building Integrated Photovoltaic (BIPV) technical guidelines.



Ian Beausoleil-Morrison has worked for the past 13 years at Carleton University, where he is a professor in the Faculty of Engineering and Design. Prior to moving to academia, he worked for 17 years at CanmetENERGY on building energy efficiency, principally on the development of building energy models and simulation tools. He recently published a textbook on the fundamentals of building performance simulation, has authored 44 articles in peer-reviewed journals in the past 6 years and has delivered conference keynote talks in Japan, Italy, the UK, the USA, and Canada, as well as appearing as a witness to the Standing Senate of Canada's Committee on Energy, the Environment, and Natural Resources. He is a past president and Fellow of the International Building Performance Simulation Association, and co-founded and co-edits the *Journal of Building Performance Simulation*, one of the top-ranked journals in construction and building technology.



Marianne Armstrong is Director of Stakeholder Engagement and Management with Canada's National Research Council (NRC) Construction Research Centre. In her current role she is managing research in support of Provincial and Territorial priorities for building codes, as well as engaging key stakeholders in the transformation of the current National codes system. From 2016-2019, she managed the Climate Resilient Buildings & Core Public Infrastructure initiative to integrate climate resiliency into Canadian building and infrastructure codes, standards and guidelines. For over a decade, Ms. Armstrong also conducted residential energy efficiency research at the Canadian Centre for Housing Technology, where she helped to assess the performance of over 60 different housing technologies. Ms. Armstrong is a member of the Professional Engineers of Ontario, holds a MSc Industrial Design from University of New South Wales, Sydney, and a BSc Mechanical Engineering from Queen's University.



Christian Bélanger joined Hydro-Quebec’s Research Institute in 2016. He is currently Director of Research, Strategic and Cross-Functional Projects. In this role, he is responsible for the partnerships and the corporate technology vision in relation to this Direction.

Prior to joining Hydro-Quebec, Mr. Bélanger worked in Research & Development in various organizations in the chemical, materials and automotive sectors, in Europe and Canada. He has extensive experience in innovation management in both the public and private sectors.

Mr. Bélanger received his Ph.D. from McGill University in Chemical Engineering in 1992 and his engineering degree in Physical Engineering from École Polytechnique de Montréal in 1986. He owns an EMBA from Concordia University.



Bryan Purcell is the Vice President of Policy and Programs at The Atmospheric Fund (TAF), an award-winning public agency dedicated to addressing climate change in the Greater Toronto and Hamilton Area, and a founding member of the Low Carbon Cities Canada partnership administered by the Federation of Canadian Municipalities. Bryan’s work focuses on accelerating decarbonization through development of innovative policies, programs, and business solutions. Bryan has been instrumental in designing and implementing a range of climate solutions, including TAF’s non-debt Energy Savings Performance Agreement which has been used to finance major energy retrofits in over twenty buildings housing over 2500 households. Bryan played a key role in the development of the Toronto’s Transform TO Climate Plan and the Toronto Green Standards for new construction, and advises cities around the region on climate policy and programs including through the Durham Community Energy Plan Steering Committee.



Sophie Hosatte-Ducassy has been working for Natural Resources Canada (NRCan) since 1992, at CanmetENERGY research center located at Varennes, Quebec, focusing on developing and implementing clean energy solutions, and building on knowledge that helps produce and use energy in ways that are more efficient and sustainable. She has been the Director of the Buildings Group managing over 35 researchers and engineers in advancing the development of renewable heating and cooling technologies as well as optimizing building operations. The group is also involved in several deployment initiatives on behalf of other government departments advancing the Science and technologies priorities of the Government of Canada. For instance, it provides technical support to federal departments to help them meet their GHG emission reduction targets in the Greening Government Operation initiative; a strong established collaboration with DND and DRDC for many years to help them reduce their diesel consumption, in particular for their mobile camps. The results raised interest from the NATO Science for peace and Security Program and the Canadian Red Cross, with which collaborations are in place.

Sophie Hosatte has been representing Canada in several international, multilateral research groups including the International Energy Agency Heat Pumping Systems Technology Collaboration Program, which she chaired from 2004 to 2014, as well as the Mission Innovation - Innovation Challenge #7 on Affordable Heating and Cooling. Sophie holds an engineering diploma and a Ph.D. in Mechanical Engineering, from France.



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Roadmap to Resilient Ultra-Low-Energy Buildings with Deep Integration of Renewables

Dr. Andreas Athienitis, P.Eng., FCAE | Concordia University

Dr. James Bambara | Concordia University

Dr. Rosamund Hyde, P.Eng. | Stantec

Dr. Chris Kennedy, P.Eng., FCAE | University of Victoria

Andrew Pape-Salmon, P.Eng., MRM, FCAE | University of Victoria

cae-acg.ca
info@cae-acg.ca

300-55 Metcalfe Street
Ottawa, Ontario K1P 6L5

(613) 235-9056