Two Degrees Celsius

Assessing the Potential of Urban Commercial Buildings in Canada to Reach the 2°C Climate Change Target

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

To avoid the catastrophic effects of climate change, scientific consensus and international convention have determined that the mean rise in global temperatures must be limited to between 1.5°C and 2.0°C. The Intergovernmental Panel on Climate Change suggests the building sector possesses the most immediate mitigation potential and has proven technological and design capability at hand. To meet this goal, a 55% reduction is required compared to a proposed Business-As-Usual Scenario forecast in emissions between 2005 and 2050. For Canadian commercial buildings, this is equivalent to emissions dropping from 88.4 MtCO_2e to 39.8 MtCO_2e/yr.

Between 2005 and 2050, the floor area of commercial building is expected to double from 654.2 million m^2 to 1,139.5 million m^2 while the emissions are to be halved. The proposed model suggests that, by 2050, new and substantially renovated buildings should emit 15.3 kgCO_2e/m^2/yr to achieve this. When combined with existing buildings, the blended emissions cap is expected to be 34.9 kgCO_2e/m^2/yr. Given that in 2013 new, renovated, and existing buildings in Canada was 46.67 kgCO_2e/m^2/yr, this ambitious target implies a significant transformation of commercial buildings

When consistently applied to every building, the 15.3 kgCO_2e/m^2/yr rate suggests an evolving approach to design. This is especially true for urban sites where passive design and renewable energy opportunities are limited. Although there are a number of built projects that meet the criteria, they remain the exception rather than the norm and deploy a maximum of energy efficient technologies and design strategies. A full range of innovative passive and active building technologies is leveraged, and many examples are most often not situated in a dense urban environment.

Using an emission rate per square metre reflects a "bottom-up" approach to transforming Canadian commercial buildings. Rather than relying on sweeping policy intervention or mandating particular technologies, this metric can be used to bring the various drivers of emissions together for a particular building, thus allowing the most applicable technologies and strategies to be selected on a case-by-case basis. The thesis will demonstrate that a suite of measures focused on the combination of energy conservation and fuel choice can not only achieve this target on urban projects with limited passive means but suggest that the adoption of further passive and active technologies could push performance even further.

To investigate the implications of the emission cap in this context, a demonstration project is proposed and sited in three different locations on a prototypical urban block. Located on a north-facing end-block, a mid-block, and a south-facing end-block site, each is designed to both current code requirements and the 2°C scenario emission limit. The selection of an urban context bridges the gap between the ideal conditions of rural or campus buildings, where few obstructions to leveraging passive design and implementing extensive on-site renewable energy systems exist, and urban buildings with tight sites and limited passive opportunities. With the world now predominantly urban, these sites are expected to represent the norm. Pablo Picasso saw constraints as sources of inspiration and invention rather than limitations to creativity. Similarly, rather than being a limitation to design, this thesis will show that it has the opportunity to become a foundational design driver motivating invention and innovation within the field's practical and conceptual foundations.

Acknowledgements

I would first like to thank my supervisor, Prof. Terri Meyer Boake. Her leadership, comradeship, and mentorship helped to direct the genesis of an idea into a series of focused questions that could be answered in a reasoned and thoughtful way. To my committee members Dr. John Straube and Dr. Geoff Lewis, your challenging questions and focused feedback were both essential and enlightening to successfully completing this work. To my entire committee, your expertise and your experience not only made our conversations challenging and illuminating, but most enjoyable and immensely insightful. I cannot thank you enough for your patience, your support, and your contributions.

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Dedication

It gives me great pleasure to dedicate this thesis to my parents, David and Peggy. Your unwavering support, love, and endless patience made this possible. Your curiosity, creativity, world experience, and humour have taught me to challenge and question the world around me and to never stop exploring. To my brother, Nick, your tough love motivated me keep at it.

To my partner Mark, thank you for your love and your patience; you are a rock. You challenge me, keep me grounded, and getting across the finish line is in large part due to your unwavering support.

To Uncle Alan, who's time was far to short. Your work on the problem of climate change inspired me.

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List of Abbreviations

AR4	The Fourth Assessment Report produced by the Intergovernmental Panel on Climate Change.
ASHRAE	The American Society of Heating, Refrigerating and Air Conditioning Engineers. Publishes standards for mechanical systems have been widely adopted by various authorities as mandatory or ideal performance requirements.
ASHRAE 90.1-2010	Energy Standard for Buildings Except Low-Rise Residential Buildings
ASHRAE 189.1-2011	Standard for the Design of High Performance, Green Buildings
CSA	Canadian Standards Association
CFC	Chlorofluorocarbon. CFC compounds have been found in refrigerants and propellants and have since been phased out under the Montreal Protocol due to their significant contribution to ozone depletion.
COP	Coefficient of Performance. It refers to the useful heating or cooling provided to work required for building heating, cooling, and air conditioning equipment.
DHW	Domestic Hot Water
HFC	Hydrofluorocarbon. HFCs have been sought as a replacement for CFC compounds and are used as refrigerants, propellants, and fire suppression systems. Although they do not have the same damaging effect on the ozone, they do have high Global Warming Potentials that have exacerbated climate change.
HVAC	Heating Ventilation and Air Conditioning equipment.
IPCC	Intergovernmental Panel on Climate Change, the United Nations organization tasked with collecting and disseminating the science and mitigation efforts of climate change globally.
IEA	International Energy Agency is an autonomous organization created in 1974 with two purposes: promote energy security and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The energy statistics and analysis have emerged as one of the fundamental sources of data and is referenced by most organizations studying energy and climate change, including the IPCC.
IGU	Insulated Glazing Unit.
ISO	International Standards Organization is the worldwide federation of national standards bodies.
ISO 14064	The ISO Greenhouse Gas Standard is comprised of the following three parts: Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancement Part 3: Specification with guidance for the validation and verification of greenhouse gas assertions

ISO 14040	The ISO Lifecycle Assessment Principles and Framework Standard includes the definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the Lifecycle Impact Assessment (LCIA) phase, the lifecycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements.
LEED	Leadership in Energy and Environmental Design is the leading third-party GBA tool in North America. 48 individual credits, associated with a particular sustainable building issue, are grouped into five categories including Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, and Innovation in Design. Credits reference recognized standards published by The US Environmental Protection Agency, ASHREA, the CSA, amongst others. A rating of Certified, Silver, Gold, or Platinum is awarded based upon the number of credits achieved.
LPD	Lighting Power Density. This refers to the amount of power consumed by lighting per square metre or square foot. The metric units are Watts per Square Metre (W/m^2)
NOAA	National Oceanic and Atmospheric Administration. It is a scientific agency within the United States Department of Commerce that measures and studies conditions in the oceans and atmosphere. Amongst other subjects, NOAA measures the concentration of greenhouse gassess in the astmosphere.
NRCan	Natural Resources Canada is the government ministry that is tasked with, amongst other things, managing energy on a national level. It is also the source for energy use statistics.
NREL	National Renewable Energy Laboratory is the United States Department of Energy's primary national laboratory for renewable energy and energy efficiency research.
OBC **OBC SB-10**	Ontario Building Code Ontario Building Code Supplement 10 - Energy Efficiency in Buildings
OECD	Organization for Economic Co-operation and Development was constituted in 1961 and is the evolution of the organization that administered the Marshall Plan for the reconstruction of Europe following World War 2. There are 34 member nations and they together represent the wealthy, developed economies in the world, with some emerging nations with close economic ties such as Mexico and Turkey.
PV	Photovoltaic Panels
SHGC	Solar Heat Gain Coefficient. This refers to the fraction of incident solar radiation admitted through a window, both directly transmitted and absorbed and subsequently released inward.
ULC	Underwriters Laboratory of Canada. Established in 1920, the ULC examines, tests, and certifies appliances, equipment, materials, constructions and systems to determine their relation to life, fire and property hazards as well as providing inspection services.
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change, a response to the challenge of climate change at the Earth Summit in Rio de Janero in 1992.
WWR	Window-Wall Ratio. This fraction measures the area of glazing relative to the area of a building enclosure.

Fig. 1.1
The Bullitt Centre Net-Zero Office Building
Seattle WA, USA

Fig. 1.2
Aldo Leopold Centre Carbon-Neutral Building
Baraboo WI, USA

1.0 Introduction

At the fifteenth Conference of Parties (COP-15) meeting of the International Framework on Climate Change at Copenhagen in 2009, the global community agreed that climate change should be limited to 2ºC[1]. Six years later, at the COP-21 Conference in Paris, the target as revised to a limit of between 1.5°C and 2°C[2]. The target was made more stringent in the light of the gap between emission reductions and pledges since the Copenhagen Accord where emissions by 2020 are expected to overshoot the 2°C target. Instead of returning the climate to its pre-industrial state by the end of the century, some warming and the associated environmental implications are inevitable. Still not an easy feat, this relaxed commitment requires the concentration of greenhouse gas emissions (GHG) in the atmosphere, measured in parts-per-million (ppm), to peak by the end of 2020 and stabilizing at approximately 450-ppm, with an upper threshold of 500-ppm[3]. To put this in context, if emissions in the year 2000 remained constant, mean temperatures would be expected to rise between 0.6ºC and 0.9ºC. However, emissions have continued to rise an average of 1.5% per annum since then. This Business-As-Usual (BAU) condition is suggested to result in runaway climate change with annual emissions in 2030 of 70 $GtCO_2e$ that continue grow to nearly 90 $GtCO_2e$ by 2050. This prediction suggests a rise in mean temperature of between 4ºC and 6ºC, more than twice the new accepted threshold of 2ºC[4].

In addition to setting targets, a key feature of the Kyoto Protocol is the standardization of reporting and measurement of emissions and their allocation into categories. Energy, industrial processes, land-use changes, agriculture and waste are the five primary sectors that in-turn support and interact with a large number of various end-uses that include, amongst others, transportation, buildings, deforestation, and steel production. The 2ºC scenario requires that all sectors and end-uses together reduce emissions by 30% compared to 1990 levels, equivalent to annual emissions of between 18-29 $GtCO_2e$[5].

The construction, operation, and demolition of buildings is suggested to consume 30% of global energy, 40% of all mined resources, and be responsible for nearly 50% of global emissions when all these aspects are considered[6, 7]. This sector presents one of the most cost-effective and readily-available methods to rapidly reduce global emissions and offers the potential of economic return[8]. Although the adoption of sustainable building practices in North America is taking hold and completed carbon-neutral buildings exist, the widespread adoption of design techniques that meet or exceed the 2ºC Scenario continue to remain elusive. Compared to the broad scope of many Green Building Assessment tools (GBAs), such as LEED and BOMA BEST, the issue of climate change is a much more specific problem[9].

However, the reality is that building sector emissions have grown since the Kyoto Protocol was signed in 1990. The share attributed to the commercial and institutional building sector continues to accelerate with a 2.2% annualized growth over the past 30 years, the past 5 years of which has increased to 3%[10]. In Canada the growth of emissions has kept pace with construction. The trend of declining energy use intensity (EUI), or how much energy is used to heat, cool and light conditioned space and measured in kilowatt-hours per square metre (kWhr/m^2), has been offset by the growth in auxiliary loads, predominantly driven by a steady increase in electronic devices in day-to-day use[11]. Without change, Natural Resources Canada (NRCan) predicts growth in commercial and institutional floor area is suggested to drive up emissions at an annualized rate of 1.5%[12].

The mitigation studies selected for this study suggest that building emissions be reduced by between 49% and 100% by 2050, compared BAU projections. These are presented in detail in Chapter 4.0. The calculated median of these targets requires building fossil fuel emissions to be slightly below 2005 levels. Specifically for Canada, the median of these global mitigation scenarios is a 55% reduction compared to the Business-As-Usual case, modelled in this study, where 2050 emissions are suggested to be 39.76 Mt-CO_2e, equivalent to an annual emissions budget of 15.3 kgCO_2e/m^2.

In this context of rising emissions and looming irreversible climate change, the world has made the transition from being predominantly rural to predominantly urban for the first time in history. The majority of construction will occur in cities, both formally and informally. In the United States alone, the Architecture 2030 Initiative suggests that this will equal to over half of the existing stock of buildings, with the developing world rapidly building many times its existing stock as GDP and socio-economic development continues to improve. The calculated trend, based on data for the years 2006 to 2012, suggest that in Canada, the total area of commercial buildings will double by the year 2050[13].

Urban sites present their own unique challenges to low-energy and low-carbon design compared to low-density or rural contexts. Sites are many times built out to the lot-line, limiting the amount and location of glazing. The surrounding built fabric, tree canopy, and orientation are often contrary to the requirements of passive design. For example, a principle street facade may face west or north and require larger than ideal glazing areas for shop-fronts while the south facade may be abutting an adjacent building, precluding glazing for passive heating. Limitations to the size or type of on-site renewable energy systems may yield an installation that cannot not meet the energy demand of even the most efficient building. However, these challenges in no way preclude urban buildings from a climate constrained future; in fact the opposite is true. The benefits of density range from supporting public transit and walkability to creating vibrant and lively streetscapes and public places that are desirable from sustainable, economic, design, and livability points of view.

1.1 Research Objectives

The primary goal of this research is to understand how new construction located in existing urban fabrics can achieve the achieve deep cuts in Scope One and Scope Two energy-related emissions required to limit climate change to 2ºC. A review of climate change mitigation scenarios that address the building sector specifically are analyzed and applied to the Canadian context to identify that an emissions cap of 15.3 kg/m^2/yr, is required. This is based on a combination of energy consumption and fuel source emissions intensity. To isolate the implications of an existing urban fabric and test the proposed emission cap against current practice, an energy simulation is conducted for a demonstration project sited in three different conditions within a prototypical block on a street typified by Ossington Avenue in Toronto, Ontario. The same building is sited on the two end-block sites, with the primary exposed first to the north and second to the south, and the mid-block with adjacent buildings abutting two sides . In each site situation, the requirements of the local code, in this case the current Ontario Building Code, will be compared to a project that achieves the 2°C emission cap. The establishment of an emissions cap and the following comparison of site conditions and performance standards will allow the following questions, critical for the building sector in Canada to meet its climate change mitigation obligations, to be addressed:

- What is the greenhouse gas emission target required for the commercial buildings to meet the 2ºC scenario in the Canadian context;
- What is the gap in current practice, represented by a demonstration project that meets the local Building Code, required to meet these emission targets
- Can a newly constructed urban building meet the energy and carbon footprint targets required by the 2ºC Scenario; and
- How do the limits of site and surrounding urban morphology, pressures of climate region, and energy fuel source affect the ability of a building to meet these targets.

1.2 Structure of the Thesis

The overall structure divides the research into two parts . The first discusses the greenhouse gas emissions (GHG) context for buildings in both the local and global context. A study of global mitigation scenarios follows and is used to derive a performance-based emission cap, measured in kg-CO_2e/m^2, that will be required by commercial buildings to limit climate change to 2°C. This approach suggests a "bottom-up" approach where a performance target is used to influence and identify project-specific design criteria. The second part evaluates this emission cap and its associated implications for buildings in an urban setting by analyzing a modest demonstration project located in three site conditions within a prototypical urban block. For each site, the same building is designed to both the standards of the local code and the 2°C mitigation emission cap. The comparison of results will suggest gaps in current practice and the challenges presented by constrained urban sites.

Chapter Two defines the GHG emissions context and the problem of climate change. It begins by introducing the concept of the 2ºC Scenario and the current state of greenhouse gas emissions. Using the international standards defined by the Kyoto Protocol, the primary and end-use categories for emissions allocation are outlined. The specific boundary of building-sector is identified and situated in this larger context.

The third chapter isolates building greenhouse gas emissions within the context of international standards of measurement and allocation. These are emissions resulting from Scope One and Two operating secondary (site) energy consumption while Scope Three embodied energy consumption from material use over a defined life-cycle are excluded. This boundary avoids double-counting industrial and power generation sector emissions and ensures consistency with the allocations used in international studies on climate change mitigation.

The important differentiation between building impacts on the environment, outlined in comprehensive Life-Cycle Assessements, and the specific issue of greenhouse gas emissions allocated to the building sector by international convention is discussed.

Chapter Four suggests that an emission cap of 15.3 $kgCO_2e/m^2$ for new and substantially renovated Canadian Commercial buildings is required by the 2°C Scenario. This is determined by first identifying six studies that comprehensively model global emission scenarios consistent with limiting climate change to 2°C and allocate Scope One and Scope Two emissions to the building sector. Many studies, for example, only include Scope One emissions. The mitigation scenarios proposed a wide range of reduction targets and a median value of 55% by 2050 is identified. Applying this value is applied to a simplified Business-As-Usual emissions forecast for commercial buildings up to the year 2050 using the decomposition method of measuring sector emissions from the Canada Emission Trends 2015 Report; the document the Canadian Government uses to track progress towards meeting international commitments. The 55% median reduction value is applied to it to establish the maximum permitted emissions, equivalent to 15.3 $kgCO_2e/m^2$. A formula is proposed using this cap in a "bottom-up" method to determine performance requirements of constituent emission drivers for any given project, site context, and region in Canada. It does not rely on broad policy interventions, such as requiring the use of all electricity or the use of a given technology while taking into account the regional differences in emission drivers across the country.

Chapter Five introduces six built examples of low energy or low carbon commercial buildings and a study by the National Renewable Energy Laboratory on performance standards for achieving net-zero. Generally, the case studies suggest that "best-in-class" energy efficiency is required and that buildings that meet this performance target did so because they had specific institutional goals or were a "one-off" property to attract specific tenants. The conclusion suggested is that standard buildings fall short. The case studies represent both rural and urban examples and suggest that the strategies and technologies are largely applicable in each site context with the exception of several passive design strategies. Nevertheless, both urban and rural examples share similar Energy Use Intensities. Strategies, such as high performance building envelopes, insulation value, and air tightness, are common The case studies are used to provide a starting point for exploring the possible measures to achieve the 2°C Scenario.

Chapter Five explores the implications of the 2°C Scenario on buildings inserted into existing urban fabrics relative to current practice. A 2,135m^2 four-storey office and retail building is tested in a prototypical block with a 23.0m Right-of-Way and represents an urban context similar to Ossington Street in Toronto. This typology and context is chosen for several reasons. Tall buildings are examples of very high density and have unique challenges for sustainable and low-energy design. Secondly, mid-rise buildings situated in multi-building blocks represent a large proportion of commercial buildings and are suggested to be of a density appropriate for sustainable, walkable and mixed-use urban fabrics. Finally, its simplicity of energy simulation ensures more accurate results. To test the implication of the 2°C target on constrained urban sites, three site conditions are tested, a two corner and a mid-block site. Each site will feature the same building designed to the standards of the local code, in this case the Ontario Building Code, and then designed to achieve the 2°C target. The three site conditions and two performance variations are compared to identify the gap in current practice, demonstrate the "bottom-up" methodology proposed by the emissions cap, and identify how the fundamental drivers of energy use and fuel source affect overall annual emissions and design choices.

1.3 Research Limitations

The research questions posed are broad and to sufficiently answer them in a way that is at once generally applicable and yet focused requires a limitation of scope and of research goals. Nevertheless, this does imply a number of additional research questions in a number of fields, such as public policy, energy simulation, climate change mitigation, and urban planning. The impact of buildings on the environment are numerous and a building project and should consider all aspects. The following limitations define the scope in order to create the necessary focus.

- The commercial building sector features a wide array of building occupancies, including offices, hospitals, warehouses and schools. Each has a unique energy and emission profile that requires a tailored approach to energy efficiency and mitigation. This thesis focuses on office and retail uses in a mixed-use building as they together represent 70% of the total nonresidential floor area in Canada[14]. Demonstration projects for each typology could be conducted and would be fertile ground for additional research.
- Buildings create numerous impacts on their environment beyond greenhouse gas emissions. Toxicity, water use, waste production and resource consumption are just a few. Lifecycle Assessments are used to measure their total and relative impact and each of these issues is worthy of in-depth research as well as their relative impact to the whole. This research focuses on the greenhouse gas emissions within the ISO 14064 Scope One and Scope Two definitions. Scope Three, including embodied energy of materials, employee commuting and other impacts are excluded.
- Halocarbons are a potent greenhouse gas and result from spray-foam insulation and refrigerants. Global mitigation studies allocate these to fugitive emissions rather than the building sector and, to remain consistent, this study follows suit. Current commitments seek to eliminate halocarbon emissions by 2050[15].
- Creating an energy efficient building is an iterative process and there are innumerable combinations of measures that can be deployed. The 2°C demonstration projects are not intended to be a comprehensive evaluation of the best combination of strategies and technologies. Any given project will value these differently for reasons of cost, site, orientation, use, and owner goals. Thus, the proposed solution is a demonstration the use of the "bottom-up" emission cap as a design tool and makes use of the design method of passive design first, active systems second, and renewable energy third to demonstrate potential. The evaluation of technologies within different contexts is a research question beyond this scope.

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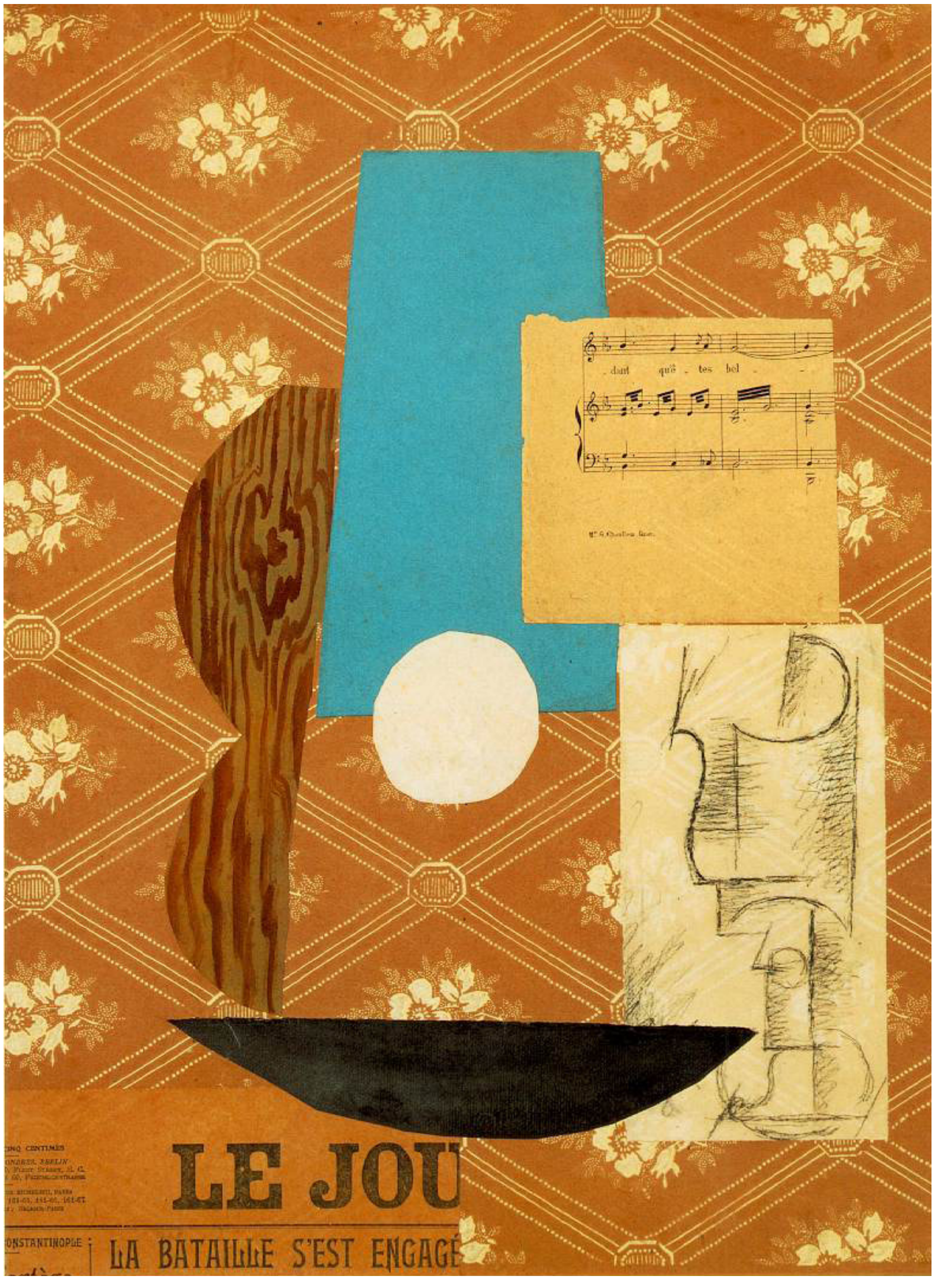


Fig. 2.1
Guitar, Sheet Music and Wine Glass
Pablo Picasso, 1912
Collage

Forcing yourself to use restricted means is the sort of restraint that liberates invention. It obligates you to make the kind of progress you can't even imagine in advance.

Art is the elimination of the unnecessary.

- Pablo Picasso

2.0 The Problem of Climate Change

Fig. 2.2
Indeterminate Facade Building,
SITE, 1974
Houston, Texas, USA

"The economy of means," writes James Wines, "is infinitely more than a prescription for conserving materials, improving operations, and spending less money; it is, most importantly, the product of a reductive sensibility - a special brand of imagination that can transform the condition of frugality itself into an inspirational source of art."[1] Inspired by Picasso's collage works from the early 20th Century, this elegant description of the spartan aesthetic characteristic of his early sculptural works in the late 1960's continues to underpin the philosophy of his multidisciplinary studio SITE. The BEST Showrooms, in particular the 1975 iconic crumbling facade of the store in Austin Texas, exemplify both this reductive aesthetic and the re-contextualization of the emerging "big-box" retail outlet by transforming the most familiar into a bold critique.[2]

It can be argued that this sensibility has since emerged not only as a philosophical approach and artistic ethos, but as a very real constraint for the future of the built environment. Scientific consensus supports the irrefutable claim that human-induced climate change is real. As climate and carbon cycles continue to exceed historic natural limits, our collective challenge has shifted from proving its scientific basis and potential disastrous implications to identifying the means and methods for its mitigation[3]. Observable effects already have begun to manifest themselves as we become increasingly aware that the pool of resources and energy that drive our economies, and the Earth's capacity for absorbing the consequential by-products, now have very real limits. In his book *Collapse, How Societies choose to Succeed or Fail*, Jared Diamond illustrates that history presents countless examples of societies exhausting their resources to catastrophic ends. For our globalized society, ignoring the lessons of the past has even more profound consequences. We now access a global pool of resources and, consequently, use the global biosphere for our waste and effluents.

> *"Thus, because we are rapidly advancing along this non-sustainable course, the world's environmental problems will get resolved, in one way or another ... The only question is whether they will become resolved in pleasant ways of our own choice, or in unpleasant ways not of our choice, such as warfare, genocide, starvation, disease epidemics, and collapses of societies. While all these grim phenomena have been endemic to humanity throughout our history, their frequency increases with environmental degradation, population pressure, and the resulting poverty and instability."*[4]

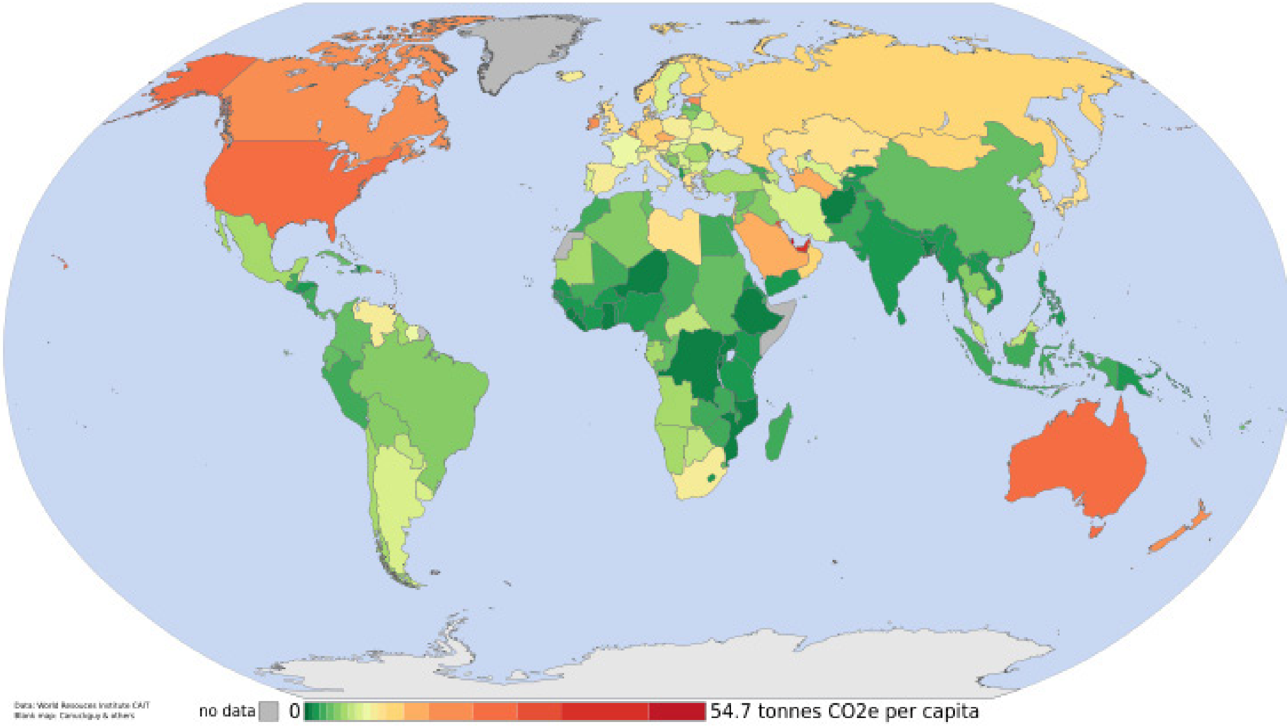


Fig. 2.3
Global Greenhouse Gas Emissions Per Capita, 2002

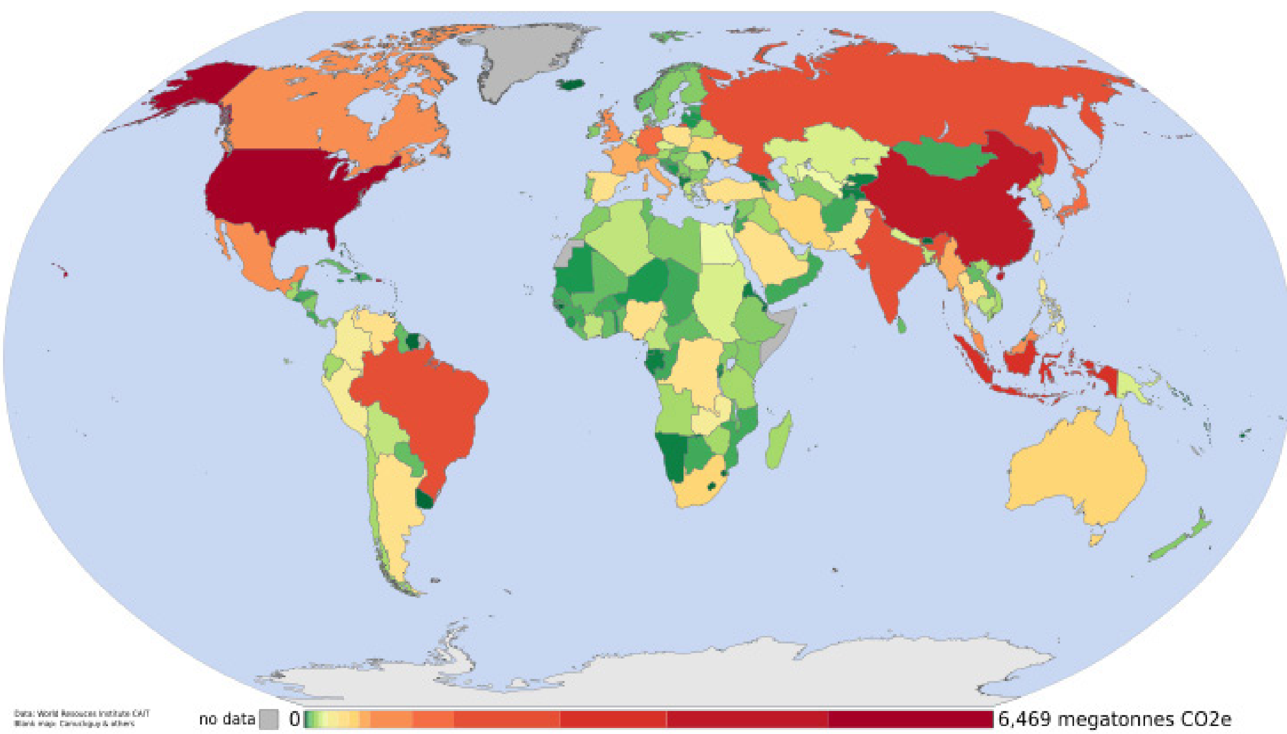


Fig. 2.4
Global Emissions by Nation, 2002

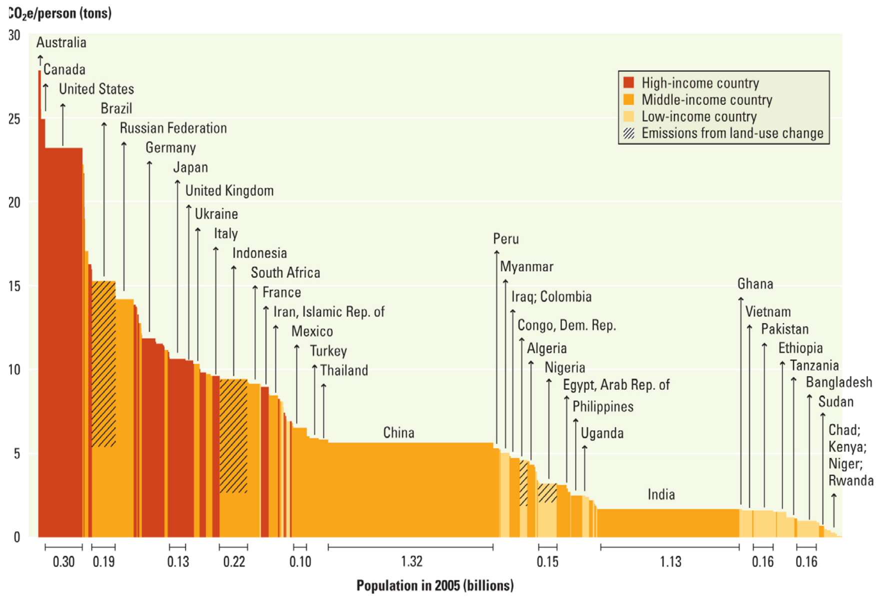


Fig. 2.5 (above)
Per Capita Greenhouse Gas Emissions and Population, 2002 (World Bank, 2009)

The predominant international response to the problem of climate change has been the Kyoto Accord, signed in 1997 at the third Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCC) and its successor agreements. Ratified by 192 parties, 37 nations, including Canada and the European Community, committed to lower the rate of emissions of greenhouse gasses to a global average of 5% below 1990 levels over a period between the years 2008 and 2012. However, as the Accord's first milestone period for emissions reduction in has come and gone, few signatories have made any reductions. As of 2011, none have made their targets[4]. Contrary to its international commitments to reduce emissions by 6% compared to 1990, Canada, the only OECD North American signatory, has instead seen them rise 26.2%, while energy use has increased 30.8%. Although, in many parts of the country the reliance on fossil fuels such as coal and oil for electricity production have waned, emissions have nevertheless grown by 155.6 $MtCO_2e$.[5] This trend is matched globally. Emissions have risen 38.8%, or 7,981.9 $MtCO_2e$ between 1990 and 2007[6]. The Intergovernmental Panel on Climate Change (IPCC) concludes with a high degree of certainty that current climate change policies and sustainable development practices are not able to cope with this increased rate of emissions and expect continued growth, rather than decline, in the coming decades.[7]

Different nations must take different paths when contemplating emission reductions. National and per-capita emissions reflect a variety of socioeconomic conditions that range from Gross Domestic Product (GDP), population growth, level of development, and sources of energy. Historically, the developed world has contributed the majority of anthropogenic emissions by far. However, due to a rapid rate of economic development, the developing world is contributing an ever increasing share. Led by the emerging economies of China and India, emissions from non-OECD countries accounted for over 60% in 2013 and are projected to grow to 70% by 2030[33]. The International Energy Agency forecasts that by 2030 world energy supplies will continue to rely largely on fossil fuels, in developing countries in particular. Coupled with increasing wealth and the emergence of a middle class, energy use is expected to grow by 40% and with it, GHG emissions[8].

A closer investigation of nations responsible for the largest proportion of emissions reveals that increasing energy demand driven by GDP and population growth has been the primary driver of increasing global emissions over the past three decades. Although the developed world is responsible for progressively less greenhouse gasses, over 65% are produced by the world's top ten economies, a group that includes both developed and developing nations. China and the United States, the top two emitters, together produced 11,800 $MtCO_2e$ of a total

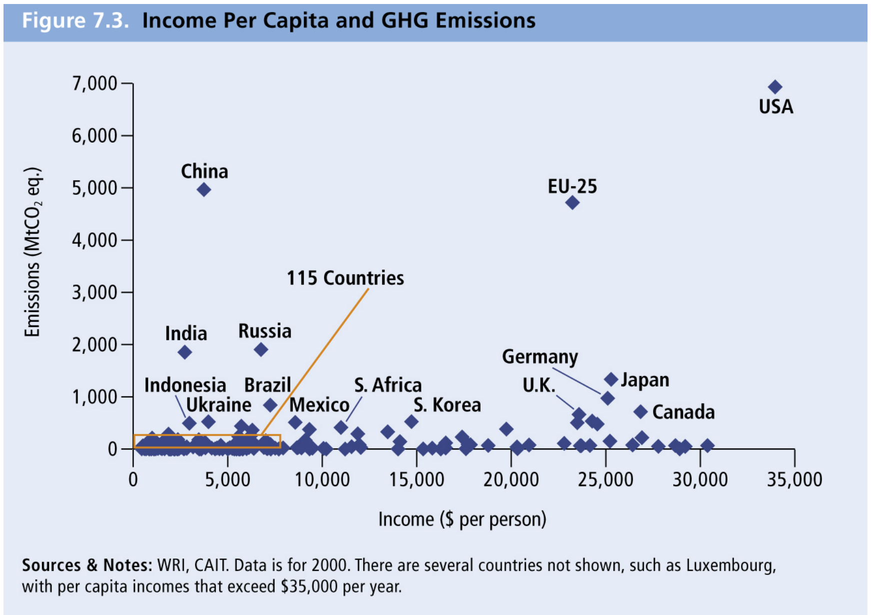


Fig. 2.6 (above)
Per-Capita Emissions versus Gross Domestic Product (World Resources Institute, 2005)

29,000 $MtCO_2e$, over 40%[9]. On the other hand, the per-capita emissions of these two nations reveal a startling difference that reflects the general lifestyle and means by which the populations of these two countries use energy and consume resources. In the United States, 307 million people produce 23.76 tCO_2e per capita whereas China's 1.3 billion people produce just 6.26 tCO_2e. Canada, the 9th largest contributor as a country, has per capita emissions of 21.83 tCO_2e[10]. On an individual level, emissions in wealthy countries continue to overwhelm those in developing countries. Per capita emissions in high-income countries are on average approximately 15.3 tCO_2e, in a middle-income approximately 4.5 tCO_2e while low-income countries, with the majority of the population, per capita emissions are only about 1.3 tCO_2e[11].

Developed countries require substantial reserves of energy and resources to fuel economic growth that, without action, will push emissions past the threshold of irreversible climate change. The relatively low per-capita emissions from developing countries reflects a lack of access to modern energy services rather than an energy efficient economy. However, as economic development continues to accelerate in the developing world, it is neither ethically nor politically acceptable that the world's poor are denied the opportunity to climb the income ladder in an effort to combat climate change. The EU Commission *Roadmap to Developing a Competitive Low Carbon Economy by 2050* and the International Energy Agency, amongst others, support the obligation of the developed world to "make room" for the maturing of emerging economies by reducing emissions by up to 80%.

By 2050, the global population is projected to swell to over 9 billion with a large share achieving a middle-class lifestyle. With current development patterns and fossil fuel sources driving total energy production, the World Bank projects this will result in a tripling of global emissions, a 4-6ºC rise in global temperatures, and irreversible climate change[12]. Although making a significant contribution both to meeting the UN's Millennium Development Goals and to fostering a positive change for millions, the stark reality is that the planet will not be able to sustain

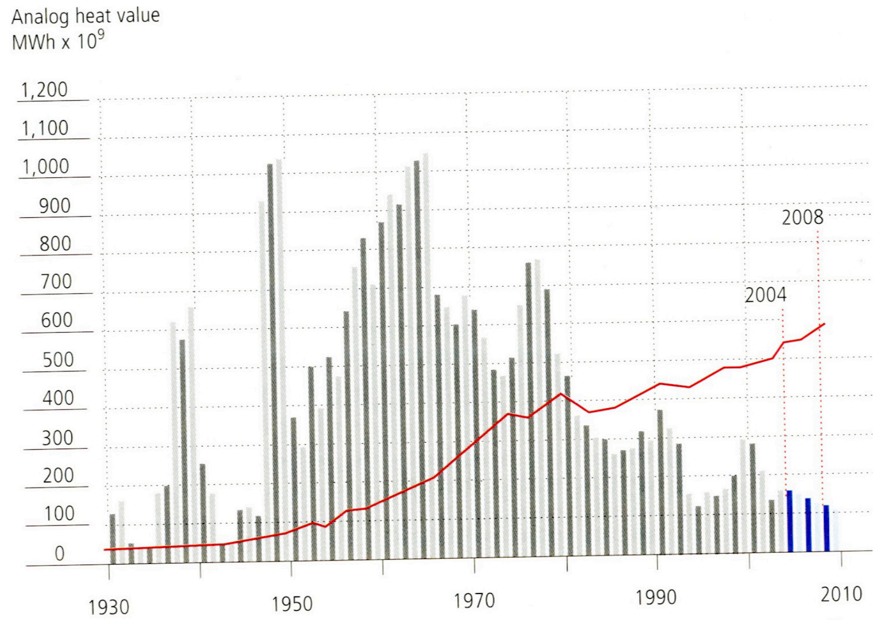


Fig. 2.7 (above)
Global Fossil Fuel Reserves and Projected Consumption
(Energy Design for Tomorrow, 2009)

the resource requirements and resulting emissions and effluents. Ironically, the exploitation of natural resources and the burning of fossil fuels have supported this improvement in social and economic well-being while the threat of climate change and resource exhaustion that are the by-products threaten to undo it. Unmitigated climate change is simply incompatible with sustainable development as rising seas, desertification, extreme weather events, and lower crop-yields stand to plunge these regions back into poverty and instability.

The challenge of rising emissions is compounded by decreasing resource availability. With over 80% of total global energy produced using coal, natural gas and oil, there is a growing consensus that reserves of fossil fuels are peaking and sources are becoming increasingly difficult and costly to obtain. Studies conducted by a range of sources, including the Association for the Study of Peak Oil, British Petroleum, The German solar industry, the IAEA, and the U.S. Geological Survey, estimate natural gas reserves will last between 29 and 66 years, oil 32 - 45 years, and coal, by far the dirtiest fuel, between 180 and 410 years.[13] Estimates vary as different agencies rely on different sources to estimate reserves and consumption levels. Regardless, the trends consistently demonstrate that oil production relies on reserves discovered in the 1980s and, as Figure 1.7 illustrates, demand will soon outstrip supply. If true, this implies that two of the three primary fuels may not outlast not only the current generation, but most buildings designed for any reasonable lifecycle. Compounding the challenge of dwindling reserves, energy costs will inevitably continue rise if the energy mix does not adapt. It is important to note that several agencies, including the IEA, maintain that reserves continue to be discovered. They however rely on alternative oil sources such as oil sands and shales that require large amounts of energy, and consequently emissions, to extract and process while generating extremely hazardous by-products. Arctic and deep sea reservoirs are located in environmentally sensitive and climatically challenging regions. Canada's oil sands industry is an illustrative example where the extraction and processing of oil has been the largest source of national emissions, growing over 246% to 17.8 $MtCO_2e$ per annum between 1990 and 2007[14].

Decision 1.1:

We underline that climate change is one of the greatest challenges of our time. We shall, recognizing the scientific view that the increase in global temperature should be below 2ºC on the basis of equity and the context of sustainable development, enhance our long-term cooperative action to combat climate change.

Decision 1.2

We agree that deep cuts in global emissions are required according to science ... and take action consistent with science and on the basis of equity. We should cooperate in achieving the peaking of global emissions as soon as possible.

- UNFCC Copenhagen Accord, December 19th, 2009[15]

Fig. 2.8 (left)
Survival of the Fattest,
Jens Galschiøt/Lars Calmar, 2009
Cast Metal

Like plastic in a landfill, greenhouse gasses, carbon dioxide in particular, linger in the atmosphere for decades. Consequently, when considering targets there are two thresholds to be considered: the first being a short-term need for a peak in emissions that will lead into the second, being a long term stabilization that looks beyond the year 2050 to the end of the century. Together, the peak and stabilization targets form the basis of any prediction of a change in mean global temperature. The natural concentration of greenhouse gasses is 275 parts-per-million and, prior to the industrial revolution, this balance was sustained by natural forces and cycles. Nature is resilient and studies have concluded that a long-term stabilization of 350 parts-per million is the outer threshold for the natural environment to return to a pre-industrial condition. However, the current concentration of 385 parts-per-million is already beginning to drive ecological change. Manifesting itself through significant reductions in ice sheet coverage, retreating glaciers, and an increase in mean global temperature by 0.6ºC, the window of opportunity for achieving a long-term concentration of 350-ppm may have already closed.

The optimism of the late 1990s that surrounded Kyoto has been unable to cope with the stunning growth the global economy experienced through the first decade of the 21st Century. "Business as Usual" (BAU) sustainable development initiatives, when matched with the projected growth of both demand for energy and the global economy, is expected to lead to irreversible climate change. This realization has lead the scientific community and world leaders to now accept that the some warming, regardless of action on climate change, is inevitable. As opposed to stopping it altogether, the question has instead become identifying what acceptable threshold of warming can be realistically achieved without compromising global goals for sustainable and ethical development whilst avoiding lasting environmental consequences. In response, organizations including the IPCC, the United Nations Environment Programme, the World Bank, McKinsey & Company, the World Resources Institute, and the IEA have developed scenarios that project emissions from a range of development patterns that look to 2030, 2050, and beyond. Recognizing a range of socioeconomic potentials and various thresholds of sustainable development, there is a general conclusion that stabilizing the concentration of greenhouse gasses in the atmosphere to a point that avoids irreversible climate change is indeed possible.

The 21st Century will see significant change. Halting climate change will require the transition of the energy supply and infrastructure, industrial processes, global economic interactions, agricultural practices, and development from its current high-carbon intensity to a low one and the reversal of centuries of both de-forestation and land-use changes. For the energy sector, this implies the "decarbonization" of supply and the implementation of significant efficiencies in the chain of use from generation to distribution to consumption. This de-coupling of the global economy from its dependency on fossil fuels while simultaneously improving how resources are used will allow growth and development to continue with clean energy, particularly in developing nations where modern infrastructures continue to emerge. When paired with sustainable land-use and development policies, the world may also avoid the potentially devastating economic and social shocks that will accompany the exhaustion of fuel reserves in addition to those caused by a warming climate.

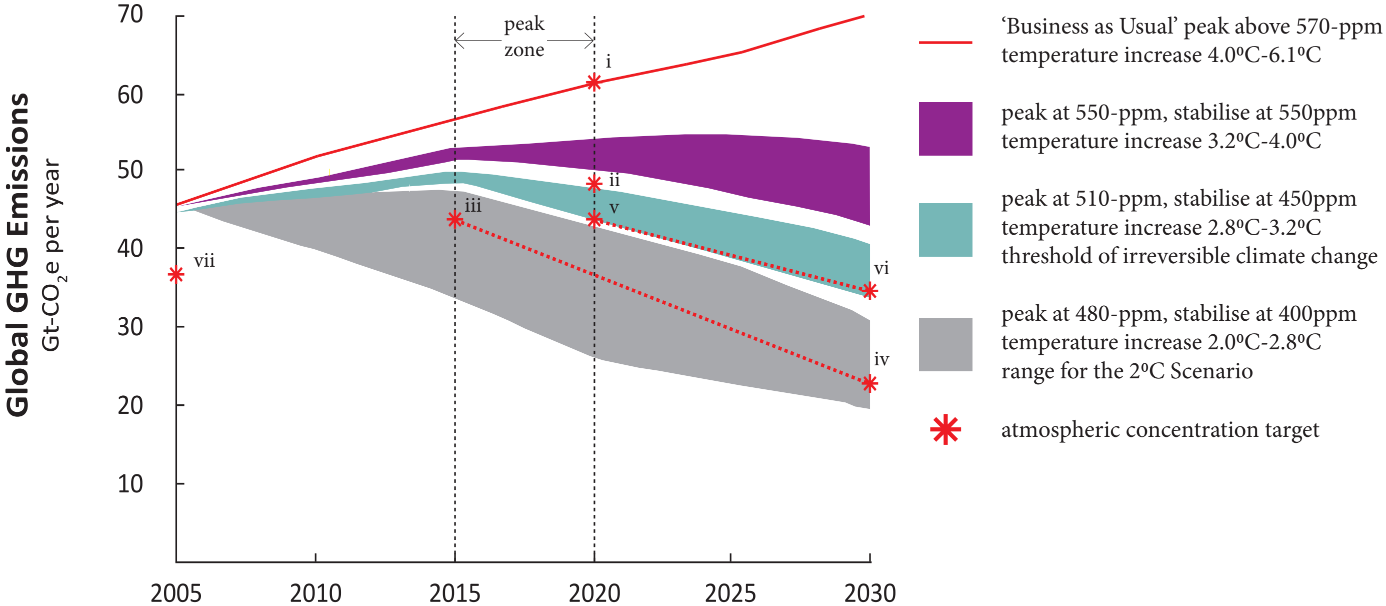


Fig. 2.9 (above)
Global Emissions Pathways Over Time
(McKinsey & Co., IPCC, IEA, UNEP 2009)

i: 55 Gt-CO_2e
BAU emissions in 2020.

ii: 49 Gt-CO_2e
All abatement measures in COP-15 pledges implemented.

iii: 44 Gt-CO_2e,
McKinsey & Company 2015 peak target emissions.

iv: 23 Gt-CO_2e,
McKinsey & Company 2030 emissions target for very likely (75-80% chance) 2ºC limit, likely (66% chance) 1.8ºC limit. Continue to 50% below 1990 emissions by 2050.

v: 44 Gt-CO_2e,
UNEP Emissions Gap Report 2020 peak target emissions for (66% chance) 2ºC limit.

vi: 34 Gt-CO_2e,
UNEP Emissions Gap Report 2030 emissions target for likely (66% chance) 2ºC limit. Continue to 50% - 60% below 1990 emissions by 2050.

vii: 36 Gt-CO_2e,
1990 emissions

It is in this context of scientific consensus, emerging political will, and public awareness that world leaders met in Copenhagen in December of 2009. The Fifteenth Meeting of the Conference of Parties to the UNFCC, or "COP-15 Conference" as it is more generally known, was successful in some ways and unsuccessful in others. The international community may have acknowledged the threat of climate change, yet aspirations to completely reverse it are no longer considered feasible and the targets of the Kyoto Accord have been relaxed. Based on extensive research, there is a revised commitment to limit the increase in mean global temperature to 2ºC relative to pre-industrial levels. At this threshold, humanity will have contributed to a permanent change to our environment; however, the most severe negative impacts could still be avoided. Most ecosystems will still be significantly effected, including bleaching of coral reefs, increased species extinction, lower agricultural productivity in lower latitudes, and an increase in severe weather and flooding in costal regions. Regardless, sweeping action is still required. Emissions must still be 70% lower than those associated with projected Business As Usual development trajectories where, similar to the contemporary condition, effective climate change policy is not widespread[16].

Although nations agreed to both an emission reduction target and individual pledges in Copenhagen, the United Nations Environment Programme (UNEP) identified a gap in the policy commitments. *The Emissions Gap Report* reviewed the published literature on pledges and development pathways and concluded that the commitments made at the COP-15 conference can only achieve 60% of the cuts needed. As summarized in Figure 1.9, these pledges are, in fact, consistent with a "likely" mean temperature increase of between 2.5ºC and 5.0ºC[17]; a range beyond the threshold of irreversible climate change. This real gap is equivalent to 5 Gt-CO_2e, equal to the total global emissions from road transportation in 2005. Limiting climate change is therefore required to go beyond the policy pledges made in Copenhagen. In the words of Achim Stiener, editor of the report, "there is a gap between science in ambition."

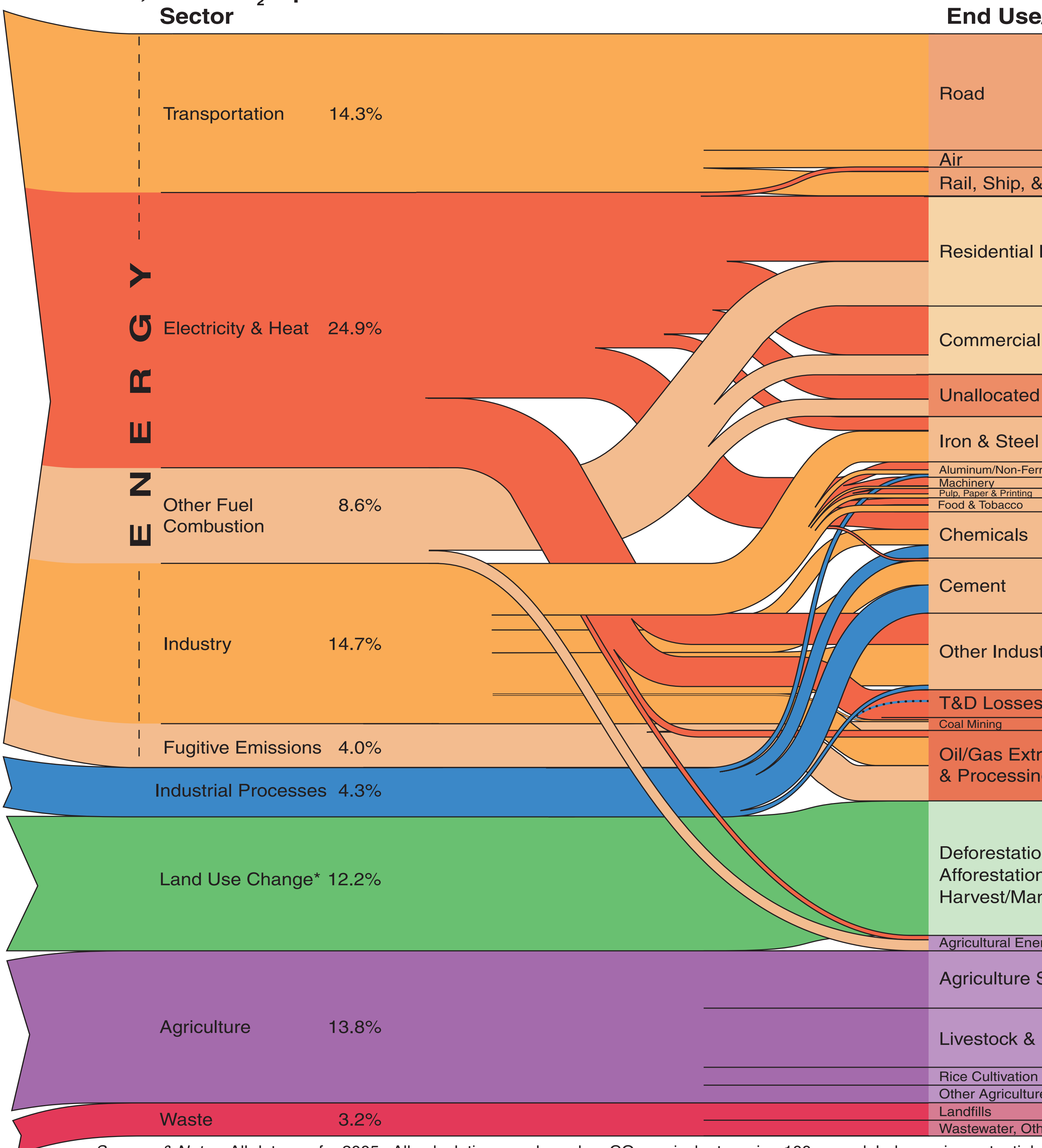
The McKinsey & Company 2009 report "Pathways to a Low Carbon Economy" and van Vurren et al's "Stabilizing Greenhouse Gas Concentrations at Low Levels", amongst others, illustrate the targets necessary for the 2ºC Scenario to be likely (considered to be an 70-85% chance that emissions targets will be effective) within economic boundaries. Based on data from the leading sources, these studies suggest the concentration of all greenhouse gasses in the atmosphere must peak at between 450- and 480-ppm as early as 2015, but no later than 2020, with emissions stabilizing at approximately 50% below 1990 levels. This is predicted to flatten at 400-ppm by the end of the 21st Century. Timing is crucial; a delay of even ten years is likely to mean missing the 2ºC target altogether, largely due in part to the resilience of gasses to persist in the atmosphere for decades. The scenario suggests that annual emissions would drop to between 18-29 Gt-CO_2e. Considering that in 2005 the number was over 44 Gt-CO_2e, leading to a concentration of 385-ppm, deep and lasting cuts are required in very short order with widespread abatement beginning in earnest this decade[18]. Studies suggest delaying widespread climate policy passed 2020 is very likely to lead warming between 3ºC and 6ºC and atmospheric GHGs in excess of 500-ppm.

This goal was re-iterated in 2015 at the COP-21 in conference in Paris where the global community committed keep mean global temperatures below 2°C. Clearly, this goal poses a significant, albeit necessary, challenge as efforts are suggested to fall far short. Business-as-Usual (BAU) energy use is projected to grow between 40% and 110% by 2030 (reflecting several development pathways), causing annual emissions to grow to 40 Gt-CO_2e. This trend is expected to lead to a temperature increase of between 2.4ºC and 6.4ºC by the end of this century.

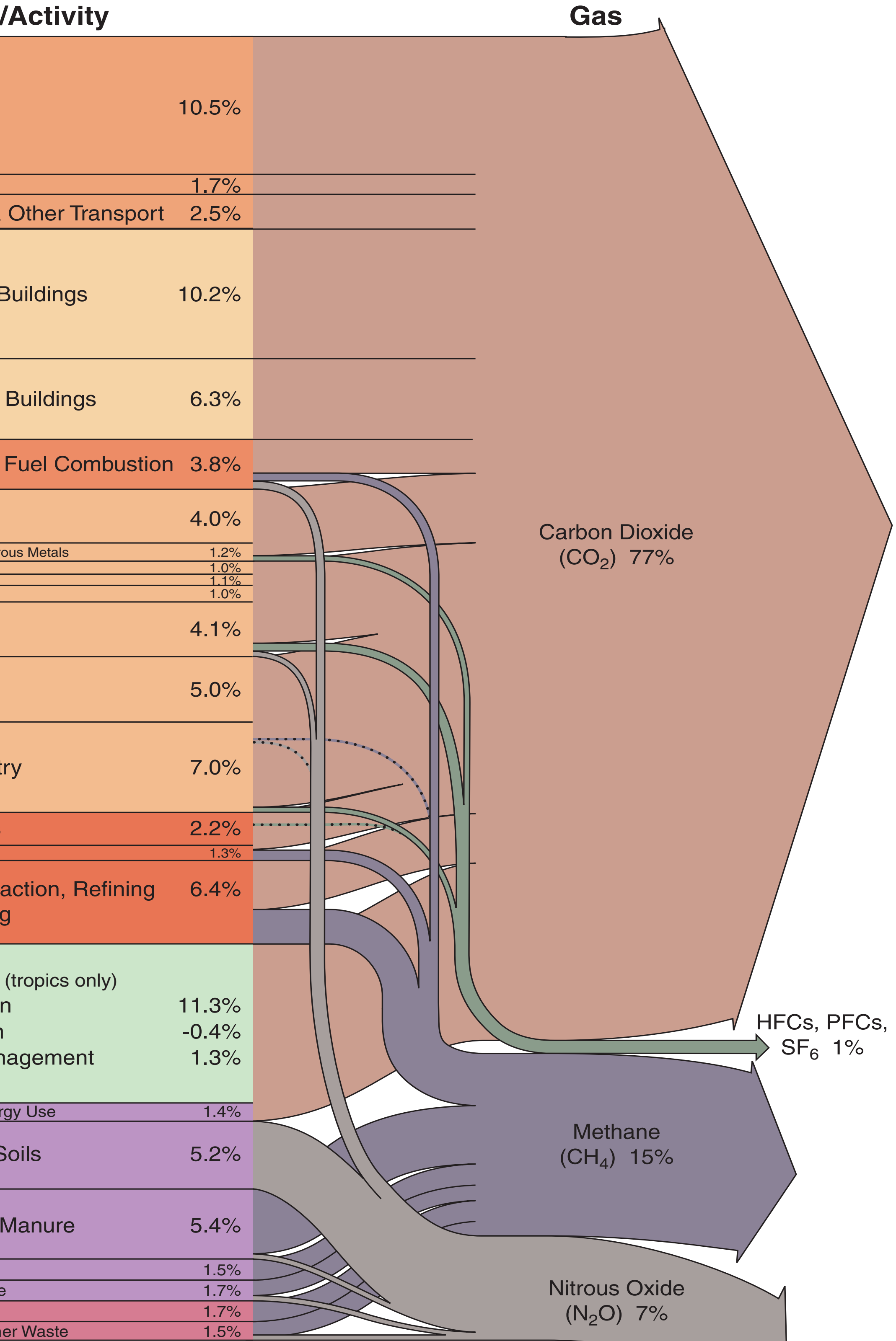
However, there is a significant cause for optimism. Studies agree that reducing GHG emissions to meet the 2ºC Scenario is possible with available technologies and global investment for low-emissions costing between 1% and 2% of Global GDP[19]. McKinsey & Company suggest that, including behavioral change, 89% of measures can implemented at a cost of €60/tonne of carbon with the remaining 11% of measures implemented at a cost of between €60 and €100. Many strategies, in particular those applicable in the short term such as increasing energy efficiency, can be net-profit positive, generating returns on investment to finance further mitigation efforts. Politics and social perspectives nevertheless remain primary barriers as efforts to match commitments with widespread and effective policy intervention and coordinated action continue to be elusive. In the Economist Magazine's November 2009 Special Report on Climate Change and the Carbon Economy, Emma Duncan concludes that neither technology, methods, nor economics should be impediments.

> "*The problem is not a technological one. The human race has almost all the tools it needs to continue leading much of the sort of life it has been enjoying without causing a net increase in greenhouse gas concentrations in the atmosphere. Nor is it a question of economics. Economists argue over the sums, but broadly agree that [emissions] can be curbed without flattening the world economy.*"[20]

World Greenhouse Gas Emissions in 2005
Total: 44,153 MtCO_2 eq.



Sources & Notes: All data are for 2005. All calculations are based on CO_2 equivalents, using 100-year global warming potentials
44,153 MtCO_2 equivalent. See Appendix 2 of *Navigating the Numbers: Greenhouse Gas Data & International Climate Policy* (WR
definitions, as well as data sources. Dotted lines represent flows of less than 0.1% percent of total GHG emissions.
* Land Use Change includes both emissions and absorptions, and is based on analysis that uses revised methodologies compar



from the IPCC (1996), based on a total global estimate of
RI, 2005) for a detailed description of sector and end use/activity

ed to previous versions of this chart. These data are subject to significant uncertainties.

Fig. 2.10
Greenhouse Gas Flow Diagram, World Greenhouse Gas Emissions (World Resources Institute, 2005)

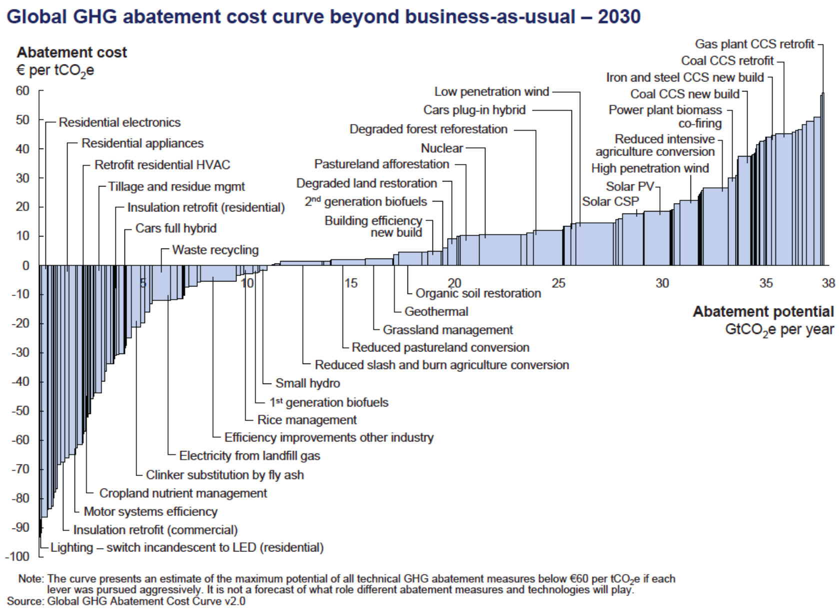


Fig. 2.11 (above)
McKinsey & Company Greenhouse Gas Abatement Curve, BAU to 2030
(McKinsey & Company, 2009)

Since the IPCC's First Assessment Report issued in 1990, pathways have been developed to predict climate-change outcomes based on various patterns of future development. They combine various possibilities of evolutions in population, wealth, and energy demand paired with different extents of climate policy intervention and action. Of course, to do so requires an inventory of the sources of global emissions. One of the most important outcomes of the Kyoto Protocol has been the creation of this inventory by member states that is calculated and collected in a consistent fashion. This data has provided the basis for informed abatement potentials and targets for the energy, transportation, buildings, materials, industrial, waste, and land-use sectors. Based on this data, widespread research over the past fifteen years has generated pathways to achieve emissions targets, including the 2ºC Scenario, and has catalyzed the investigation of "high and low" technologies and techniques to achieve them. The diversity of emissions sources demands a broad portfolio of initiatives that include zero-carbon energy sources, significant energy efficiency improvements, reducing non-CO_2 GHG emissions, avoiding deforestation, and low-carbon industrial processes.

The World Resources Institute provides one of the most comprehensive and clear summaries of the breakdown of sources of multi-greenhouse gas emissions. Using source data from the IEA and IPCC, Figure 1.10 on the preceding pages illustrates emissions in 2005 at the sector and end-use level. Sectors are broad categories such as Energy or Land-Use Changes while End-Uses are consumer-driven emissions that include residential and commercial buildings, road transportation and the cement industry. The energy sector is the single largest emissions source, and is responsible for over 65% of emissions, nearly 30 Gt-CO_2e annually. Significant efficiency improvements to avoid emissions, fuel switching to non-emitting or low-emitting sources, and carbon-capture and storage provide the range of mitigation strategies that add-up to a significant portion of the solution to climate change. McKinsey & Company have identified over 26 Gt-CO_2e of

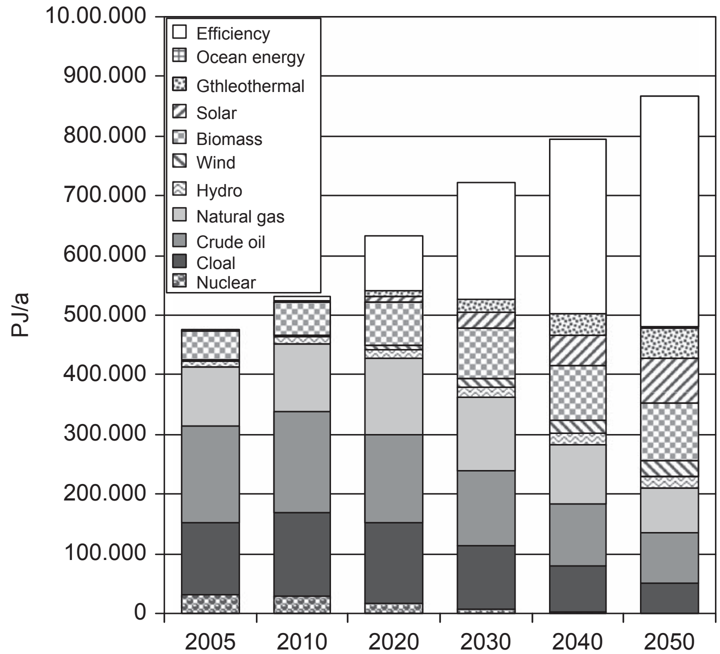


Fig. 2.12 (above)
The Contribution of Energy Efficiency
(Krewitt et al, 2008)

annual abatement potential between now and 2030 in this sector alone. This represents over 55% of the total reductions required to reduce annual emissions to approximately 23 Gt-CO_2e, a target comfortably within the range dictated by the 2ºC Scenario. In addition to the transition to a low-carbon energy supply, this potential includes the significant contribution of consumer sectors, including the building energy efficiency measures such as insulation improvements and efficient lighting technologies, or alternatively fueled vehicles. Lifestyle changes that can result in avoided emissions include lower thermostat settings and reduced hot water consumption in homes can further increase this sector's potential[22].

Krewitt et al's *Energy-(R)-Evolution*, proposes a complete overhaul in the sources and use of energy and is an example of an energy scenario for a low-carbon world. van Vuuren, et al echo this transformation and suggest this transition will extend beyond 2050 and continue through to the end of this century. Although development will lead to continued growth, annual emissions from the energy sector are projected be reduced to less than 1 Gt-CO_2e by 2100, leading to a stabilization of GHGs in the atmosphere of 400-ppm or lower. Figure 1.11 illustrates the projected mix of energy sources and includes a 20% reduction in energy end-use compared to the year 2000, a significant improvement in efficiency that includes new and existing infrastructure and all end-uses[23]. Given that energy demand is expected to double by 2050, Krewitt et al suggest that demand can be reduced up to 45% from business-as-usual development patterns. The proposed energy mix relies significantly on renewable energy sources, contributing 94% of electricity and heat generation, with nuclear energy phased out. Interestingly, van Vurren et al propose a different energy mix that relies more on nuclear energy and fossil fuels offset with a rapid and widespread adoption of carbon capture and storage. Although the quantity of fossil fuel reserves is hotly debated, this latter scenario still has the potential of exposing energy stocks to the pressures and shocks of dwindling reserves.

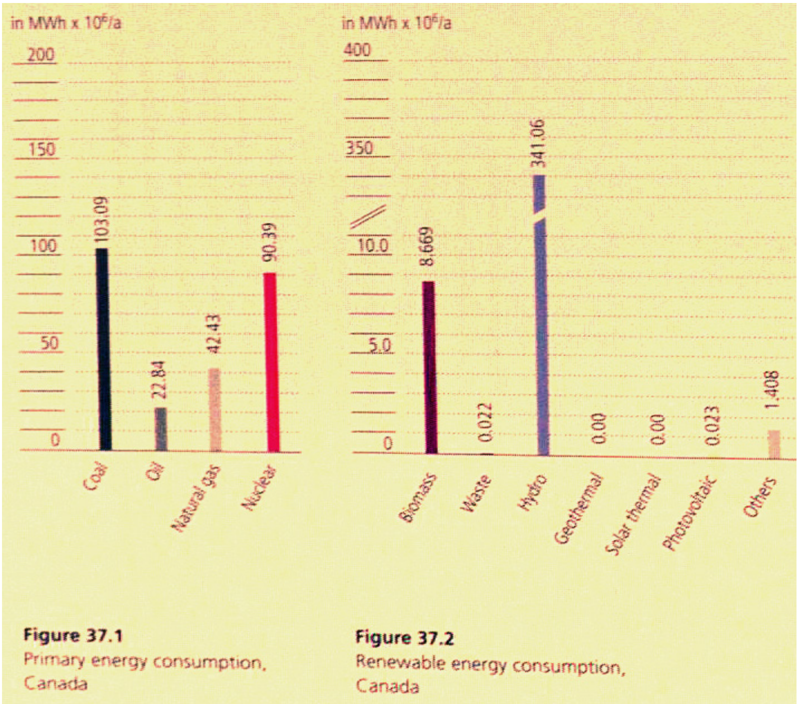


Fig. 2.13 (above)
Primary Energy Consumption and Renewables Mix in Canada, 2009
(Klaus and Ralphe, 2009)

Although mitigation scenarios consistent with the 2ºC Scenario suggest different development pathways for the de-carbonoization of the energy sector, exhausting all available energy efficiency strategies is nevertheless a consistent variable and is, in many cases, considered as offering the biggest scope of emissions mitigation (van Vurrent et al 2007, Krewitt et al 2007, Riahi et al 2007, IPCC 2007 SRES Scenario B1, IEA 2009, SDSN and IDDRI, 2014). Exploiting energy efficiency opportunities makes room for projected growth in population, construction, economic activity, and GDP without an associated increase in energy demand. Figure 2.13 illustrates the significant contribution of efficiency between 2005 and 2050[24].

The energy, manufacturing and resource context of the Canadian economy stands in stark contrast to countries that have seen greater progress, such as Germany, the UK and Austria. The energy-intensive resource and industrial-based economy has engendered the opinion that growth and reduced emissions are irreconcilable. Where OECD Europe has seen strong governmental leadership, Canada's public and private sectors continue to wait for government initiative to create a coherent vision and update lagging legislation[29]. On the other hand, the current energy mix relies on a remarkable amount of hydro-electric power and renewable sources, contributing to over 61% of the total, not including nuclear power. The result is an overall carbon intensity for energy use is a low 200g-CO_2e/kWhr. This intensity does however vary provincially. In Quebec for example, hydro-electric sources contribute almost 90% of electricity while in contrast, Alberta and Saskatchewan rely on coal as the predominant source. **Nationally, the energy sector is responsible for over 82% of emissions[30] with the dominant end-use sectors being industrial manufacturing, residential, and commercial buildings.**

"...exhausting all available energy efficiency strategies is nevertheless a consistent variable and in many cases considered as offering the biggest scope of emissions mitigation..."

Given the dominant role of energy in emissions on the one hand and the large contribution of renewable energy on the other, it is a startling fact that Canadians have one of the largest carbon-footprints per capita in the world. In contrast to European moves to mandate efficiency, Canada's Model National Energy Code has been updated once since 1997 and remains voluntary while efficiency measures mandated by Building Codes are applied on a jurisdictional basis rather than universally. Improvements in efficiency continue to be outstripped by growth in energy use. Emissions from electricity and heat generation have increased 32% since 1990, from 95 $MtCO_2e$ to 119 $MtCO_2e$, while on-site combustion of fuels in the construction, residential and commercial/institutional sectors have increased emissions by 10%, from 70 $MtCO_2e$ to 79 $MtCO_2e$[31]. Oilsands production cannot be completely blamed for Canada's increasing footprint.

The contrasting climate change policies and resulting emissions between OECD Europe and OECD North America demonstrate the vital importance of significantly improving efficiency throughout the energy system, from generation to delivery to end-use consumption[31]. Clearly, policies in Canada to date have resulted in growing energy use and emissions with the lack of mandatory efficiency legislation being the most glaring cause. However if, like OECD Europe, government and regulatory agencies take a leadership role and make significant policy interventions to facilitate the evolution of energy efficiency and generation, Canada's ability to transform its energy sector and end-use consumption patterns to be in line with the mid- and long-term goals of the various published scenarios is entirely possible. For example, the contribution of renewable energy to the overall energy-mix in Quebec is already consistent with the latter study's suggestions. For Canada, and the world, to collectively limit climate change to 2ºC, facilitating significant change across all sectors. This is particularly true of the energy sector, of which buildings are suggested to be the predominant end-user.

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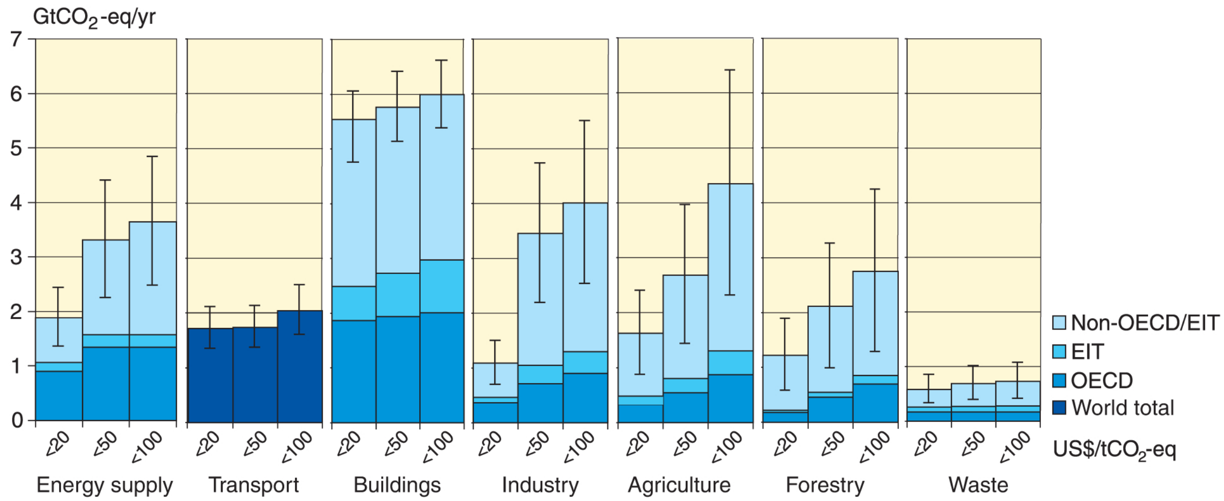


3.0 Buildings and Climate Change

Fig. 3.1 (above)
Mitigation Potentials by Sector by 2030
(IPCC AR4, 2007

The building sector is one of the more significant consumers of both energy and materials worldwide; consequently it is a significant end-use source of greenhouse gas emissions. It has been suggested that the construction and operation of buildings consumes nearly a third of all energy and nearly 40% of all mined resources[1]. The United Nations Environment Programme *Report on Buildings and the Environment* suggests that the combined impact of resource consumption and energy consumption translates into nearly half of global emissions[2]. The Architecture 2030 Initiative suggests that the construction, operation, and demolition of buildings consumes 77% of electricity generated and 46.7% of the GHG emissions in the United States[3]. Furthermore, the IEA suggests that the generation of electricity and heat, of which the built environment is the predominant consumer, is one of the key impediments to the decoupling of emissions from economic growth[4].

Although inconsistent, the available data suggests the building sector plays a key role in solving the climate problem and could be one of the largest opportunities for the reduction of emissions. Some suggest it is, in fact fundamental to it. Studies investigating the comprehensive picture of emissions agree that the potential of buildings is underestimated because the measures studied are either too limited or relate to limited policy frameworks, creating a condition where individual elements are considered as opposed to the building as a whole[5]. In his book *Carbon-Neutral Architectural Design*, Pablo La Roche summarizes that although there is inconsistency in the extent to which the built environment contributes to climate change, it nevertheless remains a critical factor in halting or reversing it:

> *"It is difficult to determine the exact amount of energy used by the building sector because it is usually not considered an independent sector with its own data. Furthermore, there is a lack of consistent data from the different entities that collect this information. ... [however] The IPCC's 4th Assessment report estimated that building related GHG emissions [could double by 2030 to 15.6 billion tCO2-e]. This means that just from the sheer quantity of these emissions, to have any real impact on climate change it is crucial that emissions from the building sector be addressed."*[6]

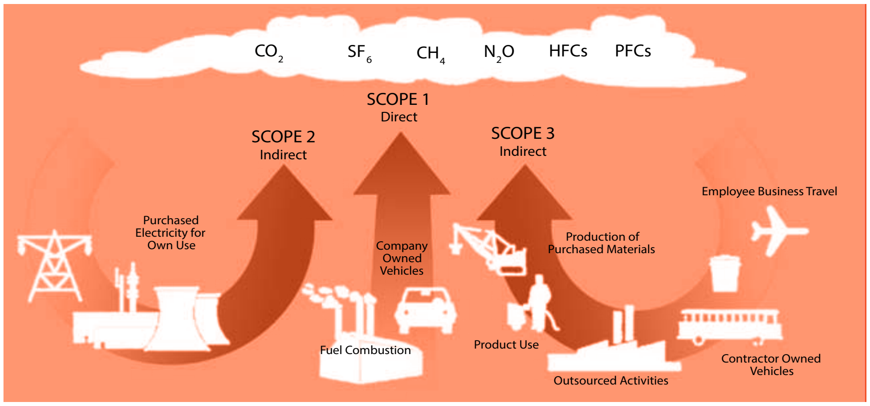


Fig. 3.2 (above)
Greenhouse Gas Emission Scopes
(UNEP Common Carbon Metric, 2010)

3.1 Allocating GHG Emissions in Buildings

The Canadian Standards Association (CSA) / International Standards Organization (ISO) Standard 14064 *Protocol on Greenhouse Gasses* is the primary method to both categorize and quantify greenhouse gas emissions. It is used by organizations such as the CSA and the Greenhouse Gas Protocol as the basis for third-party verification services to ensure the intent, rigour, and requirements for GHG accounting is consistent. ISO 14064 divides emissions into three categories within a specifically defined project, corporate or institutional boundary: direct, energy in-direct and indirect, or Scope One, Two and Three respectively. GHG Removals are a separate, and final, category[7]. Achieved with either on-site sinks or acquired through certified offset providers, removals play are important as they can reduce rather than increase final emissions footprint.

The four categories are general and are intended to apply to a complete corporate, organizational, or system value chain, illustrated by Figure 3.2 above. It is important to note that buildings are not defined as their discrete entity. Rather, it is the emissions resulting from their role in a larger system that are; buildings are nested within a larger context[8]. The *UNEP-SBCI Common Carbon Metric for Measuring Greenhouse Gas Emissions and Energy Use in Buildings* is emerging as a common standard and outlines the methods to allocate emissions from fuel combustion for energy use, purchased electricity, and purchased materials that occur because of a facility within a larger operational context. For example, achieving a carbon-neutral certification in Hong Kong requires corporate-owned vehicles to be included[13] and the Aldo Leopold Centre GHG accounting includes employee travel[52]. Here, the building is one of several aspects of emissions in these scenarios and emissions are tabulated at the organizational level.

Scope One: (Direct) Emissions tend to be the most straightforward and include GHG emissions from greenhouse gas sources over which the organization has direct operational control[9]. In the context of a building project, this is commonly known as ***Operating Energy*** and includes three specific activities: direct on-site emissions, stationary combustion emissions, and fugitive emissions.

- ***Direct On-Site Emissions*** result from sources within the boundary of the building, or group of buildings, that include stationary combustion sources, process emissions, and fugitive emissions. Process emissions must be carefully included and are contextual. They do not include industrial processes such as the assembly of products, but do include equipment such as computers or refrigeration equipment. In ISO 14064, biomass is reported separately.
- ***Stationary Combustion Emissions*** include the burning of fuels to create electricity, steam, or heat within the boundary of the building. This does not include purchased electricity, or local sources such as Combined Heat and Power Plants that are not owned.

- ***Fugitive Emissions*** are not controlled by the reporting entity, but result from the unintentional release of GHGs. Common examples include the storage, transmission, and use of other fuels and chemicals. There are many important non-CO_2 gasses that have high Global Warming Potentials (GWP) emitted from various processes and equipment. The most notable are halocarbons present the refrigerants used in HVAC systems and equipment. The leakage of refrigerant can have a significant contribution to a buildings GHG footprint, particularly in low-energy buildings.

Scope Two: (Energy-Indirect) Emissions include GHG emissions resulting from energy demand supplied by imported energy, heat or steam[10]. This includes not only large-scale utility infrastructure, but more local combined heat and power installations outside of the boundaries of the subject building or multiple-building within the project scope and is also considered Operating Energy. Energy-Indirect emissions can be broken into two categories. Primary, or source, Energy where the emissions associated with energy expended to transform and transport energy from the generation point to the end-user. Secondary, or Site, Energy refers to energy consumed by the end-user only. In the case of this research, Secondary energy will be used to avoid double-counting with the Energy Generation sector which has emission reduction measures distinct from the building-sector. When creating an emission inventory, it is important to clearly state which is being used.

Scope Three: (Other Indirect) Emissions are both wide-ranging and subjective, this category is dominated by the initial and recurring embodied energy of materials, assemblies and the construction process. Other important operational considerations include waste generation, the use and disposal of potable water, occupant commuting, and company vehicles. The organizational boundary for the GHG inventory becomes essential when considering the Scope Three emissions that will be included[11]. Materials may also have qualifiable and significant fugitive emissions that include non CO_2-gasses. For example, halocarbons are present in the blowing agent of spray-foam insulation that are emitted both during installation and over time. When assessing a building project, the impact of material use and construction activities over the complete lifecycle of a building are commonly known as Embodied Energy.

GHG Removals is a unique category that accounts for a reduction in emissions rather than their accumulation[12]. Wide ranging and at times controversial, strategies and installations that sequester a quantifiable amount of greenhouse gasses on-site or offset through validated off-site projects can both be considered if the criteria of *additionality* as defined by the Kyoto Regime Clean Development Mechanisms. To be considered, it must be an on- or off-site action that sequesters greenhouse gasses that would otherwise occur. The most common example is afforestation or the installation of a grid-tied renewable energy array that exceeds the metered annual energy requirements. On-site carbon sinks, such as a stand of trees, can only be considered if a change in capacity is added; an existing tree-stand cannot be included as it is considered an existing sink prior to the intervention of the project. GHG removal projects must be certified by a designated national authority and are rigorously measured.

This study investigates building-specific impacts that are nested within the larger value-chain of a reporting entity. This allows the findings and methodology to be relevant to any context, scope, or situation. An owner built, operated and occupied building has a different operational scope than a building that is part of a larger property portfolio that is leased to many different individual tenants. For example, the Hong Kong reporting standard includes vehicular shuttles that are a part of a building operator's activities in Scope One emissions as they are a regular direct emission associated with an occupant's operation of a building[13]. It is the responsibility of the reporting entity to properly define and allocate all relevant emissions within their operational boundary. The methodology outlined in this study allows those responsible for building design and construction to feed building-specific emissions information into a larger reporting context.

It is important to note that emissions are not limited to carbon dioxide. Emissions from process loads, such as a manufacturing line, and fugitive emissions from equipment can include greenhouse gasses with an warming impact that can be substantially higher. The concept of Global Warming Potential (GWP) was established to normalize their weighted contribution to climate change. With carbon dioxide responsible for over 75% of global emissions in both volume and impact, the Intergovernmental Panel on Climate Change established it as the benchmark and the warming effect of all greenhouse gasses are expressed as carbon-dioxide equivalent (CO_2-e)[14]. For example, some cooking fuels in developing countries release predominantly methane, a greenhouse gas that is 21 times more damaging than CO_2 while HFCs emitted from air handling and conditioning units in modern buildings can be over 1000 times more damaging. HFCs are particularly troublesome. Sought out as a replacement for CFC's because they do not deplete the ozone layer, they have unfortunately exacerbated the climate problem. The IPCC estimates that 60% of total halocarbon emissions were the result of air-conditioning, appliance refrigeration, and blowing agents for insulation[15]. Table 2.3, below is a select list of greenhouse gasses common to buildings and their associated GWP.

Table 2.3 GHG Global Warming Potentials[16]

Gas	Chemical Formula	GWP (CO_2-e)	Emission Source
Carbon Dioxide	CO2	1	Heating, Cooling, Electricity
Methane	CH4	21	Landfills, Natural Gas
Nitrous Oxide	N2O	310	Vehicles
HFC-23	CHF3	11700	Fire Suppression
HFC-125	C2HF5	2800	Fire Suppression, component in A/C Refrigerant
HFC-134a	C2H2F4	1300	A/C Refrigerant, Chillers
HFC-143a	C2H3F3	3800	Appliance Refrigerant
HCFC-22	CHCIF2	1780	A/C Refrigerant
HFC-236fa	C3H2F6	6300	Chillers
R600a	C4H10	20	Appliance Refrigerant

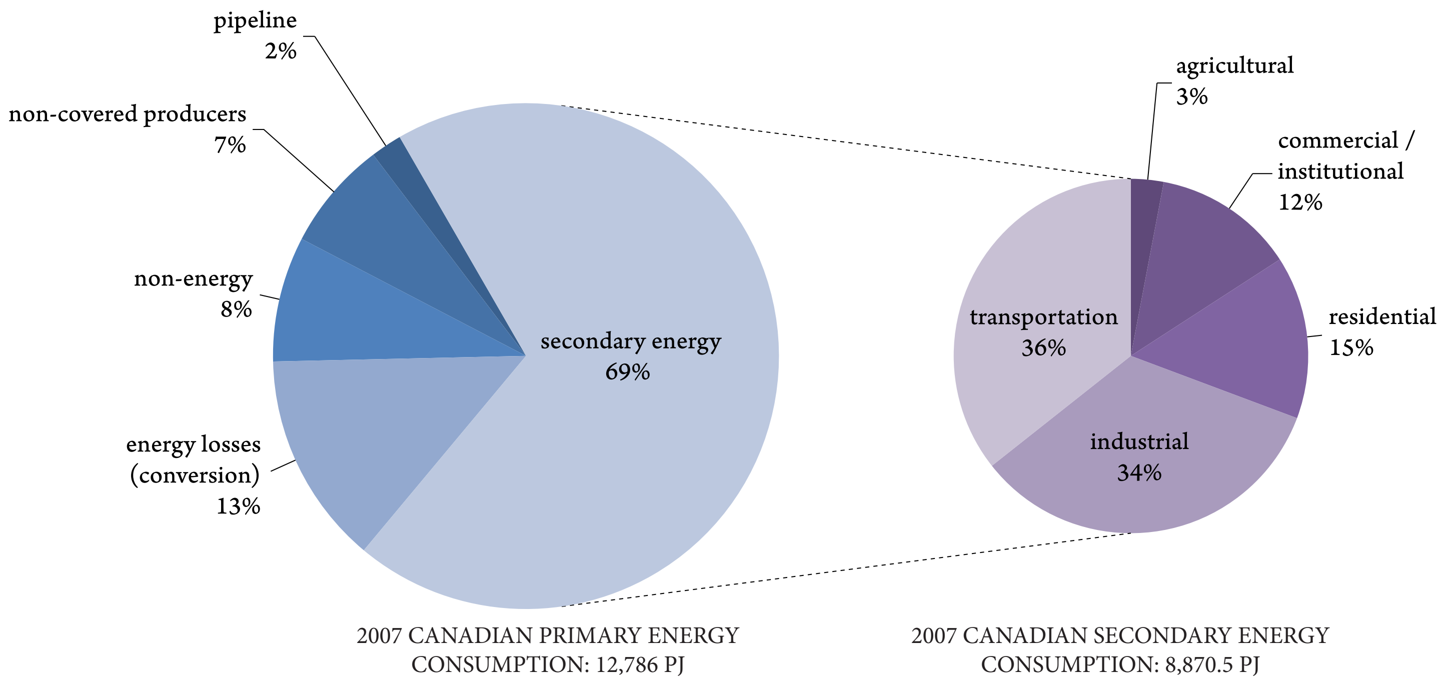
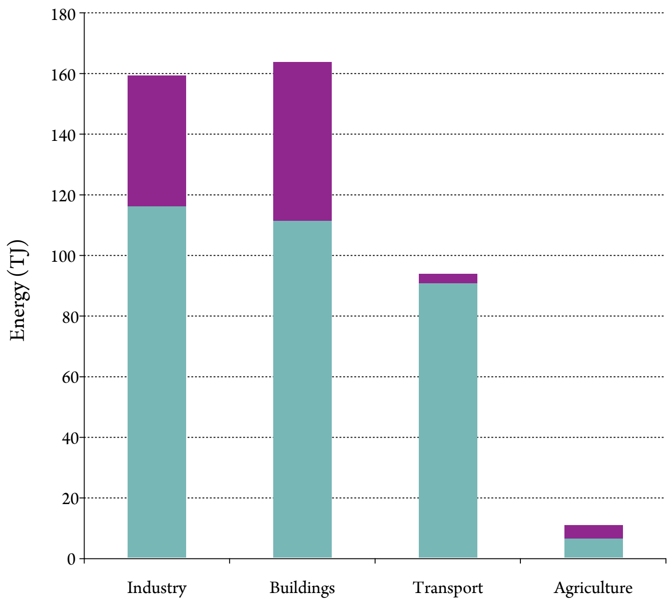


Fig. 3.3 (above)
Primary and Secondary Energy Consumption in Canada in 2007
(NRCan, 2009)

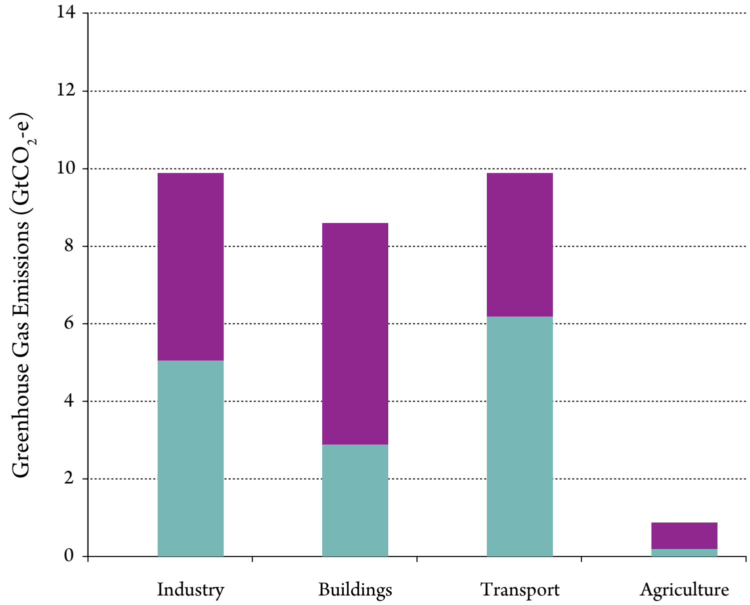
3.2 Scope One and Two Emissions (Operating Energy)

Scope One direct energy-related emissions from on-site activities and Scope Two energy indirect emissions from energy sourced beyond the building's operational boundary are combined into Operating Energy. Both scopes together represent the largest share of a building's energy use, and consequently greenhouse gas emissions, over its total lifecycle[17]. Typically measured in equivalent Kilowatt-hours (ekWh), operating energy includes the energy consumed for heating, cooling, ventilation, lighting, equipment, and plug loads while process loads, such as a manufacturing assembly line, are excluded. Examples of direct emissions would include on-site combustion equipment such as furnaces. Energy indirect sources are generated off-site and delivered to the site. They include grid-sourced electricity and associated transmission losses. Connections to local shared infrastructure such as combined heat and power plants or steam connections between adjacent buildings are also important indirect considerations. Natural Resources Canada provides the following definitions to allocate Scope One and Scope Two emissions:

> *"Secondary energy use is the energy used by the final consumer in various sectors of the economy. This includes, for example, the energy used by vehicles in the transportation sector. Secondary energy use also encompasses energy required to heat and cool homes or businesses in the residential and commercial/institutional sectors. In addition, it comprises energy required to run machinery in the industrial and agricultural sectors.*
>
> *Primary energy use encompasses the total requirements for all uses of energy. This includes secondary energy use. Additionally, primary energy use refers to the energy required to transform one form of energy to another (e.g. coal to electricity). It also includes the energy used to bring energy supplies to the consumer (e.g. pipeline). Further, it entails the energy used to feed industrial production processes (e.g. the natural gas used by the chemical industries)"*[18]



GLOBAL END-USE PRIMARY ENERGY CONSUMPTION WITH ENERGY CONVERSION REALLOCATED



GLOBAL END-USE GHG EMISSIONS FROM PRIMARY ENERGY CONSUMPTION WITH ENERGY CONVERSION REALLOCATED

primary energy allocated to end-use sector

secondary energy allocated to end-use sector

Fig. 3.4 (above)
Allocation of Primary Energy and Resulting Greenhouse Gas Emissions to End-Use Sectors (de la Rue du Can and Price, 2008)

The building sector is an end-use category and, thus, energy consumption can be presented as either primary or secondary depending on the analysis context. It is important to define which is being used and the distinction becomes particularly important when on-site renewable energy is considered. The IEA suggests that, on a global basis, direct energy use in buildings contributes to 10% of global emissions, while energy indirect grows this number to over 30%[20]. la Rue de Can and Price suggest that, globally, the building sector requires more primary energy per unit of secondary energy than any other end-use sector and, consequently has a higher GHG footprint[21]; this upstream effect is thus a critical component. **Mitigation studies that investigate global and multi-sectoral emissions typically apply the secondary definition to the building sector while the upstream component of primary energy is allocated to the energy generation sector** (van Vurrent et al 2007, Krewitt et al 2007, Riahi et al 2007, IPCC 2007 SRES Scenario B1, IEA 2009, SDSN and IDDRI, 2014, McKinsey & Company 2009, Socolow and Pacala, 2004).

Energy use in buildings is generally divided into seven categories: space heating, space cooling, water heating, auxiliary equipment including plug loads, auxiliary motors and fans, and lighting. Location, climate, typology, size, and occupancy changes the relative impact of each category. Figures 3.5 illustrates the distribution of energy use and GHG emissions in office and retail buildings in 2009. In Canada's cold climate, heating is the dominant building load, representing over 50% [22].

Across all building types, plug loads represent the single most significant increase in energy consumption by a large margin, driven by continued computerization and the growth number of electronic devices required per employee and per household[23]. The heat generated from more and more devices drives a higher cooling load and together, these two categories are reducing the impact of efficiency improvements made in other areas, such as lighting. In low energy buildings, these auxiliary loads can account for a significant proportion. At the Bullitt Centre, for example, net-zero energy office building in Seattle, Washington, for example, computers, monitors, printers and other miscellaneous equipment accounts for 43%, or 104,000 kWhr of a total energy budget of 236,400 kWhr[24]. The ASHRAE Advanced Energy Design Guideline suggests the number can be up to 50% in a building that uses 50% less energy than a baseline case meeting the minimum requirements of ASHRAE 90.1-2004[25].

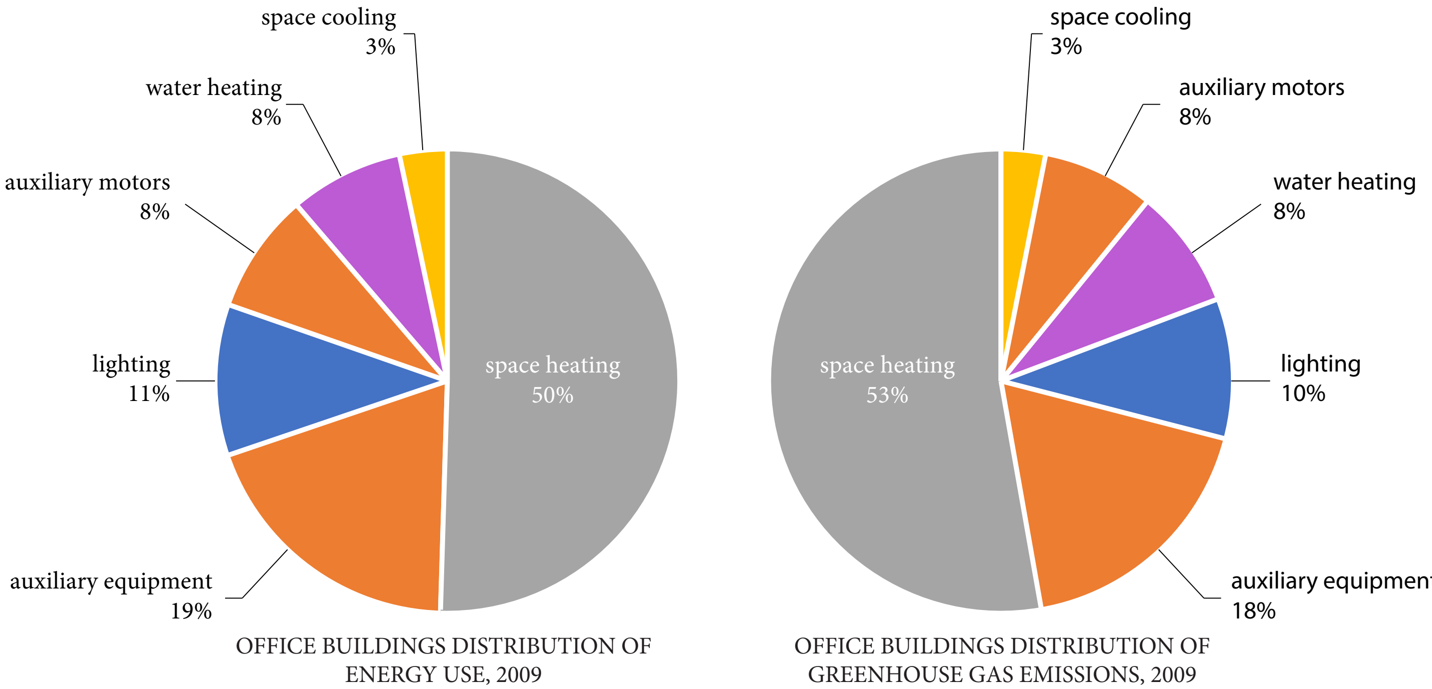


Fig. 3.5 (above)
Office Energy Use and Greenhouse Gas Emissions Distribution in Canada, 2009
(NRCan, 2009)

3.3 Scope Three Emissions (Material Embodied Energy)

Embodied energy includes the energy consumed in the acquisition and processing of raw materials, including manufacturing, transportation, and final installation[26]. In the case of buildings, the energy and emissions footprint of both materials and the on-site construction are considered. Unlike operating energy, which has been the primary focus of research and attention, embodied energy is more subtle and less familiar. Given that the building industry is suggested to consume approximately 40% of all mined resources, embodied energy is a necessary consideration for a low-carbon built future. It expands both the mitigation potential beyond the scope suggested by the majority of published scenarios, allowing both the manufacturer and end-user to extend their scope and impact.

Material and construction effects are not limited to the initial construction phase of a building, but recur over time in the form of maintenance, replacement, and renovation. The former is classified as initial embodied energy and the latter recurring embodied energy[27]. The relationship between them was investigated by Cole & Kernan in their influential study *Life-Cycle Energy Use in an Office Building*. Their conclusions suggest that between 25 and 50 years of building operation, recurring embodied energy becomes greater than the initial embodied energy and after 100 years of operation, becomes 3.4 times greater[28]. Thus, establishing an operational lifespan of a building is an important step when developing the operational boundary for counting emissions.

The embodied energy and emissions, of a material are typically reported as a measure of mass, or the amount of primary energy (MJ or GJ) required to produce a kilogram of the final product. Like operating energy, emissions closely follow the amount of energy used. Although it can appear to be a simple exercise to calculate it, there are a wide variety of circumstances that affect the outcome that, when combined with the lack of a consistently applied and recognized third-party methodology, lead to a wide variation in reported numbers. Fabrication methods, technologies, and fuel sources for the required energy to run equipment vary widely by location. To further complicate matters, the distance and shipping method to transport the raw materials to the production facility and, after fabrication, of the final product to the construction site are also included while composite materials such as concrete add another layer complication as each constituent component requires consideration. These subtleties result in a single material having a variety of embodied energy outcomes depending on a very large number of linkages[29].

Considering emissions closely follow energy use, materials with high embodied energy tend to have a higher emission footprint. Table 3.1 at right, compiled from van Ooteghem's *Life-Cycle Assessment of a Single Storey Retail Building in Canada*, illustrates this trend. For example, virgin aluminum, used in everything from window frames to cladding panels, has an embodied energy of between 201 and 217 MJ/kg and emissions of between 8.4-11.2 kgCO2-e/kg. On the other hand, kiln-dried softwood, primarily used as dimensional framing lumber, has an embodied energy of between 1.6 and 7.4 MJ/kg and emissions of 0.5 kgCO2-e/kg. When comparing different materials for a particular application, it is important to consider several factors. First is relative amount of each material required. For example, a steel column requires less tonnage of material than a concrete column, although steel has a higher impact. Second, recycled content typically results in lowered embodied energy when compared with virgin resources. Thirdly, naturally occurring materials such as wood or stone require less energy than highly processed or composite materials such as plastic or concrete[30].

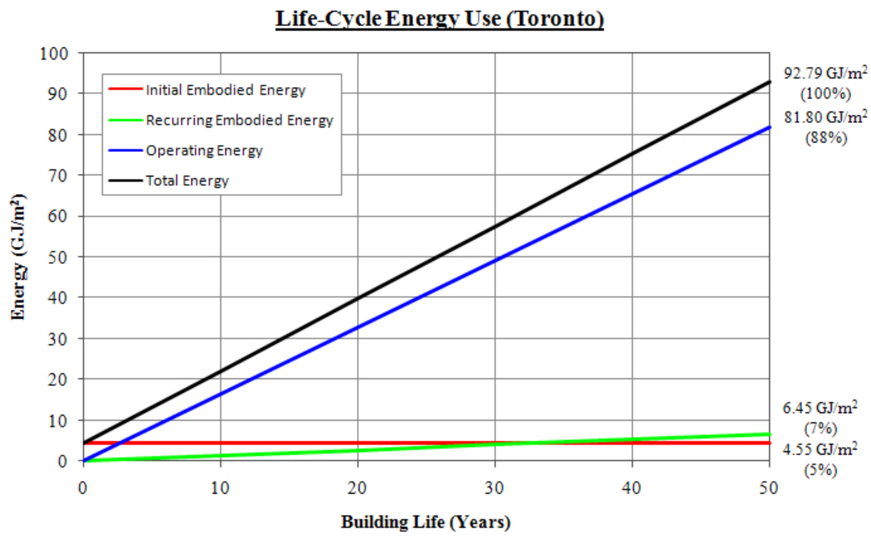
Cole and Kernan's *Life-Cycle Energy use in an Office Building* is one of the foundational studies of initial and recurring embodied energy throughout the lifecycle of a building. It remains current and continues to be referenced in building LCA studies. The embodied and operating energy over a 50 year period was tabulated for a three storey, 4,620m^2 office building located in Toronto, Canada and compared a concrete, wood, and steel structural system. Figure 3.6, following, illustrates that amongst the three variations, the envelope, services, finishes, construction and site work demonstrated very little variation and moderated the effects of the structural system, which was the only category with any noteworthy change. The study concludes that envelope (27%), services (23%) and structure (25%) accounted for roughly 3/4 of an office building's initial embodied energy[29]. Directly related to the operational lifespan of a building, recurring embodied energy can accrue significant emissions over time and after 50 years is suggested to exceed initial embodied energy with retail and office buildings exhibiting higher renovation and replacement rates than other building types[31].

van Ooteghem investigated the relative sensitivity that various components, such as structure, roofing, or glazing, have on the total embodied energy and their impact on operating energy over 50 years. Five case studies of the same building using combinations of timber, steel, and light-gauge sheet steel structure were combined with over 50 building envelope variations. Across the case studies, these building components contributed a relatively similar share to the total embodied energy while the structural systems varied. The steel structure required 476 GJ compared to the heavy timber structure requiring only 156 GJ. Although the wood case studies were generally lower, when optimized building systems are considered, timber may not always exhibit this quality. The sheet steel building system case

Table 3.1: Initial Embodied Energy and Global Warming Potential of Common Building Materials[32]		
Building Material	Initial Embodied Energy (MJ/kg) (low / high)	Initial Embodied GHG Emissions ($kgCO_2$-e/kg)
Aluminum (recycled)	17.3 / 34.1	1.9 / 2.0
Aluminum (virgin)	201.0 / 217.0	8.4 / 11.2
Bitumen	44.1 / 47.0	0.2 / 0.5
Cement	4.6 / 15.0	0.8 / 0.9
Concrete (30 MPa)	1.1 / 4.5	0.2
Concrete Block	0.7 / 0.9	0.1
Float Glass	15.0 / 15.9	0.9 / 1.7
Gypsum Board	4.5 / 6.8	0.4
Cellulose Insulation	0.9 / 3.3	0.1
Polystyrene Insulation	88.6 / 117.0	2.5
Insulation (fibreglass)	28.0 / 30.3	0.8 / 1.4
Paint (solvent based)	68.0 / 91.1	3.6
Plywood	10.4 / 15.0	0.8
PVC Plastic	70.0 / 77.2	2.4 / 4.3
Steel (general, recycled)	9.5 / 10.1	0.4
Steel (general, virgin)	15.4 / 35.3	1.2 / 2.8
Steel (reinforcing)	8.9 / 13.3	0.4
Timber (glulam)	4.6 / 12.0	0.7
Timber (kiln dried)	1.6 / 7.4	0.5

study resulted in the lowest embodied energy when considered holistically and can be attributed to the high level of material optimization. In this case, materials with a high embodied energy per kilogram used efficiently and systematically yielded a lower result than timber, which has a lower per kilogram value[33].

However tempting it may be to select materials on their embodied energy values alone, it is important to consider the implications of their use on operational energy use, design ambitions, occupant health, and regulatory requirements. Materials and systems over the design service life should be considered holistically over the design lifecycle and in relation to impacts on operating energy, which are responsible for the vast majority of the energy footprint. For example, glass, although high in embodied energy, is used for passive heating and daylighting and thus provides an operational energy savings. On the other hand, a building with too much glass, or an envelope with little insulation, but using a low-embodied wood structure, can result in a significant operational energy requirement that outweighs any embodied energy savings.



3.4 Relating Operating and Embodied Energy

Over the typical lifecycle of a building, operating energy is, by a large margin, the predominant source of energy consumption compared to material embodied energy, notwithstanding the effect of material choices on operating energy. Cole and Kernan suggest that, after 50 years, operating energy accounted for 85% of the total energy footprint[34]. When materials and construction techniques are optimized, such as the use of prefabrication to limit waste and optimize components, this ratio can reach 90%[51]. van Ooteghamʼs comprehensive review of Lifecycle Assessments are consistent with this finding and suggests that, even in low-energy buildings, operating energy retains the larger share[35].

Fig. 3.6 (above)
Lifecycle Energy Use of a 4,620m² Office Building in Toronto, Ontario
(Cole and Kernan, 1996)

Given that greenhouse gas emissions closely follow energy use, this relationship can be extended to the distribution of emissions that make up a buildingʼs Global Warming Potential (GWP). With the overwhelming share of emissions attributed to operating energy, The United Nations Environment Program *Protocol for Measuring Energy Use and Reporting Greenhouse Gas Emissions from Building Operations* excludes material embodied energy from its GHG calculations[36]. **The protocolʼs logic suggests that the GWP of materials is a part of the footprint of the industrial sector and their exclusion avoids a double-counting of emissions**. For example, the emissions from the concrete used in a building structure is part of the concrete industryʼs emissions footprint and, thus, the concrete manufacturer and supplier is accountable for the consequences of their product. This is not to say that embodied energy should not be considered during the construction of a building. van Ooteghamʼs comparative study suggests that embodied energy can be lowered when building materials are carefully considered. Therefore, embodied energy should form a part of the decision making process in buildings that are considering GHG emissions even if it is excluded from the reporting protocol or analysis scope.

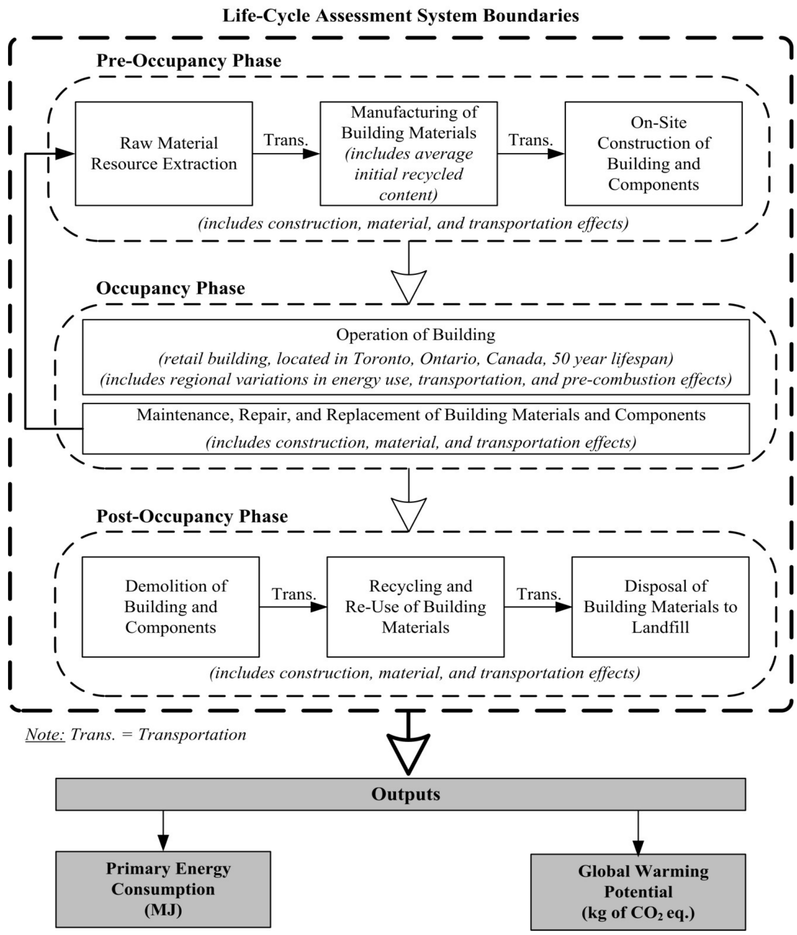


Fig. 3.7 (above)
Energy and Emissions Lifecycle Assessment Boundary for Scopes One, Two, and Three (van Ooteghem, 2010)

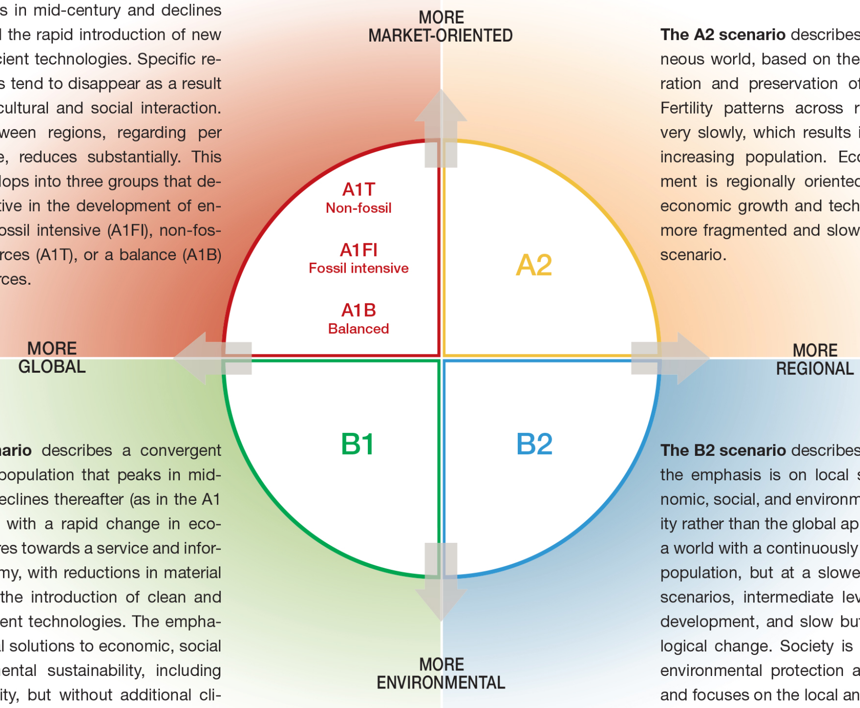
3.5 Total Building Impact and GHG Emissions

Lifecycle Assessments (LCA) have emerged as the method to accurately determine the impact of a building project by relating the various constituent components over time. ISO Standard 14040 defines an LCA as a study that "addresses the environmental aspects and potential environmental impacts throughout a product's lifecycle from raw material acquisition through production, use, end-of-life treatment, recycling, and final disposal."[37] The various products and activities are broken down and itemized, allowing the final analysis to identify the relative impacts of every aspect of the constituent parts to the whole. Impacts range widely and can include water consumption, toxicity, acidification, and waste generation, in addition to energy consumption and greenhouse gas emissions. The ATHENA Impact Estimator, for example, includes many of these in its database.[38]

The first and most important part of any LCA is the definition of the system boundary and listing the impacts that will be included. Thus, an LCA can include one or all impacts. Figure 3.7, above, is an example of an assessment that is limited to energy consumption and emissions from operating energy and embodied energy. LCA Studies demonstrate that material selection and energy consumption are related and careful choices can reduce the overall impact. **However, within the context of global emission allocations and reductions to achieve the 2°C Scenario, only operating energy emissions are allocated to the building sector whilst embodied energy effects for products are within the scope of the manufacturer and their associated industrial emissions.** To be consistent with this international standard, only greenhouse gas emissions from Scope One and Scope Two Operating Energy will be considered[39].

The A1 scenario describes a future world of very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Specific regional patterns tend to disappear as a result of increased cultural and social interaction. The gap between regions, regarding per capita income, reduces substantially. This scenario develops into three groups that describe alternative in the development of energy supply: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance (A1B) across all sources.

The A2 scenario describes a very heterogeneous world, based on the continued separation and preservation of local identities. Fertility patterns across regions converge very slowly, which results in a continuously increasing population. Economic development is regionally oriented and per capita economic growth and technological change more fragmented and slower than in the A1 scenario.



The B1 scenario describes a convergent world with a population that peaks in mid-century and declines thereafter (as in the A1 scenario), but with a rapid change in economic structures towards a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 scenario describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability rather than the global approach in B1. It is a world with a continuously increasing global population, but at a slower rate than other scenarios, intermediate levels of economic development, and slow but diverse technological change. Society is oriented towards environmental protection and social equity, and focuses on the local and regional level.

Fig. 3.8 (above)
International Governmental Panel on Climate Change Marker Scenarios for Business-As-Usual Emission Scenarios
(IPCC, 2005)

3.6 Global Mitigation Scenarios for 2°C

Limiting climate change to 2ºC requires significant changes across all Greenhouse Gas emitting sectors, from industry to land-use management to buildings to the structure of the energy system. Predictive scenarios produced by key international organizations suggest various approaches to accomplish the necessary reduction and mitigation. The Intergovernmental Panel on Climate Change *Special Report on Emissions Scenarios* (SRES) provides six scenarios that predict different patterns of change in the fundamental socio-eoncomic drivers of emissions, namely energy use, GDP, population, economic and physical development, governance, raw material consumption and the rate of adoption of climate change measures[40]. These are updated with each Assessment Report. They form the baseline assumptions for scenarios to assess annual emissions, mitigation potentials, and the requirements for change at a given point in time to meet various climate change thresholds.

Historic data points to an acceleration of greenhouse gas emissions at the high end of the SRES Scenarios. Predicting an annual growth of between over 2%, global emissions are suggested to reach between 75 and 140 Gt-CO_2-e by 2100. Studies suggest that the building sector could contribute between 9 and 13 Gt-CO2-e per annum from primary and secondary energy use by 2050. This Business-as-Usual (BAU) condition would lead to an atmospheric GHG concentration in excess of 750ppm, exceeding the stabilization target of 450ppm, and result in a mean increase in global temperature of between more than 3.7 and 4.8ºC. Uncertainties in projections suggest that the upper threshold could be 7.8°C[41].

"When setting building performance targets ... the context of global mitigation scenarios, the sector definitions must be carefully respected to avoid double-counting, incomplete, or exaggerated calculations."

Comprehensive global mitigation scenarios allocate building-related greenhouse gas emissions to Scope One and Scope Two secondary energy consumption, consistent with IPCC Common Reporting Format. Some scenarios include only Scope One Emissions; however, with the significant upstream effects of grid-supplied energy and the important role of energy efficiency to the energy sector, these studies are not an effective baseline to analyze or model the impacts attributable to the building sector. Although material and construction decisions also have important emissions implications, Scope Three emissions and halocarbons are outside of the sector's scope[42]. **When setting building performance targets to limit climate change within the context of global mitigation scenarios, the sector definitions must be carefully respected to avoid double-counting, incomplete, or exaggerated calculations.**

Halocarbons are an important emission factor that should be acknowledged. The UNEP Common Carbon Metric includes them, as they are directly related to materials and systems and account for a growing share of the sectors Global Warming Potential. 23% of global emissions are related to non-energy related halo and hydrocarbons, of which 60% of this total share is attributed to the blowing agents used for insulation, and refrigerant leaks and disposal from cooling and refrigeration systems. With global warming potentials up to 23,00 times higher than carbon dioxide, they represent up to 1.5 Gt/CO_2e above and beyond energy-related emissions without concerted action. *Canada's Emissions Trends 2014* report suggests that, by 2020, halocarbon emissions may be up to 30% of the total building emission footprint. Like embodied energy, as energy efficiency increases, halocarbon emissions can represent a consequently larger share. However, when considering emission reductions within the accounting methodologies used across mitigation studies, they are excluded from this particular study[43]. To remain consistent, this study will do so also. Nevertheless, concerted international efforts are being made to find alternative refrigerants and blowing agents. The Montreal Protocol seeks to phase out CFCs and HFCs from them by 2030[53].

Six mitigation scenarios were found to include a detailed description of building sector Scope One and Scope Two secondary energy and emissions forecast. Many scenarios include only Scope One emissions or do not provide enough background detail on the drivers of building emissions, the Business-As-Usual (BAU) baseline, or the final target and are thus excluded. Figure 3.12, following, illustrates the substantial impact of Scope Two emissions in the building sector and why it is so important to include it. In particular, the Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA) discuss building sector emissions this way. These two scenarios are critical as they also form the basis for most other mitigation studies and are considered primary data. Therefore, the scenarios included provide a comprehensive literature review of building emission thresholds to limit climate change to 2ºC.

Although sharing similar approaches to achieving a similar emissions goal, the six scenarios represent two methodologies when identifying building sector mitigation potential. The first deals with the global mitigation context of which buildings are a part and the final target relies upon a particular assignment of emissions and measures to the sector. These particular studies admit this

Cumulative Efficiency-Related CO_2 Emission Savings by Sector and Region

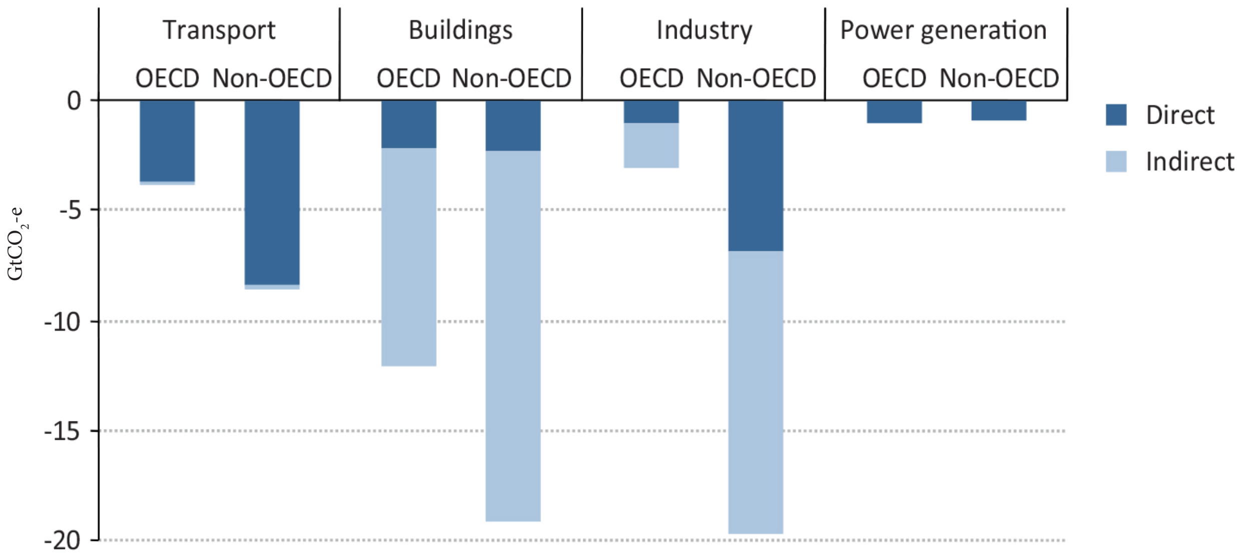


Fig. 3.9 (above)
Direct and In-Direct Emissions Reduction Potential by Region and Sector
(IEA, 2012)

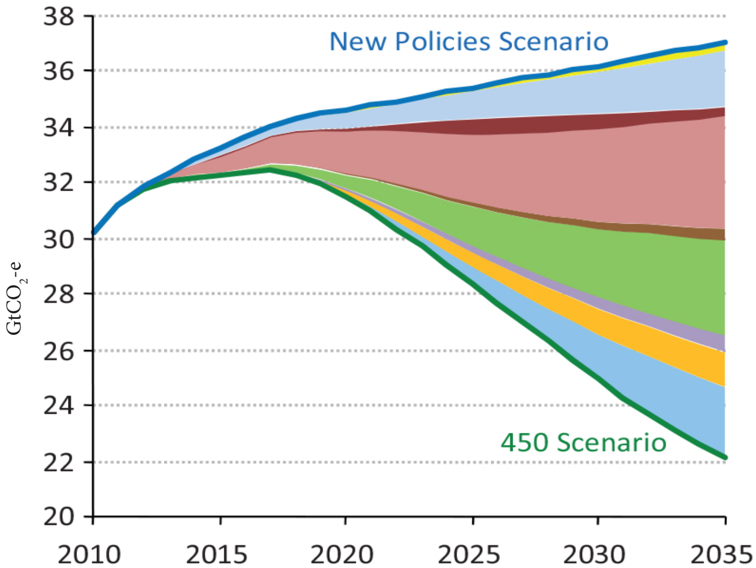
approach suffers from over-compartmentalization and can underestimate the sector's potential secondary impacts on other sectors due to a reliance upon a list of distinct technological approaches. The second acknowledges the context of global emissions, but works from the bottom up and simply applies a reduction regardless of how emissions are assigned to the sector. In both cases, cross-sector implications are acknowledged but not identified and whole-building solutions that include more subtle, design based strategies such as the impact of building orientation, aspect ratio, local or regional fuel emission intensity, and passive design strategies can increase reduction potential event further.

In all scenarios, on-site renewable energy is not accounted for within the sector's emission reduction targets. Rather in the power sector where on-site systems are seen as contributing to the larger target share of renewable energy in the overall mix of electricity generation fuel sources. Therefore, energy consumption and emission targets for achieving 2°C are based on lower building loads lower Scope One and Scope Two energy consumption through energy efficiency measures, and associated emissions from the selected fuel sources.

Scenario 1: International Energy Agency (IEA) World Energy Outlook 2012[44]

Energy Technology Perspectives 2012 summarizes the global energy landscape in terms of both .sources and consumption and projects current trends forward to the year 2035. The key finding suggests that current policies are failing to put the global energy system on a sustainable path and that new policy commitments, while making some impact, are not sufficient to solve the climate change problem. Focusing on energy use emissions only, this Business-as-Usual (BAU) projection, described as the "New Policies Scenario" predicts energy demand will grow by over 30%, with the majority coming from the emerging economies of India, China and the Middle East while the growth of demand in the Organization of Economic Cooperation and Development (OECD) region to slow. Fossil fuels are predicted to retain their dominance in the world energy structure and the huge promise of efficiency remains unrealized, with four-fifths of the opportunity in the building sector untapped. Current policies are suggested to lead to a 1.5% annual growth in GHG emissions. This scenario is suggested to exceed the climate change threshold by nearly two-fold with a rise in mean global temperature of 3.6°C. To achieve the

Global Energy-Related CO_2 Emissions Abatement



CO_2 abatement	2020	2035
Activity	2%	2%
End-use efficiency	18%	13%
Power plant efficiency	3%	2%
Electricity savings	50%	27%
Fuel and technology switching in end-uses	2%	3%
Renewables	15%	23%
Biofuels	2%	4%
Nuclear	5%	8%
CCS	4%	17%
Total (Gt CO_2)	**3.1**	**15.0**

Fig. 3.10 (above)
International Energy Agency 450ppm Mitigation Scenario relative to the New Policies Business-As-Usual Emissions Scenario.
(IEA, 2012)

2°C Scenario and limit the concentration of emission to 450-ppm, annual emissions by the year 2035 are required to be 33.2 $GtCO_2e$. This "450 Scenario" requires a 51% reduction from the BAU projection of current global energy policies with OECD countries contributing 30%, with non-OECD countries contributing 70%.

The IEA suggests buildings will play a significant role in achieving their 450 Scenario. Globally, emissions related to secondary energy consumption are to be reduced from 9 $GtCO_2e$ to 2.9 $GtCO_2e$, a reduction of 69% compared to the BAU baseline. Although the study allocates secondary energy only to the building sector, when primary energy is considered, the mitigation potential could include at least 50% of electricity and heat generation emissions. Efficiency is key. The projected annual global construction rate of 1.7% corresponds to an annual increase in energy use of only 0.4%. To achieve this target, the IEA model applies improved efficiency to building insulation and energy management systems, space and water heating technologies, appliances, cooling technologies, lighting, and in the case of residential buildings, cooking fuels. This final category is most important in developing nations that lack modern infrastructures.

79% of emissions in the OECD region are implicit in the existing infrastructure. When considering buildings, existing building stock is suggested to have the biggest potential. Although low-energy new construction consumes less energy, they are nonetheless additive while retrofitting existing buildings to be more efficient is reductive. Recognizing that the state, design, and consumption of energy in buildings varies considerably around the world, different regions are assigned different pathways. In the United States, the IEA suggests building emissions are to be reduced by 80% by 2035, owing to the maturity of the built environment and the energy infrastructure, with energy demand approximately equivalent to the year 2000. Given that Canada shares a region, economy and energy infrastructure and has similar GDP and relative per-capita emissions footprint, this requirement can be logically extended.

Secondary energy is considered while the associated upstream primary energy consumption is assigned to the energy generation sector and creates a further cross-sector abatement potential. Building improvements included in the model

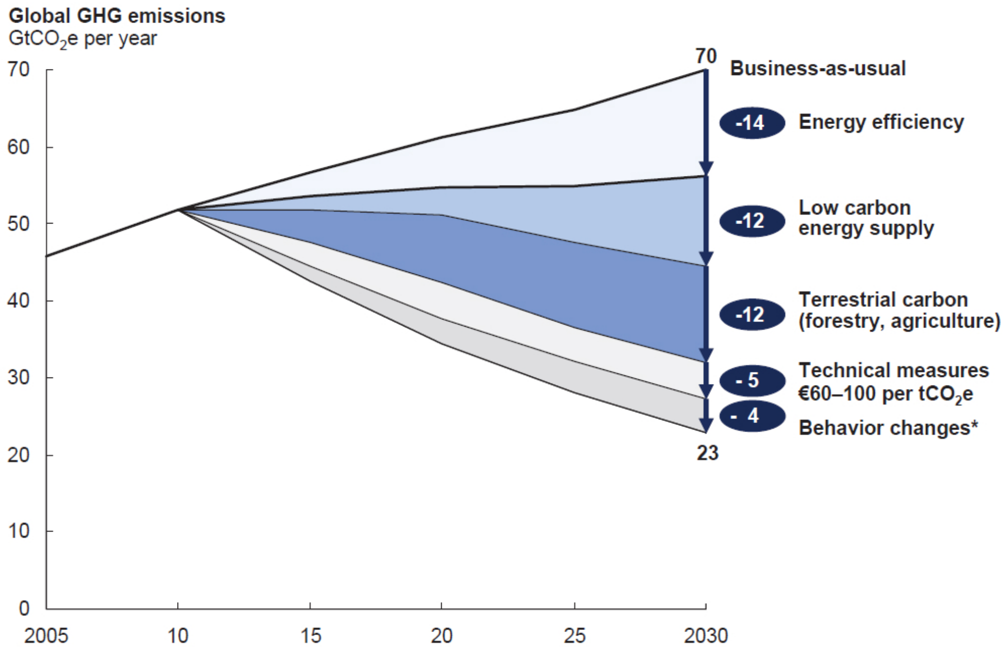


Fig. 3.11 (above)
Greenhouse Gas Abatement Potential by Activity (McKinsey & Co, 2009)

are focused on independent technologies as opposed to a broad, performance-based reduction in building EUI derived from a holistic approach to building design. Opportunities for passive design are not considered, likely due to the difficulty of consistently modelling the effects on a global scale. Thus, mitigation potential could be significantly underestimated. The scenario also assumes all technical measures would be implemented as the interaction between them is cumulative. For example, lower lighting loads can create a higher heating load that must be offset if the full technical potential of that measure is to be realized.

<u>Scenario 2: McKinsey & Company Pathways to a Low-Carbon Economy</u>[45]
The Pathway to a Low-Carbon Economy identifies a slate of specific strategies to reduce GHG emissions by 35% compared to 1990 levels or 70% compared to a Business-As-Usual projection that assumes the world makes little attempt to curb emissions. This abatement potential of 47 $GtCO_2e$ is expected to result in a peak atmospheric concentration of 480-ppm, with a long-term stabilization of 400-ppm and a likely chance of limiting climate change to 2°C. The building-sector abatement potential is 3.5 $GtCO_2e$ between 2005 and 2030, a reduction 28% compared to the BAU scenario. Existing buildings contribute 26% while retrofits to various aspects of existing buildings contribute the remaining 74%. The model identifies strategies grouped into the following six categories:

- ***New Build Efficiency Package: abatement potential of 0.920 $GtCO_2e$ by 2030***
  The model assumes aggressive new building standards that approach passive house standards, with an extremely low EUI of 35 ekWh/m²/year for site energy consumption. A study in the potential for zero energy buildings conducted by NREL suggests that this EUI can achieved on a broad basis when on-site renewable energy is considered. Regardless, the Pathways to a Low Carbon Economy study is the only global mitigation scenario found thus far that suggests a holistic energy-use target, albeit aggressive one that has been largely achieved on only the most advanced projects.

- ***Retrofit Building Envelopes: abatement potential of 0.74 Gt-CO_2e by 203***0
  Existing residential and commercial building envelopes are significantly renovated to improve insulating capacity of walls, roofs and windows, air-tightness, heat recovery, and taking advantage of solar orientation to reduce HVAC loads.

- ***Retrofit Existing HVAC: abatement potential of 0.29 GtCO2e by 2030***
  Systems are replaced with high-efficiency alternatives, heat pumps are introduced, improved system commissioning, and building control and automation systems are introduced as existing systems are retired. The model is conservative and assumes no premature replacement occurs.

- ***Retrofit Existing Water Heating: abatement potential of 0.35 GtCO$_2$e by 2030***
  High efficiency water heating systems replace existing systems without premature replacement. The penetration of solar hot water heating is considered to be low in developed economies due to cost.

- ***Retrofit Existing Lighting: abatement potential of 0.67 GtCO2e by 2030***
  Incandescent and compact fluorescent bulbs are largely replaced by LED, dimmable ballasts permit daylight harvesting and occupant sensors, and commercial T5 and T8 bulbs are replaced with T12 and super T8. It is assumed here that the increased heating load in cool climates is offset.

- ***Appliances and Electronics: abatement potential of 0.55 GtCO2e by 2030***
  High efficiency appliances replace older models at a rapid rate with an average 35% improvement in efficiency for residential appliances and commercial refrigerators and freezers between 15% and 20%.

The McKinsey study considers only secondary energy efficiency while the associated primary energy consumption is assigned to the energy generation sector. Although an extremely aggressive new construction EUI derived from a holistic approach to building design is proposed, the mitigation potential is markedly lower than other studies, perhaps due to a different assumption for the rate of renovation and the technical potential of each measure. Similar to other studies, the cross-sectoral effects for the energy sector are implied while a whole-building approach that includes passive design and additional savings by combining measures could increase the potential.

<u>Scenario 3: IPCC 4th Assessment Report</u>[46]
The IPCC 4th Assessment Report on Climate Change is comprised of reports from four working groups that investigate the physical science basis of climate change; the impacts, adaptation and vulnerabilities that result; mitigation; and a synthesis. Issued every five to seven years, these reports are a literature review of current research and conclusions. The third working group report on mitigation suggests the building industry is a sector with a significant abatement potential that can be realized with mature technologies. Compared to other sectors, it offers the largest share of cost-effective opportunities for GHG reductions.

The BAU emissions projection is suggested to be somewhere between the IPCC SRES B2 and A1B Marker scenarios that projects a regional rather than global approach to climate change mitigation. Emissions are projected to increase annually between 1.5% and 2.4% depending on the year. This is equivalent to 11.1 GtCO$_2$e in the year 2020 and 14.3 GtCO$_2$e by 2030 from Scope One and Scope Two energy consumption. When this trend is projected out to the year 2050, annual GHG emissions are suggested to be in excess of 13.5 GtCO$_2$e. Although non-CO$_2$ emissions contributed 15% of the total in 2004, the IPCC projects that many non-CO$_2$ gasses will begin to be phased out after 2015. Thus, when building envelopes, cooling systems and appliances are selected, non-CO_2 gasses must be considered. The study identifies an abatement potential of 5.6 $GtCO_2e$ by the year 2030, a 40% reduction. The largest reduction in energy use is with the immediate implementation of efficiency standards in new buildings while the largest portion of emissions reductions comes from retrofitting existing buildings. The study takes into account the following energy efficiency principles, compiled from nearly 80 studies:

- ***Reduce Heating, Cooling and Lighting Loads*** through an optimized building envelope, make use of ambient energy sources such as computers and people, make use of heat sinks such as thermal mass, and finally specifying efficient equipment and effective control strategies.
- ***Utilize Active Solar Energy and Other Environmental Heat Sources and Sinks*** through using on-site renewable electricity generation and hot water, using ground, water, mass, or air sinks either directly or with heat pumps, and passive cooling.
- ***Increase Efficiency of Appliances and HVAC Equipmen***t can reduce the number and size of appliances and equipment, provide effective lighting with less energy, and have the co-benefit of reducing cooling loads.
- ***Implement Commissioning and Improve Operations and Maintenance*** can bring the actual performance of a building closer to the modelled or expected performance. Improperly or incomplete systems commissioning and poor maintenance regimes lead to higher energy consumption. The case studies presented later suggest that modelling and reality are rarely aligned. In the case of the Aldo Leopold Centre, it took several years of commissioning and attention to building operations to achieve the desired energy target.
- ***Changing Occupant Behavior*** can have significant impacts. Studies have shown that the same building with different occupants can have higher energy use by a factor of two. Manual control combined with well-designed occupant feedback systems can substantially reduce energy consumption.
- ***Utilize A Systems Approach to Building Design*** through integrated design processes allows the co-benefits of various strategies to be realized. Examples include taking into account load reduction through passive design to shrink HVAC systems or the reduced cooling load from implementing daylight sensors on lighting. Not only does a systems approach take into account whole-building performance, it can also keep capital costs in-line with conventional buildings. Studies suggest that energy use reduction can range from 35% to 80% when this team approach is utilized.
- ***Consider Building Form, Orientation, and Related Attributes*** to reduce the need to use systems for heating, cooling and lighting. Building form, orientation, site and self-shading, and massing ratios of height-to-width are essential to take advantage of passive design strategies.

The IPCC study, in the chapter specifically discussing the building sector, does incorporate Scope One and Scope Two electricity-related secondary energy in its mitigation potential figures and acknowledges the upstream potential of primary energy. Like other studies, the authors recognize that the reliance on technical strategies only and the lack of coordination with impacts on other sectors and secondary effects underestimates the mitigation potential. Although seen as a foundational strategy to combat climate change, particularly in the short term, significant efforts to enhance existing policy for low-energy buildings and low-carbon energy sources are required.

Scenario 4: Architecture 2030 Initiative[47]

The 2030 Initiative was established to support the building sector's transformation to a low-carbon future by calling for the world-wide elimination of greenhouse gasses from building energy use by the year 2030. Based in the United States, it is a lobby organization that seeks to advance carbon-neutral standards in building legislation and proposes energy efficiency as the first priority with fuel-switching within the boundary of an individual project as the second. The process and targets identified for the global community include the following criteria.

All new buildings, developments and major renovations shall be designed to meet a fossil fuel, GHG-emitting, and energy consumption performance standard of 50% of the regional (or country) average for that building type.

At a minimum, an equal amount of existing building area shall be renovated annually to meet a fossil fuel, GHG-emitting, and energy consumption performance standard of 50% of the regional (or country) average for that building type.

The fossil fuel reduction standard, compared to the year 2002 for all new buildings shall be increased at the rate of 10% every five years, beginning with 60% reduction in 2010 and ending with 100% by 2030. Figure 3.13, following, suggests EUI targets for Canadian commercial buildings, broken out by region and type to achieve these benchmarks. At a maximum, 20% of the annual energy requirements may be met with purchased non-emitting renewable energy credits. This restriction does not apply to on-site renewable energy generation.

Unlike typical abatement studies that discuss building sector as one of many sectors, the Architecture 2030 initiative instead takes the principle that this end-use sector is both significant and the easiest to address quickly and simply proposes to completely eliminate of its emissions. If the linkages of the building sector discussed previously are considered, this bottom-up approach has the potential to drive change up the chain from a more accessible and smaller scale than, for example, the entirety of an electricity grid. Furthermore, the use of a performance based standard rather than relying on a limited list of technologies, such as T8 lights or programmable thermostats, the Architecture 2030 initiative allows holistic solutions that acknowledge the sector's full potential. Thus, the critical gap identified in other studies that underestimate the possible emissions savings is addressed by leveraging other sectors, such as power generation, and provide for design-based and passive solutions, such as building orientation and aspect ratio. The low EUI targets proposed for new buildings are similar to those in the McKinsey study and suggest that on-site renewables are required. Lastly, this approach eliminates the uncertainty in establishing absolute reduction targets relative to a baseline that, as the studies have demonstrated, is exceptionally difficult to establish due to the numerous upstream cross-sectoral affects and the interaction

2030 CHALLENGE Targets: Canadian Commercial Regional Averages

Averages for Site Energy Use and 2030 Challenge Energy Reduction Targets by Commercial Space/Building Type[1]						
Commercial Space/Building Type	**Average Site EUI ($GJ/m^2/yr$)**	**2030 Challenge Site EUI Targets ($GJ/m^2/Yr$)**				
		50% Target	**60% Target**	**70% Target**	**80% Target**	**90% Target**
Canada						
Wholesale Trade	1.470	**0.735**	0.588	0.441	0.294	0.147
Retail Trade	1.707	**0.854**	0.683	0.512	0.341	0.171
Transportation and Warehousing	1.323	**0.661**	0.529	0.397	0.265	0.132
Information and Cultural Industries	1.892	**0.946**	0.757	0.568	0.378	0.189
Offices	1.382	**0.691**	0.553	0.415	0.276	0.138
Educational Services	1.696	**0.848**	0.678	0.509	0.339	0.170
Healthcare and Social Assistance	2.212	**1.106**	0.885	0.664	0.442	0.221
Arts, Entertainment and Recreation	2.156	**1.078**	0.863	0.647	0.431	0.216
Accommodation and Food Services	4.670	**2.335**	1.868	1.401	0.934	0.467
Other Services	1.439	**0.719**	0.576	0.432	0.288	0.144
Atlantic						
Wholesale Trade	1.330	**0.665**	0.532	0.399	0.266	0.133
Retail Trade	1.605	**0.803**	0.642	0.482	0.321	0.161
Transportation and Warehousing	1.067	**0.533**	0.427	0.320	0.213	0.107
Information and Cultural Industries	2.078	**1.039**	0.831	0.624	0.416	0.208
Offices	1.373	**0.687**	0.549	0.412	0.275	0.137
Educational Services	1.493	**0.747**	0.597	0.448	0.299	0.149
Healthcare and Social Assistance	2.486	**1.243**	0.995	0.746	0.497	0.249
Arts, Entertainment and Recreation	1.720	**0.860**	0.688	0.516	0.344	0.172
Accommodation and Food Services	2.310	**1.155**	0.924	0.693	0.462	0.231
Other Services	1.314	**0.657**	0.526	0.394	0.263	0.131
Quebec						
Wholesale Trade	1.689	**0.845**	0.676	0.507	0.338	0.169
Retail Trade	1.777	**0.888**	0.711	0.533	0.355	0.178
Transportation and Warehousing	1.474	**0.737**	0.590	0.442	0.295	0.147
Information and Cultural Industries	2.650	**1.325**	1.060	0.795	0.530	0.265
Offices	1.477	**0.739**	0.591	0.443	0.295	0.148
Educational Services	1.897	**0.949**	0.759	0.569	0.379	0.190
Healthcare and Social Assistance	2.817	**1.408**	1.127	0.845	0.563	0.282
Arts, Entertainment and Recreation	2.199	**1.099**	0.880	0.660	0.440	0.220
Accommodation and Food Services	2.786	**1.393**	1.114	0.836	0.557	0.279
Other Services	1.654	**0.827**	0.662	0.496	0.331	0.165
Ontario						
Wholesale Trade	1.853	**0.926**	0.741	0.556	0.371	0.185
Retail Trade	1.622	**0.811**	0.649	0.487	0.324	0.162
Transportation and Warehousing	1.398	**0.699**	0.559	0.419	0.280	0.140
Information and Cultural Industries	1.734	**0.867**	0.693	0.520	0.347	0.173
Offices	1.421	**0.710**	0.568	0.426	0.284	0.142
Educational Services	1.768	**0.884**	0.707	0.530	0.354	0.177
Healthcare and Social Assistance	2.038	**1.019**	0.815	0.611	0.408	0.204
Arts, Entertainment and Recreation	2.677	**1.338**	1.071	0.803	0.535	0.268
Accommodation and Food Services	2.597	**1.299**	1.039	0.779	0.519	0.260
Other Services	1.568	**0.784**	0.627	0.470	0.314	0.157

[1] Natural Resources Canada, Office of Energy Efficiency, Comprehensive Energy Use Database

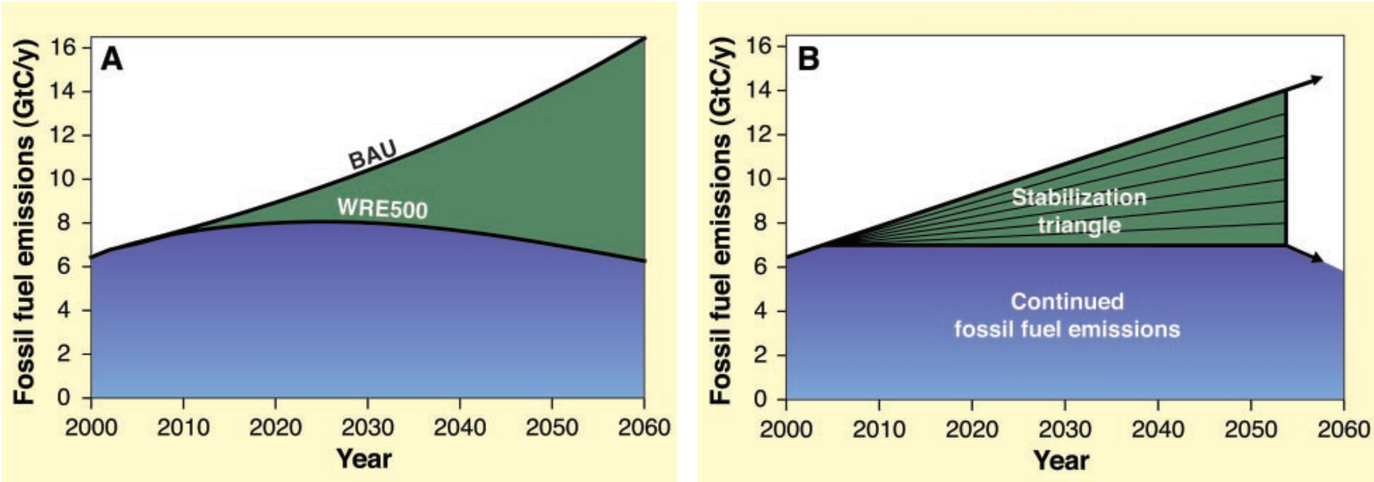


Fig. 3.12 (left)
Architecture 2030 Energy Use Intensity Guidelines for Canadian Commercial Buildings (Architecture 2030, 2000)

Fig. 3.13 (above)
Stabilization wedges representing 1.0 $GtCO_2e$ between the year 2005 and 2055.
(Socolow and Pacala, 2004)

between various technical measures. By simply reducing emissions, historic targets for a particular region can be used and an end goal that, when considering the emission thresholds suggested by the other studies, the requirements for the sector to limit climate change to 2°C can be met without uncertainty.

Scenario 5: Socolow & Pacala: Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies[48]

Socolow and Pacala developed the concept of stabilization wedges to address the climate change problem through assessing a portfolio of technologies, grouped into seven "wedges" that each contribute 1 $GtCO_2$-e of mitigation over a 50 year period, from 2004 through 2054. The study's BAU projections of global emissions are based upon the IPCC 3rd Assessment Report on Climate Change, where global emissions are predicted to rise from 7.0 $GtCO_2e$ to 13.8 $GtCO_2e$, equivalent to an annual rate of 1.5% per year. This results in a growth in annual emissions. The target reduction is 50% compared to this BAU scenario. Equivalent to stabilizing emissions at a concentration of 500-ppm, achieving the reductions suggested would limit the global rise in mean temperature to between 2.80°C and 3.2°C, a target right on the edge of run-away climate change. Although slightly above the 2°C Scenario, the study nevertheless provides insight into the interconnected nature of emissions sources and places the importance of the built environment in context.

Two wedges, or 2 $GtCO_2e$ of avoided annual emissions between the year 2005 and 2055, represents capping building sector emissions at 2005 levels. Following the sectoral definition outlined in the IPCC 3rd Assessment Report on Climate Change, this translates into a reduction in emissions from 3.9 $GtCO_2e$/yr to 2.0 $GtCO_2e$/yr. 65% of this mitigation potential is suggested to be possible in the commercial buildings sector with the remaining 45% allocated to residential buildings. Without exhaustively discussing the various technical elements, the study identifies space heating, space cooling, lighting, and electric appliances. Similar to most studies presented, the latent technical potential currently available suggests that buildings are one of the more promising sectors for mitigation.

However, the study cautions the reliance on "known and established" techniques to achieve both stabilization wedges and thus, in its overall assessment, takes a conservative approach and only claims 25% reduction in emissions, equivalent to one wedge. This is because the IPCC report suggests that between 35% and 60% of the efficiency measures that are technically and economically feasible... [and] could be adopted in the market through known and established approaches.

Scolow and Pacala thus consider these to be part of the BAU scenario. When considering the limited number of net-zero energy and carbon-neutral buildings and the trend that the pace of construction generally matches the sector's growth in emissions the importance of this final conclusion cannot be underestimated.

<u>Scenario 6: Institute for Sustainable Development and International Relations Pathways to Deep Decarbonization, 2014 Report</u>[49]

The Pathways to Deep Decarbonization is the product of a collaboration of various international research institutes and was produced to support the UNFCC COP-15 Paris Conference, held in 2015. Linking the concept of sustainable development to the avoidance of climate change, the report is unique in providing specific pathways for the top 10 global emitters, including Canada. Using the IPCC 5th Assessment Report as a BAU scenario, the study suggests that, without any action over and above current efforts, the mean global temperature is set to rise between 3.7°C and 4.8°C, nearly twice the accepted target of 2°C. Furthermore, the study concludes that, as of 2014, few governments have seriously investigated the implications of staying within the 2°C limit and fall short of commitments made at the 2010 UNFCC conference in Cancun.

The emission pathways are divided into two time periods, 2011 through 2050 and 2051 through 2100. The majority of emissions are suggested to occur in the first period while the global community implements mitigation measures that result in a decline to zero during the second. In other words, during the second half of the century, emissions are expected to stabilize with GHG concentrations below 480 parts per million. The mean atmospheric concentration of CO_2 in May of 2017, measured by NOAA, averaged 409.7 ppm[54].

The global CO_2 emission budget for energy-related emissions in all primary and end-use sectors by the year 2050, based on the median of scenarios surveyed by the IPCC 5th Assessment report, is suggested to be between 11 and 12 $GtCO_2$. This equates to a 47% reduction compared to the measured emissions in 2010 where the annual emissions of the top 10 nations were 21.8 $GtCO_2$. To reach this target, three primary "pillars" are identified: energy efficiency and conservation, low-carbon electricity, and fuel-switching. The switch to a low-carbon energy system cannot be driven by fuel scarcity as the carbon footprint of proven reserves exceeds the 2°C limit.

Globally, the energy generation sector is represents the largest mitigation potential by a large margin. The carbon intensity of electricity is proposed to drop by 94%, going from 590 gCO_2/kWh to 34 gCO_2/kWh while the share of electricity in final energy production is proposed to nearly double. The Canada-specific pathway projects that 43% of total energy supply will come from electricity by 2050. For the energy structure in Canada, this implies the near elimination of fossil fuels for electricity generation by 2050, with approximately 80% supplied by a combination of hydro, wind and solar

These three factors imply widespread fuel-switching towards electricity as a predominant energy source, the introduction of widespread efficiency measures and the near complete reliance on renewable and low-carbon generation technologies. For the Canadian building sector in particular, the pathway suggests that emissions from secondary energy consumption (grid supplied energy) are reduced by 96%, from 69 $MtCO_2e$ in 2010 to 3 $MtCO_2e$ in 2050. This nearly complete decarbonization is driven by three primary and interrelated factors: energy efficiency that reduces building EUI to approximately 194 $ekWh/m_2/yr$ and fuel switching to electricity for nearly 100% of energy demand. The greenhouse gas intensity per equivalent kilowatt-hour of secondary energy is projected to drop from 106.5 gCO_2/MJ to 2.9$gCO_2/ekWh$ by 2050. When combined with greenhouse gas intensity of primary energy supplied by electricity, the overall blended GHG-I per ekWh is proposed to be 4.3 $gCO_2/ekWh$. Fuel-switching is suggested to provide a larger abatement potential than energy efficiency.

It is important to note that this study does not provide a global building sector target in the same fashion as typical mitigation studies and is therefore difficult to summarize comparatively. It is, however; valuable in that it provides a country-specific scenario for the subject region of this research, Canada. The base data is taken from the IPCC 5th Assessment Report, and it can thus be assumed that the scope of reductions required by the building sector are in-line. All studies agree that the developed world, OECD countries in particular, bear the burden of more drastic emission cuts than the developing world.

Summary and Median Target Scenario for 2°C:

The literature suggests a broad range in mitigation targets of between 44% and 100%, with four of the six suggesting more than 50%. The remaining two assume a nearly 100% reduction and are considered outliers.. **Because of the distribution of the scenarios, a median has been taken to establish a global emissions reduction target of 59%.** These outlying scenarios have been retained because, although there is a building sector specific focus, they present a very ambitious technical potential that is in-line with the best performing case studies presented in Chapter 5. They also embody a more drastic overall emissions cut across all sectors to limit climate change. Architecture 2030, in particular, is a prevailing standard recognized by practitioners and organizations and provides a valuable reference point.

Table 3.2: Global Building Sector Mitigation Targets for the 2°C Scenario

Study	2050 BAU	2050 Target	Reduction
IEA World Energy Outlook 2012-450 Scenario, Global Avg.	10.6 Gt-CO_2-e	3.5 Gt-CO_2-e	67%
Pathways to a Low-Carbon Economy, Global	17.6 Gt-CO_2-e	9.8 Gt-CO_2-e	44%
IPCC AR4, Global Avg.	18.6 Gt-CO_2-e	9.2 Gt-CO_2-e	51%
Architecture 2030, Canada/USA	13.5 Gt-CO_2-e	0 Gt-CO_2-e	100%
Socolow and Pacala, Global	11.1 Gt-CO_2-e	5.7 Gt-CO_2-e	49%
Pathways to Deep Decarbonization, Canada	18.6 Gt-CO_2-e	0.74Gt-CO_2-e	96%
MEDIAN			***59%***

The first outlying scenario, Architecture 2030, suggests that current technology allows buildings to completely eliminate the emissions from Scope One and Two energy consumption through the combination of a 90% reduction in energy use, the introduction of on-site non-emitting renewable energy, and limited GHG removals through green power contracts. This study does not take a holistic view and place the building sector in context of the larger emissions landscape, but suggests that the technical potential can exceed, by a large margin, the minimum requirements of the 2ºC Scenario. Being one of the prevailing emission standards referenced by practitioners, building owners, institutions, and governments, it is an important point of reference. Pathways to Deep Decarbonization is the second outlying scenario and suggests a 96% reduction in building emissions and includes the larger emissions context. The primary difference is that it fully exploits the vast technical potential of the building sector, proposes a nearly complete de-carbonization of the energy supply, and projects less commercial square-footage per capita.

Many of the studies take a regional approach to recognize that emission drivers vary around the world. The IEA, IPCC AR4, Architecture 2030, and Pathways to Deep Decarbonization scenarios all provide reduction targets for either OECD North America, or Canada in particular. Summarized in Table 3.4 below, the studies suggest that more developed regions, with their high per-capita emissions and mature infrastructures, carry different burdens than less developed countries. In most cases, the responsibility for change and for reducing emissions is much more difficult because of existing infrastructure. **In this regional context, the median reduction scenario for Canada is 55%.** It is interesting to note that the IEA World Energy Outlook suggests a larger reduction potential in non-OECD countries by introducing low-emitting infrastructure and an aggressive building efficiency policy. With over 70% of emissions “locked-in” through 2035 in existing infrastructure, the abatement potential in developing countries is larger if significant energy efficiency and non-emitting energy technologies are incorporated relative to the business-as-usual assumptions[50].

"In this regional context, the median reduction scenario for Canada is 55%."

Table 3.3: Regional to Canada Building Sector Mitigation Targets for the 2ºC Scenario

Study	2050 BAU	2050 Target	% Reduction
IEA World Energy Outlook 2012-450 Scenario, OECD	4.02 Gt-CO_2-e	1.72 Gt-CO_2-e	57%
Pathways to a Low-Carbon Economy, Global	17.6 Gt-CO_2-e	9.8 Gt-CO_2-e	44%
IPCC AR4, OECD	6.7 Gt-CO_2-e	3.1 Gt-CO_2-e	53%
Architecture 2030, Canada	13.5 Gt-CO_2-e	0 Gt-CO_2-e	100%
Socolow and Pacala, Global	11.1 Gt-CO_2-e	5.7 Gt-CO_2-e	49%
Pathways to Deep Decarbonization, Canada	18.6 Gt-CO_2-e	0.74Gt-CO_2-e	96%
MEDIAN			***55%***

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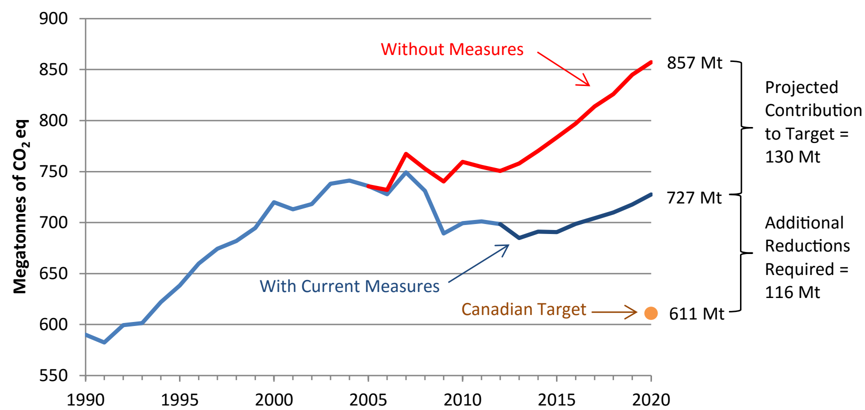


4.0 Canadian Commercial Building GHG Emissions Model for 2°C

Fig. 4.1
Progress on Canada's 2020 Target (Environment Canada, 2014)

Canada is currently falling short of its climate change obligations. The *Canada's Emissions Trends 2014* report projects that measures implemented between 2005 and 2014 will yield 727 MtCO_2e of GHG emissions per annum by 2020 while the commitments in the Copenhagen Accord cap them at 611 MtCO_2e. This threshold is above the annual emissions in 2005 rather than a reduction of 17%[1]. Compared to the Business-As-Usual scenario that excludes measures to reduce greenhouse gasses implemented after 2005, efforts are projected to yield just over half of the emissions reductions required in all sectors combined.

The report projects building sector emissions in 2020 will be 98 MtCO_2e by 2020, a growth of 14 MtCO_2e since 2005, with the growth in square footage expected to offset energy efficiency measures. Across all emission sectors, a majority of the mitigation potential resulting from the transition to cleaner grid-supplied electricity and energy efficiency are expected to be nearly equal to by a growth in GHGs from the oil and gas industry. Although emissions in 2020 from all sectors are expected to be 9 MtCO_2e lower than 2005, a significant achievement given that GDP is expected to grow by 38% over this same period, current measures nevertheless fall short. Given the technical maturity of measures in the building sector suggested by the global mitigation studies, a substantial mitigation potential to make up this shortfall remains to be exploited.

To achieve the 2°C Scenario threshold, a model for the building sector that reduces emissions by 55% by the year 2050 relative to a Business-As-Usual (BAU) Scenario is proposed that is consistent with the methodology used in *Canada's Emissions Trends 2014*. When considered in the context of historic emissions, the proposed annual emission target is approximately equal to the baseline year 2005 and suggests that, if existing building stock remains unchanged, new construction has been required to be carbon-neutral since then if the structure of energy supply and existing building stock remains unchanged. Reducing emissions in new construction alone is not enough; both new and existing buildings are equally important to not only accommodate growth, but allow a phased implementation of measures. The locked-in emissions from existing infrastructure can present a substantial barrier if it cannot be addressed.

4.1 Methodology and Emission Drivers

The emissions and broader environmental footprint of a building is multi-faceted and are a consequence of many issues that include energy use, material consumption, and the operational practices of building users[2]. In a comprehensive lifecycle assessment, all these elements can be included. This study focuses one aspect: emissions allocated to the building sector as defined by the Intergovernmental Panel on Climate Change. This specific boundary isolates the contribution of buildings to climate change within the global context of quantified emissions. Thus, only Scope One and Scope Two emissions from secondary operating energy are included. Scope Three emissions, including material, fugitive halocarbon, process, and organizational infrastructure such as commuting or employee travel are excluded. This scope intended not to diminish the larger scope of building emissions, but rather to be consistent with international convention for allocating greenhouse gas emissions to the building sector.

The fundamental goal of the emission projection model is to determine a national emission cap for Scope One and Scope Two emissions in the year 2050. To do so, the median scenario reduction target of 55% is applied to a Business-As-Usual (BAU) emission projection of emissions between the years 2005 and 2050, with emission reduction measures up to the year 2005 included. The model is simplistic and does not address the pace of policy intervention or the implications of when peak emissions might occur. Therefore, the requirements for emissions reductions are applied year-over-year equally and, thus decline at a regular interval to arrive at the 2050 emission cap. It does serve to answer the fundamental question of this research, which is identifying the emission cap for a Canadian Commercial building to meet the 2ºC threshold, which are relative to 2050 emissions.

The projections for the BAU and Mitigation scenarios follow a simplified approach to the decomposition methodology identified in the *Canada's Emission Trends 2014* Report[5]. Total national emissions are the sum of emissions from each sector, each of which is derived from the product of three fundamental components. This captures the interactions of the many drivers of each sector in a dynamic way. The components are related in the formula below and defined in further detail following:

$$E = \sum_{\text{sectors}} [A_s \cdot S_s \cdot I_s]$$

where:

E = emissions ($MtCO_2e$)

A_s = Activity Effect of sector (units will vary depending on sector)

S_s = Structural Effect of sector (units will vary depending on sector)

I_s = Emissions Intensity Effect of sector (units will vary depending on sector)

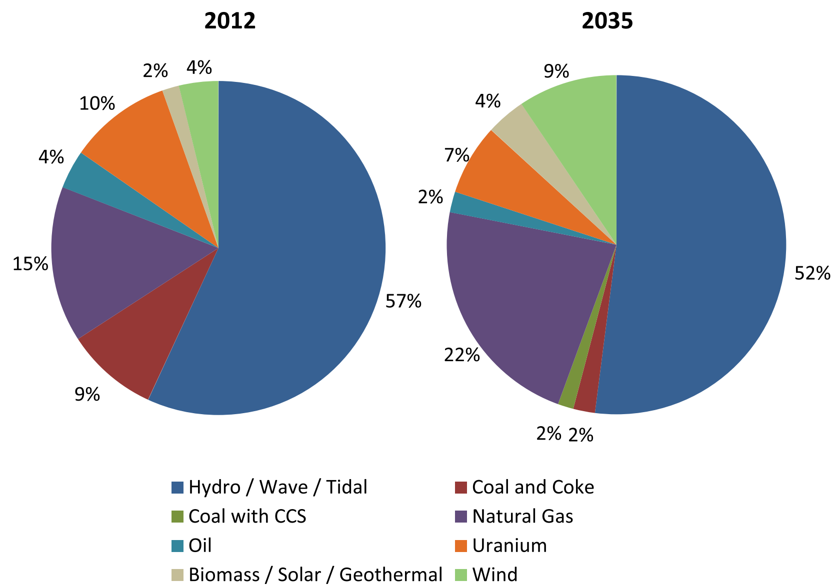


Fig. 4.2 (above)
The Emissions Intensity Effect: Canadian Electricity Generation Capacity Outlook in 2035 (National Energy Board, 2013)

Activity Effect and Constituent Drivers:

The activity effect is the change in economic growth over time and varies by sector. For the commercial building sector, this is the change in area of building over time and is composed of two constituent drivers. The first is the rate of new construction and is derived by projecting the trend of construction between 2006 and 2012[6], the macro-economic time horizon used by the *Canada's Emissions Trend 2014* Report. The second is the rate of substantial renovation and demolition where the scope includes space heating and cooling, lighting, and building envelope. An annual rate of 1.05%, measured from data collected between 2005 and 2009, is projected forward in all scenarios[7].

Structural Effect and Constituent Drivers:

The structural effect refers to the change in macro-economic factors that constitute a sector. For buildings, this refers to the amount and make-up of energy consumed and is primarily driven by commodity price or policy intervention. The annual energy required for a building is thus driven by a change in energy efficiency and the cost of fuel, such as electricity, natural gas or heating oil. This is equivalent to Energy Use Intensity (EUI) and is measured in ekWh/m^2 for each of the primary energy sources: electricity, natural gas, and other.

Emissions Intensity Effect and Constituent Drivers:

The structural composition of a sector has an emissions intensity associated with it. Each fuel source has an emissions rate per ekWh that is either direct, like in the case of natural gas combustion in an on-site boiler, or the result of a blend of sources, like in the case of grid-supplied electricity that can include coal, natural gas, hydroelectricity, or nuclear. The emissions intensity, measured in kgCO_2e/ekWh, is driven by the ratio of each fuel used or the changes in composition of blended energy sources, such as electricity. Figure 4.2 above, illustrates the how the compositional change in electricity generation between 2012 and 2035 is expected to lower greenhouse gas emissions[8].

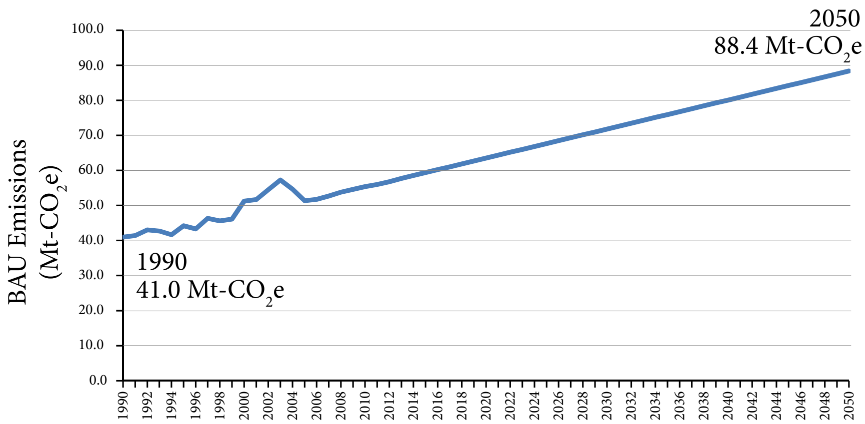


Fig. 4.3 (above)
Business-As-Usual Emissions Projection for Canadian Commercial Buildings

4.2 Business-As-Usual (BAU) Emissions Scenario for Canadian Commercial Buildings

The BAU trend for commercial building greenhouse gas emissions is steady growth. In 1990, Scope One and Two emissions were 41 MtCO_2e[9] and, without measures introduced after the reference year 2005, this number is expected to more than double to 88.4 MtCO_2e. This is the marker to which the median reduction scenario of 55% will be applied. The BAU assumes that the energy efficiency, structure and mix of energy sources, and emission intensity remain constant while the pace of construction extrapolates the trend between the years 2006 through 2012. The activity effects and their constituent drivers suggest that as of 2005, the growth in new construction has not been de-coupled from growing GHG emissions.

The BAU Activity Effect:
The total area of commercial space in Canada has grown consistently, with an average of 10 million m^2 of new construction added every year[10]. The trend in new construction between 2006 and 2012 projected out to the year 2050 suggests there will be 1,139.5 million m^2 of commercial building. Compared to 654 million m^2 in the reference year of 2005, the amount of floor area is expected to nearly double.

The BAU Structural Effect:
The model's first variable driver, Energy Use Intensity (EUI), is fixed at the 2005 level of 400 ekWh/m^2/yr to account for energy efficiency trends and policy interventions up to the common reference year and represent both existing and new construction. In 1990, when data began to be collected, EUI was also 400ekWh/m^2/yr[11], suggesting that between 1990 and 2005, energy efficiency efforts were either flat, or that a trend of growing EUI was reversed. Interestingly, this was also the lowest measured rate in any of the intervening years. Overall improvements to the structural effect following the baseline year of 2005 to 2013 form part of the 2°C Median Scenario. The second variable driver is the mix of energy sources used to meet operational energy demand. The mix of fuels is driven primarily by the cost of each type, and consequently, the share of electricity, natural gas, and other fuel types, such as heating oil or kerosene, is based on the measured trend between the years 2006 and 2012 and is projected forward to the year 2050. It is assumed that the EUI of new, renovated, and existing untouched up to the year 2050 has a blended EUI of 400 ekWh/m^2/yr to represent energy efficiency trends up to 2005.

The BAU Emissions Intensity Effect:

The national emissions intensity of grid-supplied electricity supply and others match the rates measured in 2005 and assumes they remain consistent up to 2050. The national rate for electricity was 0.204 $kgCO_2e/kWh$ and represented 39.5% of total energy consumption. This rate declined 5% between 1990 and 2005 and suggests a gradual shift to lower-emitting fuel sources. Natural Gas, the predominant fuel for heating, was 0.180 $kgCO_2e/ekWh$ and represented 52.3% of total energy consumption[12]. This energy mix suggests that natural gas will remain the primary energy source for heating, a condition that remains consistent up to 2050 in the BAU scenario.

There is a significant regional variation in the emissions intensity effect in Canada. The varied geography, resource availability, and prevailing climate drive unique patterns in energy use and fuel sources. Alberta and Saskatchewan have abundant coal reserves and rely on it for nearly 75% of grid-supplied electricity. This drives a GHG-I for delivered electricity of 0.91 $kgCO_2e/kWh$ and 0.880 $kgCO_2e/kWh$ respectively, far above the national average Quebec and Ontario, on the other-hand, have a substantial hydroelectric capacity that contributes to over 50% of grid-supplied energy. These provinces are below the national average with a delivered electricity GHG-I of 0.034 $kgCO_2e/kWh$ and 0.110 $kgCO_2e/kWh$ respectively[13]. Nevertheless, global mitigation scenarios model emissions on a Canadian or OECD North American level and, thus, the national average will be used in this emission forecast model. This regional variation creates different relative impacts of energy efficiency measures on end-use sector greenhouse gas emissions, the building industry in particular, and will affect the regional approaches to mitigation.

The BAU Scenario suggests that Scope One and Scope Two emissions from commercial buildings between 1990 and 2050 will double. Policy and practice measures up to 2005 have led to a condition where the growth in new commercial building construction outweighs efficiency measures, leading to year-over-year growth in energy consumption. Changes to the structure and mix of the energy supply have declined only marginally over this same period. The consequence is that the sector will exceed the 2ºC Scenario climate threshold. Although energy efficiency since 2005 has continued to improve, this trend suggests that emissions have yet to peak. The primary challenge becomes developing a capacity for new construction while at the same time creating a decline in overall annual emissions.

Measured data from 2005 to 2013 suggest that there have been significant measures implemented to reverse this trend. Approaching emission reductions from all fronts, commercial buildings have seen improvements in energy efficiency while large-scale infrastructure programs have led to a drastic decline in the emissions intensity of delivered electricity. Building EUI has declined by 18%, from 400 $ekWhr/m^2$ to 339 $ekWh/m^2$, while the emissions intensity of electricity has declined 5%. Because these trends have accelerated the reduction of emissions, the 2°C Median Scenario is broken into two parts: efforts up to 2013 and the remaining gap to achieve the emissions goal by 2050. This represents the gap in current practice relative to climate change mitigation goals.

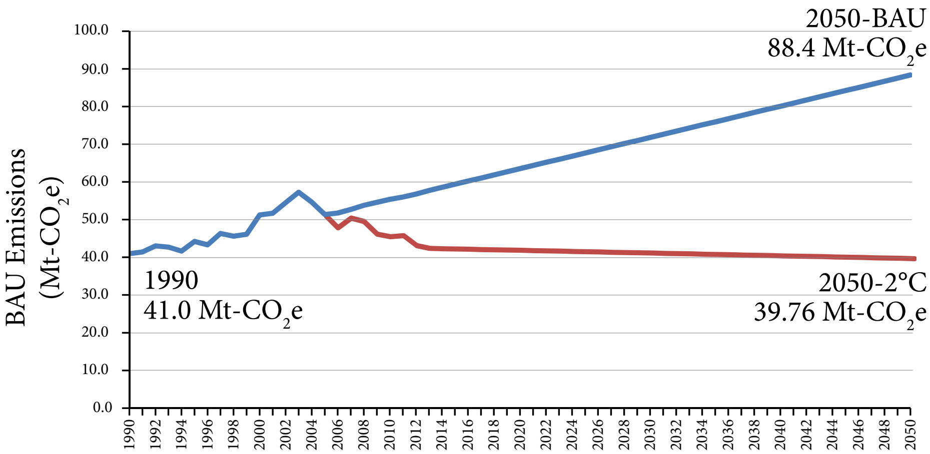


Fig. 4.4 (above)
2°C Median Mitigation Scenario Emissions Projection for Canadian Commercial Buildings

4.3 Median 2°C Mitigation Scenario for Canadian Commercial Buildings

The global mitigation studies presented in Section 3.2 suggest commercial building emissions need to be reduced by between 44% and 100%. Applying these targets to the Canadian Business-As-Usual (BAU) scenario suggests a reduction of between 34.1 MtCO_2e and 77.4 MtCO_2e is required, summarized in Table 4.1 below. Taking the median value of 55%, target emissions in 2050 are 34.9 MtCO_2e for the sector to limit climate change to 2°C, 1.24 MtCO_2e lower than 1990 levels. Although ambitious, these targets are consistent with the Intergovernmental Panel on Climate Change's conclusion that the building sector provides a large and accessible abatement potential using mature and available technology [14].

Table 4.1: Canadian Building Sector Emissions Targets for the 2°C Scenario

Study	% Reduction	Reduction by 2050	2050 Target
IEA World Energy Outlook 2012-450 Scenario, OECD	57%	44.14 Mt-CO_2e	33.30 Mt-CO_2e
Pathways to a Low Carbon Economy	44%	34.07 Mt-CO_2e	43.37 Mt-CO_2e
IPCC AR4, OECD	53%	41.04 Mt-CO_2e	36.39 Mt-CO_2e
Architecture 2030, Canada	100%	77.44 Mt-CO_2e	0.00 Mt-CO_2e
Socolow and Pacala	49%	37.95 Mt-CO_2e	39.49 Mt-CO_2e
Pathways to Deep Carbonization, Canada	96%	74.34 Mt-CO_2e	3.10 Mt-CO_2e
MEDIAN	***55%***	***42.59 Mt-CO_2e***	***39.76 Mt-CO_2e***

Current Measures committed between 2005 and 2020:
Since 2005, the reference year for the BAU scenario, there have been a number of concerted efforts to address building emissions that have impacted both the structural and intensity effects. Together, these improvements have seen energy efficiency increase and the greenhouse gas intensity of electricity drop. *Canada's Emissions Trend 2014* Report suggests these two activities will drive overall emissions reductions on a national level[15].

If trends remain consistent, current efforts could reduce building sector emissions by 29%, equivalent to 25.9 $MtCO_2e$. The gap to achieve the 2°C Scenario is reduced by more than half with the shortfall of current commitments equal to 22.9 $MtCO_2e$. These projections are based on the model assumption that the rate of construction is the same in both the BAU and 2°C scenarios.

- *Structural Effect - Measures between 2005 and 2013:*

  Between 2005 and 2013, the combined Energy Use Intensity (EUI) of new, renovated, and existing construction dropped from 400 $ekWh/m^2/yr$ to 339 $ekWh/m^2/yr$[16]. Assuming this 15% increase in energy efficiency in remains consistent, emissions will be reduced by 13.0 $Mt\text{-}CO_2e$ compared to the BAU scenario. Given that there was 90.2 million m^2 of new construction over this period, it can be concluded that measures to improve energy efficiency have had a significant effect. 2013 represents the last year of published data and current measures are assumed to be equivalent up to the year 2050 for the purposes of establishing the emission reduction gap.

- *Intensity Effect - Measures between 2005 and 2020:*

  On a national basis, reducing the emissions intensity of electricity is expected to be the largest mitigation strategy of all sectors. The National Energy Board projects that by 2020, emissions from electricity generation are expected to be 41% lower than the BAU scenario. This is driven by both increased efficiency, thus creating less demand, and a change in the fuel mix. By 2020, coal is predicted to decline substantially and be replaced with natural gas, carbon capture and storage installations, and non-hydro renewables, with the latter doubling from 6% to 13%. Natural gas is projected to increase from 15% to 22%. The share of greenhouse gas emitting fossil fuels used to generate and transport electricity will decline 28% to 26%[17].

  Canada's Emissions Trend 2014 suggests that by 2020, the emissions intensity of electricity will drop to 0.120 $kgCO_2e/kWh$[18] nearly half of the 0.204 $kgCO_2e/kWh$ measured in 2005. On the other hand, The National Energy Board also projects that natural gas will remain the primary fuel for heating[19]. Similar to the BAU scenario, the emission intensity of natural gas will remain at 0.180 $kgCO_2e/ekWh$ and will represent 52% of total energy consumption.

  Nevertheless, the model suggests that switching to cleaner electricity could reduce emissions from commercial buildings by 12.9 $MtCO_2e$, nearly equal to the contribution of energy efficiency. This demonstrates the important relationship between how much energy is used and the emissions intensity of the fuel source. Achieving the 2°C Scenario in the building sector requires action on the scale of both the individual building and of energy infrastructure.

Closing the Gap between Current Measures and the 2°C Target:
The 2°C target requires annual emissions to drop from 88.4 $MtCO_2e$ to 39.8 $MtCO_2e$ by 2050. The model suggests that current measures to increase energy efficiency as of 2013 and to increase the share of low and non-emitting fuel sources for electricity by 2020 are expected to reduce annual emissions to 62.5 $MtCO_2e$ compared to the BAU. The remaining gap of 22.7 $MtCO_2e$ requires strategies applied to each of the three emission activity drivers to precipitate the significant transformation of commercial buildings that is required.

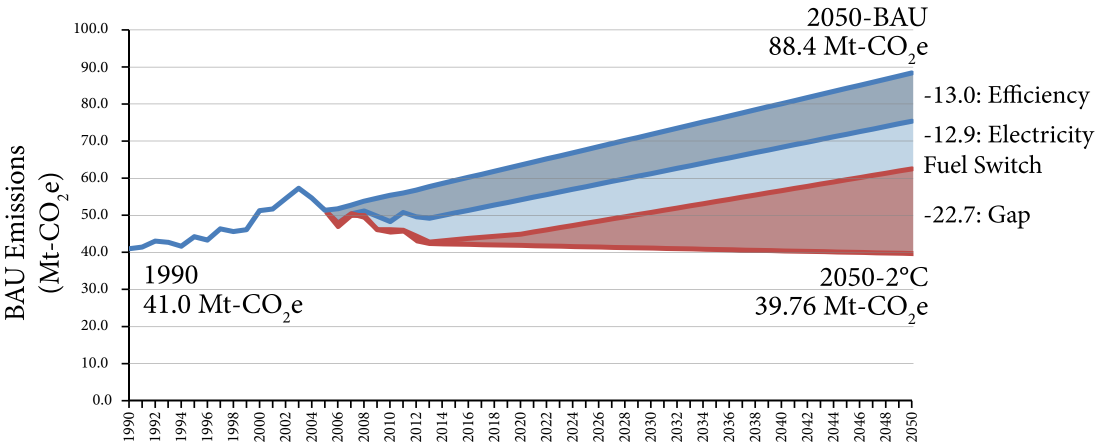


Fig. 4.5 (above)
Current Measures Gap to achieve the 2°C Scenario for Canadian Commercial Buildings

Each of the emission activity components is a set of variables driven by large-scale infrastructure, regional policy initiatives, and individual building design strategies. With the focus of this research to define the latter, the approach is to follow a bottom-up methodology and define a greenhouse gas emission budget per square metre of building area for the year 2050. Assumptions will fix various large-scale variables that will allow techniques and technologies that are within the scope of an individual building to be deployed. This strategy recognizes the "end-use" nature of buildings and does not encumber the ability of the commercial building sector to achieve specific climate change goals with the emission drivers that are beyond its realistic scope. Any changes to these larger scale drivers, such as the electricity generation sector or the rate of renovation driven by macro-economic forces, can thus adjust this emission budget over time to be larger or smaller and should be revisited periodically up to the year 2050.

- *Emission Budget - 2°C Target:*
  Achieving annual emissions of 39.76 $MtCO_2e$ in 2050 requires an emission budget of 15.3 $kgCO_2e/m^2$ for all new construction and substantial renovations. The blended budget for new, renovated and existing buildings combined is 22.3 $kgCO_2e/m^2$ while existing construction is projected to emit 35.3 $kgCO_2e/m^2$. This wide disparity between existing and new/renovated construction demonstrates the significant impact of built-in emissions and is directly related to the rate of renovation. The following section will explore the assumptions made for the emission drivers, the regional implications and how the emission budget can shape building performance.

- *Activity Effect - 2°C Target:*
  The first variable is the rate of new construction. The 2°C Target model retains the rate of construction of the BAU scenario and is based upon the macro-economic trends between 2006 and 2012, where 10.7 million m^2 is projected to be added on an annual basis. 1,139.5 million m^2 in 2050 will be required to have total Scope 1 and Scope 2 emissions remain at or below 39.8 $MtCO_2e$. Any change in space efficiency is assumed to keep pace with patterns embodied in the measured trend.

The second key variable is the rate of demolition and substantial renovation of existing buildings to reduce energy consumption, and thus emissions. This variable is crucial as it is fundamentally reductive and creates capacity within the emission cap for new construction. The 2°C Median Scenario model assumes that the renovation of buildings that include heating and cooling systems, lighting, windows and insulation will continue at the annualized pace of 1.05% that was measured between 2005 and 2009[20] and that the energy efficiency of these improvements will equal the targets set for new construction. The rate of renovation and its corresponding energy efficiency will increase or decrease the emission budget per square metre of new construction.

- *Structural Effect - 2°C Target:*
  Energy efficiency is the key building performance metric for design and follows from the emission budget and fuel emission intensity. The amount of energy that can be consumed is derived from the blended emission intensity of energy supplied relative to the emission budget per square metre and total building area. The emission rates are described in the Intensity Effect section, following, and are based on using a combination of national gas and other fuels for heating and grid-supplied electricity for all other energy needs. Because the model is national in scope, the national, rather than the regional, rates are used. The result is a total national energy budget of 880.1 PJ for the 1,139 million m^2 of new, renovated, and existing buildings in 2050, equivalent to a blended EUI of 216.7 ekWh/m^2/yr. The rate renovation affects the share of this energy budget, and thus EUI, available for new construction. Of the total energy budget in 2050, 7.5 PJ is projected to be available for new/renovated construction, equivalent to 94.4 ekWh/m^2/yr. One important characteristic of the proposed model is that the energy budget assumes a mix of grid-supplied electricity, natural gas, and a marginal amount of other fuels, such as heating oil.

- *Intensity Effect - 2°C Target:*
  When the *Intensity Effect* is considered, an annual emission budget of 15.3 kgCO_2e/m^2/yr for buildings in 2050 can be derived. Two drivers are considered. The first is the emissions intensity of each fuel source. The national rate for electricity of 0.120 kgCO_2e/kWh projected for 2020 accounts for current commitments to reduce emissions from electricity generation, the rate for natural gas is at 0.180 kgCO_2e/ekWh, and the rate for other fuels is 0.243 kgCO_2e/ekWh. The second driver is the ratio of each fuel used and is based on the values from 2013, the last year of measured data. The resulting blended rate per ekWh is based on the assumption that natural gas remains the predominant fuel for heating and represents 52.3% of the total share, other fuels are 8.2%, and electricity is 39.5%. This yields an emissions intensity of 0.161 kgCO_2e/ekWh. Regional variations will generate different total energy budgets for both existing and new/renovated construction based on the emission budget. For example, if the national average for electricity supply was equivalent to Ontario, the emissions intensity of 0.157 kgCO_2e/ekWh allows a total 913.1 PJ while the rate of 0.461 kgCO_2e/ekWh in Alberta yields just 310.6 PJ.

Table 4.2: 2°C Median Scenario Summary			
Driver	BAU Value	Measures 2013-2020	2°C Scenario Value
Emissions in 2050			
Total Emissions	**88.37 $MtCO_2e$**	**62.49 $MtCO_2e$**	**39.76 $MtCO_2e$**
2050 Building Emission Intensity - New/Renovated	72.4 $kgCO_2e/m^2$	47.5 $kgCO_2e/m^2$	15.3 $kgCO_2e/m^2$
2050 Building Emission Intensity - Existing	77.7 $kgCO_2e/m^2$	55.0 $kgCO_2e/m^2$	35.3 $kgCO_2e/m^2$
2050 Building Emission Intensity - Blended New/Reno and Existing	77.6 $kgCO_2e/m^2$	54.84 $kgCO_2e/m^2$	34.9 $kgCO_2e/m^2$
Activity Effect			
Annual New Construction	$10.7x10^6$ m^2	$10.7x10^6$ m^2	$10.7x10^6$ m^2
Annual Renovation Rate	1.05%	1.05%	1.05%
Structural Effect			
Permissible Energy - Blended	1,636.15 PJ	1,395.01 PJ	887.64 PJ
EUI - Blended	400 $ekWh/m^2/yr$	338.9 $ekWh/m^2/yr$	216.7 $ekWh/m^2/yr$
Permissible Energy - New/Reno	30.19 PJ	23.88 PJ	7.71 PJ
EUI - New/Reno	372.2 $ekWh/m^2/yr$	294.4 $ekWh/m^2/yr$	94.4 $ekWh/m^2/yr$
Permissible Energy - Existing	1,605.96 PJ	1,368.3 PJ	879.93 PJ
EUI - Existing	400 $ekWh/m^2/yr$	341.7 $ekWh/m^2/yr$	219.4 $ekWh/m^2/yr$
Intensity Effect			
Intensity Electricity	0.204 $kgCO_2e/kWh$	0.120 $kgCO_2e/kWh$	0.120 $kgCO_2e/kWh$
Share Electricity of Total	39.5%	39.5%	39.5%
Intensity of Natural Gas	0.180 $kgCO_2e/kWh$	0.180 $kgCO_2e/kWh$	0.180 $kgCO_2e/kWh$
Share Natural Gas	52.3%	52.3%	52.3%
Intensity other Fuels	0.243 $kgCO_2e/kWh$	0.243 $kgCO_2e/kWh$	0.243 $kgCO_2e/kWh$
Share other Fuels	8.2%	8.2%	8.2%
Blended Energy Intensity	0.194 $kgCO_2e/kWh$	0.161 $kgCO_2e/kWh$	0.161 $kgCO_2e/kWh$

The emission budget of 15.3 $kg/m^2/yr$ suggests the building sector must continue to transform while not necessarily requiring net-zero or carbon-neutral construction. By using the emission cap as a "bottom-up" design tool, the onus of meeting the 2°C Median Scenario is on each project while separating the larger issues of infrastructure and top-down energy policy interventions from the tasks of building design, construction and operation. The extent of this transformation can be moderated by changes at both scales. At the larger scale, changes in energy infrastructure beyond current commitments or increasing the rate of substantial renovation can increase or decrease the emission cap. At the scale of a building, altering the blend of fuel sources can increase the permitted EUI.

On a national basis, the emission cap suggests the total building stock in 2050 will have a combined EUI 216.7 $ekWh/m^2/yr$, 46% below the measured value in 2013. The EUI for new and renovated buildings is suggested to be 94.4 $ekWh/m^2/yr$, a 68% lower than buildings built after 2005[21]. Case studies and assessments of technical potential in Section 5.0, following, are compared to assess the built potential of achieving these targets and suggest this level of energy efficiency is practicable without the contribution of on-site renewable energy and is approximately equivalent to "best-in-class" energy-efficient buildings.

"The emission budget of 15.3 $kg/m^2/yr$ suggests the building sector must continue to transform while not necessarily requiring net-zero or carbon-neutral construction."

4.4 Building Energy and Emission Budget

The emissions cap of 15.3 kg-CO_2e/m^2 is the fundamental performance metric for achieving the emission reductions required by 2°C Median Scenario on a project-by-project basis. The key attributes that comprise it can be derived using the emission factor method outlined in the *United Nations Environment Programme Common Carbon Metric*[22]. The Metric includes methodologies for calculating emission intensities for unique fuel sources such as purchased steam and heat, shared energy systems, and CHP facilities. It should be noted that it also includes halocarbon emissions from refrigerants and blown insulation, emissions that are not included in the scope of this research as they are considered fugitive emissions and are accounted for in a different sector. This limitation of scope is consistent with the method and limits of the global mitigation scenarios in Section Three.

The key strength of the emission factor method is the ability to consider project-specific attributes, thus making it a powerful design tool. Detailed metrics can be derived by relating the emission drivers and their constituent emission factor to suit a particular context. **Regional variations in electricity emission intensity, fuel choices, on-site renewable energy choices, and energy efficiency thresholds are inter-related in the formula and can thus inform the most effective way to achieve an emissions cap within a projects unique context and constraints.** The proposed formula is:

$$E_i \cdot m^2 = \Sigma\ (I_f \cdot E_f)$$

where:
E_i= annual emissions intensity budget (kgCO_2e/m^2/yr)
m^2 = area of proposed building
I_f = Emissions Intensity of fuel type (kgCO_2e/ekWh)
E_f = Annual Energy Use of Fuel Type (ekWh/yr)

Two examples will illustrate how the regional context and fuel choices can generate very different performance requirements for the same building that meets the 2°C Median Scenario emission target. The formula will be applied to a 1,601.6 m^2 building, similar to the demonstration buildings analyzed in Section 6, in three emission contexts: the national average, Ontario, and Alberta. For each region, two different fuel mix scenarios are proposed and the results compared.

Fuel Mix A: uses both Natural Gas and Electricity and is consistent with the 2°C Median Scenario where both fuels are assumed to be used. Natural gas is used for Space Heating and Domestic Hot Water and represents 58% of the total energy consumption. Electricity is used for all other loads and represents 42% of the total energy consumption. It includes plug (auxiliary) loads, lighting, fans/motors, and space cooling. This allocation reflects a typical commercial building in 2013.

Fuel Mix B: assumes an all-electric building and is representative of many net-zero and carbon-neutral buildings with on-site renewable energy. Table 4.3, following, summarizes how the emission cap of 15.3 kgCO2e/m^2 creates a wide range of regional variation based on the emission intensity of the local grid.

Table 4.3: 2°C Energy Budget by Region and Fuel Type			
Input / Output	National Average	Ontario	Alberta
Fuel Mix A - Natural Gas and Electricity			
Total Emission Budget			
Emission Intensity Budget (E_i)	15.3 $kgCO_2e\text{-}m^2$		
Area of Proposed Building (m^2)	1,601.6 m^2		
Permissible Emissions	***24.5 tCO_2e***		
Emissions Rate by Fuel Source			
Emission Intensity - Electricity (I_e)	0.120 $kgCO_2e$/ekWh	0.110 $kgCO_2e$/ekWh	0.910 $kgCO_2e$/ekWh
Fuel Ratio	0.42		
Emission Intensity - Natural Gas (I_g)	0.180 $kgCO_2e$/ekWh		
Fuel Ratio	0.58		
Permissible Energy Use and Emissions - Electricity			
Energy from Electricity	85,595 ekWh	93,429 ekWh	11,308 ekWh
Energy Use Intensity Electricity (EUI_e)	52.8 ekWh/m^2/yr	58.3 ekWh/m^2/yr	8.3 ekWh/m^2/yr
Emissions from Electricity	10.29 tCO_2e		
Permissible Energy Use and Emissions - Natural Gas			
Energy From Natural Gas	79,117 ekWh	79,117 ekWhJ	79,117 ekWh
Energy Use Intensity Nat. Gas (EUI_g)	50.0 ekWh/m^2/yr	50.0 ekWh/m^2/yr	50.0 ekWh/m^2/yr
Emissions from Natural Gas	14.21 tCO_2e		
Total Permissible Energy Use			
Total Permissible Energy Budget	***156,529 ekWh***	***172,546 ekWh***	***90,426 ekWh***
Total Permissible EUI	***97.2 ekWh/m^2/yr***	***108.3 ekWh/m^2/yr***	***55.6 ekWh/m^2/yr***
Fuel Mix B - Electricity Only			
Total Emission Budget			
Emission Intensity Budget (E_i)	15.3 $kgCO_2e\text{-}m^2$		
Area of Proposed Building (m^2)	1,601.6 m^2		
Permissible Emissions	***24.5 tCO_2e***		
Emissions Rate by Fuel Source			
Emission Intensity - Electricity (I_e)	0.120 $kgCO_2e$/ekWh	0.110 $kgCO_2e$/ekWh	0.910 $kgCO_2e$/ekWh
Fuel Ratio	1.00		
Emission Intensity - Natural Gas (I_g)	0.180 $kgCO_2e$/ekWh		
Fuel Ratio	0.00		
Permissible Energy Use and Emissions - Electricity			
Energy from Electricity	203,799 ekWh	222,446 ekWh	29,925 ekWh
Energy Use Intensity Electricity (EUI_e)	127.8 kWh/m^2/yr	138.9 kWh/m^2/yr	16.7 kWh/m^2/yr
Emissions from Electricity	10.29 tCO_2e		
Total Permissible Energy Use			
Total Permissible Energy Budget	***203,799 ekWh***	***222,446 ekWh***	***29,925 ekWh***
Total Permissible EUI	***127.8 kWh/m^2/yr***	***138.9 kWh/m^2/yr***	***16.7 kWh/m^2/yr***

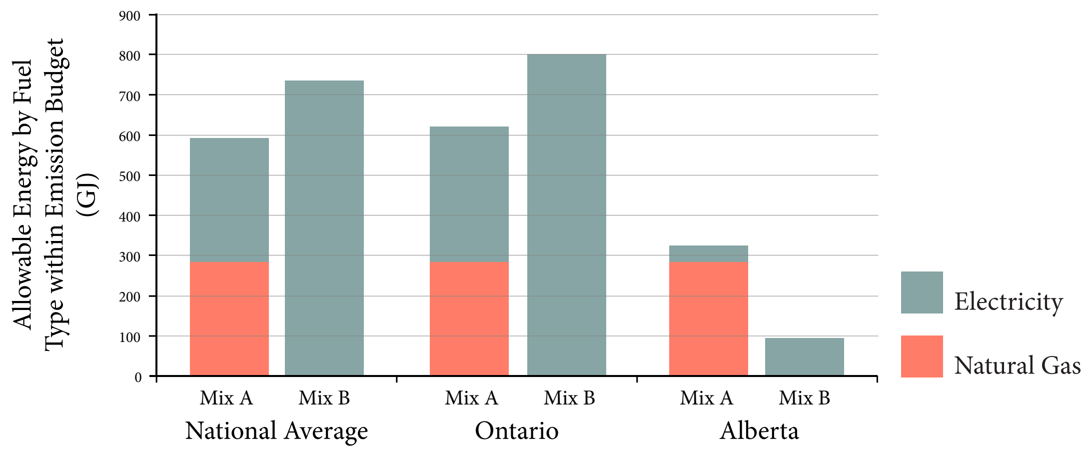


Fig. 4.6 (above)
Annual Energy Budget (ekWh) for a 1,601.6m^2 Commercial Building in Three Regions with Equivalent Annual Emissions of 24.5 $MtCO_2e$

Figure 4.6, above, illustrates how differences in the emission intensity of electricity in each region effect the permissible energy consumption within the same emission cap. Regardless of fuel choice, the high emissions factor of 0.910 $kgCO_2e$/ekWhr in Alberta significantly reduces the permissible amount of energy that a building can consume; approximately half of the national average in the mixed-fuel scenario and approximately a quarter in the all electric scenario. On the other hand, the electricity grid in Ontario, where the electricity grid emits 0.110 $kgCO_2e$/ekWhr, permits a building to consume slightly more than the national average.

The relative emissions of each fuel source reveal an interesting pattern. Where natural gas emits more than the electricity grid, using more electricity permits a larger energy budget. Conversely, in a region where natural gas emits less than electricity, the use of a fossil-fuel can increase the permitted energy. Of course, the permitted energy thresholds for each building load and associated fuel type must be able to realistically meet these loads. In the Alberta example where natural gas is used, the heating and domestic hot water load are limited to 50.0 ekWh/m^2/yr while all other remaining uses, including plug loads, are limited to merely 8.3 ekWh/m^2/yr. The implication is that on-site renewable energy and passive design must be able to essentially eliminate energy consumption from lights, plug-loads, fans/motors, and space cooling. Given that 5.6 ekWh/m^2/yr is the lighting load in a best-in-class energy-efficient building suggested by the National Renewable Energy Laboratory[23], the permissible energy budget will be very difficult to achieve in the Alberta region without changes to the electricity system. Nevertheless, on the basis of the national average, built examples do demonstrate that these targets can be achieved, but that they remain exceptions rather than the norm.

1 Environment Canada. (2014). *Canada's Emission Trends, 2014*. (Cat. No.: En81-18/2014E-PDF). Ottawa, Ontario: Her Majesty the Queen in Right of Canada: Author.

2 United Nations Environment Programme-Sustainable Buildings and Climate Initiative. (2010). *Protocol for Measuring Energy Use and Reporting Greenhouse Gas Emissions from Building Operations*. Paris, France: Author.

3 Environment Canada. (2014). *Canada's Emission Trends, 2014*. (Cat. No.: En81-18/2014E-PDF). Ottawa, Ontario: Her Majesty the Queen in Right of Canada: Author.

4 Reserved

5 Environment Canada. (2014). *Canada's Emission Trends, 2014.*

6 Natural Resources Canada, Office of Energy Efficiency. (2016). *Statistics and Analysis, Energy Use Data Handbook Tables 1990-2013* [Data File]. Retrieved from: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive/trends_com_ca.cfm

7 Natural Resources Canada, Office of Energy Efficiency. (2012). *Survey of Commercial and Institutional Energy Use - Buildings 2009, Detailed Statistical Report.* Her Majesty the Queen in Right of Canada. Ottawa, Ontario: Author.

8 National Energy Board. (2013). *Canada's Energy Future 2013, Energy Supply and Demand Projections to 2035.* Her Majesty the Queen in Right of Canada. Ottawa, Ontario: Author.

9 Natural Resources Canada, Office of Energy Efficiency. (2016). *Statistics and Analysis, Energy Use Data Handbook Tables 1990-2013* [Data File].

10 Ibid.

11 Ibid.

12 Ibid.

13 Environment Canada. (2014). *National Inventory Report 1990–2012: Greenhouse Gas Sources and Sinks in Canada, Part 3.* Her Majesty the Queen in Right of Canada. Ottawa, Ontario: Author.

14 IPCC. (2014). *Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA.

15 Environment Canada. (2014). *Canada's Emission Trends, 2014.*

16 Natural Resources Canada, Office of Energy Efficiency. (2016). *Statistics and Analysis, Energy Use Data Handbook Tables 1990-2013* [Data File].

17 National Energy Board. (2013). *Canada's Energy Future 2013, Energy Supply and Demand Projections to 2035.* Her Majesty the Queen in Right of Canada. Ottawa, Ontario: Author.

18 Environment Canada. (2014). *Canada's Emission Trends, 2014.*

19 National Energy Board. (2013). *Canada's Energy Future 2013, Energy Supply and Demand Projections to 2035.*

20 Natural Resources Canada, Office of Energy Efficiency. (2012). *Survey of Commercial and Institutional Energy Use - Buildings 2009, Detailed Statistical Report.* Her Majesty the Queen in Right of Canada. Ottawa, Ontario: Author

21 Natural Resources Canada, Office of Energy Efficiency. (2016). *Statistics and Analysis, Energy Use Data Handbook Tables 1990-2013* [Data File].

22 United Nations Environment Programme-Sustainable Buildings and Climate Initiative. (2010). *Protocol for Measuring Energy Use and Reporting Greenhouse Gas Emissions from Building Operations*.

23 Griffith, B., Long, N., Torcellini, P., Judkoff, R., Crawley, D., & Ryan, J. (2007). *Assessment of the Technical Potential for Achieving Net-Zero Energy Buildings in the Commercial Sector*. (National Renewable Energy Laboratory Technical Report NREL/TP-550-41957). Golden, Colorado, USA.

5.0 Case Studies

Mitigating commercial building emission to achieve the 2°C Scenario requires a significant transformation. The emission cap suggests that an EUI of 94.4 ekWh/m^2/yr is required, when the national average emissions intensity for electricity and natural gas is used. The variation in the regional emissions intensity of electricity and the chosen fuel profile can generate a range from 138.9 ekWh/m^2/yr to 17.7 ekWh/m^2/yr, as illustrated in the previous section. Although a significant departure from current practice, leading-edge low-energy and low-carbon projects have been able to achieve and exceed this. However, a survey of built examples implies that the site context has a significant impact on the opportunity to reduce energy use and to deploy on-site renewable energy.

Most "best-in-class" examples were found to be either in rural or sub-urban settings where the ability to optimize passive design is possible and overshadowing by surrounding buildings is not an issue. For this study, buildings with a site EUI of 127.2 kWh/m^2/yr or better are considered "best-in-class". This threshold is defined by the US National Renewable Energy Laboratory (NREL) A*ssessment of the Technical Potential for Achieving Net-Zero Energy Buildings in the Commercial Sector* as the Maximum Technology scenario for energy efficiency[1]. Projects have been selected largely from a review of the National Renewable Energy Laboratory (NREL) High Performance Buildings Database, the Living Building Institute, and the AIA Top Ten database and should be considered representative rather than exclusive. Six projects, three rural and three urban, have been selected because their size and program generally reflect the demonstration projects in this research and they provide a cross-section of issues that arise when considering low-energy buildings and greenhouse gas emissions.

Table 5.1: Low Energy Building Case Studies

Project	Site Context	Size (m^2)	EUI (ekWh/m^2/yr)	ASHRAE Zone
Woods Hole Research Centre, Falmouth, Mass., USA	Rural	1,780	58.3	5A
Aldo Leopold Legacy Centre, Baraboo, Wisconsin, USA	Rural	1,100	49.3	6A
Bullitt Centre, Seattle, Washington, USA	Urban	4,831	50.0	4C
Clockshadow Building, Milwaukee, Wisconsin, USA	Urban	2,821	158.4	6A
Artists For Humanity Epicentre, Boston, Mass., USA	Urban	2,183	80.6	5A
Earth Rangers Centre, Woodbridge, ON, Canada	Rural	5,500	94.5	6A
NREL, all climate zones in the USA	All	All	38.9 *(office)* 133.3 *(retail)*	6A
Canadian Commercial 2013/ Energy Star Median (50)	All	All	225.7	6+

Fig. 5.1 (above)
Gilman Ordway Building at theWoods Hole Research Centre

For each project, a concise summary of site context, design solutions, systems and materials as they relate to operating and embodied energy are provided. It is important to note that not all case studies addressed the issue of GHG emissions. The broader issues of sustainable design, such as water use and indoor air quality are addressed and, although acknowledged to be important, are not included as the research focus is on Scope One and Scope 2 energy and GHG emissions.

Gilman Ordway Building at the Woods Hole Research Centre:
The Woods Hole Research Centre (WHRC) is located on a rural site in Falmouth, Massachusetts, USA. The Centre is an independent, non-profit, non-governmental organization that focuses on environmental science, climate change, interdisciplinary analysis, policy innovation, and public education on the impacts of human activities on the natural environment. In 2003, it outgrew its existing facilities, anticipating a growth in staff from 45 to 60. William McDonough + Partners were charged with the challenge of designing a net-zero energy and carbon-neutral facility on a constrained site that combined both new and existing construction. The 1,780m^2 facility houses primarily laboratories, common, and commercial office spaces 38% of which is located in a heritage converted house with the remaining 62% in the new three-storey addition.

With the goal of net-zero energy in mind, passive design strategies were investigated to reduce the energy demand. However, the local climate presented a challenge. Falmouth, located on Cape Cod, is situated in ASHRAE Climate Zone 5A, Cool-Humid, where available sun for passive heating and daylighting is both modest and seasonally opposite in availability. In winter, when the sun is needed for passive heating, there can be less than two hours of full sun while, in summer, when cooling is required, there are over six hours[2]. The desire for the existing heritage building to be visible from the street further constrained the

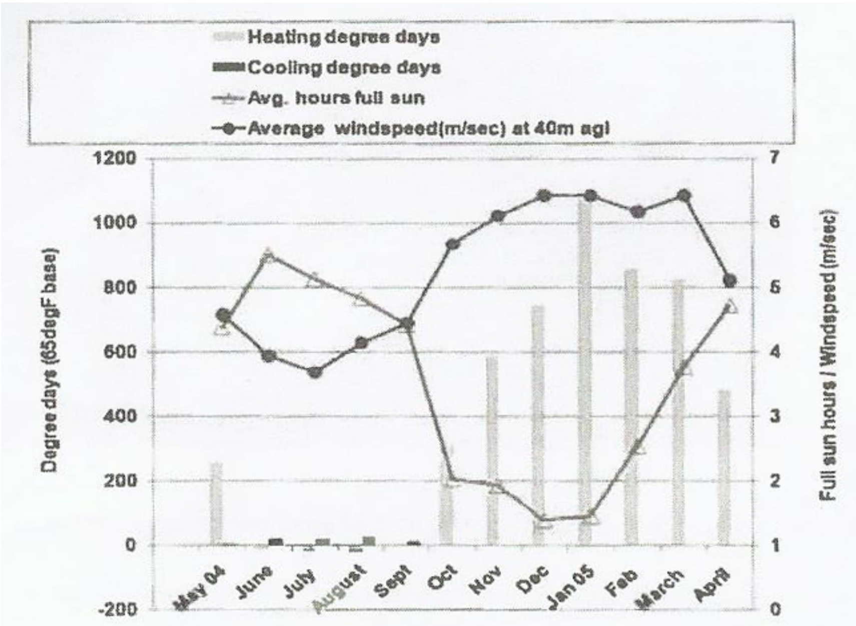


Fig. 5.2 (above)
Heating and Cooling Degree Days relative to available solar hours at Cape Cod.
(Hackler and Holdren, 2008)

project's passive design opportunities. Although solar resources are not ideal for passive heating, the site is rural and access to daylight and view of the surrounding countryside was prioritized. This created a condition where the predominant facade, and thus the largest expanses of glazing, was oriented to the north.

To achieve net-zero energy performance, the project team used an integrated design process, making use of Energy-10 software to parametrically analyze design and systems iterations to make use of every opportunity to increase energy efficiency. An all-electric HVAC system was selected so that on-site solar and wind energy generation systems could account for the entire energy demand. To determine a starting point, a model building conforming to ASHRAE 90.1-1989 was created and was estimated to have an EUI of 263.9 ekWh/m^2/yr[3]. This is compared to the average EUI of 283.3 ekWh/m^2/yr for office buildings in the US in 2003[4], the same year as the Centre was completed. A number of key strategies were determined at the outset to optimize efficiency such that 41% of the energy load could be met with roof-mounted photovoltaics and 59% with an on-site wind turbine[5].

The first strategy is the building envelope. An off-set wood stud wall construction was specified to eliminate thermal bridging and increase the cavity to between 200mm / 8" and 250mm /10" inches to achieve an R-20 rating. The cavity was filled with an HCFC-Free polyurethane spray insulation, a technology that also significantly improves air-tightness. The roof features 100mm / 4" of polyurethane rigid insulation board applied on-top of the roof deck, with spray insulation on the underside to achieve a combined rating of R45[6].

The second was to focus on windows and doors. The existing facility was retrofitted with double-glazed low-e insulated glazing units (IGUs) with an argon fill to achieve a centre-glass R_{si}-0.42 / R-4.1. The new facility features triple-glazed IGUs with argon and a low-E coating for an of Rsi-0.95 / R-5.4 and a SHGC of 0.24 and limited the area of glazing to a Window Wall Ratio to a low 20%[7]. The new facility made use of improved glazing owing to the predominantly north orientation.

Thirdly, the HVAC systems have been designed to be all-electric to avoid the combustion of fossil fuels to the site and permit the entire building demand to be met through on-site energy sources. A 15-ton open-loop ground source system, connected to six heat pumps, satisfies the bulk of the heating and cooling loads.

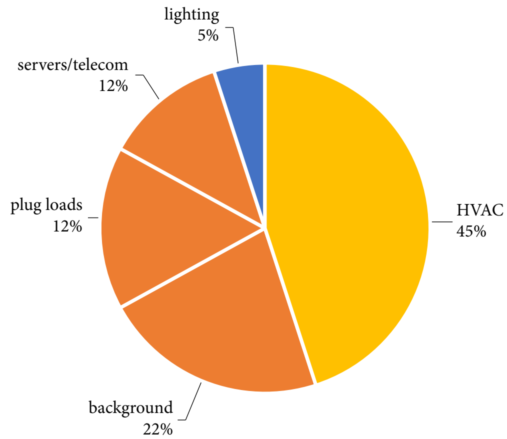


Fig. 5.3 (right)
Measured energy use distribution for the Woods Hole Research Centre
(Hackler and Holdren, 2008)

Two water-to-water heat pumps supply a low-temperature hydronic heating system for offices while four water-to-air heat pumps provide heating and cooling to large open and public spaces such as the commons, laboratory, and auditorium. Between March 2004 and February 2005, the ground-source heating system met all cooling and heating loads while accounting for only 23% of the total energy requirement for the building. Enthalpic heat-recovery ventilators (ERVs) are used to harvest both latent and sensible energy from exhaust air[8].

Daylighting combines with efficient lighting technology and occupancy sensors to dramatically reduce the need for electric lighting. Due to the nature of the climate, daylighting is the predominant passive design technique[9]. Auxiliary, or plug, loads in low-energy buildings can represent a large proportion of the electricity demand. The WHRC acknowledged this by selecting low-energy office equipment and appliances. Where available, Energy Star rated equipment was specified.

A significant monitoring system was installed to track the performance of the building over time to provide data for research efforts. A suite of over 72 sensors monitor both building loads and the contribution of grid-supplied energy versus the on-site energy systems, including the photovoltaic array, wind turbine, and ground-source heat pump. The wind turbine was added after several years of operation and this real-time building performance data was used to size it to achieve measured carbon neutrality on an annual basis[10].

In its first year of operation, between March 2004 and February 2005, the facility had a measured EUI of 50.7 kWh/m^2/yr, a reduction in energy demand of 81% compared to the baseline model, and 79% compared to the US average. Over a three year period, the EUI averaged at 57.7 kWh/m^2/yr, demonstrating the importance of annual monitoring as drivers such as climate conditions, occupancy patterns, or renovations change over time[11]. The energy profile, illustrated in Figure 3.17 above, shows that HVAC loads (heating, cooling, fans and ventilation) were the primary type with 45% of the total load. Auxiliary loads, including plug loads and servers, combined to represent 28%. Included in the auxiliary load category, but broken out as their own segment, are background loads. This includes "parasitic" loads from equipment that is left on or in a dormant state, surge protectors, elevators, smoke detectors, automated systems etc. When base building loads become very efficient, this load segment becomes significant in the overall footprint. In the first year of operation, these background loads accounted for nearly 50% of the total energy produced by the photovoltaic system. Together, HVAC and auxiliary loads represent 95% of the energy requirements. The design for daylight strategies, combined with occupancy and daylight sensors, are by far the smallest load and represent the remaining 5%.

Achieving carbon neutrality at the WHRC did not occur immediately. Although available roof area was maximized to house the photovoltaic array, annual monitoring showed it produced enough energy to satisfy 28% of the annual load, roughly equal to the demand of one of the three storeys.

Aldo Leopold Legacy Centre:
The Aldo Leopold Foundation is dedicated non-profit, donor-supported advocacy organization with a stated mission "of weav[ing] a land ethic into the fabric of our society; to advance the understanding, stewardship and restoration of land health; and to cultivate leadership for conservation." In 2007, the Aldo Leopold Legacy Centre was constructed as the Foundation's headquarters on the 300-acres surrounding the original farm of Aldo Leopold, after whom the foundation is named. Designed to directly reflect these values, carbon neutrality, including a number of Scope 3 emissions, was a goal from the outset[12]. The selection of materials was also informed by greenhouse gas emissions and made use of wood harvested from lands owned and managed by the Foundation.

The 1,100 square metre building is sited in a fully rural context and consists of three one-storey buildings that house meeting rooms, offices, archives and public spaces for exhibits, tours, lectures and programs. The campus is oriented around a south-facing landscaped space featuring a rain garden, restored native prairie and several gardens of drought-tolerant and native vegetation. The landscape design and building organization thus optimize the site's solar geometry to maximize potential for passive heating, ventilation and daylighting.

To meet the aggressive energy efficiency and Scope-Three carbon neutral performance, the integrated design team began with the premise of maximizing the time the building can operate without lighting and mechanical systems through passive design techniques. To achieve carbon neutrality, a roof-mounted PV system was specified to satisfy the remaining heating, cooling, lighting, auxiliary, and ventilation loads. At the outset, an energy budget was determined such that a rooftop PV array could, on an annual basis, meet the energy demands completely on-site. An ambitious target EUI of 5kWh/m^2/yr was selected based on a rooftop photovoltaic array capacity of 278.9 square metres[13]. This design philosophy and aggressive EUI goal together illustrate the importance of placing a quantifiable carbon footprint and energy use budget on an equal footing as a building's program and financial budget if aggressive performance targets are to be met.

Baraboo, Wisconsin is located in ASHRAE Climate Zone 6A cold-humid with between 4000 and 5000 heating degree days at 18ºC. Typical of central North America, there is a large annual temperature range with a summer high of 43ºC and winter low of -40ºC. The heating season is predominant, lasting between the months of October through April; swing seasons May through June in the spring and September in the fall; and finally the cooling season between July and August.

The building responds directly to this climate context with massing and orientation to reduce energy consumption. A long, narrow footprint was chosen and oriented along the east-west axis to maximize the facade area exposed to winter sun and

Fig. 5.4 (above)
Aldo Leopold Centre

prevailing summer winds for natural ventilation and cooling. Large overhangs along the south facade shade glazing in the cooling seasons to limit unwanted heat gain. Clerestory glazing facing the north provides an even natural light to the building interior without unwanted heat gain and are carefully sized to provide a target level of illumination while minimizing heat loss. A roof below the clerestory serves as a light shelf to increase the daylighting effectiveness and aid in the even distribution of light.

The building program is also shaped by climate and energy conservation. Program spaces that are used year-around are located in the main building. Two smaller outer buildings house program uses that are seasonal in the summer, thus limiting the square footage that must be mechanically conditioned to areas with regular occupation throughout the year. All regularly occupied spaces are located in perimeter zones to optimize opportunities for passive design[14]. In the main building, the circulation corridor is arranged along the south facade. Because it is not regularly occupied, this zone can act as a thermal buffer to regularly occupied spaces. The transfer of harvested heat, the management of natural ventilation, and the protection from glare and excess heat gain is all managed by this space through the use of interior glazing and large doors between the corridor and adjacent spaces. Figures 5.5 and 5.6, following, illustrate how these strategies shape a building that carefully and intentionally responds to the prevailing climate.

Passive design strategies are only truly effective if a robust building envelope is used. The use of glazing is optimized to provide light, admit heat from the south during winter, and provide view from selected spaces. An extremely low window wall ratio of 12.6% was designed, with the south accounting for 4.3% and north 3.9%. Considering the ASHRAE Standard 90.1-2004 specifies a limit of 40%, the Aldo Leopold Centre demonstrates the substantial contribution of lower glazing ratios in cold climates. Opaque elements of the building envelope are insulated to nearly twice the recommended standard. A combination of 8" wood framed cavity walls and wood-framed Structurally Insulated Panels (SIPs) filled with spray-applied polyisocyanurate insulation achieve a nominal R-value of 64. A continuous line of insulation along the inside face between the interior sheathing and the structural wood studs eliminates through-and-through thermal bridging. The project team, in this case, chose to measure the performance of the envelope by the *Enclosure Heat Transfer Rate* method, or the heat transfer rate between the building and outdoor environment from all surfaces, at 0.14 Btu/^{0}F/ft$_2$/hr[15].

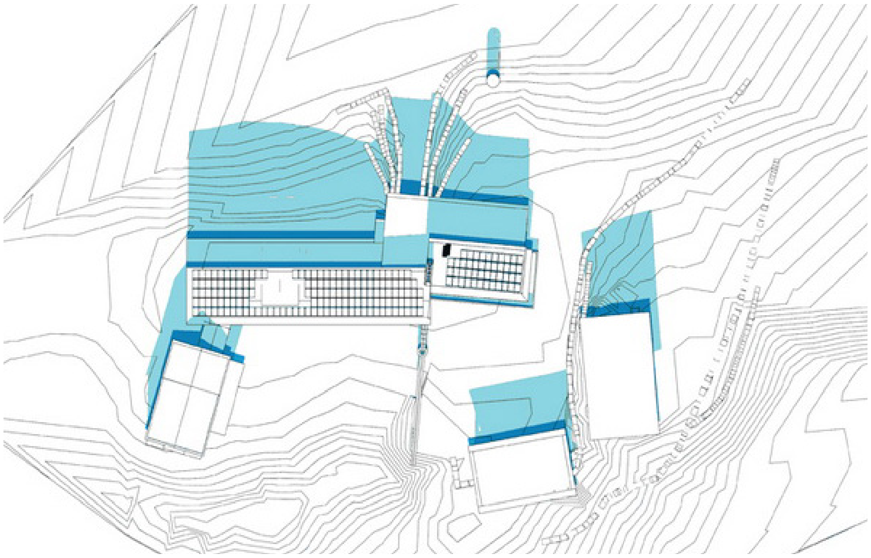


Fig. 5.5 (right)
Aldo Leopold Centre Sun Shadow Diagram

The mechanical system is all-electric such that on-site renewable sources of power can satisfy 100% of the building's needs. They also make use of some passive aspects to reduce the amount of energy required. Heating and cooling is provided by a water-based in-slab radiant system and supplied through a 14-well geothermal loop system. A 500-gallon tank keeps water at between 40ºC and 45ºC in the winter and between 5ºC and 10ºC in summer. The radiant loops are zoned by space to ensure that when spaces are not occupied, the temperature is allowed to fluctuate. Three wood-burning stoves, supplied by wood harvested from the adjacent tree stands, satisfy and peak heating loads. An earth-tube system supplies the building with ventilation air when passive ventilation via operable windows is not possible. A series of underground concrete pipes, buried below the frost-line, pre-condition incoming air to a constant temperature of 13ºC year-round. Demand-controlled variable-speed ventilation fans provide only the required amount of air to each space to reduce fanpower by up to 80% compared to typical systems[16].

The target EUI of 5 kWh/ft^2/yr, confirmed through energy simulation, predicted the Centre would have an average annual energy demand of approximately 54,299 kWhr. The 278.9m^2 PV array is rated at 39.6 kW and has been predicted to generate as much as 61,250 kWhr/yr, providing 110% of the annual demand. The simulations predicted that the system would produce as much as 34,341 kWhr above on-site needs and would need to purchase only 26,180 kWhr to supply systems when demand exceeds the on-site generation capacity. When compared to typical commercial buildings in the US, the simulated performance is predicted to be 75% lower[17].

Embodied energy was a primary driver in the selection of materials. The design team selected a design service life (DSL) of 100 years, consistent with a permanent building type, and both materials and assemblies were selected with this durability goal in mind. The primary strategy was to use a heavy timber structure and wood for much of the window frames, doors, siding, flooring and furniture. To limit the emission of greenhouse gasses, approximately 90,000 board feet of this timber was harvested from the woodlot owned by the Aldo Leopold Foundation where the Centre is sited. This timber was not simply harvested to construct the building, but was a part of the regular forest management activities. The roof trusses, in particular, were debarked on-site and used in their natural shapes. When materials could not be directly reclaimed, they contained high recycled content and were sourced as locally as possible to limit emissions from transportation. The durability of a product was balanced with its embodied energy content[18].

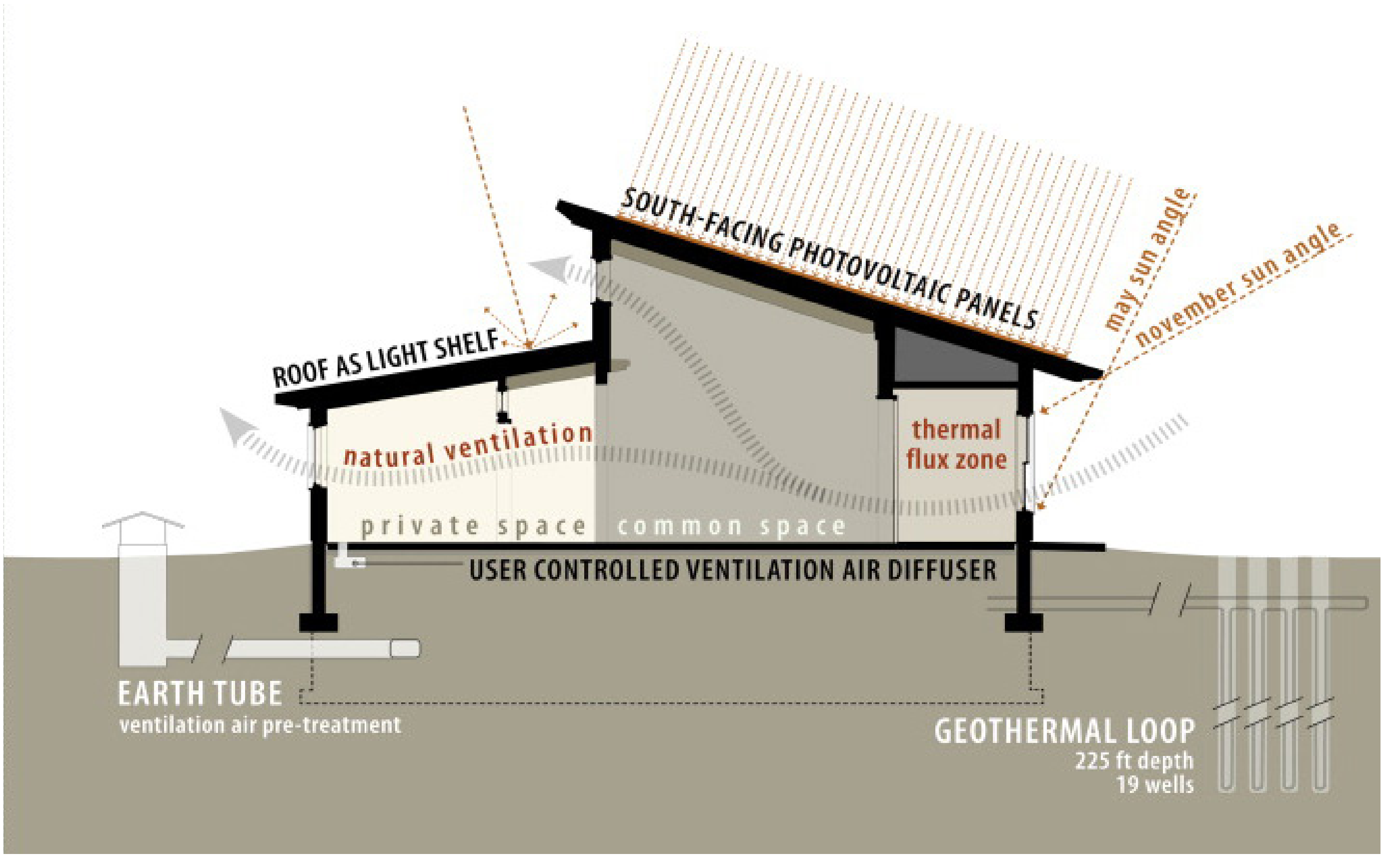


Fig. 5.6 (above)
Aldo Leopold Centre Sustainable Design Strategies

For example, an aluminium roof with recycled content and copper piping were selected due to their long service life. Construction and design techniques also reduce recurring embodied energy. Large roof overhangs, for example, shelter the building envelope from sun and driving rain to extend their lifespan.

Table 5.2 Aldo Leopold Centre Carbon Balance[19]		
Source	Amount	tCO_2-e
Scope 1: Direct Emissions		**+19.9 tCO_2-e**
Wood Stoves	2 cords	+6.7 tCO_2-e
Foundation Vehicles	1,490 gallons gasoline	+13.2 tCO_2-e
Scope 2: Energy-Indirect Emissions		**-20.8 tCO_2-e**
Wind Power Contract	33,400 kWhr/yr	-10.6 tCO_2-e
On-Site Solar	32,300 kWhr/yr	-10.2 tCO_2-e
Scope 3: Other-Indirect Emissions		**+25.4 tCO_2-e**
Employee Commuting	1,800 gallons gasoline	+16.0 tCO_2-e
Business Travel	36,500 air miles	+6.0 tCO_2-e
Solid Waste Removal	5,200 lbs	+3.4 tCO_2-e
GHG Removals		**-20.8 tCO_2-e**
Managed Forest	35 acres	-29.1 tCO_2-e
FINAL CARBON BALANCE		**-4.6 tCO_2-e**

The project considers an ambitious approach to carbon neutrality by addressing all emission scopes and GHG removals. Table 3.5, above, illustrates that on an annual basis the building is predicted to sequester more carbon than is released.

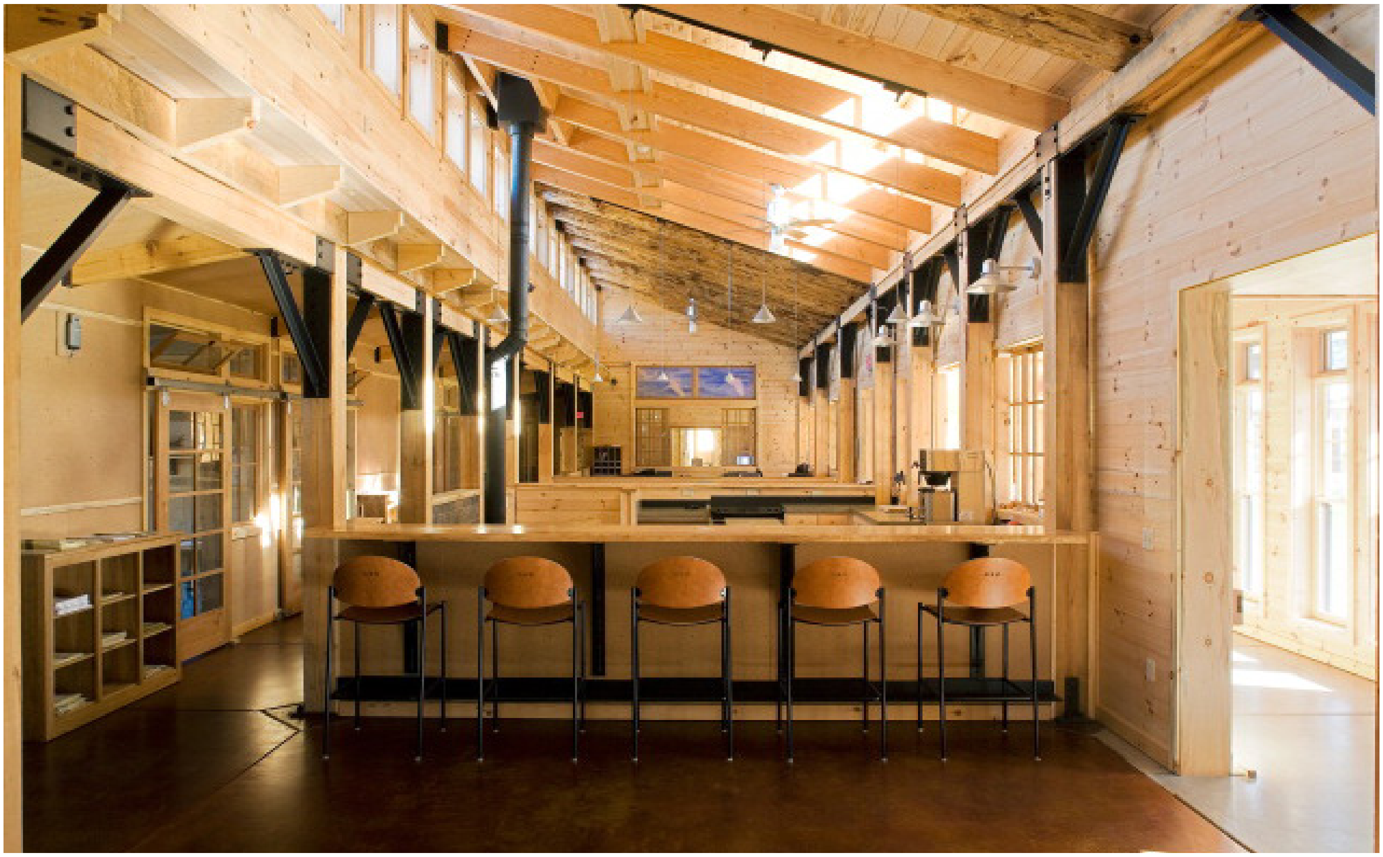


Fig. 5.7 (above)
Aldo Leopold Centre Main Event Space and Thermal Flux Zone

A third-party carbon accounting study was undertaken that meets the guidelines of the World Resource Institute's Greenhouse Gas Protocol. The study set the organizational boundary to include the activities of the Aldo Leopold Foundation with the specific project boundary as the Aldo Leopold Legacy Centre and adjacent woodlots certified for sustainable harvest. The emissions are allocated as follows[20]:

- **Scope 1 Direct Emissions** includes on-site and stationary combustion from wood-burning stoves. In 2007-2008, approximately two cords of wood were allocated for the heating season. Vehicles that are a part of the Foundation's parking pool are also included and all travel is logged.
- **Scope 2 Energy-Indirect Emission** includes grid-sourced electricity that is purchased when the on-site photovoltaic array is unable to meet the building's energy demands. To offset the carbon footprint of this purchased energy, a contract for wind-energy was purchased from the utility provider. The site makes use of an on-site well and septic field, thus emissions related to pumping and processing water are already included in the metered electricity demand.
- **Scope 3 Other-Indirect Emissions** includes emissions attributed to the organization's operational activities. Employee commuting and business travel is tracked. The emissions from solid waste removal, including both garbage destined for the landfill and recyclables, is estimated by estimating emission per unit mass of material removed.
- **GHG Removals** is the final scope and is attributed to the 35 acres of 500 owned by the foundation, that certified for sustainable harvest at the time of the construction of the building. The woodlot was catalogued and in six years will be re-catalogued to establish the true sequestering potential. In the meantime, a conservative estimate of 0.25 tons of carbon per acre per year will be assumed.

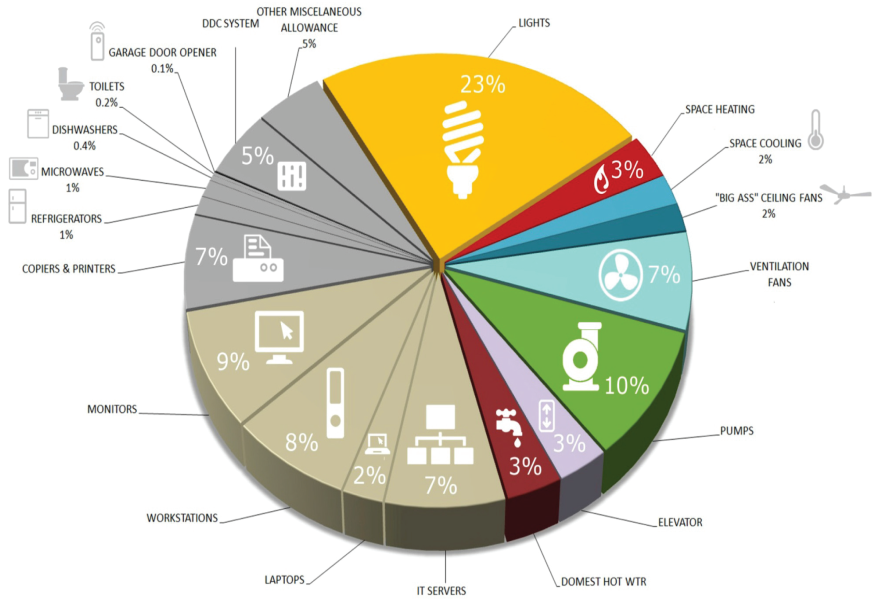
Fig. 5.8 (above)
The Bullitt Centre

The Bullitt Centre

The Bullitt Centre, located in Seattle, Washington is a six-storey multi-tenant office building with a total Gross Floor Area (GFA) of 4,831 m^2. The climate, defined as ASHRAE Zone 4C: Mild-Marine is characterized by relatively few heating degree days, between 2000 and 3000. Developed by the Bullitt Foundation as the anchor tenant, the project is, at this time, the first multi-storey urban building in the world attempting a full Living Building Certification, widely considered to be the world's most stringent third-party Green Building Assessment (GBA) program. Opened in 2012, the Centre has attracted a number of tenants that include the property's developer and the project's mechanical, electrical and plumbing engineer.

The Living Building Challenge is administered by the International Living Futures Institute and is comprised of twenty imperatives relating to ambitious sustainable and social objectives. Unlike other GBAs, such as LEED, Green Globes in North America, or BREEAM in the UK, all imperatives relevant to a particular building typology or project scale are mandatory and require a full year of post-occupancy data that successfully achieves them to be submitted and demonstrated[21]. Grouped into seven categories called "petals", a project must address issues of site, water, energy, health, materials, equity, and beauty. The performance requirements in each petal are ambitious and include, amongst others, net-zero energy and net-zero water. Of the total projects registered for the program, only 28 have thus far achieved full certification[22], illustrating both the stringency of the program but also the gap in contemporary practice.

Inspired both by the US Department of Energy's Net-Zero Energy Commercial Buildings Initiative goal of achieving a market transition to net-zero energy commercial buildings by 2030 and the Living Building Challenge, the Centre aims to achieve net-zero energy by the end of its first year of operation. To do so an



annual energy budget was set using the size of a PV array that could be deployed within the boundaries of the site. A variance with local planning authorities was required to allow the array to stretch over the sidewalk. This hard limit required an unusual amount of detail in the E-Quest energy simulation models; electricity consumed by sensors, thermostats, and building control systems were included as no additional on-site renewable energy systems could be added. Summarized in Table 3.6 below, the predicted EUI is approximately 66.1 ekWh/m^2/yr. To that end, simulated results suggest the project will be "best-in-class" for urban commercial buildings when compared to similar projects listed in the US-DOE High Performance Building Database.

Fig. 5.9 (above)
Estimated operating energy breakdown of the Bullitt Centre
(Hayes, Court, Hanford and Schwer, 2011)

Table 5.3: Bullitt Centre Estimated Annual Energy Breakdown[23]

Category	Energy Use (kWhr)	Percent of Total
Lights	53,000	22.6%
IT Server	20,000	8.5%
Computers, Monitors, Printers, Copiers and other Misc. Equipment	104,000	44.0%
Space Heating	6,000	2.5%
Space Cooling	5,600	2.4%
Pumps, including water treatment	21,000	8.9%
Ventilation Fans	12,000	5.1%
Elevator	7,000	3.0%
Domestic Hot Water	7,800	3.3%
TOTAL	**236,400**	

The maximum potential for energy generation on the site from PV is 230,000 kWh/year provided by a 242-kilowatt PV array, 1,300 square metres and 575 panels in size, that is also a primary architectural feature. The target EUI of 66.1 ekWh/m^2/yr allows a razor-thin margin of only two to three percent in annual energy demand if net-zero is to be achieved[24]. Nevertheless, the design team was required to reduce energy demand by nearly 80% compared to the US average, and 84% compared to the Canadian average. To do so, the first step was to first reduce loads and second to meet the remaining with efficient systems.

Fig. 5.10 (above)
Bullitt Centre Photovoltaic Array

- **The building envelope**[25] is optimized for both in performance and site orientation. The design target window-wall ratio was between 25% and 35%, with the final design achieving 40%. To limit heat gain while permitting daylight and views, openings in envelope were focused to the north and south faces as are the open office spaces. Service spaces and lobbies are located on the west and east facades, where spaces are not regularly occupied. The opaque envelope components are an insulated 38x152mm insulated steel-stud cavity wall, with a nominal insulation R-value of 13, and a zinc cladding with continuous exterior mineral wool insulation with a nominal R-value of 16.8. The system achieves an effective thermal resistance of R-26.6 / R_{si}-4.68, nearly 30% higher than the local energy code requirements. Simulations showed that further improvements to the building envelope would have had little impact on reducing energy use. Air-tightness was of paramount importance and 0.19 cfm/ft^2 at 75psi was achieved. A triple-glazed curtainwall system achieves an overall thermal transmittance of U-0.25 / U_{si}-1.42, a Solar Heat Gain Coefficient (SHGC) of 0.31, and a visible light transmittance of 53%.

- **Daylighting** is a key passive strategy and is anticipated to reduce lighting loads by upwards of 67%. Not simply integrating sensors into the equipment, the building design and massing was carefully articulated to maximize its potential. The Lighting Power Density (LPD) was set at 0.037 Watts/m^2 when local energy codes require a maximum of 0.084 Watts/m^2 [26]. Lighting simulations using Autodesk Ecotect showed a 4.267 floor-to-floor height was optimal for providing adequate daylighting. To do so, the developer required a zoning change from the City Planning Department for an overall increase of 3.048m from the permitted heights[27]. LED lights connected to dimmable ballasts and daylight sensors ensure lighting levels are provided with the least energy.

- **Thermostatic Setpoints** are set with a wider comfort range to reduce the times in which the mechanical system must operate, in addition to reducing the size of equipment, such as the number of wells in the geothermal loops. It is anticipated that some parts of the building could float up past 25.6^{o}C, the upper limit of comfort in conventional office spaces[28].

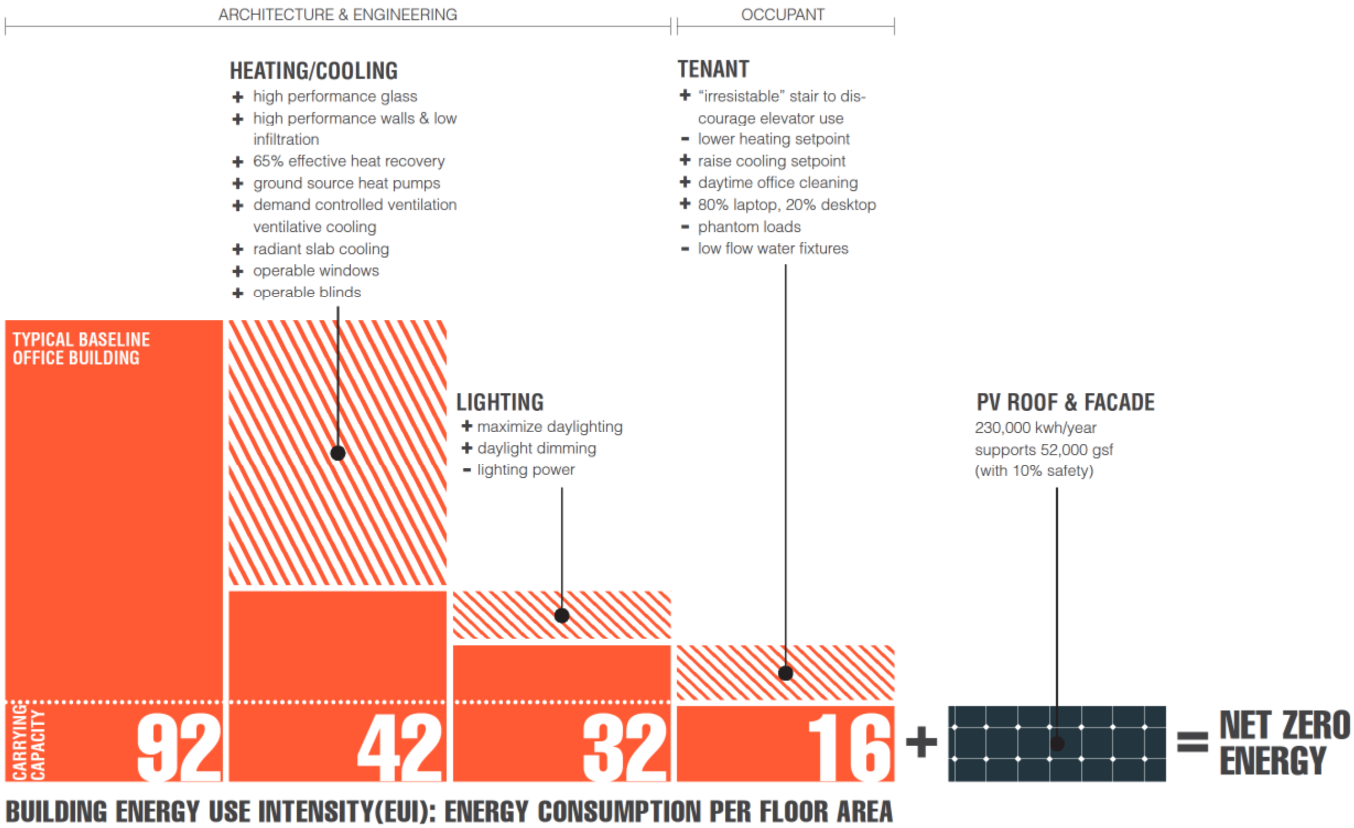


Fig. 5.11 (above)
Bullitt Centre Energy Use Reduction Pathway (Hanford, 2013)

- **Passive Ventilation, Night-Purge Cooling, and Automated Exterior Shades** are achieved through intelligent features integrated into the curtainwall system. Exterior shades on the lower five floors of the building, the topmost floor is shaded by the PV array that extends up to 20 feet from the building face, are automated and track the position of the sun to limit heat gain. Operable windows are controlled by the building management system and, when outdoor temperatures and humidity are within the comfort range, are opened to passively cool the interior. At night, the windows are also opened to flush excess heat stored by the three-inch thick concrete slab[29].

- **Heat Recovery and Demand Controlled Ventilation** provide fresh air when outdoor conditions preclude the use of free cooling from the operable vents in the curtainwall. A dedicated 100% outdoor air unit is paired with an air-to-air heat exchanger, with a 60% sensible heat efficiency, to precondition incoming ventilation air. CO_2 sensors connected to a variable-air-volume system ensure ventilation is provided at rates that match occupancy demands[30].

- **Closed-Loop Geothermal System, Radiant Floors with Thermal Mass, and Ceiling Fans** satisfy the modest heating and cooling loads in the building. A ground-source heat pump connected to 26 wells 121 metres deep supplies radiant coils situated in the poured concrete slabs on each floor. Coupled with ceiling fans, the thermal mass of the slab will make rooms feel cooler than the actual air temperature. Although the heat pump is responsible for 5% of the electricity load, the building does not have an air conditioning system[31].

- **Aggressive Reduction of Plug and Equipment Loads and Tenant Operations** were critical to achieving net-zero. The EQuest energy modelling incorporated plug and equipment loads and provided a budget to tenants of 0.074 Watts/m^2, compared to the average commercial rate of 0.14 Watts/m^2. This required tenants to agree to a budget in the lease documents and prompted the creation an internal "cap and trade" system. One tenant, PAE Engineering, conducted a thorough analysis of its current equipment energy demand prior to taking occupancy and, throughout the course of the study, revamped its IT system and infrastructure. Phantom loads, or the draw of equipment when in a dormant state or hibernating, were reduced and tenants were encouraged to use a ratio for 80% laptops and 20% desktop computers to reduce energy demands. The most efficient equipment and appliances were used. Other operational decisions of note include daytime cleaning services to reduce the number of hours lighting is required at night, reduced heating and cooling setpoints, and low-flow fixtures that limit the need for domestic hot water.

- **Vertical Transportation** became an important consideration in the energy budget and was approached with both a technological and design solution. An energy-efficient elevator product was specified, and a feature stair that connects all floors was designed. Not merely a stair core for exiting, the design team dubbed the convenience stair the "irresistible stair" and ensured it was articulated as a space. Filled with light, views and accessed from the lobby, the design intends occupants to use the stairs as opposed to the elevator and emphasized it as a social space.

Material considerations were central to the sustainable agenda of the project, and are also a "petal" in the Living Building Challenge. Although the embodied energy footprint was not catalogued, the building assemblies were nevertheless considered in concert with energy performance and sustainable attributes. The structural system is a hybrid of concrete, heavy timber, and steel. The primary beams, columns, and decking are heavy timber. A three-inch deep concrete topping was poured to increase durability provide a medium for the radiant system, and contribute to the thermal mass of the interior spaces. Steel was used sparingly in the structural system to provide rigidity and allow the structure to meet the enhanced seismic requirements of the pacific northwest. To limit recurring embodied energy, the heavy timber structure was designed to allow reconfiguration and modification. The flexibility and multiple systems combine to provide a system that is expected to last 250 years[32]. The design team claims that the amount of heavy timber offsets the carbon footprint of the steel and concrete such that the system is carbon-positive[33]. The structure and concrete floor are left exposed to celebrate the use of timber and limit the addition of finishes.

Fig 5.12 (above)
Clockshadow Building Site Context

The Clockshadow Building
The four-storey Clockshadow Building is located in the historic downtown Walker's Point neighbourhood in Milwaukee, Wisconsin. The site context is truly urban and sought to transform a brownfield site. Bound by West Bruce and South 2nd Street, the 4,000 ft^2 rectangular site is oriented east-west on a corner with an abutting building directly to the north. To reach the desired development density of 30,370ft^2 (2,821m^2), this commercial-retail building is zero-property line and covers the full extent of the site. Milwaukee is located in ASHRAE Climate Zone 6A where the cold continental climate provides a challenge to low-energy and passive design techniques.

Built by Fix Developments, the Clockshadow building was completed in March, 2012. The developer sought to create a unique project that would have a transformative effect on the larger community and have a positive net contribution on a sustainable basis. The primary development goals are rooted in a "quadruple bottom-line" approach that is informed by, but not registered with, the Living Building Challenge[34].

- Generate long-term returns for investors while remaining affordable for the range of tenants that include three non-profit health and wellness organizations dedicated to the health and wellbeing of the neighbourhood, an urban cheese producer, and a premium ice-cream store. The project was funded entirely by social investors. Most tenants generate employment opportunities for the residents of the Walker's Point area.
- Create a commercial building that is aggressively sustainable and strives to meet the criteria of the Living Building Challenge. The techniques and technologies were to be affordable and repeatable while meeting the stringent performance targets.
- Create a community of tenants who provide enrichment to the surrounding neighbourhood and the community of Milwuakee as a whole.
- Ensure the building architecture and and nature of its tenants are culturally complimentary to the fabric of the local neighbourhood.

Fig 5.13 (above)
Clockshadow Building view from West Bruce and South 2nd Street.

The project addresses a broad range of sustainable issues that range from material selection to energy efficiency to stormwater management. This case study will focus on techniques, issues, and technologies that address energy consumption and greenhouse gases to isolate its contribution to climate change and its mitigation. The design team's approach was to study and exploit passive design strategies first to reduce the energy requirements by 50% compared to a conventional building its size[35]. Active technologies to meet these loads in the most efficient way possible were applied second. The energy simulation showed the ground-level retail and cheese factory was responsible for 30% of energy consumption, predominantly due to the cheese-making process and equipment[36]. The predicted energy consumption, accessed from the AIA Top Ten submittal by the project team, is 322,502 eKwh/yr, with an EUI of 158.3 ekWh/m^2/yr[37]. Plug loads are attributed to 38.1% of the annual energy consumption, contrary to a comparative building designed to current standards where heating is the dominant load.

Table 5.4: Clock Shadow Building Estimated Annual Energy Breakdown[38]

Category	Energy Use (ekWhr)	Percent of Total
Lights	56,256	12.6%
Plug Loads	170,467	38.1%
Space Heating	94,698	21.2%
Space Cooling	32,875	7.3%
Pumps	23,352	5.2%
Fans	34,369	7.7%
heat rejection	2,549	0.6%
Base Utilities	32,693	7.4%
TOTAL	**447,528**	

The Clockshadow Building is the product of a collaborative design strategy that involved not only the developer and consultant team, but also the City of

Milwaukee and the future tenants of the space. This allowed various strategies to be tested with the fullest possible information available and involve all possible stakeholders. The primary strategies to achieve the energy and emissions goals include the following.

- **Building Encroachments** were negotiated with the City of Milwaukee. The boundaries of the site, combined with the need for brownfield remediation, caused many developers to consider developing the site not feasible. The sustainable and community-focused goals of the project made the City amenable to an encroachment to not only increase net leasable area, but also to increase available roof area by nearly 2,000ft^2, for which two uses were investigated The first was a renewable energy array to enable the site to be carbon-neutral or net-zero energy. However, the roof area was not deemed large enough to meet the energy production goals an and the expense and equipment relative to the energy produced was not justified. Purchasing renewable energy credits, on the other hand, allowed carbon-neutrality to be achieved through a GHG reduction[39]. The second use was as a community garden space, for which the project received a grant.

- **A Geothermal system** satisfies a majority of the heating and cooling needs for the building. 27 wells with a depth of 300 feet were drilled under the foundation and are connected to a heat pump. Any additional heat required is supplied by an electric system to permit the energy needs to be supplied by zero-emission renewable energy sources. The system allows the overall building to be 50% more energy efficient than a comparative, standard building[41].

- **Passive Design Strategies** begin with building orientation and planning takes advantage of the site orientation. The north face is an abutting building while the south exposure faces West Bruce Street. Public and work zones are oriented to the south while services are oriented to the north. The site also is elongated in the east-west direction, providing an ideal site for passive solar design. Sun-shades are provided on south-facing glazing to limit solar gain in summer months[42].

- **A well insulated and air-tight envelope** features an R-16 masonry rainscreen as the primary facade and an R-42 roof. Operable windows fitted to the building control system permit natural ventilation during swing seasons and occupant control for fresh air. The window-wall ratio is less than 40%[43].

Artists for Humanity EpiCentre

Artists for Humanity is a Boston-based not-for-profit organization with the mission to bridge economic, social, and racial divisions to provide underprivileged youth with an opportunity for self-sufficiency through employment in the arts. Founded in 1991, the organization completed its new headquarters in 2004. The four storey, 2,183m^2 (23,200ft^2) facility is multi-functional and provides for a variety of uses that include art studio space, gallery and exhibition space, event rentals, and office space. Artists for Humanity saw sustainable building performance as an intrinsic extension of the organization's social mission and targeted an aggressive energy efficiency target as well as a LEED-Platinum certification[44].

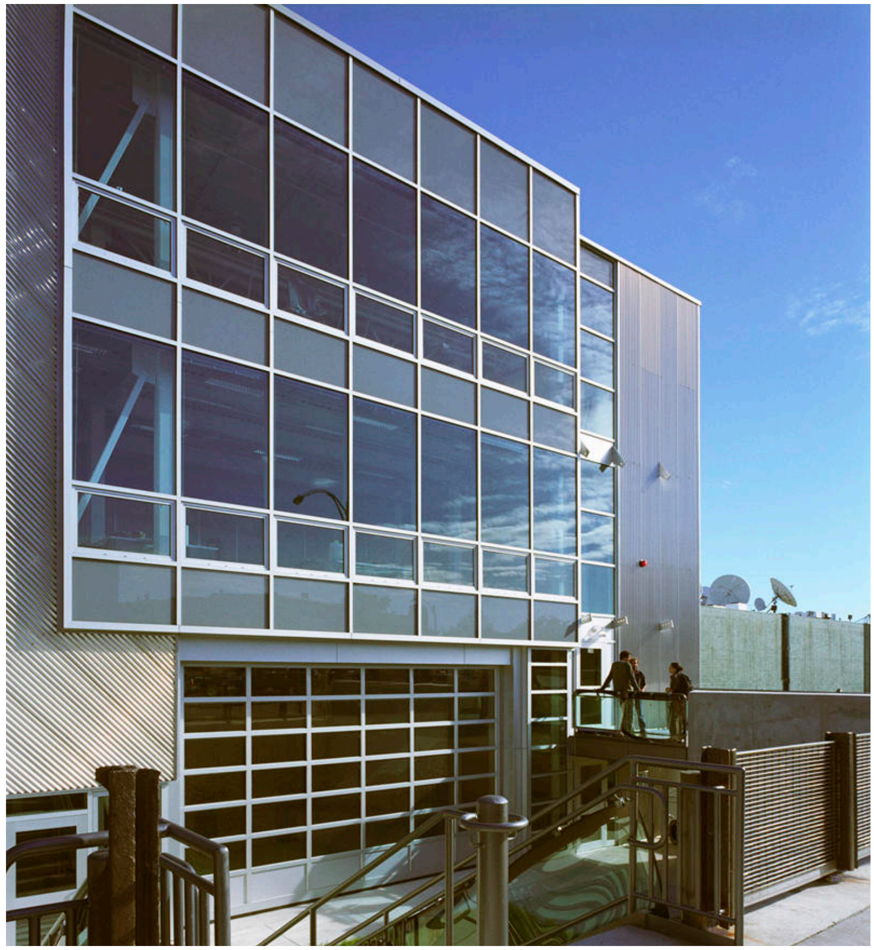


Fig. 5.14 (above)
Artists for Humanity EpiCentre South Elevation

The tight urban site is situated to the south of Boston's city centre. Oriented north-south, the rectangular property constraints required the team to build to the east and west property lines. This condition precludes any glazing on the east and west facades. Energy modelling during design suggested it was advantageous to limit glazing to the short north and south facades. The team was able to achieve a very low EUI of 80.6 ekWh/m^2/yr through a variety of techniques. A 45 kW roof-mounted photovoltaic produces 156% of projected electricity consumption and 40% of total energy consumption. The remaining heating and domestic hot water loads are met with natural gas boilers and together, represent nearly half of the annual energy needs[45]. Table 5.5, below is a summary of the energy consumption.

Table 5.5: EpiCentre Building Estimated Annual Energy Breakdown[46]

Category	Energy Use (kWhr)	Percent of Total
Lights	27,724	15.7%
Plug Loads	30,125	17.1%
Space Heating	75,095	42.6%
Space Cooling	4,148	2.4%
Domestic Hot Water	36,238	5.2%
Fans / Ventilation	3,056	20.5%
TOTAL	**176,386**	

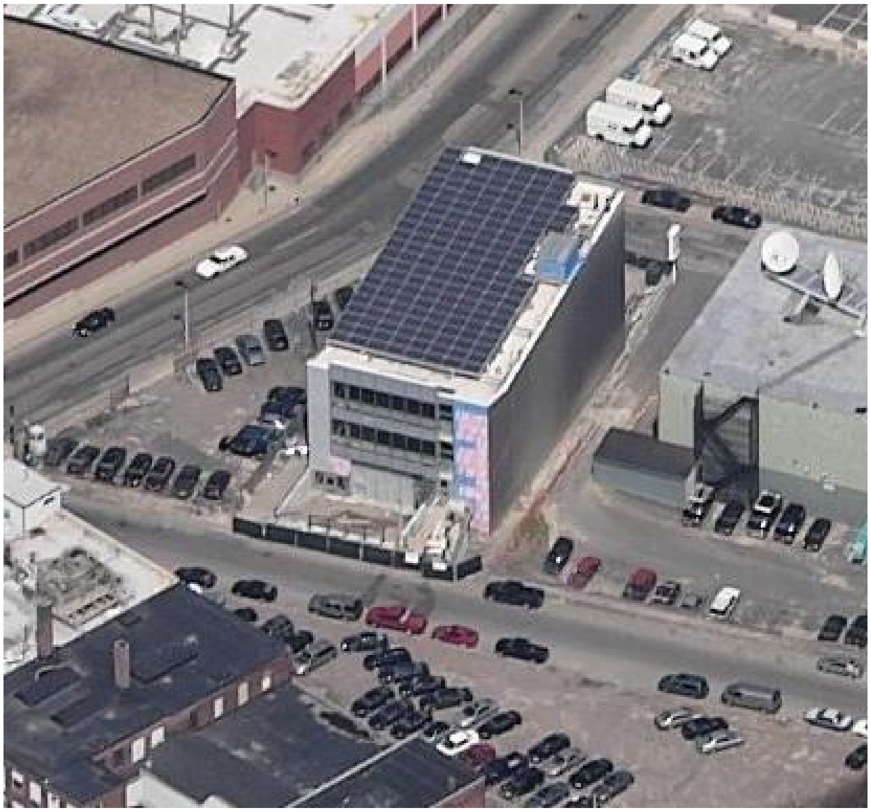


Fig. 5.15 (above)
Artists for Humanity EpiCentre Aerial View

Attaining a LEED Platinum rating ensured the project addressed a broad range of sustainable issues that include site, energy, water, and material concerns. The design strategies focused on passive design and a high performance building envelope to reduce the energy loads. The combination of design-centric strategies such as large and interconnected spaces down the centre of the plan with enclosed rooms and support spaces along the opaque facades ensures that passive design strategies can be effectively employed.

- **Passive Ventilation** is achieved through the use of operable windows, open and interconnected spaces in the centre of the building, and a roof-top clerestory with fan-assisted openings. Natural ventilation essentially eliminated the need for artificial cooling altogether. At the time of construction, the EpiCentre was the largest passively ventilated commercial building in Boston[47].

- **Daylighting and daylight harvesting** reduced energy consumption for lighting by nearly 70% compared to a similar building meeting ASHRAE 90.1-1999. Deep penetration of daylight from the large expanses of north and south glazing is achieved by the organization of the building section. Large, interconnected spaces along the long axis allows daylight to penetrate deep into the building for effective daylight harvesting using automatic dimmers, yielding a low lighting power density (LPD) of 0.15 W/m^2 [48].

- **High Performance Building Envelope and a low window-wall ratio** reduced the heating and cooling loads for the building. With the long faces of the building on the east and west required to be solid because they abut the property lines, the envelope achieves a low window wall ratio of 19.8%. The use of a well insulated facade and high-performance glazing, the overall envelope achieves a low U-value of 0.14 Btu/hr-ft2-f[49]. This is especially important considering the aspect ratio and height of the building creates a skin-loaded condition for heating and cooling. The south facing glazing

Fig. 5.16 (above)
Artists for Humanity EpiCentre Interior Gallery

does provide some passive heating in winter months. A tight envelope with minimal air leakage was important to limit heating.

- **Heat Recovery and high-efficiency boilers** combine to efficiently meet the annual heating load. With cooling nearly eliminated, heating and domestic hot water combine to represent 47.6% of the buildings energy needs[50].

- **Roof Mounted Photovoltaics** create an excess of electricity on an annual basis. the 47 kW array was, at the time of construction, the largest single roof-mounted PV installation in Boston. The project cannot be considered entirely carbon neutral. However, electricity represents only 40% of the energy consumed. The remainder is natural gas, with the sale of excess electricity to the municipal grid covering the remaining utility costs for the building[51].

Earth Rangers Centre:

The Earth Rangers Foundation is a non-profit group dedicated to the protection and rescue of wildlife and the education of youth on the impacts of human activity and development on biodiversity and habitat. With a focus on education and outreach, the Foundation sought to build a facility that was an embodiment of this mission. The design and construction, completed in 2004, achieved LEED-Gold and achieved a LEED-Platinum for Operations and Maintenance in 2012[52]. The measured energy consumption of 97.2 ekWh/m^2/yr is approximately 90% below a typical comparable building in Canada. According to the Earth Rangers Foundation, the facilitiy is the highest-rated LEED O+M building in Canad and achieves all credits associated with energy consumption[53]. Here, those issues specifically related to energy use and associated fuel consumption are described. Continual monitoring, retrofits, and maintenance of systems have been the key strategy for continuing to reduce energy consumption over time. The overall approach to design was to maximize passive design strategies, apply high-efficiency systems, and finally, supplement with renewable energy.

Fig. 5.15 (above)
Earth Rangers Centre
(Schonberger, Andy, 2014)

The 5,800 square metre building is located in Woodbridge, Ontario, Canada on a wooded rural site, set-back far from the road. The region is classified as ASHRAE Climate Zone 6A, Cold-Humid. The unique goals of the Foundation drive a varied program located on two stories. At grade, a world-class veterinary hospital, cafeteria, large lobby and multi-purpose room are for the wildlife rescue and public outreach aspects. The second-floor is an open-office to support the administration and fundraising activities. The basement houses the mechanical and electrical systems as well as an extensive earth-tube installation. The energy balance is heavily weighted to grid-supplied electricity, reflecting the desire to lower greenhouse gas emissions. In 2012, the site EUI for electricity was 94.4 ekWh/m^2/yr, of which 0.88.9 ekWh/m^2/yr was supplied by the grid. Natural Gas reflected only 5.8 ekWh/m^2/yr. The total blended EUI for all fuels that would be considered to emit greenhouse gasses would be 94.4 ekWh/m^2/yr[54].

The energy breakdown of the Earth Rangers Centre reflects years of operations and maintenance study to understand and optimize energy use. Its breakdown is thus more detailed that the standard energy-use scopes defined by National Resources Canada. Precipitated by the installation of the in-depth monitoring system, the LEED-Platinum retrofit sought to understand the finer grain of how and where energy is consumed. Like other low-energy building case studies, plug, technology and appliance loads emerge to consume the largest share of energy as base building systems become very efficient. For example, the building servers consume 12% of the total energy footprint while its directly associated cooling load represents 30% of the total cooling load [55]. The key features include:

- **High Performance Building Envelope and a low window-wall ratio** reduced the heating and cooling loads for the building. The envelope achieves a low window wall ratio of 26.4% while still ensuring over 75% of spaces are daylit. The predominant driver was to construct a thermally massive building. All floors, roofs and structural walls are cast concrete or concrete masonry infill. Select areas used structural steel stud. A continuous 140mm thick layer of rigid insulation ensures an effective R30 for the walls. Similarly, the R40 roof with 200mm sloped insulation finished with either a reflective TPO rubber

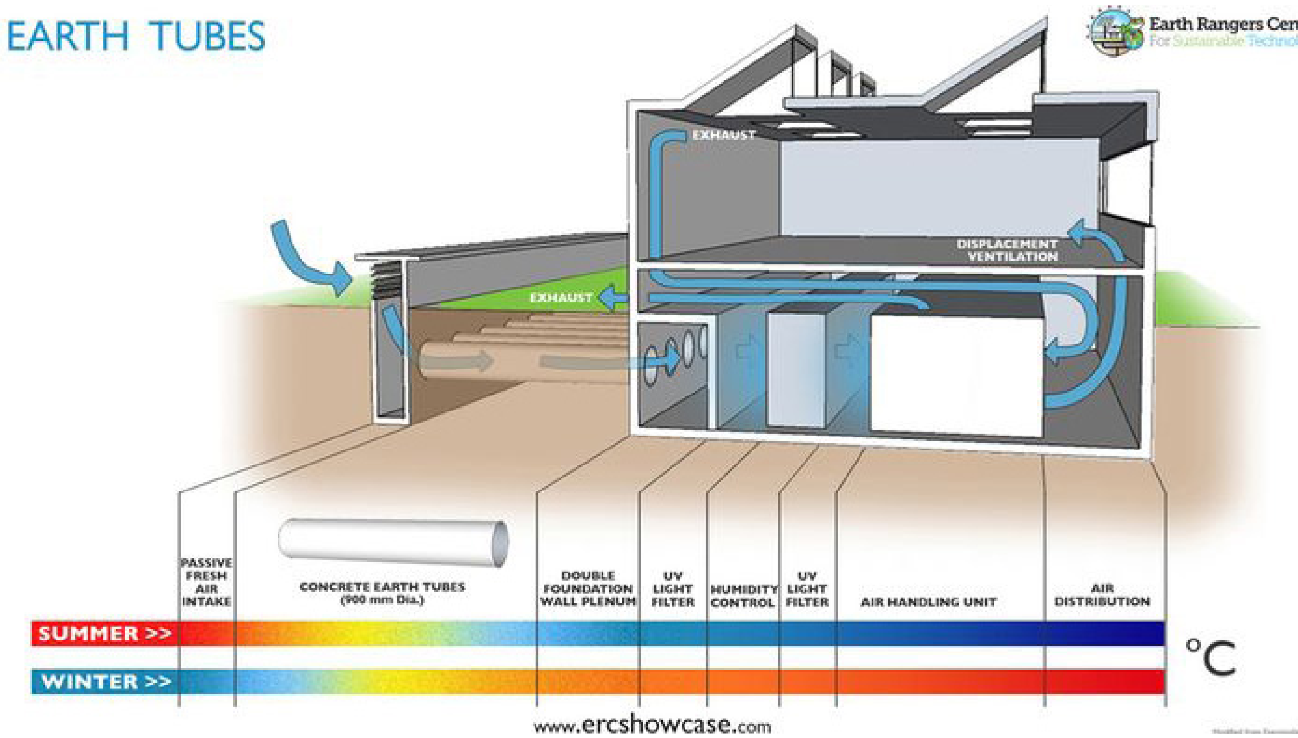


Fig. 5.16 (above)
Earth Rangers Centre Earth Tube Ventilation System Diagram (Schonberger, Andy, 2013)

single-ply membrane or an intensive green roof. Double-glazed windows with argon and Low-E coatings feature a centre-glass U_{si} value of 2.13, a SHGC of 0.32, and a visible light transmittance of 0.57[56].

- **Daylighting** applies to over 75% of spaces within the building, to reduce electricity demand by over half. A variety of strategies are deployed. A series of north facing skylights and perimeter glazing permit full daylighting on the second level housing open offices. North facing skylights and carefully tuned glazing allow lighting without glare or unnecessary heat gain without the need for substantial shading devices. T5, T8 and LED lights are connected to continuous dimming ballasts and controls to ensure optimal daylight harvesting. On the ground level, the building programme is arranged to ensure regularly-occupied spaces are located at the perimeter and service spaces or uses where daylight is detrimental, such as the multi-purpose room where presentations occur, are located in the core of building[57].

- **Earth Tube Ventilation with 100% Outdoor Air Demand-Controlled Ventilation and displacement ventilation** is a central passive design strategy The veterinary uses drive a substantial ventilation rate of 2.5 air changes per hour in office spaces and 6.0 air changes/hr in the medical areas. This could have been the largest energy cost for the building with a conventional system. To offset this, nine concrete earth-tubes 20 metres in length were constructed three metres below the frost line to pre-condition ventilation air. Measured performance suggests this system functions best in heating and cooling seasons rather than shoulder seasons. Ventilation air is drawn through the tubes where the surrounding ground temperature varies between 4°C and 17°C regardless of outdoor air temperature. Air is passed through several filtration layers to remove bacteria, microbes, and dust prior to being fed into an enthalpy wheel heat-exchanger. The system reduces the heating and cooling load by 30 kW, equivalent to a 12% increase in ventilation heat recovery effectiveness. Ventilation air is provided via a displacement ventilation system to limit fan power and improve occupant comfort[58].

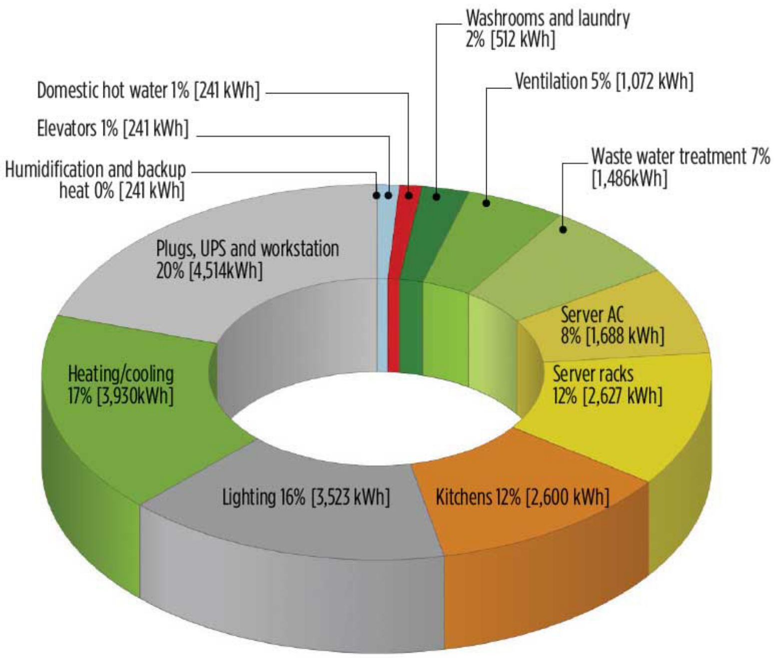


Fig. 5.17 (above)
Earth Rangers Centre Monthly Energy Use Breakdown (Schonberger, Andy, 2013)

- **Thermal Mass, Chilled Beam and Radiant Heating** provide the fundamental heating and cooling system. The use of a thermally massive construction for the building not only creates an exceptionally durable envelope, but provides substantial thermal mass to dampen peak heating and cooling loads. 13.7 miles of PEX tubing were installed in the slabs and roof to not only collect heat radiating from the PV array mounted on the skylights, but evenly heat and cool spaces through the ceilings. Thermal energy is supplied by a ground-source heat pump. Specific controls are required in the cooling seasons to ensure the slabs to not reach their dewpoint and create condensation[59].

- **A Ground Source Heat Pump** provides thermal energy to the radiant system and was installed as part of the substantial retrofit completed in 2010. Although the system has an 18-year payback, the integration with the radiant system and reduced emissions footprint drove the decision for its implementation. It features a field of 44 wells at 400' deep[60].

- **Energy and System Monitoring** has been a substantial component to the energy efficiency and system performance in the building. Over 80 sensors feed a real-time monitoring system that provides read-outs to building users and building operation staff. It has allowed a targeted energy retrofit in 2010 by providing detailed information on system performance and providing data to target the largest consumers of energy. It also ensures systems are functioning optimally at all times For example, detailed energy monitoring allows the earth-tubes to be used for free cooling for most of the summer[61].

- **Renewable Energy** installations have been installed over time in the building. In 2004, when initially constructed, a 28.06 kW fixed roof-mounted photovoltaic array was installed. Over time, an additional 57.6 kW dual-tracking set six of PV arrays was installed in the parking lots where overshadowing was not a problem and were visible to visitors. The roof-mounted PV is used by the building while the parking lot PV is exported directly to the grid. In 2012, these two arrays together contributed 20% of the electricity consumed[62].

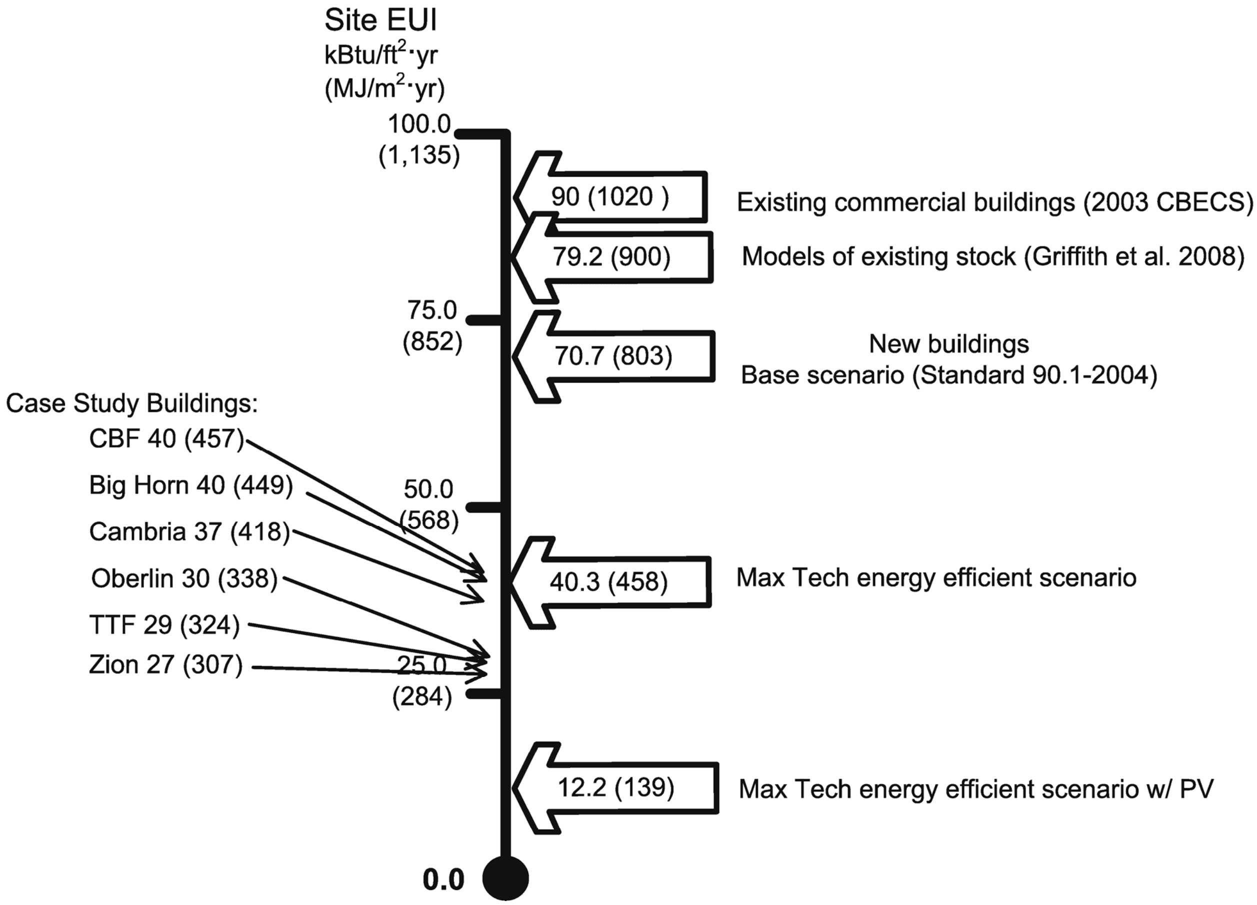


Fig. 5.18 (above)
Average Results for EUI of Current Stock, Minimum Standard, and Max Tech Scenarios (Griffith et al, 2007)

__Assessment of the Technical Potential for Achieving Net-Zero Energy Buildings in the Commercial Sector__[63]

The National Renewable Energy Laboratory (NREL) conducted an exhaustive survey of the technical potential of commercial / institutional buildings for achieving net-zero by comparing the baseline national energy use data to numerous computer simulations of speculative projects in all climate zones. Although not a built project with proven energy use data, this study nevertheless provides an important baseline dataset and serves as an aggregation of recommended design techniques, building systems and energy simulation specifications, and performance standards. One of the most valuable components of this study is the differentiation of climate zones, reflecting the importance of site in low-energy building design. The following precis will focus on the study data and recommendations that match the occupancy type, size and climate of the demonstration projects in this thesis. This includes data for ASHRAE Climate Zone 6A, Cold-Humid, office and retail occupancy types, and buildings under 3 storeys and less than 6,967.7m^2 (75,000f^{t2}). Detailed assumptions and system descriptions are provided.

The study focuses on two primary goals supporting the US Department of Energy (DOE) Building Technology Program's mandate of creating market-viable low- and zero-energy buildings. The first is to determine to what extent commercially available and emerging technologies can achieve net-zero in the context of current energy consumption patterns. The second is the identification of the *technical potential* for energy savings. To do so, EnergyPlus was used to generate an exhaustive data set of energy performance metrics broken out both into commercial building type sub-sectors, including retail and office, and into the various ASHRAE Climate Zones. The data and study conclusions illustrate

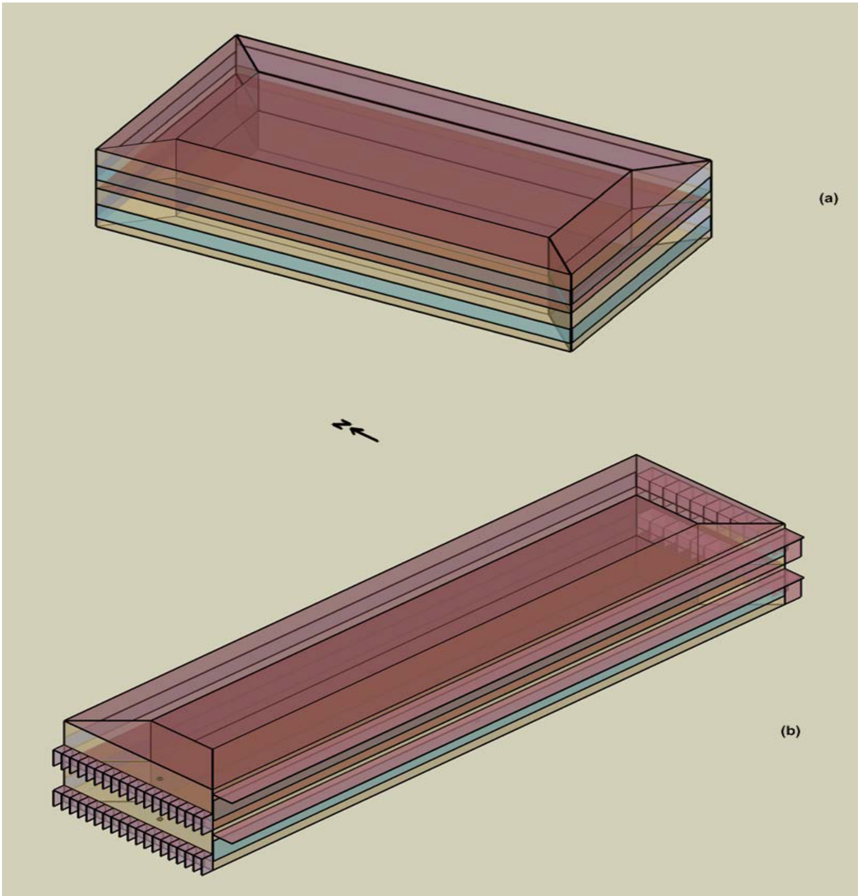


Fig. 5.19 (above)
EnergyPlus Baseline (Model A) and Max Technology (Model B) Scenario Energy Simulation Models (Griffith et al, 2007)

the impact of climate and building program on final energy demand. The term t*echnical potential* in the study refers to the maximum deployment of identified strategies to achieve net-zero and includes the contribution of both energy efficiency to reduce consumption and the potential of on-site photovoltaic arrays to offset the remaining demand on a net-annual basis.

The primary findings suggest that net-zero is possible for 62% of buildings, by total floor area and across all climate zones, with commercially available technologies and practices. In climate zone 6A, applying all recommendations in the study, approximately 68% of buildings by floor area can meet zero-energy performance with roof-mounted photovoltaics. The critical factor as to why this number is not higher is availability of roof area versus the number of floors served. As the number of floors increases, the potential for net-zero decreases with a negligible number of buildings above six storeys. When considering the range of technology areas, the study results illustrate the importance of integrated whole-building design that captures the complex interactions of the various components and systems.

To investigate the means by which energy consumption can be reduced, a limited set of technology areas affecting energy use and GHG emissions were studied. Together, the strategies that form the maximum technology potential scenario are suggested to result in an average site EUI across all building occcupancy types and climate zones of approximately 10.7 eKwh/m^2/yr. When sited in ASHRAE Climate Zone A, office occupancies can reach an EUI of 10.5 ekWh/m^2/yr and retail occupancies can reach an EUI of 37.0 eKwh/m^2/yr. The general conclusion is that building occupancies with higher EUIs, including retail buildings amongst others, have the greatest potential for reduction, implying that current practice baseline energy use is much higher than necessary.

Table 5.6: Technical Potential for Net Zero Energy Building Technology Summary[64]				
Technology	Zero-Energy Baseline Case	Max Technology Case	% Change from Base	EUI Impact on Baseline
Thermal Insulation in the building envelope	ASHRAE 90.1-2004 R_{SI} ($m^2 \cdot k/W$)	ASHRAE 189.1 R_{SI} ($m^2 \cdot k/W$)		
Walls, Metal Building	1.56	2.86	+ 45.5%	-15.6 ekWh/ m^2/yr (6.9%)
Walls, Steel Framed	2.08	3.23	+ 35.6%	
Walls, Wood Framed	1.96	3.85	+ 49.1%	
Roofs, Insulation Entirely Above Deck	2.78	5.56	+ 50.0%	
Roofs, Metal Building	2.70	5.56	+ 51.4%	
Fenestration Thermal Transmittance (by WWR)	ASHRAE 90.1-2004 U_{SI} ($W/m^2 \cdot k$)	ASHRAE 189.1 U_{SI} ($W/m^2 \cdot k$)		
Metal Frame, Fixed Vertical Glazing: WWR 20.1% - 30%	3.24	2.56	- 21.0%	
Metal Frame, Fixed Vertical Glazing: WWR 30.1% - 40%	3.24	2.56	- 21.0%	
Metal Frame, Fixed Vertical Glazing: WWR 40.1% - 100%	2.61	2.56	- 1.9%	
Fenestration Solar Heat Gain Coefficient (by WWR)	ASHRAE 90.1-2004	ASHRAE 189.1		
SHGC, Fixed Vertical Glazing: WWR 20.1%-30%	0.39	0.4		
SHGC, Fixed Vertical Glazing: WWR 30.1%-40%	0.39	0.4		
SHGC, Fixed Vertical Glazing: WWR 40.1%-100%	0.26	0.4		
Fenestration Performance for Dynamic Glazing	Max Tech			
	Clear	Dark		
SHGC	0.4	0.058		-16.7 ekWh/ m^2/yr (7.5%)
Thermal Transmittance (Usi: W/m2·k)	0.565	0.565		
Visible Transmittance (Tvis)	0.65	0.02		
Infiltration Rate (continuous A/V Barrier)	Existing Stock $m^3/s/m^2$	Max Tech $m^3/s/m^2$		
75 Pa	0.0018	0.00043	- 418.6%	
4 Pa	0.000268	0.0000669	- 400.6%	
Plug and Process Loads	Baseline	Max Tech		
Apply 25% reduction to internal electric and gas loads	None	Applied		-13.9 ekWh/ m^2/yr (50%)
Lighting Power Density (LPD)	ASHRAE 90.1-2004 W/m^2	Max Tech W/m^2		
Office	11.0	5.5	- 50.0%	-21.4 ekWh/ m^2/yr (-10%)
Retail	16.0	8.0	- 50.0%	
HVAC System Type (<3 storeys, <6,967.7m2)	ASHRAE 90.1-2004			
Heating Fuel / Unitary Heat Pump	Electricity			
Table 3.7 Continued: Technical Potential for ZEB Technology Area Summary				
Heat Pump COP	ASHRAE 90.1-2004	Max Tech		
Small (< 65 kBtu)	3.4	4.42	+ 23.1%	
Medium (> 65 kBtu; < 135 kBtu)	3.2	4.16	+ 23.1%	
Boiler Combustion Efficiency (DHW)	0.80	0.96	+ 16.7%	

Each technology is modelled as an alternate scenario and compared to isolate not only their direct effect, but also how they effect other technology areas. For example, daylighting directly reduces electricity consumption for lights but also HVAC and fan power through the associated changes in heating and cooling loads. It is important to note that, particularly within the context of this thesis, the simulations were conducted as single entities without a site context, as illustrated in Figure 3.27. There were no natural impediments or surrounding urban fabric to affect the placement of glazing, window-wall ratio, or impose challenges such as overshadowing, building aspect ratio, or limitations to daylight availability. Nevertheless, the following list of technology areas provides a baseline for a broad-base of application.

- **Energy Efficiency Versus Energy Supply** is a key conclusion that supports the intuitive idea that significant energy savings over ASHRAE 90.1-2004 study reference standard is required for 63% of commercial building stock to meet a Net Zero Energy state. When the limitation of roof area is considered, the application of Max Tech efficiency strategies increases the Net Zero potential by 3 fold. Across all commercial occupancies, a 59% improvement in efficiency over the reference standard is required, with office uses requiring 67% and retail uses requiring 45%. The correlation of EUI to type is emphasized by suggesting high intensity occupancies such as inpatient healthcare, laboratories, and food service attain a 90% efficiency improvement to meet zero energy.

- **Lighting Technology** addresses lighting technology exclusive of daylight harvesting. The Max Tech Scenario assumes a 50% reduction in Lighting Power Density (LPD) over the baseline case defined by ASHRAE 90.1-2004. This target is achieved with the the improvement of lighting technology, such solid state lighting and the manipulation of schedule. Modelled separately for each occupancy type, the percent of floor area lit for each hour of the day is based upon actual occupancy patterns compiled in the CEBEUS database. For retail, the resulting LPD is reduced from 16 W/m^2 to 8 W/m^2 while office uses are reduced from 11.0 W/m^2 to 5.5 W/m^2. When all uses are considered, the commercial sector could, reduce EUI by 10%, or 21.4 ekWh/m^2/yr. This includes a 13% reduction in cooling load and a 6% increase in heating load.

- **Daylight Harvesting** is achieved in the Max Tech scenario with a 3-phase stepped daylight sensor. Relative to baseline lighting technology, energy use is reduced by 5%, or 11.7 ekWh/m^2/yr. However, when the Max Tech lighting technology is applied, the impact is reduced by half, illustrating the linear relationship between daylight harvesting, lighting technology and design.

- **Dynamic Fenestration** is a low U-factor thermochromatic glazing where SHGC and visible transmittance change in relation to heating, cooling and daylight needs. The Max Tech scenario assumes thermal transmittance equivalent to ASHRAE 189.1, an aggressive target suggesting some maturity in the technology is required at the time the study was published. The results suggest an average EUI reduction of 16.7 ekWh/m^2/yr, or 7.5% savings over the base scenario.

Table 5.6: Technical Potential for Net Zero Energy Building Technology Summary Continued				
Natural Gas Heating Coils	0.8	0.9	+ 11.1%	
Central Chiller Coefficient of Performance	ASHRAE 90.1-2004	Max Tech		
Small (< 150 Tons)	4.45	5.79	+ 23.1%	
Medium (> 150 kBtu; < 300 kBtu)	4.90	6.37	+ 23.1%	
Variable Volume Central Air System	ASHRAE 90.1-2004	Max Tech		
Total Efficiency	0.65	0.70	+ 7.1%	
Static Pressure (Pa)	600	498	- 17.0%	
Heat Recovery Ventilation Efficiency (Latent)	50	70	+ 28.6%	
Heat Recovery Ventilation Efficiency (Sensible)	50	62	+ 19.4%	
Hydronic System Pumps	CBECS	Max Tech		
Pump Head Pressure (Pa)	179,352	148,862	- 17.0%	
Refrigeration Power Density by Occupancy Use	CBECS W/m^2	Max. Tech W/m^2		
Office (< 2,787m2 / 30,000ft2)	0.074	0.052	- 29.7%	
Retail	0.149	0.104	- 30.2%	
Photovoltaic Performance Characteristics	ASHRAE 189.1	Max Tech		
Photovoltaic Module Efficiency	10	20	+ 200.0%	
Inverter Efficiency	92	95	+ 3.2%	
Passive Solar Design	Baseline	Max Tech		
Daylight Control Harvesting	None	400 Lux, 3 Step Dimming		-11.7 ekWh/ m^2/yr (-5%)
Shading Devices	None	Applied		-10 ekWh/ m^2/yr (1%)
Building Aspect Ratioand alignment along East-West	None	Applied		

- **Thermal Insulation in the Building Envelope** is one of the foundational techniques for reducing energy use, particularly in zero energy buildings. The study suggests that matching the ASHRAE 189.1 insulation standards are a minimum performance target, particularly in colder climates. The average EUI reduction compared to a baseline defined by ASHRAE 90.1-2004 is 15.6 ekWh/m^2/yr, or 6.9%. Similar to the pattern demonstrated by dynamic windows, the relative impact increases as energy efficiency improves. If the recommended insulation levels are removed from the Max Tech scenario, energy use increases by 39%.
- **HVAC System** efficiency and selection was shown to have the most significant impact on energy use. If the combined HVAC system performance levels are deployed, the EUI reduction is suggested to be 25.8 ekWh/m^2/yr, or an 11.9% reduction compared to systems meeting ASHRAE 90.1-2004. The system selections highlighted here include natural gas to reflect the baseline condition predominant in current practice and electricity based systems to reflect non-GHG emitting systems serviced by on-site renewable energy sources.

- **Plug and Process Loads (defined by NRCan as Auxiliary Loads)** are shown in the study to have a progressively more pronounced effect on overall energy use as building efficiency improves. Decreasing process and plug load power densities by 25% can reduce EUI by 13.9 ekWh/m^2/yr across the entire commercial sector, or 7%. With the reduced heating, cooling, and ventilation loads of a building with Max Tech scenario mechanical and electrical systems and building envelope, the proportional effect increases dramatically, reducing whole building EUI by 40%, or 15.6 ekWh/m^2/yr.

- **Passive Solar Architecture** refers to the building form, proportion, and the use of shading devices. The study found little impact on energy use but acknowledged the difficulty associated with assigning a "one-size fits all" set of rules, particularly given the fact the study models did not feature a site per-se. Limited by changing aspect ratio, orientation, and adding shading devices, the result is a 1% decrease in total site energy, equivalent to an EUI decrease of 10.0 ekWh/m^2/yr. Furthermore, the results hide the fact that arbitrary form decisions can have significant detrimental effects. Acknowledging the counter-intuitive nature of this result, the study authors suggest this particular conclusion is primarily the result of study limitations.

- **Implementing ASHRAE 189.1 versus ASHRAE 90.1-2004** as a baseline standard can improve energy efficiency by 28% if applied properly and diligently, having an EUI impact of 25.8 ekWh/m^2/yr.

Case Study Comparisons and Conclusions

A comparison of the case studies suggests a number of conclusions. All case studies have very strong corporate or institutional identities that have driven aggressive sustainable design achievement. The Bullitt Centre and the Clockshadow Building are somewhat unique in this grouping as they are the only two tenant-occupied buildings rather than solely owner-occupied and operated. In these two cases, the projects have explicit market-differentiation goals through sustainable design and target very particular occupant groups; for example, Fix Developments approaches all projects with a quadruple bottom line approach[65,66]. It can be concluded that the level of energy efficiency achieved is the result of unique project drivers and remain "one-off" examples, with the exception of the Clockshadow Building. A survey of commercial buildings in the NREL A*ssessment of the Technical Potential for Achieving Net-Zero Energy Buildings in the Commercial Sector* supports this conclusion where existing and modelled building stock exhibits an average EUI of 283.3 ekWh/m^2/yr and 250 ekWh/m^2/yr and the voluntary ASHRAE 90.1 -2004 Standard suggests an average of 222.2 ekWh/m^2/yr.

"Nevertheless, the case studies suggest that proven technologies and design strategies are able to reduce energy consumption equal to or less than the limits proposed in the 2°C Scenario in both rural and urban contexts."

Nevertheless, the case studies suggest that proven technologies and design strategies are able to reduce energy consumption equal to or less than the limits proposed in the 2°C Scenario in both rural and urban contexts. There is no discernible trend in overall energy use in either site context. This suggests that high levels of energy efficiency and passive design can be achieved on an urban site. Shaan Cory's study into the ability of urban buildings to achieve net-zero energy performance suggests that the urban context does not limit the ability to achieve deep energy efficiency, but does limit on-site renewable energy opportunities[67].

Table 5.7: Case Study Strategy Summary						
Strategy / Technology	**Gilman Ordway**	**Aldo Leopold**	**Bullitt Centre**	**Clock Shadow**	**EpiCentre**	**Earth Rangers**
Climate Zone	**5A**	**6A**	**4C**	**6A**	**5A**	**6A**
Energy-Use-Intensity (ekWh/m²/yr)	**58.3**	**49.3**	**50.0**	**158.4**	**80.6**	**94.5**
Site Context	**Rural**	**Rural**	**Urban**	**Urban**	**Urban**	**Rural**
Building Envelope	R45 Roof R20 Wall Triple-Glz, Low-E, Argon	Wall, Roof combined R64	Wall R26.6, Triple Glz, SHGC: 0.31, VT: 0.53	Wall R16, Roof R42	Wall R19, Roof R32, Glz U0.33, SHGC 0.53, VT 0.76	Wall R30, Roof R40 Glz U0.38, SHGC 0.32, VT 0.57
Daylighting / Daylight Harvesting	Yes, manual Occ. Sensor	Yes, manual on-off switch	Yes, dimmable ballast	Yes	Yes, dimmable ballast	Yes, dimmable ballast
Window-Wall Ratio	20%	12.6%	40%	Less than 40%	19.8%	26.4%
Fixed or Mobile Shading Device to mitigate heat gain	No	Yes, fixed	Yes, automated exterior shades	Yes, fixed	No	No
Natural Ventilation / Night-Purge	Yes, manual operable windows	Yes, manual operable windows	Yes, BMS controlled windows	Yes, manual operable windows	Yes, BMS controlled windows/fans	Yes, manual operable windows
Passive Solar Heating	No	Yes, thermal flux zone	No	No	No	No
Thermal Mass	No	Yes	Yes	No	Yes	Yes
Earth-Tube	No	Yes	No	No	No	Yes
Lighting Technology	T8	Not Available	LED	Not Available	T8	T5, T8, LED
Renewable Energy	PV, Wind, Solar Hot Water	PV, solar hot water	PV	No	PV	PV
Primary Heating System	Ground Source Heat Pump/In-Floor Radiant, Solar Hot Water	Ground Source Heat Pump, Radiant Slab,Wood Stove	Ground Source Heat Pump, Radiant Slab	Ground Source Heat Pump, electric back-up	Natural Gas Boilers, Radiant slab	Natural Gas Boiler/Ground Source Heat Pump, Radiant Slab
Primary Cooling System	Ceiling Valence Units, on-demand	Radiant Slab, Natural Ventilation	Ceiling Fan, Night Purge	Not Available	Fan Assist Natural Ventilation, Ceiling Fan	Ground Source Heat Pump Radiant Slab
Ventilation	Ceiling Valence Units, on-demand, 100% OA	Mixed-Mode, on-demand, displacement, 100% OA	Mixed-Mode VAV on-demand, 100% OA	Not Available	Mixed-Mode, VAV-Fan Assist Natural Ventilation, 100% OA	Mixed-Mode, On-demand displacement, 100% OA
Plug Loads Limited	Yes, appliances and computers	Yes, appliances and computers	Yes, computers and appliances	No	Yes	No
Energy Fuel Sources	On-Site PV, Solar Hot Water, Wind Turbine, Grid Electricity	On-site PV, wood stove, grid-electricity	On-Site PV, grid electricity	Grid Electricity	On-site PV, grid electricity, natural gas	On-Site PV, grid electricity, natural gas
Heat Recovery	Yes Enthalpy Wheel	Yes, from PV inverter room only	Yes	Yes	Yes, limited to areas of high occupancy	Yes, Enthalpy Wheel
Energy Monitoring/Feedback System	Yes	No	Yes	No	No	Yes

The use of ground-source heat pumps is consistent however, as bore-holes can be installed beneath the building footprint. One site constraint that drove a marked difference between the urban and rural sites was the ratio and placement of glazing. With "zero-property line" development and abutting buildings to contend with, glazing could only be placed on certain facades. At least one facade on all three urban sites could not have any glazing and in two of the three cases, only two facades were available for glazing. In the case of the Artists for Humanity EpiCentre, the east and west facades were near fully glazed while the north and south facades were solid. A large interconnected atrium and high floor-to-floor heights promoted daylight penetration deep into the floorplate while the heat gain penalty from west glazing was not enough to require mechanical cooling; natural ventilation was still able to handle the cooling load. This suggests that, while a low window-wall ratio is a consistent strategy amongst all buildings, the limitations of a site may require traditional passive design limitations on glazing placement to be relaxed. In all cases, high-performance glazing with carefully studied Solar Heat Gain Coefficients was still required.

In all cases, the building envelope was several orders of magnitude above the minimum requirements of local codes. Even the Clockshadow Building, which features the lowest overall R-Value for the envelope compared to the other case studies in its climate region, is still twice the local minimum requirement. Combined with low window-wall ratio on a total building facade basis, a high performance envelope is suggested to be a central strategy. Many case studies were very vigorous in the calculation of thermal bridges, took care in detailing for insulation continuity, and achieved very good air-tightness. The Aldo Leopold Centre, for example, provides a whole building effective R-value for the facade that takes all thermal bridges and glazing into account. This approach to effective R-value drove the use of wooden SIP panels to limit thermal bridges and the Woods Hole Research Centre used an off-set stud configuration for the framing.

Consistent active strategies include the use of ground-source heat pumps, heat recovery, and radiant slabs for both heating and some cooling. The case studies revealed that, coupled with ground source heating, the use of radiant heating and cooling was the most efficient way to use the heat. All studies included some passive ventilation, but with a variety of control mechanisms. Operable windows were consistent in all examples, while building automation system control for the windows was limited to the Bullitt Centre and the Artists for Humanity EpiCentre. The Aldo Leopold Centre and Earth Rangers Centre passively treat ventilation air using earth tubes as they have the available site area to install the system. In all case studies, heating and cooling was separated from ventilation.

All of the case studies, with the exception of the Clockshadow Building, feature very detailed monitoring systems and feature at least some level of post-occupancy verification. In the case of the Earth Rangers Centre, this level of monitoring lead to an extensive retrofit of building systems six years after it was constructed to significantly improve energy efficiency. These projects all feature a calibration of the building operation with the energy model over time. In most cases, this level of review and commissioning has lead to the repair of deficient systems and the challenging of assumptions made during design. In the example of the Aldo

Fig. 5.20 (above)
Bullitt Centre Typical Daylit Office Space

Leopold Centre, the wood stove for supplemental heating required replacing because the space was used more than expected. Combined with a cold winter, twice the predicted amount of wood was consumed. **The experience of these case studies suggest that continual tuning of building performance and monitoring is required to achieve the targeted energy consumption.** The Aldo Leopold Centre was not able to achieve carbon neutrality until two years into operation[68].

Renewable energy is a consistent feature, with the exception of the Clockshadow Building where a rooftop array was not deemed economically viable nor could projected energy production measurably reduce total annual energy use. In the case of the Bullitt Centre and the Aldo Leopold Centre, a renewable energy budget was established at the outset and the building designed around it. Carbon neutrality and net-zero energy were stated design ambitions. The Gilman Ordway Building maximized rooftop PV production and matched domestic hot water use to a solar thermal system and achieved carbon neutrality several years after operation with an on-site wind turbine. The Artists for Humanity EpiCentre matched electric load to the rooftop PV and used natural gas for remaining heating and domestic hot water loads. The medical program associated with the Earth Rangers Centre drove very high ventilation rates and consequently, heating, cooling and fan load. Renewable energy is installed to a more nominal level, but is consistent with the ambitions of the organization and still contribute approximately 30% of the total electric load. In all case studies, including the Clockshadow building, the purchase of renewable power credits and the purchase or use of available greenhouse gas removals and carbon credits were used to balance greenhouse gas emissions.

The EUI of each case study, with the exception of the Clockshadow Building,exceeds that suggested by the 2°C Scenario when considering the national average Emission Intensity of electricity and natural gas in Canada, . They also are within the 70% and 90% EUI targets of the Architecture 2030 Initiative, equivalent to between 122.5 ekWhr/m^2 and 40.8 eKwhr/m^2, before renewable energy arrays are considered. Reducing energy consumption is the key factor in achieving the emission reductions within the scope of the IPCC building sector and these examples demonstrate that current techniques can exceed the minimum requirements. With the demonstration projects requiring an EUI of no more than 146.9 ekWhr to achieve the 2°C scenario, the case studies demonstrate that thresholds below 100 ekWhr are achievable. When an all-electric system is considered for the demonstration projects, the EUI achieved is within this range. Given that some case studies achieve this with a mixed fuel system in urban scenarios, greater reductions are possible and that best-in class projects show the sector's potential.

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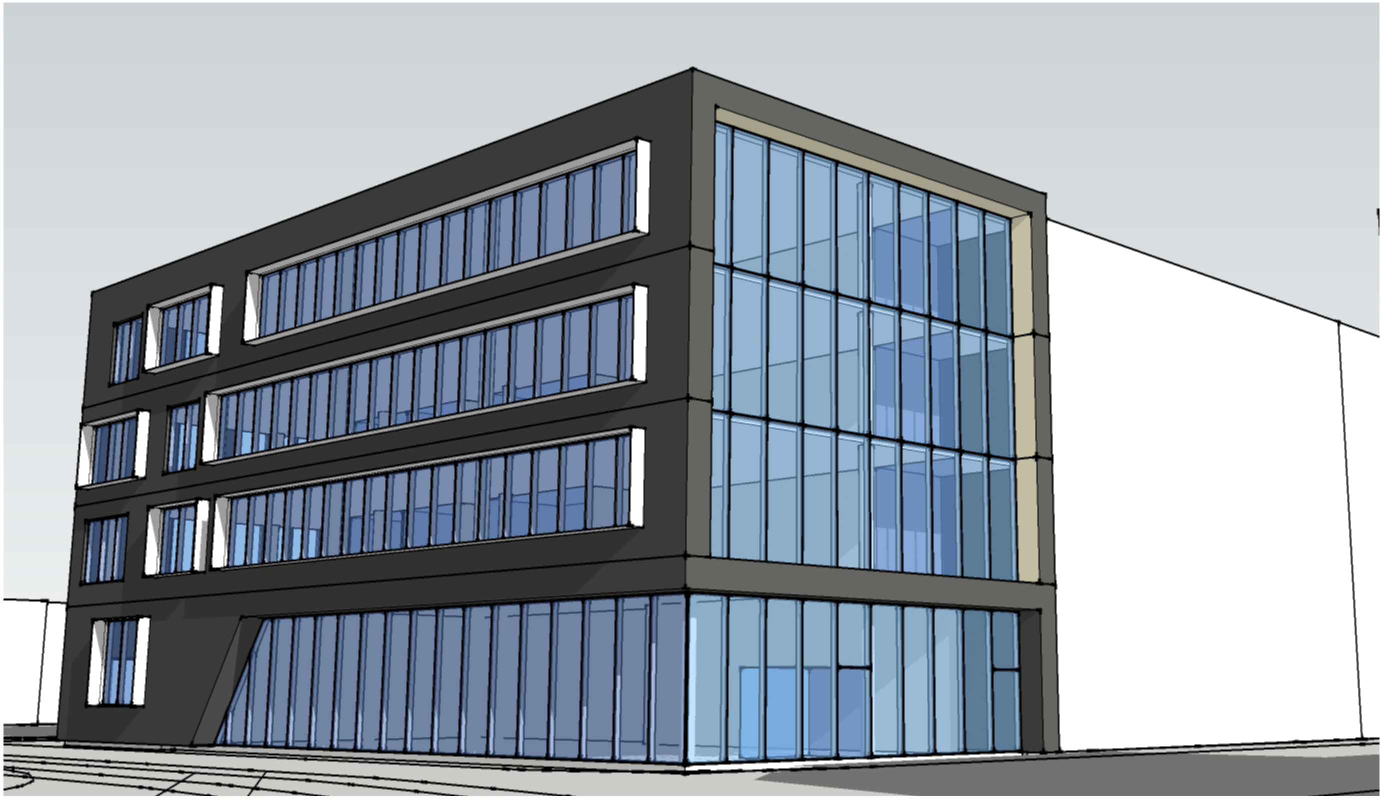


Fig. 6.1 (above)
Corner Site, View looking Southeast

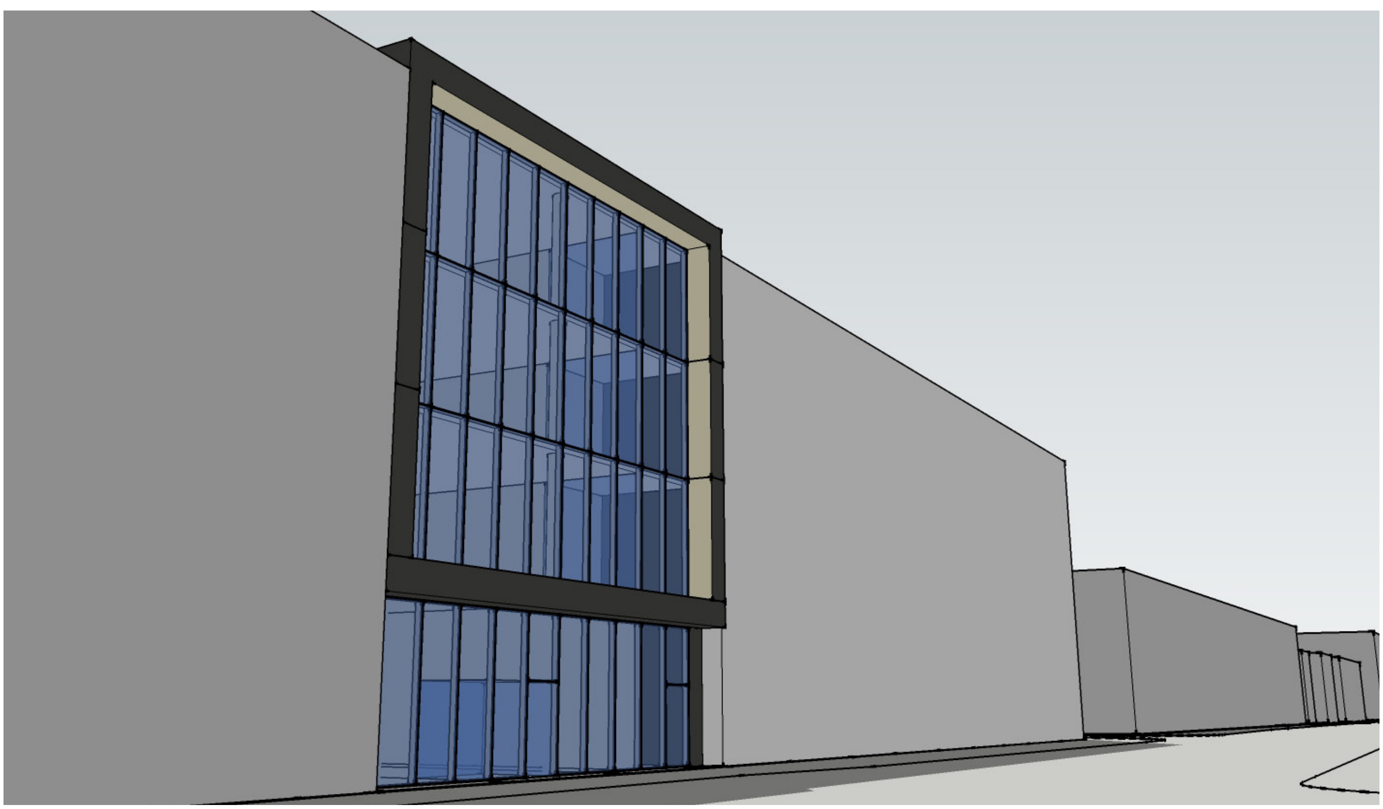


Fig. 6.2 (above)
Mid-Block Site, View looking Southeast

6.0 Demonstration Projects

Urban sites present challenges when considering a low-energy and low-emission design. Surrounding buildings, open spaces and street configurations can intrude into the solar envelope, affect access to wind, and block facades. In most cities, projects typically maximize site coverage and build out to property lines. This can limit the of glazing permitted or completely block entire facades. The urban fabric controls access to site resources of sun, wind, and light with the consequence of driving higher heating, cooling and lighting loads[1]. These impacts are not just at the time of construction or renovation, but can also change in the future as construction takes place on adjacent sites.

This layer of concern is the basis for assessing the feasibility of Canadian commercial buildings achieving the emission cap of 15.3 kg/m^2/yr suggested by the 2°C Mitigation Scenario. The case studies presented in the previous section illustrate that this emission cap can be achieved in rural or suburban contexts where building configurations, envelope, systems, and orientation can be optimized for low-energy consumption and low-emissions. In the case of the Aldo Leopold Centre, the site boundary includes a managed tree stand that provides a source for GHG Removals. The urban buildings, on the other hand, illustrate a higher Energy Use Intensity and, in the case of the Clockshadow Building in Milwaukee would exceed the cap despite a concerted effort to create a sustainable building.

However, low-emitting urban buildings are critical to a climate constrained future. In 2007, the global population became more urban than rural[27]. With this trend expected to continue, it can be concluded that the majority of construction will be in urban areas. Current Green Building Assessments (GBAs) recognize this fact and promote urban building. The Leadership in Energy and Environmental Design (LEED) system, for example, an urban building can earn, by virtue of its site, 18% of the total available credits. When the density exceeds 1.5x the site area, this increases to 20% of total credits. On the other hand, site strategies on rural sites have an opposite effect and, in addition to having some credits simply not available, are directed to limiting the building footprint on a site and avoiding ecologically or productive greenfield sites[2].

The urban fabric features a variety of contexts and built forms that each require a unique set of responses to achieve low emissions. This study is located in Toronto and focuses on a new building that fits into an existing mid-rise mixed-use urban

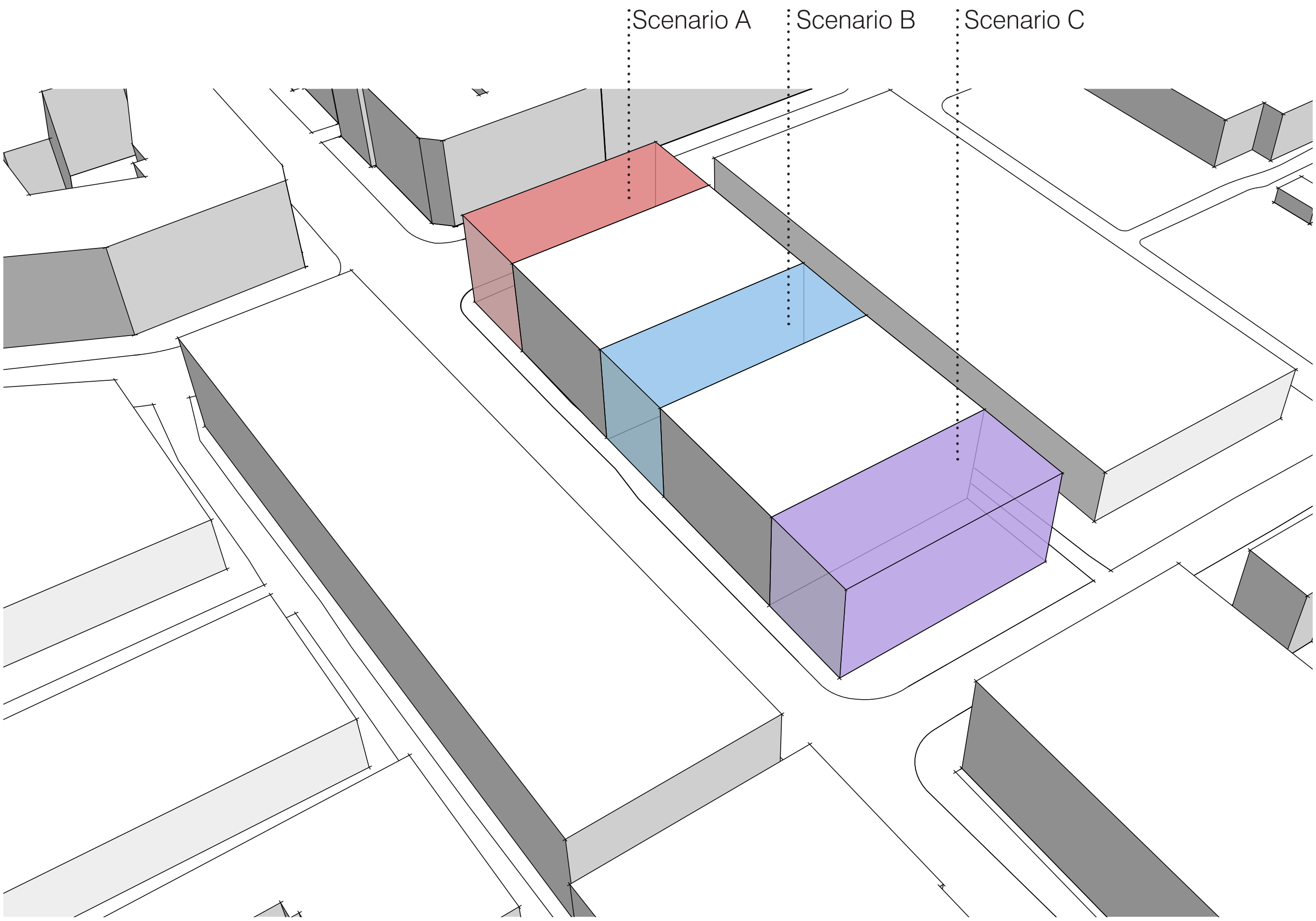


Fig. 6.3 (above)
Demonstration project analysis scenarios in the prototypical block

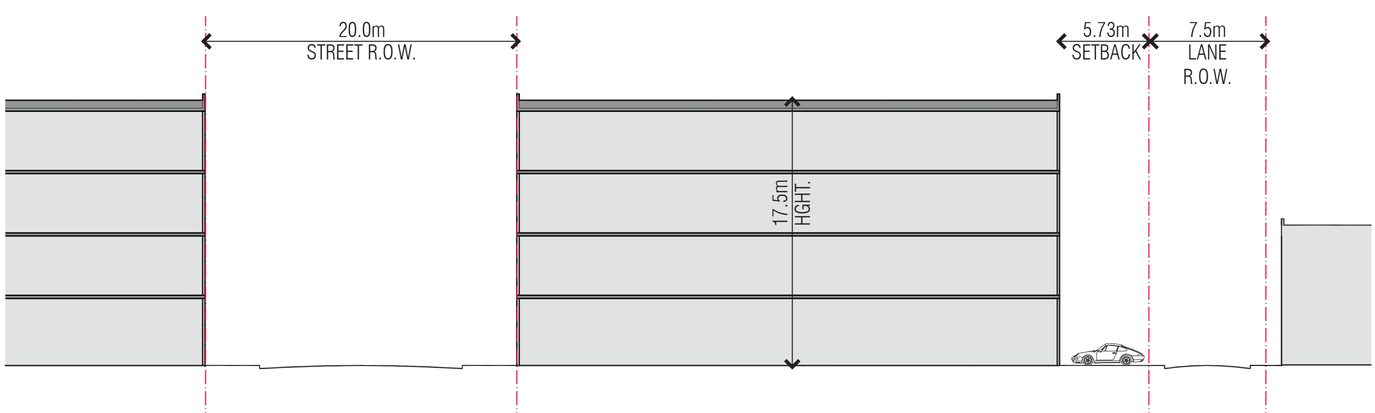


Fig. 6.4 (above)
Demonstration Project Rights-of-Way Context

fabric with a four-storey streetwall. This is representative of commercial boulevards both in Toronto and in the centres of Canadian cities both large and small. "Hyper-dense" urban areas that feature high-rises, such as Toronto's Financial District with towers of up to 80 storeys, require a different set of responses. Although important to solving the climate problem, this type of fabric is limited to large cities and is thus not as broadly applicable. It is the subject of further research.

The emissions cap potential of a building in an urban context is comprised of two questions. The first is what the impacts of the larger site context are, in terms of both surrounding and immediately adjacent abutting buildings. This is assessed by analyzing building lot configurations within a prototypical block: a north-facing end, a south-facing end, and a mid-block, illustrated in Figure 6.3 at left. To properly compare the implications, a mixed commercial-retail building of the same area, height, and general configuration is placed into each lot type and the facade is adjusted to suit. The building in each lot configuration is then modelled to the standards of the prevailing local code.

The second is what the potential scope of changes to the building configuration, attributes and components could be to achieve the 2°C emissions cap of 15.3 kg/m^2/year. To do so, each of the three lot scenarios in the prototypical block that are set into the surrounding urban fabric and meet the current building code are adjusted to meet the emission cap. Table 6.1, below, outlines the scenarios.

Table 6.1: Demonstration Building Scenarios

Analysis Case	Site Condition	Design Target
Scenario A1	North-Facing End	Current Local Code (OBC 2012/Supplement SB10)
Scenario A2	South-Facing End	2°C Mitigation Scenario
Scenario B1	Mid-Block	Current Local Code (OBC 2012/Supplement SB10)
Scenario B2	Mid-Block	2°C Mitigation Scenario
Scenario C1	South-Facing End	Current Local Code (OBC 2012/Supplement SB10)
Scenario C2	South-Facing End	2°C Mitigation Scenario

Site and Block Typology:
The speculative urban block is representative of typical mixed-use boulevards seen in many Canadian cities outside of high-density cores and of emerging planning best practices for relating building height to fronting street rights-of-way. On either side of the street, four-storey buildings 17.5m in height abut each other to create a continuous street wall. Typically, retail, including both restaurants and shops, occupy the ground floors with the upper floors featuring apartments, offices, or support spaces for the retail at grade.

The view along Ossington Street in Toronto, Ontario presented in Figure 6.5, following, is a representative example of this urban structure. For this study, a street right-of-way of 20.0m between building faces on the primary and flanking streets

Fig. 6.5 (above)
Ossington Street, Toronto, Ontario

is proposed. This accounts for four lanes of traffic and generous sidewalks. The rear facade fronts onto a service laneway and has a right-of-way between building faces of 7.5m. The street section in Figure 6.4 at left illustrates this configuration.

The relationship of building height and right-of-way is informed by the planning rational for avenues and mid-rise buildings. For example, the City of Toronto Mid-Rise and Avenues Study[3], which is now part of the city's Official Plan, suggests that the building height should be no taller than the street right-of-way. The 17.5m high four-storey mixed retail and commercial building as proposed in this analysis thus corresponds to a recommended practicable right-of-way of 20.0m.

The buildings that compose a block of this type are rectangular, with the short sides facing the streets and the long-sides abutting the adjacent buildings or side-streets. With the cold climate prevailing in Canada, east-west oriented rectangular buildings with glazing predominant on the south facade are most appropriate for passive solar heating while square forms, which are more compact, can reduce thermal loss through the envelope by having a lower floor-area to enclosure ratio[28]. In both cases, the facade responses of limiting glazing on facades with high solar stress, providing a heavily insulated north facade to limit excess heat loss, and making use of the south facade to harvest solar heat gain should be considered to limit heating and cooling loads in this climate zone. However, when working within the confines of the urban block typology, these design options may not be available. Although the common form is rectangular, the optimal placement of glazing for daylighting and managing heat gain and solar stress is not available. The block orientation under study exhibits these qualities of aspect ratio and exposed facades The short sides face east and west while the long sides abut an adjacent building on either one or two sides.

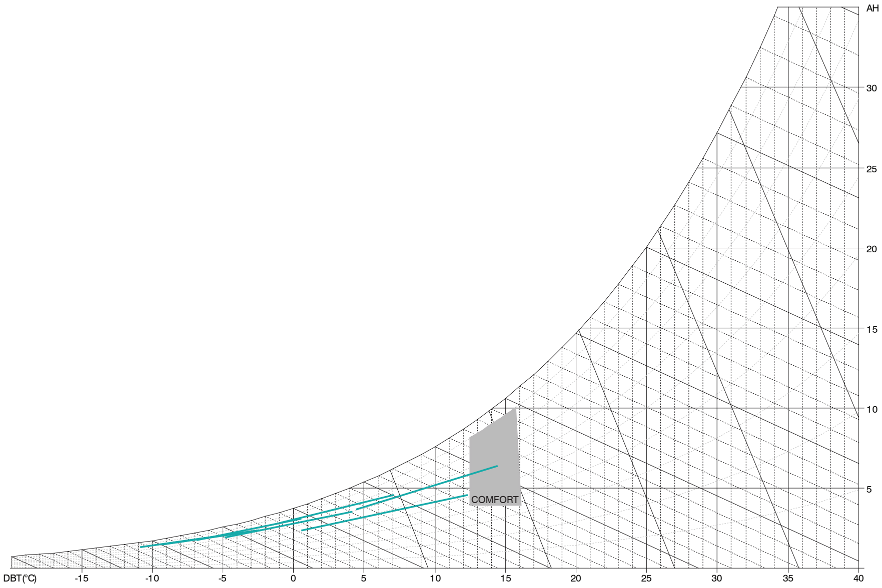
It is important to note this block proposal is representative of observed typical conditions and prevailing planning rationales. This allows a series of general conclusions to be drawn that can be applicable beyond any single instance. Every site and block condition is, of course, unique. In some cases, streetwalls will vary in height across a block, rights of way will be different, street orientations will vary relative to true north, and some sites may not have a narrow back laneway. In practical application, every individual project requires a site-specific analysis.

Demonstration Projects Overview and Analysis Methodology:
The demonstration project is a mixed-use, four storey building with a total floor area of 2,135.6m^2 and a site coverage of approximately 3.3x. Each floorplate is approximately 534m^2 with the building footprint extending to the property line on three sides Parking and access to a shared at-grade loading area is from a rear lane. The ground floor is retail space and includes 465m^2 of leasable area with washroom, storage and supporting office space. A 19.4m^2 lobby with elevator is located in the southwest corner and provides access to the office space on the upper three floors. On the two corner sites, glazing is provided on the three facades facing a public street and the rear service lane. The mid-block side, with abutting buildings on two sides, has only two facades available for glazing.

A study of this kind requires a site to be located in a specific climate and region. In the case of this research, the prototypical block is located in Toronto, Ontario, Canada. This allows the use of a specific climate and weather file, a set of codes and standards to define current practice, and provides a greenhouse gas emissions rate for electricity and natural gas. Although these variables differ by region and even municipality, in some cases drastically, the general implications of urban typology can be discussed. The regional standards gap between those specified by local practice and those required by the emission rate of 15.3kgCO_2e/m^2/yr will differ greatly. However, when the local prevailing codes are used as a benchmark, broader conclusions can be drawn.

All scenarios have been designed to be fully compliant with the prevailing Building Code, not just in terms of energy compliance, but in all aspects including life safety, exposing building facades, and combustibility. The prevailing standard is the 2012 Ontario Building Code (OBC). For the baseline scenarios A1, B1, and C1, the Energy Efficiency Supplement SB-10 for buildings built after December 1st, 2011 is used to define the performance metrics. These requirements generate constraints when investigating a urban sites where a large proportion, if not all, of the site area is developed. Facade design, material selection, and areas of glazing can be limited and issues of building performance and life safety must be balanced. Refer to each demonstration project for a detailed description and Appendices A, B, and C for the Ontario Building Code Matrix for each site scenario.

The study is organized to provide an analysis at both the scale of the building and at the scale of the prototypical block. Each Scenario (A, B, and C) are analyzed individually followed by a comparison of all scenarios together. The current code iteration is presented for each site, followed by a passive analysis that is applicable for both the baseline and high-performance cases. Lastly, the 2°C Median Mitigation Scenario iteration is presented and makes use of the passive assessment to comply with the emission budget. Measures applied to the building are grouped into three categories: building envelope, internal load measures, and building system efficiency and fuel switching. This process provides a framework discussing the implications of meeting the emissions cap of 15.3 kg/m^2/yr at the scale of the building, at the scale of the block, and the influence of the urban fabric. This is in-line with the design process recommended for high performance buildings where the first step is to reduce loads and the second is to meet them efficiently as possible[12].



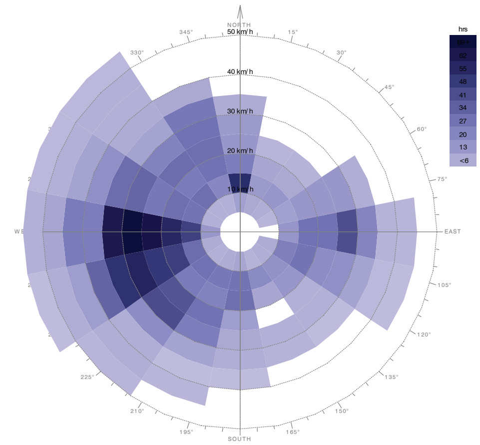
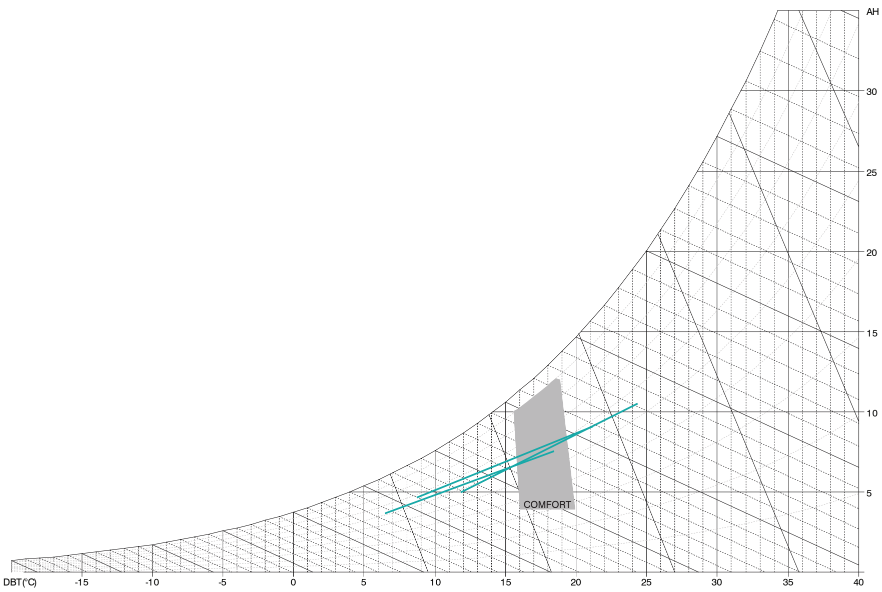


Fig. 6.6
Heating Season Psychrometric Chart and Wind-Rose
January - April, October - December
(Ecotect Weathertool©)



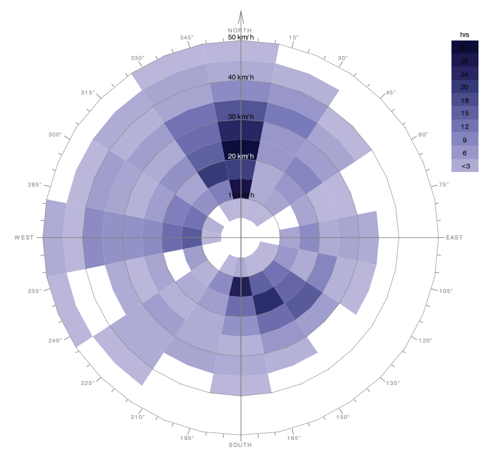
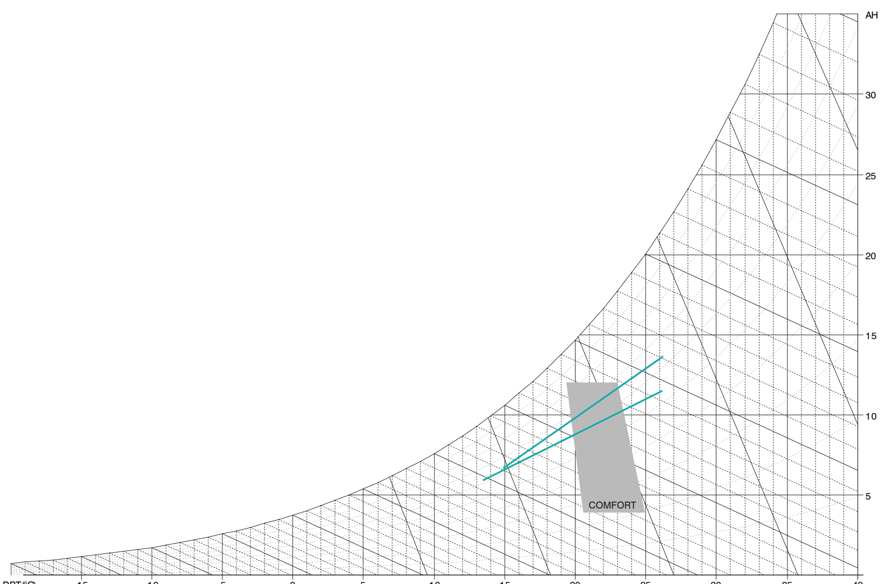


Fig. 6.7
Swing Season Psychrometric Chart and Wind-Rose
May - June, September
(Ecotect Weathertool©)



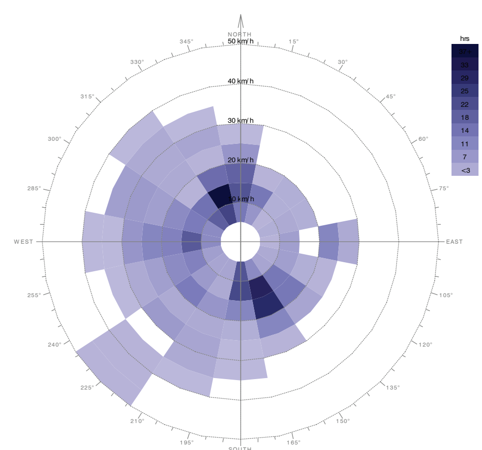


Fig. 6.8
Cooling Season Psychrometric Chart and Wind-Rose
July, August
(Ecotect Weathertool©)

The annual energy consumption is predicted using EQuest Version 3.65. It is a recognized standard in local codes and Green Building Assessment Programs and continues to have post-occupancy verification. The DOE2 simulation engine that powers it provides reasonably accurate results at a schematic design phase where the minutiae of equipment specification and performance are not known. Mechanical system energy consumption is estimated by applying a Coefficient of Performance (COP) that approximates a system-wide efficiency to the predicted heating and cooling load. The energy consumption presented will refer to Secondary, or Site, energy and is presented in equivalent kilowatt hours (ekWh). The consumption of natural gas is converted to this unit.

The annual equivalent greenhouse gas emissions are calculated based on the consumer emissions rate per ekWh for the province of Ontario listed in the 2016 issue of Canada's Greenhouse Gas Inventory submitted to the United Nations Framework on Climate Change (UNFCC)[13]. The document also provides a breakdown by province to allow for local calculations. This source was chosen for two of reasons. First, electricity emission rates fluctuate as demand placed on the grid drives different ratios of fuel sources to meet demand. Secondly, the 2°C Scenario is based on international climate change studies and metrics that make use of standardized IPCC data sources. Further research into both policy and emissions patterns are required to establish a consistent set of regional metrics. Refer to each study for the emission factors.

Climate Assessment:
Toronto's climate is classified as ASHRAE Climate Zone 6A, cold-humid. Located on the edge of Lake Ontario, this large body of water moderates the temperature relative to surrounding areas. Although there are four distinct seasons with a warm and humid summer, the heating season is nonetheless dominant. Heating degree days vastly outnumber cooling degree days, 220.3 versus 4,145 respectively. The heating season extends from January through April and October through December. The average temperatures ranges from -7°C to -1°C with lows of -20°C for brief periods of time. A building and surrounding site should be sheltered from the prevailing, and at times, strong winds from the north. Glazing and openings should be limited along this facade. However, trends have shown that Canada is warming at a faster rate than the global mean and the heating degree days are expected to grow[30]. In Southern Ontario, heat wave frequency events are expected to increase five-fold[31]. Climate change is already beginning to change the heating and cooling profiles and updated weather files are required.

The shoulder seasons, extending from May to June in spring and September in the fall, are generally pleasant with the climate in-line with average expectations for comfort. Temperatures and conditions vary from warm days to cool nights. These months are the best times for passive design as the climate is generally in line with comfort expectations during the day. Pleasant winds that blow from the north-west and south-east are suitable for natural ventilation. The cooling season represents only two months of the year. The summer months of July and August have temperatures consistently within or above the comfort zone with high levels of humidity and temperatures ranging from 23°C to 31°C Similar to the swing seasons, prevailing winds are from both the north-west and south-east.

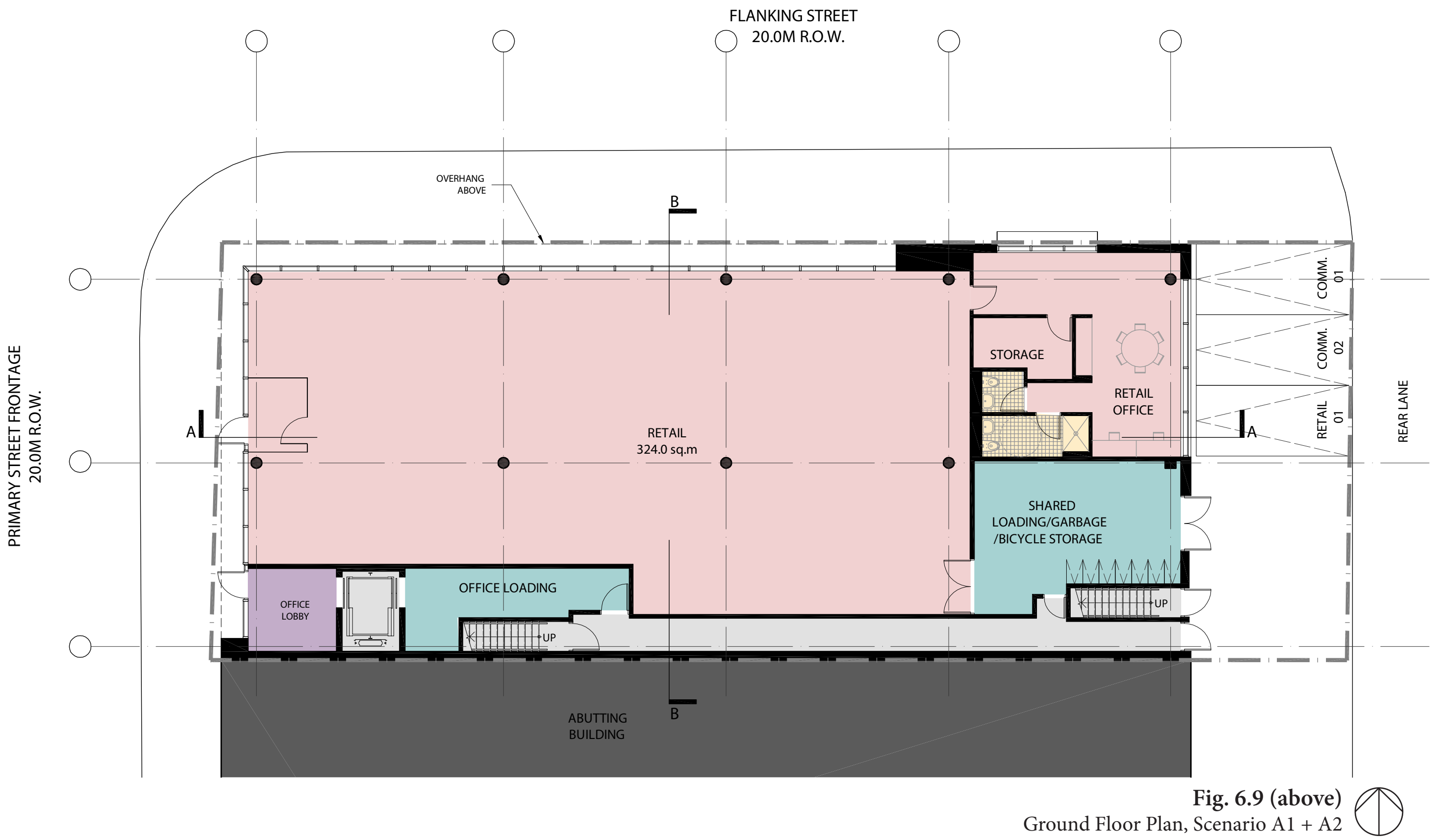


Fig. 6.9 (above)
Ground Floor Plan, Scenario A1 + A2

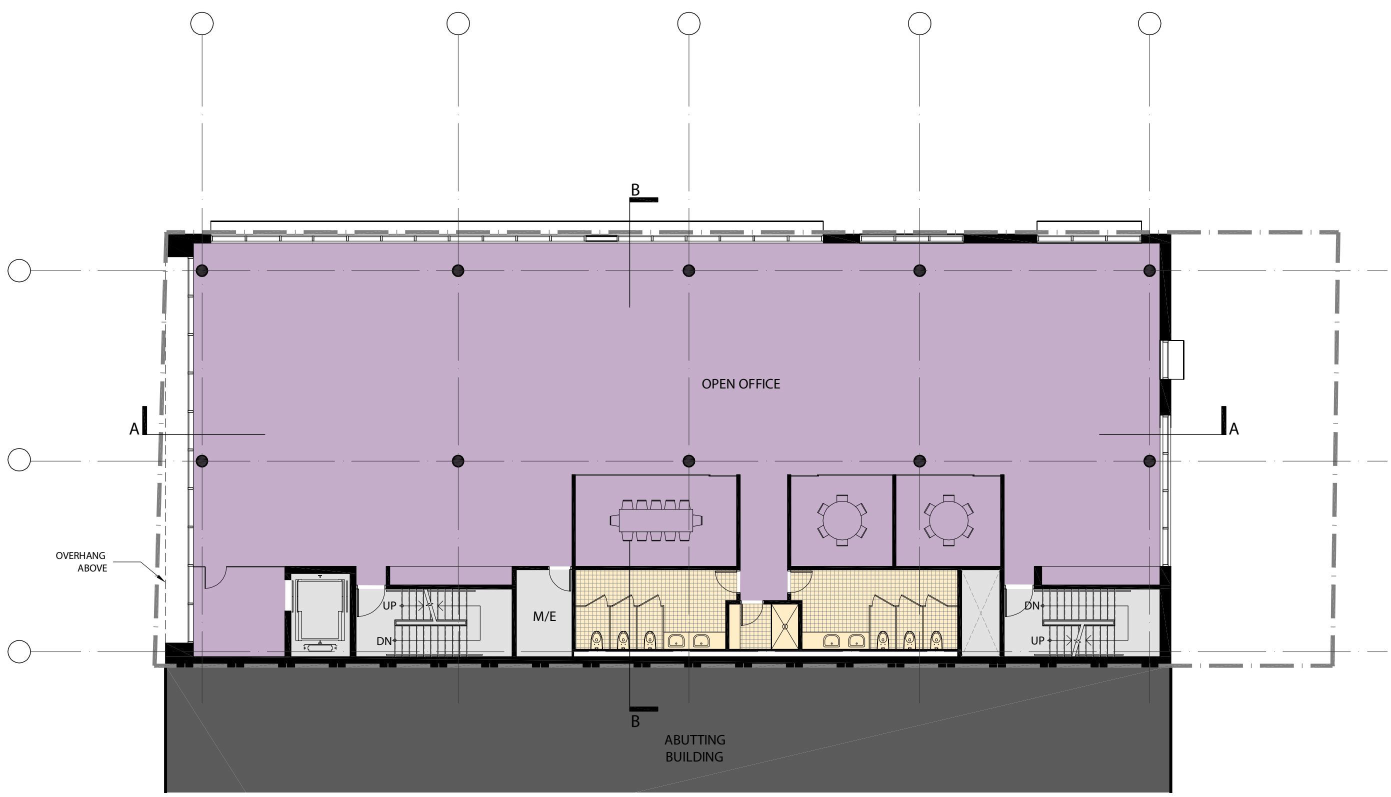
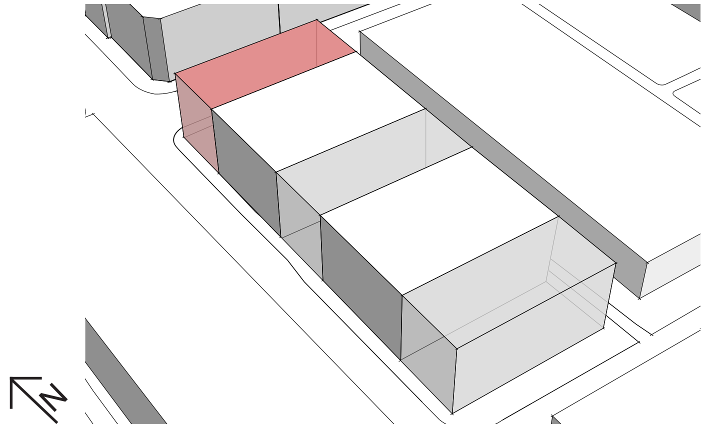


Fig. 6.10 (above)
Typical Upper Floor Plan (Levels 02-04), Scenario A1 + A2



6.1 Scenario A: North-Facing End Lot

Fig. 6.11 (above)
Location of Scenario A in the prototypical block

Scenario A investigates the north end of the prototypical block. The building occupies the entire site and is built out to the property line on all sides except the laneway where it is pulled back to accommodate four parking stalls. ***Scenario A1*** analyses the predicted annual energy consumption and greenhouse gas emissions of a building that is designed to meet the current building codes A daylighting, solar insolation, and solar access analysis is then conducted to determine the impact of the surrounding urban fabric and suggest passive strategies to improve energy efficiency. ***Scenario A2*** follows and makes adjustments to the building configuration, systems, and components that bring the building energy performance within the 15.3 kg/m^2/yr emissions cap suggested by the 2°C Scenario. This second scenario does not investigate the implications to achieve neither net-zero energy or carbon-neutral. Although an important topic, this comparison focuses on the implications of achieving the emissions cap within the context of current practices.

<u>*Scenario A1: Current Code Standard, Building Description*</u>
The site located at the north-end of the prototypical block has three exposed facades. A 2,135m^2 (22,980ft^2) four-storey building that is 17.5m in height to the top of the roof is proposed. It features a rectangular a footprint of 534m^2 that is oriented along the east-west axis. Therefore, the southern facade, although long, abuts an adjacent building while the north facade is exposed to a 20.0m right-of-way along the flanking street. The primary entrances are located on the west facade as it fronts onto the main Avenue that also features a 20.0m right-of-way. Service access, bike storage, and vehicular parking is along the east facade and faces a 7.5m right-of-way and laneway. The typical plans are illustrated in Figures 6.9 and 6.10 opposite, and full building drawings can be found in Appendix A.

The building is mixed-use to reflect the typical context of main, public avenues. The ground floor is predominantly retail. A modest 12.3m^2 (132ft^2) elevator lobby fronts onto the main avenue and provides access to the upper three floors. The floor-to-floor height of 5.0m yields high ceilings and allows for drops from the office uses above. The at-grade retail features a 324m^2 (3,488ft^2) sales floor that fronts onto both the main avenue, which has the entry doors, and the side-street. These are fully glazed to provide views into the space and to animate the street-front. A 63.8m^2 (687ft^2) support area at the rear includes office space, staff room, washrooms, and storage. A 40.0m^2 (433ft^2) shared loading area is accessed from the laneway and includes wall-mounted bicycle racks, storage for garbage and recycling, and a corridor connecting the elevator to the upper floors. The total leasable area for the retail is 367.2m^2.

Table 6.1.1: Scenario A1 Energy Model Inputs and Building Attributes		
Building Description		
Building Height	Total Height: 17.5m, Four Storeys Floor-to-Floor L01: 5.0m, L02-L04: 4.0m	
Building Area	2,135m^2 \ Floorplates: Approx 534m^2 each	
L01 Program Allocation	Retail Sales: 63.0% Conditioned Storage: 2.2% General Office: 8.7% Washroom: 1.5% Mechanical/Electrical: 2.0% Office Elevator Lobby: 3.8% Corridor: 18.8%	
L02-L04 Program Allocation	Open Office: 65.0% Conference Room: 8.4% Kitchen: 2.8% Washroom: 8.5% Mechanical/Electrical: 2.0% Office Elevator Lobby: 3.7% Corridor: 7.7% Print/Copy: 2.0%	
Site Coverage (FAR)	Site Area: 639.5m^2 / FAR: 3.3x	
Retail Plannable Gross Area[4]	367.2m^2	
Office Plannable Gross Area[4]	439.5m^2 / floor, 1,318.5m^2 total	
Building Envelope Attributes		
Exterior Wall - Typical (calculated with THERM)	W1: Charred Cedar W2: Black Masonry	R: 18.4 / U: 0.0545 R_{si}: 3.23 / U_{si}: 0.31
Exterior Wall - Abutting Zero Property line Wall[5]	W3: CMU, unsealed.	R: 11.4 / U: 0.088 R_{si}: 2.0 / U_{si}: 0.5
Roof (calculated with THERM)	R1: Inverted, Intensive Green	R: 26.2 / U: 0.038 Rsi: 4.6 / Usi: 0.217
Glazing - Curtainwall	DOE Glass Library 6458: (Guardian SunGuard LE40/Clr-12.7mm Air/Clr 6mm Aluminium C/W Frame, Thermally Broken, Metal Spacer	Centre-Glass U_{si}: 1.87 Centre-Glass U: 0.33 SHGC: 0.37 VT: 0.67
Glazing - Ribbon/Punched	DOE Glass Library 6458: Guardian SunGuard LE40/Clr-12.7mm Air/Clr 6mm Aluminium Frame, Thermally Broken, Metal Spacer	Centre-Glass U_{si}: 1.87 Centre-Glass U: 0.33 SHGC: 0.37 VT: 0.67
Daylight Settings	Off - no daylight harvesting	
Window-Wall Ratio (WWR)	West (primary street frontage): 85% North (flanking street frontage): 54% East (rear laneway frontage): 36% South (abutting building frontage): 0%	Max Permitted: 40% Overall: 37%
Air-Tightness	0.04 cfm/ft^2	

Table 6.1.1 Continued: Scenario A1 Energy Model Inputs and Building Attributes		
HVAC Systems		
Hours of Operation	Retail-Monday to Saturday: 9am - 8pm, Sunday Closed Office-Monday to Friday: 8am - 7pm, Saturday/Sunday Closed Statutory Holidays Closed	
Temperature Set-Points	Cooling Setpoint: 24°C Heating Sepoint: 22°C	
Heating System	Modelled as Electric Baseboard to determine load. Proposed system: Natural Gas, COP of 0.85 applied to heating load, resulting converted to kBTU to calculate emissions. (Table 6.8.1E, ASHRAE 900.1-2007)	Load / COP = heating system demand
Cooling System	Modelled as PTAC Through-Wall A/C. COP of 3.0 applied to approximate system-wide efficiency. Converted to cooling EIR of 0.28025.	Load = Demand
Ventilation[6]	ASHRAE 62.1 Table 6.1: Ventilation Rates for Outdoor Air Retail: 0.25cfm/ft2 outdoor air (combined occupancy + area rate) Office: 0.11cfm/ft (combined occupancy+area rate) Airflow (general): 0.5cfm/ft2	
Heat Recovery	None	
Domestic Hot Water	Natural Gas	
Electrical, Plug Loads, and Lighting		
Lighting Loads[7]	SB-10 Table 4.3.3.4: LPD Using the Space-by-Space Method Retail Sales: 18 W/m^2 Storage: 9 W/m^2 Office/Open Office: 12 W/m^2 Washroom: 10 W/m^2 M/E: 16 W/m^2 Lobby: 14 W/m^2 Corridors: 5 W/m^2 Conference Room: 14 W/m^2 Kitchen: 13 W/m^2 Print/Copy: 14 W/m^2	
Equipment Loads[8]	SB-10 Table 5-4: Equipmennt Power Density Retail Level: 2.69 W/m^2 Office: 8.07 W/m^2	
Exterior Lighting	Not Considered	
Elevator[9]	Thyssen-Krupp hydrolic elevator with a 3500kg capacity and incandescent bulbs. Annual energy consumption estimate included in Auxiliary Loads.	4,205 ekWh/yr

The upper three floors are office with a typical plan that accommodates one tenant per level. A 319m^2 open office area takes up a majority of the plan and fronts onto the three exposed facades and has an average depth of 8.2m. It includes a print-copy room and kitchen/staff area. A glazed vestibule separates the lobby from the main space. Meeting rooms are located in the core and face towards the office space while bathrooms, exit stairs, and service shafts are arranged along the blank south wall. The floor-to-floor height of 4.0m allows for a 12-foot clear ceiling height below lights and services. The leasable area for the office is 439.5m^2 per floor, for a total of 1,318.5m^2.

The building is articulated in response to the program and urban context by continuing the mass and presence of the streetwall while, at the same time, juxtaposing the adjacent fabric of heritage buildings. Rather than mimic an historic facade, the modern language creates a variety in the urban fabric while respecting the mass and street relationship of the block. The facade of four-storey rectangular mass is expressed as a crisp volume of charred cedar that is punctuated by glazing. The north elevation is broken into a series of linear glazed strips that are randomly defined by stainless steel box projections to break up the bulk and mass of the facade. The west facade is predominantly glazing and, as the primary frontage, features the entries to the office lobby and retail. The corner is dissolved to promote a transparent at-grade expression to animate the street that, as one turns the corner and moves along the side street, plunges down at a sharp angle. A black surround on the upper floors of west face defines the office and retail uses while bringing the scale down to the pedestrian level along the sidewalk. Glazing is limited along the east and black masonry at grade provides a durable envelope adjacent to vehicular parking and loading. An overall Window-Wall-Ratio (WWR) of 37% is achieved, primary because the entire south facade is blank. Along the north facade, the WWR is 54%, roughly equivalent to the maximum permitted glazing at grade by code while the west facade is 85% and the east facade is 37%. The maximum whole-building value permitted by the Code is 40%. An intensive green roof manages stormwater and contributes to mitigating the urban heat island effect.

The prevailing local code is the Ontario Building Code (OBC). There are a number of life safety, combustibility, and assembly requirements that arise for a building of this size, height, and site context that intersect with low-energy design goals. The first is the limiting distance of the exposing building faces and the resulting maximum permitted area of unprotected glazing. The south facade abuts another building and thus, cannot have any glazing. In the case of any elements that pop-up above the abutting building, the south facade is not permitted any glazing as its limiting distance is zero. The limiting distance of the remaining exposing building faces permits the area of unprotected glazing to be 100% west (primary) facade; 64% at grade and 100% for the upper floors of the north (side street) facade; and 79% at grade and 91% for the upper floors of the east facade (rear laneway). The building is permitted to have foam plastic insulation provided it is separated by a continuous thermal barrier from the interior and a non-combustible cladding is provided. On the other hand, if no foam plastics are used, a combustible cladding is permitted given that the building is sprinklered. This later condition is proposed for Scenario A1. Please refer to Appendix A for the full OBC Matrix.

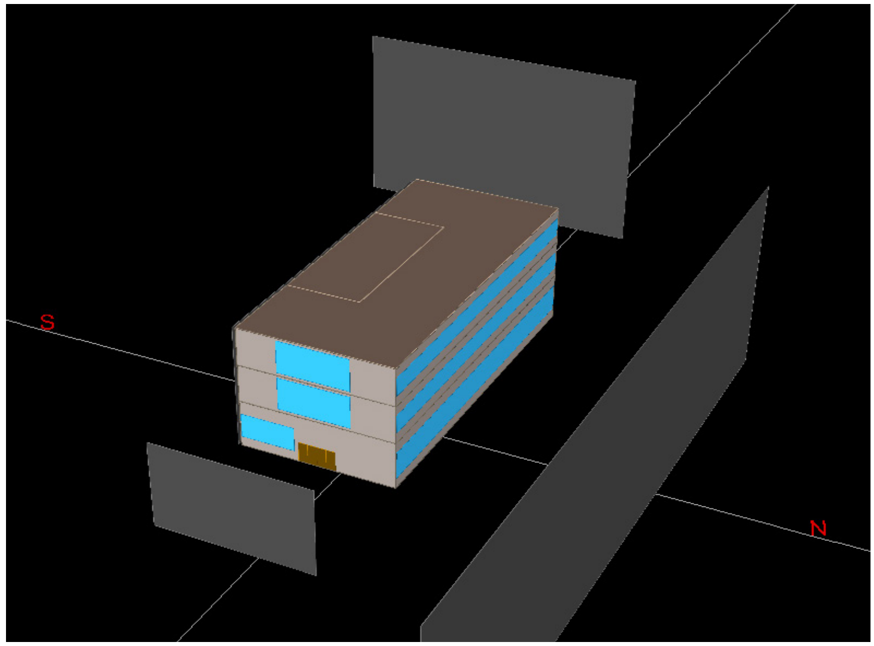


Fig. 6.12 (above)
Scenario A EQuest Model Screenshot

Scenario A1: Current Code Standard, Energy Model Attributes
The forecast annual heating, cooling, and system loads for Scenario A1 are based on detailed architectural and general system inputs, including building area, window wall ratio, envelope characteristics, lighting power density, and HVAC system COP. The prescriptive requirements of the OBC SB-10 energy supplement are used for each input. All new buildings in Ontario are required to meet this standard for envelope design, window-wall ratios, mechanical and electrical system efficiency, and detailing for continuity of insulation and air-tightness. Where the supplement and the base code provide differ, such as the maximum area of unprotected openings allowed by the Code relative to the maximum window-wall ratio allowed by the supplement, the most stringent is used. Table 6.1.1, opposite, summarizes the building and energy model attributes that define the current code scenario.

The building envelope has been modelled based on three key attributes. The first is the use of THERM to calculate a two-dimensional assembly U-value for each building envelope component to properly account for thermal bridges. This is, in turn, used in EQuest rather than the layer-by-layer method. The second is the treatment of the the south exterior wall that abuts an adjacent building. A common practice is to model this surface as adiabatic with no heat transfer because the effect of the two buildings is assumed to be, relatively, thermally balanced. When using energy models for comparison purposes, as long as this is consistent, it is an accepted practice. However, when creating a model to understand true heating and cooling loads, this method has been shown to be inaccurate. Using measurements of as-built conditions, Row, Wingfield, Bell, and Bell suggest that, when the space between zero property line walls is neither insulated nor sealed, an abutting building face has a measured U_{si}-value 0.5 W/m^2-k, equivalent to an R_{si}-value of 2.0 k-m^2/W [4]. Double-glazed units with metal spacers are selected from the DOE Glazing Library and match the prescriptive requirements of the SB-10. Finally, the surrounding urban context has been modelled using building shades and are illustrated in Figure 6.12, above. Note that the second level has a shell multiplier of two to represent a four-storey building.

The heating and cooling systems have been specified as a through-wall air conditioner and electric baseboard heating with ventilation rates matching the

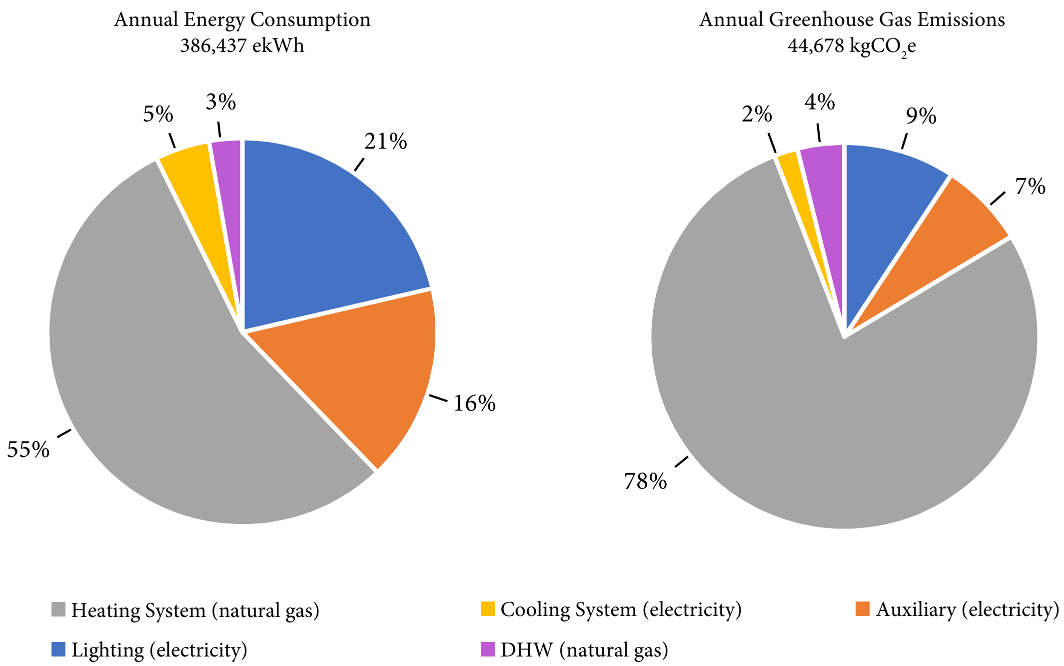


Fig. 6.13 (above)
Scenario A1 breakdown of annual energy consumption and greenhouse gas emissions.

ASHRAE Standard 62.1. Doing so generates a heating and cooling load in EQuest as opposed to system energy consumption. A system COP is then applied to these loads outside EQuest to derive the approximate energy consumption. The A1 scenario uses natural gas as the heating fuel and electricity to supply the remaining loads. The chosen system is a packaged DX rooftop unit providing both heating with no heat recovery at a COP of 0.85 and cooling at a COP of 3.0. A typical natural gas system is specified for domestic hot water. The lighting system meets the prescriptive requirements for Lighting Power Density Space by Space method with no daylight harvesting. The model assumes an air-tightness of 0.04cfm/ft^2 and elevator energy consumption is added outside of the EQuest model.

Scenario A1: Annual Energy and Emissions Predictions

The annual secondary (site) energy consumption in ekWh and greenhouse gas emissions in $kgCO_2e$ for the north-facing end block building are summarized in Table 6.1.2. The results suggest the annual energy consumption will be 163,695 kWh of electricity and 699,855 kBTU of natural gas. This is equivalent to an Energy Use Intensity (EUI) of 180.9 ekWh/m^2/yr when the fuel sources are combined. Figure 6.12, above, illustrates that heating is by far the dominant load and represents 55% of the total energy use with cooling loads representing only 5%. Lighting is the second-highest category and represents 21% of the annual total. This allocation generally follow the historic measured data presented by Natural Resources Canada's Energy Use Data Handbook for commercial buildings and is in-line with the climate zone. Table 6.1.2, following, summarizes the energy consumption allocation and values.

Emissions Intensity (E_i) is calculated to be 20.9 $kgCO_2e/m^2/yr$, 37% higher than the emissions budget of 15.3 $kgCO_2e$/m2/yr suggested by the 2°C mitigation scenario. This calculation is based on the following consumer emission factors for Ontario:

- Electricity: 0.05 $kgCO_2e$/ekWh[10],
- Natural Gas: 0.164 $kgCO_2e$/ekWh[11].

Scenario A1:North-Facing End Block Monthly Energy Consumption

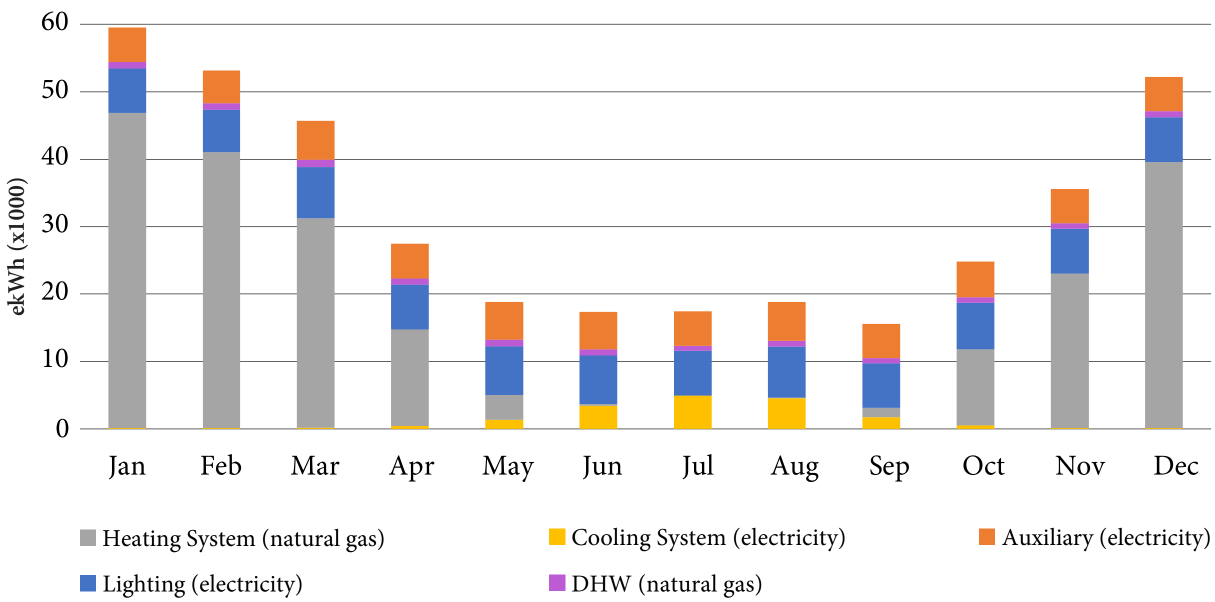


Fig. 6.14 (above)
Scenario A1 breakdown of monthly energy consumption and greenhouse gas emissions.

The allocation generally follows the pattern of energy consumption. Heating and lighting are the two highest categories, representing 78% and 9% respectively, while cooling represents only 5%. Although the relative allocation between energy use and emissions are the same, the absolute values are different due to the fuel choice. In Ontario, natural gas has an emission factor more than three times that of electricity on an equivalent kilowatt-hour basis. In this case, the relative share of energy consumed versus natural gas for heating grows from 55% to 78%.

Table 6.1.2: Scenario A1 Energy and Emissions Summary

Category	Energy (ekWh)	Allocation	Emissions ($kgCO_2e$)	Allocation
Heating	212,153	55%	34,759	78%
Lighting	82,550	21%	4,128	9%
Auxiliary	63,645	16%	3,182	7%
Cooling	17,500	5%	875	2%
DHW	10,589	3%	1,735	4%
Total	386,437		44,678	
Intensity	180.9 $ekWh/m^2$		20.9 $kgCO_2e/m^2$	

Scenario A: Passive Assessment
Passive design to reduce heating, cooling, and lighting loads at the north-facing end-block site is limited by the surrounding urban fabric. For example, the most basic strategies of a rectangular building with glazing facing south and limited glazing to the north is not possible. Considering that the heating load represents more than 50% of the building load and nearly 80% of the total emissions, this strategy would prove to be beneficial. With this site context and energy use profile in mind, a study of the overshadowing impacts by the surrounding buildings, solar stress, and daylight availability will illustrate the passive opportunities.

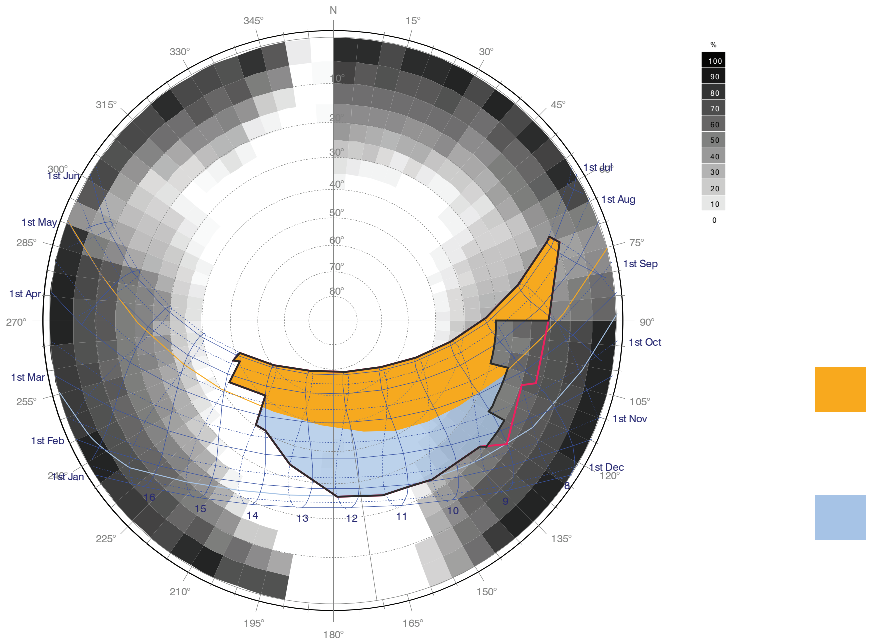


Fig. 6.15 (above)
Scenario A east and west facade overshadowing created in Ecotect Analysis. Shading requirement overlay based on a balance-point temperature of 8.3°C and solar cutoff of 263.4 W/m². Process derived from Brown and DeKay, 2001.

Scenario A, Overshadowing + Shading:
One of the fundamental effects of a surrounding urban fabric on any particular building is with solar access. Site constraints limit orientation, contribute to overshadowing, and limit daylight access. In the case of a building where the heating load is dominant, impeded solar access can significantly reduce passive design opportunities.

The A1 scenario has the south exposure completely obstructed, and street canyons 20 metres in width and 17.5m in height to the west while the east facade is pulled back from the property line and has lower facing buildings that create a more open condition. Using Ecotect Analysis, the average shading coefficient of the west facade, on an annual basis, is shown to be 35.9%. In the summer cooling season when excess solar gain should be avoided, it is slightly higher at 40.1%. This means that, of available solar radiation falling on the facade, 40.1% is blocked. The east facade is shaded to a similar extent with the average annual shading coefficient equal to 34.6% and 38.1% during the summer cooling season. The stereographic diagram above shows that this overshadowing does contribute to reducing the periods that should be covered by a shading device when the facade is overshadowed by more than 30%. In this case, the urban context helps to reduce the cooling load. Conversely, it also does help contributes to a higher heating load. The stereographic diagram also shows that, on the west facade in particular, the overshadowing tends to happen at times of year and day when shading is not required. Table 6.1.4, below, summarizes the heating and cooling loads of the A1 Scenario with and without the urban context and suggests that the total thermal loads are lower, with heating load decreasing and cooling load increasing. It can be concluded that the urban context does contribute to a comparable increase in loads by 18.7%.

Table 6.1.3: Impact of Surrounding Buildings on Annual Heating and Cooling Loads for the A1 Scenario in ekWh

	With Surrounding Buildings	Without Surrounding Buildings
Heating	212,153	163,540
Cooling	17,500	23,150
Total Thermal Loads	229,653	186,690

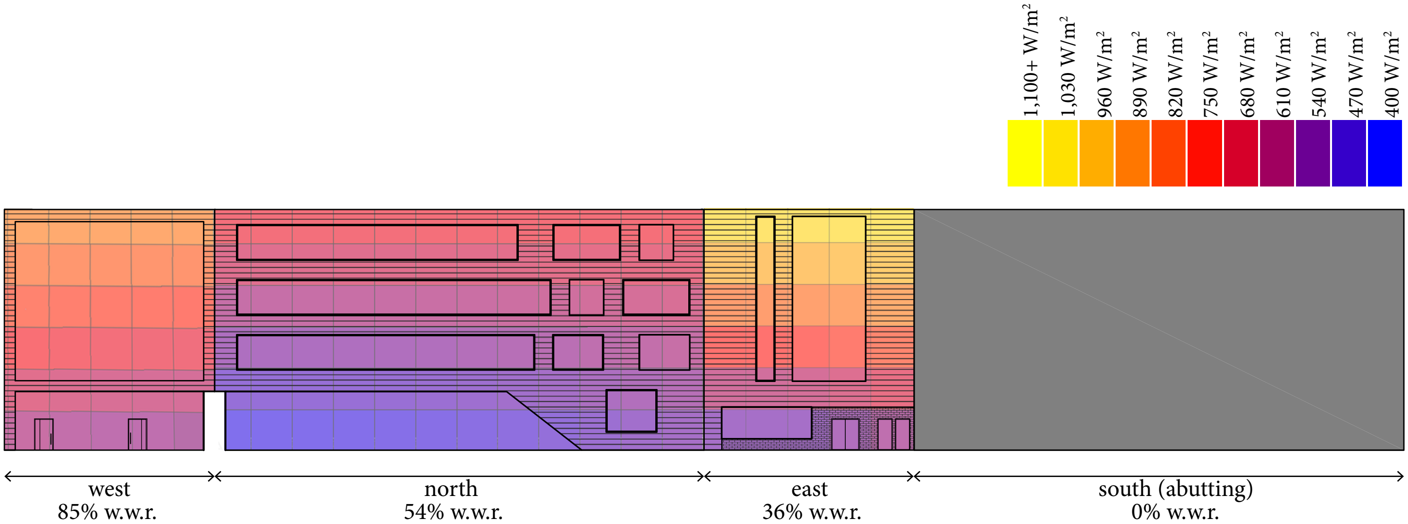


Fig 6.16 (above)
Scenario A1 Facade Average Daily Insolation (Wh/m^2)
Calculated with Ecotect Analysis

The overshadowing conditions require a careful study of solar angles to determine optimal shading. Figure 6.15 suggests that glazing on the west facade should be shaded between May 14th and August 15th using a vertical shading device that provides coverage from 1:00pm through 4:00pm. The cooling loads and overshadowing show that shoulder seasons do not need shading. Shading is not as critical towards the east except in the height of the summer cooling season until 11:00am. Overshadowing makes the most pronounced contribution, keeping the ground floor shaded nearly all the time early in the day. The south facade abuts an adjacent building and is not relevant in this scenario.

Scenario A, Solar Stress:
The average annual insolation striking the exposed facades is affected by the overshadowing of the surrounding buildings. Direct insolation is more limited and thus solar stress leading to cooling load is lower. On the west facade in particular, the majority is diffuse rather than direct, leading to a relatively even distribution of solar energy across the facade and a lower solar stress than the east facade. The insolation distribution has more in common with the North facade than the East. This suggestion is supported by the heating and cooling load analysis presented in Table 6.1.3 where the overshadowing caused by neighbouring buildings increases the heating load significantly. Figure 6.15, above, illustrates the distribution of direct and diffuse average daily insolation on the three exposed facades.

The west facade in the current code iteration is over 85% glazed. Across the entire facade, the average direct insolation does not exceed 200Wh/m^2 while the combined direct and indirect insolation ranges from 573Wh/m^2 on the southwest corner of the ground floor to 871Wh/m^2 on the northwest corner, reflecting the most and least overshadowed areas. The analysis suggests that glazing is a cooling liability and shading could be effective. Solar gain and glare is limited as the facade is generally overshadowed from direct gain during the heating seasons and there are no "hotspots" where significant gain is expected. The east facade, on the other hand, is more exposed to direct insolation. The ground level is shaded nearly all the time while the upper floors are exposed can receive an average daily insolation in excess 1,100 Wh/m^2, creating a cooling liability. Glazing should be limited on the northeast corner to avoid summer overheating. The north facade receives diffuse radiation and, in general, is considered a heating liability in northern climates. Glazing should be optimized for daylighting and view only.

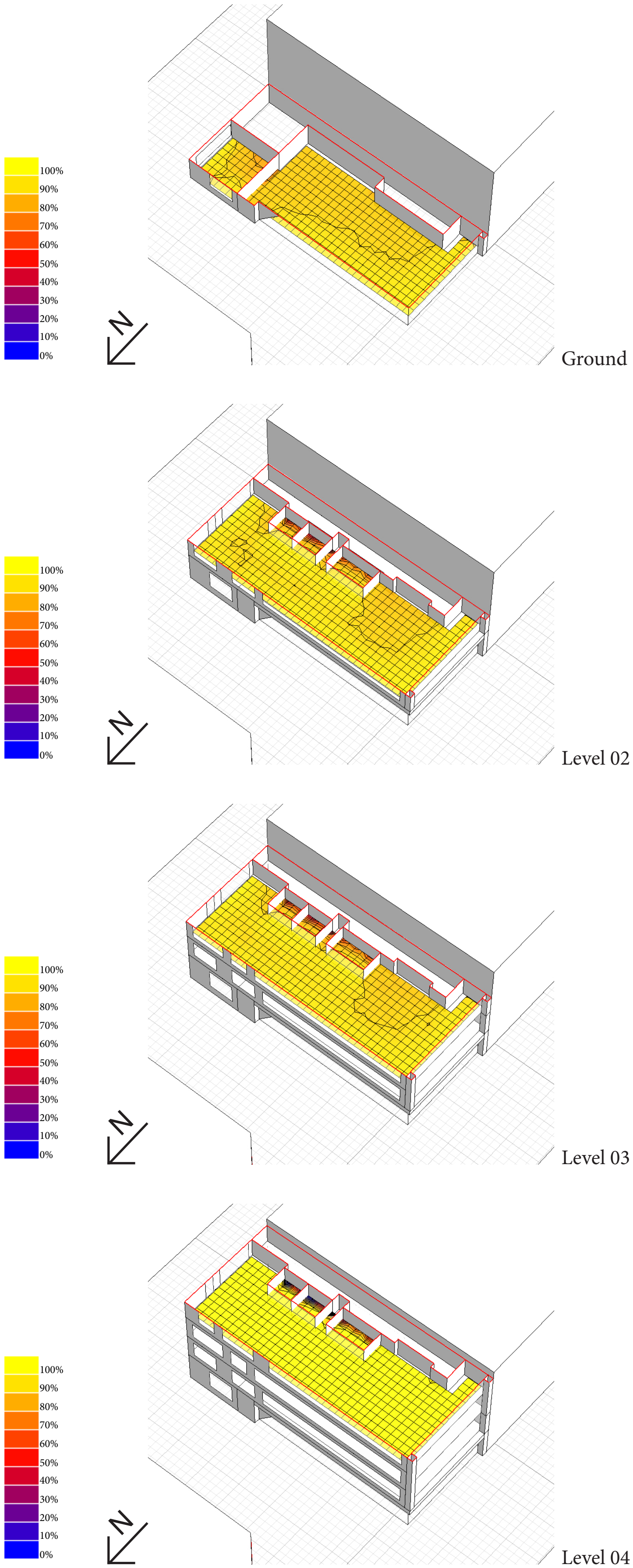


Fig. 6.17 (left)
Scenario A1 floor-by-floor daylight autonomy based on 300lux at 762mm above the floor, calculated in Ecotect Analysis

Scenario A, Daylight Availability:
The rectangular building floorplate and floor-to-floor heights are conducive to good daylighting. The depth of the retail sales floor and office spaces are within 8.5m to 9.0m of any facade while service spaces, elevator, exit stairs, mechanical shafts and washrooms are arranged along the blank south side. The orientation of the building along the east-west axis allows the north elevation to be the primary face for daylight harvesting, where even light is present without excess heat gain. The glazed west facade, combined with the overshadowing of surrounding buildings, creates a daylighting condition similar to the north where diffuse insolation is predominant and direct insolation is limited. However, the depth of daylit space from this facade falls off more quickly than the rest of the space, suggesting the significant shading impacts of the surrounding buildings. The east has more limited glazing where direct insolation is more prevalent. Similar to the west facade, daylight autonomy is affected by overshadowing. Daylight is not as evenly distributed on the lower two floors where the facade is overshadowed for much of the year and very even and deeply distributed where the building rises above surrounding obstructions.

The daylight autonomy analysis, presented in Figure 6.16 at left, suggests that the occupied spaces receive 300lux at 762mm above the finished floor between 80% and 100% of the time when daylight is available, in other words, the entire occupied floorplate achieves daylight autonomy and suggests there is a significant potential to reduce lighting energy. Less light is available on the lower levels compared to the higher levels, reflecting the overshadowing of the surrounding buildings. The results also suggest that the amount of glazing could be reduced as one moves higher in the building and still achieve daylight autonomy. The depth for regularly occupied spaces from a daylight device generally follows the rule of thumb where 2.5x the height of the glazing will yield an effectively daylit zone[29].

The passive analysis of Scenario A suggests opportunities to lower building loads and illustrates the constraints and challenges presented by the surrounding buildings. The urban fabric impedes on the solar envelope in a measurable way, driving a significantly higher heating load and a slightly reduced cooling load that, together, generate a higher overall energy demand. Overshadowing is not always protecting the building at the right times, as a purpose-built shading device might. For example, the building is overshadowed on the east and west facades during the heating season and exposed to solar gain during the cooling seasons.

However, opportunities exist to reduce these loads. During the cooling season, shading can be added to the west and east facades to reduce solar gain during specific times of year. The daylight distribution suggests that the plan configuration of the floor levels supports daylight autonomy. Glazing distribution can also be adjusted by level as the building appears over-glazed for daylighting, the upper floors in particular. However, with heating being such a dominant load, reduced glazing to increase the overall thermal resistance of the envelope should be balanced. It may be true where sacrificing daylight autonomy for a more solid envelope will have a more significant relative impact on reducing heating and cooling loads.

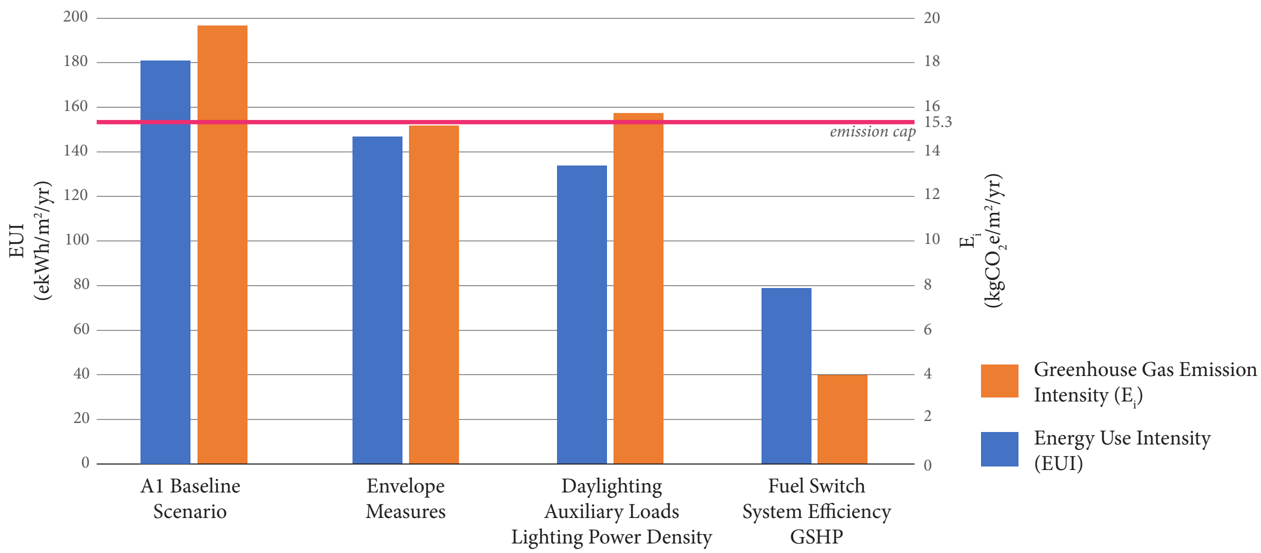


Fig. 6.18 (above)
Scenario A2 energy and emission reductions by category

Scenario A2: 2°C Mitigation Scenario

The annual emissions intensity (E_i) of the north-facing end block scenario is 20.9 $kgCO_2e/m^2/yr$, 27% higher than the 15.3 $kgCO_2e/m^2/yr$ budget suggested by the 2°C mitigation scenario. This can be reduced by addressing both the energy consumption and the E_i of fuel sources used. A study of each of these two aspects of the emissions equation suggests that each can independently achieve the target and, as a result, a project has a suite of options available.

The approach taken to reducing energy and GHG emissions is based on the recommended design process for high performance buildings where loads are first reduced and then subsequently met using high-efficiency systems. Nine energy reducing measures are incrementally applied to the baseline A1 scenario and can be grouped into three categories. The first is comprised of three measures that improve the performance of the building envelope. The second passively reduces internal loads by incorporating high-performance lighting technology, daylight harvesting, and reduced plug-loads that represent low-consumption equipment and appliances. The third and final category incorporates fuel switching to lower emitting energy sources in conjunction with high efficiency mechanical systems. The cumulative effect of these measures suggests that achieving the emissions cap of the 2°C scenario is possible without on-site renewable energy sources and with technologies that are both proven and readily available.

Scenario A2, Category 1- Building Envelope Measures:

Three measures are applied to the A1 scenario to reduce heating and cooling loads driven by the building envelope. The results suggest that the EUI can be reduced by 18.8%, from 180.9 $ekWh/m^2/yr$ to 146.9 $ekWh/m^2/yr$. E_i can be reduced by 27.5% from 20.9 $kgCO_2e/m^2/yr$ to 15.2 $kgCO_2e/m^2/yr$ and achieve the emissions cap required by the 2°C Median Mitigation Scenario. The difference in relative impact of energy consumption and emissions illustrates the impact of fuel choice. In this case, the envelope measures reduce heating load significantly more than cooling load. As Natural gas is the fuel choice for heating and the heating system's COP is 0.85 compared to 3.0 for the cooling system, a change in energy consumption will have a larger emissions impact per equivalent kilowatt-hour than a change in cooling load. The Gilman Ordway Centre features a similar condition where glazing is predominantly north facing and vegetation in an adjacent ravine limits direct insolation. The envelope measures in this case study are similar to the proposed measures and include triple-glazing and high insulation values.

Fixed shading for the west facade was investigated but did not yield overall energy savings. The modelling suggests that shading devices sized for the seasons where cooling was dominant also blocked solar gains for the heating season such that the heating load increased more than the cooling load decreased. This factor is also likely due to the overshadowing effects of the surrounding buildings. This does suggest, however; that dynamic shading devices or thermochromatic glazing would reduce cooling loads as they activate only when needed. The modelling of these effects is complicated and, given that all measures selected are suggested to be substantially lower than the emission cap, this specific measure could be useful to achieve more ambitious targets, such as net-zero or carbon-neutral.

Scenario A2, Envelope Measure 1 - Reduce Window-to-Wall Ratio (WWR):
The window-wall ratio in the A2 scenario is reduced by 9%, from 37% to 28%. The most substantial reduction is on the west facade, where the curtainwall facade is transformed into a strip-window composition on the upper floors. Along the north elevation, pieces of the strip windows are filled in with opaque wall to create a punched expression. The east facade remains unchanged as the WWR is already low and both daylight availability and view are optimized along this frontage. This measure reduces both heating and cooling loads without sacrificing daylight availability. Analysis suggests that an annual average of 300lux across the regularly occupied floor areas can be achieved and, thus, not impede daylight harvesting.

Scenario A2, Envelope Measure 2 - Reduce Thermal Transmittance of the Building Envelope:
The second measure increases the R-values of both the roof and exterior walls and increases the performance of the glazing system. The thermal resistance of the exterior walls with north, east, and west exposure is increased by 22%, from R18.4 to R23.8. The cavity wall is increased from 92mm to 152mm and filled with polyurethane foam insulation while the 50mm of continuous expanded polystyrene insulation remains. The abutting south wall is sealed and continuously insulated at the exposing ends, increasing the equivalent R-value from R11.4 to R28.6[15]. The roof R-value increases 33%, from R26.2 to R45.5, by nearly doubling the thickness of the polyisocyanurate insulation from 112mm to 200mm. The double-glazed Low-E coated insulated glazing units (IGU) in the baseline scenario are replaced with triple-glazed Low-E coated units and the highly conductive metal spacers are upgraded to insulating spacers. The Centre-Glass U-Value decreases from 0.33 to 0.22. The envelope measures also effect plannable leasable area as defined by the ASTM *Standard Practice for Building Floor Area Measurements for Facility Management*[4]. The thicker building envelope reduces it by less than 1%, from 1,685.7m^2 to 1,678m^2.

Fixed shading devices on the west facade, designed to mitigate cooling at the times suggested by the passive analysis, were found to also provide shade during the heating seasons. More useful heat was blocked than was mitigated in the cooling season and increased the overall combined annual heating and cooling load. Given that the heating has a higher E_i per equivalent kilowatt-hour than cooling in this case, it also created a higher emission penalty that was even higher than the increased load. Therefore, fixed shading was not implemented.

Table 6.1.4: Scenario A2 Energy Model Inputs and Building Attributes		
Building Description		
Building Height	Total Height: 17.5m, Four Storeys Floor-to-Floor L01: 5.0m, L02-L04: 4.0m	
Building Area	2,135m^2 \ Floorplates: Approx 534m^2 each	
L01 Program Allocation	Retail Sales: 63.0% Conditioned Storage: 2.2% General Office: 8.7% Washroom: 1.5% Mechanical/Electrical: 2.0% Office Elevator Lobby: 3.8% Corridor: 18.8%	
L02-L04 Program Allocation	Open Office: 65.0% Conference Room: 8.4% Kitchen: 2.8% Washroom: 8.5% Mechanical/Electrical: 2.0% Office Elevator Lobby: 3.7% Corridor: 7.7% Print/Copy: 2.0%	
Site Coverage (FAR)	Site Area: 639.5m^2 / FAR: 3.3x	
Retail Plannable Gross Area[4]	366.4m^2	
Office Plannable Gross Area[4]	437.2m^2 / floor, 1,311.6m^2 total	
Building Envelope Attributes		
Exterior Wall - Typical (calculated with THERM)	W1A: Charcoal Cementitious Panel W2A: Black Masonry	R: 23.8 / U: 0.042 R_{si}: 4.19 / U_{si}: 0.24
Exterior Wall - Abutting Zero Property line Wall[5]	W3A: CMU, sealed and insulated	R: 28.6 / U: 0.035 R_{si}: 5.04 / U_{si}: 0.20
Roof (calculated with THERM)	R1A: Inverted, Intensive Green	R: 45.5 / U: 0.022 Rsi: 8.0 / Usi: 0.125
Glazing - Curtainwall	DOE Glass Library 3652: (Triple Low-E Film (77) Clear) Aluminium C/W Frame, Thermally Broken, Insulating Spacer	Centre-Glass U_{si}: 1.25 Centre-Glass U: 0.22 SHGC: 0.47 VT: 0.64
Glazing - Ribbon/Punched	DOE Glass Library 3652: (Triple Low-E Film (77) Clear) Aluminium C/W Frame, Thermally Broken, Insulating Spacer	Centre-Glass U_{si}: 1.25 Centre-Glass U: 0.22 SHGC: 0.47 VT: 0.64
Daylight Settings	On -Continuous Dimming	
Window-Wall Ratio (WWR)	West (primary street frontage): 57% North (flanking street frontage): 40% East (rear laneway frontage): 36% South (abutting building frontage): 0%	Max Permitted: 40% Overall: 29%
Air-Tightness	0.04 cfm/ft^2	

Table 6.1.4 Continued: Scenario A2 Energy Model Inputs and Building Attributes		
HVAC Systems		
Hours of Operation	Retail-Monday to Saturday: 9am - 8pm, Sunday Closed Office-Monday to Friday: 8am - 7pm, Saturday/Sunday Closed Statutory Holidays Closed	
Temperature Set-Points	Cooling Setpoint: 24°C Heating Sepoint: 22° C	
Heating System	Modelled as Electric Baseboard to determine load. Proposed system: Electric Ground Source Heat Pump, COP of 2.8 applied to heating load.	Load / COP = heating system demand
Cooling System	Modelled as PTAC Through-Wall A/C. COP of 4.0 applied to approximate system-wide efficiency. Converted to cooling EIR of 0.2175.	Load = Demand
Ventilation[6]	ASHRAE 62.1 Table 6.1: Ventilation Rates for Outdoor Air Retail: 0.25cfm/ft2 outdoor air (combined occupancy + area rate) Office: 0.11cfm/ft (combined occupancy+area rate) Airflow (general): 0.5cfm/ft2	
Heat Recovery	Applied; contributions taken into account with system COP	
Domestic Hot Water	Electric	
Electrical, Plug Loads, and Lighting		
Lighting Loads[7]	ASHRAE Advanced Energy Design Guideline Retail and Office Retail Floor (L01): 0.98 W/m^2 Office Floors (L02-L04): 0.75 W/m^2	
Equipment Loads[8]	SB-10 Table 5-4: Equipmennt Power Density reduced 25% Retail Level: 1.92 W/m^2 Office: 6.06 W/m^2	
Exterior Lighting	Not Considered	
Elevator[9]	Thyssen-Krupp regenerative elevator with a 3500kg capacity and LED bulbs. Annual energy consumption estimate included in Auxiliary Loads.	1,360 ekWh/yr

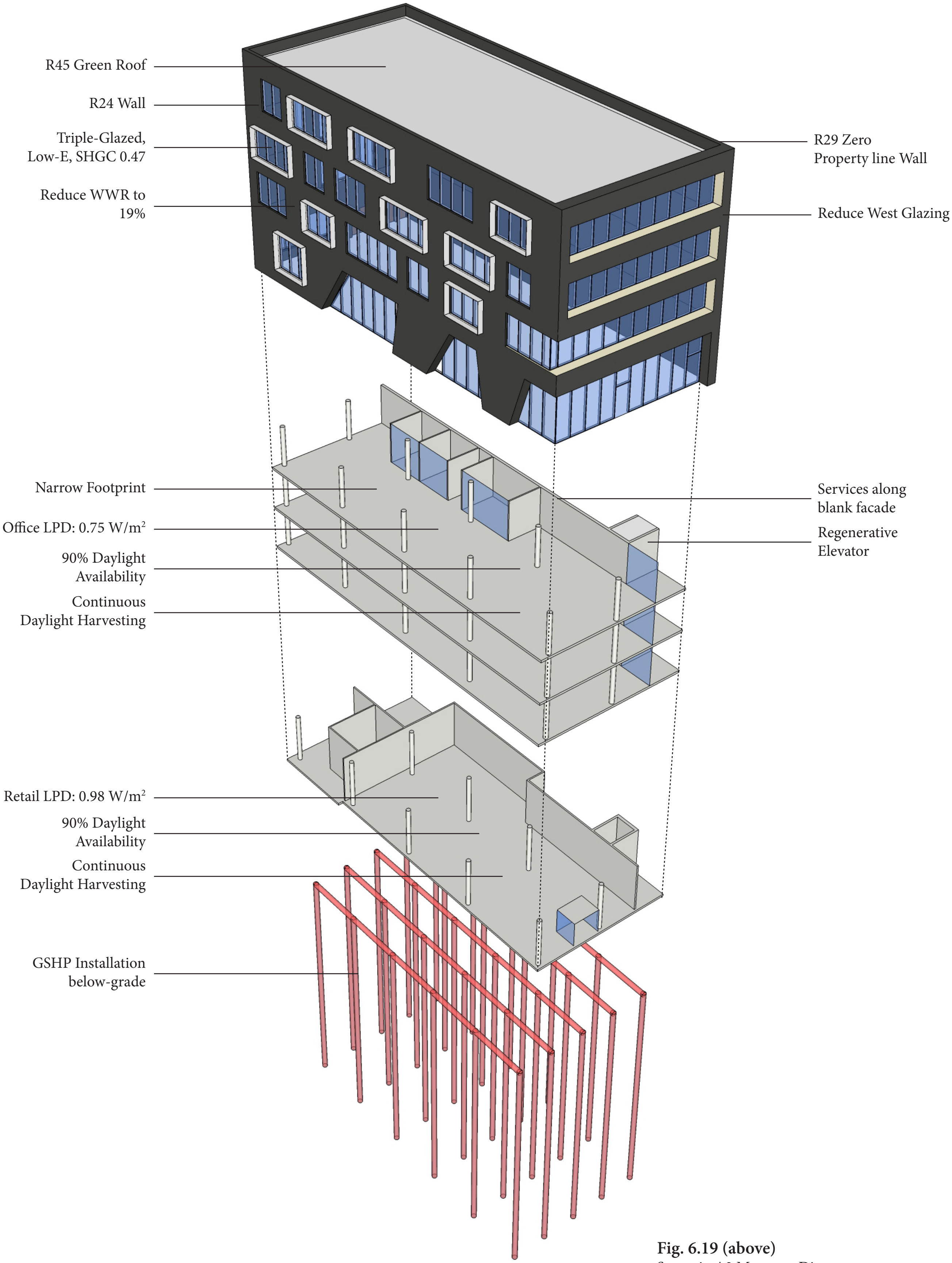


Fig. 6.19 (above)
Scenario A2 Measures Diagram

Scenario A2, Envelope Measure 3 - Increase Glazing SHGC from 0.36 to 0.47
The solar heat gain coefficient of the triple-glazed IGUs is increased from 0.36 to 0.47. This measure was studied separately from the general envelope improvements to test the impact separately. The model suggests that, because the heating load represents 55% of the total annual heating load and is thus dominant, the reduction of heating load by increasing the SHGC is more than the associated increase in cooling load and thus reduces the overall energy use intensity. The overall EUI drops from 147.9 ekWh/m^2/yr to 146.9 ekWh/m^2/yr when this measure is applied to the triple-glazed units. Furthermore, when natural gas is used as a fuel source, heating load has a higher emissions intensity than the cooling load that is met using electricity in the regional context of this study. Therefore, it is advantageous from both an energy efficiency and emissions intensity point of view to increase the SHGC. This may not always be the case. Most of the case studies in Chapter 5, with the exception of the EpiCentre building, have a lower SHGC, suggesting avoiding heat gain is preferred. In a situation where the WWR is higher, this could be the case. However, results suggest a higher SHGC is more beneficial here.

Scenario A2, Category 2- Internal Load Measures:
The internal load category applies three strategies to the envelope measures that increase the energy efficiency of non-mechanical system loads. In some cases, such as daylight harvesting, passive design attributes are incorporated. Reducing the energy consumption of these systems does have an effect on heating and cooling load and is the primary reason why these measures are investigated separately from the mechanical systems. Energy consumption is reduced by a further 7.2% on-top of the building envelope measures and the EUI is reduced to 133.9 ekWh/m^2/yr. However, emissions increase to 15.7 $kgCO_2e/m^2$/yr, slightly above the cap, 0.5 $kgCO_2e/m^2$/yr above the level achieved by the envelope measures. This is due to an increase in heating load as a result of less heat generated by lights, appliances, computers and other auxiliary equipment. With the higher emissions intensity associated with heating load, 0.164 $kgCO_2e$/ekWh for natural gas versus 0.05 $kgCO_2e$/ekWh for electricity, the emission savings from lower plug and lighting loads are offset. It should be noted that if electricity was the fuel source for heating, the emissions decrease rather than increase. This demonstrates the interconnected nature of building loads, systems, and fuel selection when energy consumption and greenhouse gas emissions are considered together.

Scenario A2, Internal Load Measure 1 - Reduce Lighting Power Density
The ASHRAE Advanced Energy Design Guidelines for retail and office buildings suggest technologies and design practices to reduce energy consumption by 50%. This guideline provides a Lighting Power Density (LPD) recommendation of 0.98 W/m^2 for retail uses and 0.75W/m^2 for office uses. These numbers take into account all program types within a typical retail or office building, such as washrooms and support spaces, and are applied to the entire floor area of the primary occupancy of each respective floor. This reflects a combination of different technologies and includes high-efficiency lighting technology, occupancy sensors, and design techniques to reduce the overall number and wattage of fixtures required[16,17]. Compared to the baseline A1 scenario, retail LPD is reduced by 29% and office LPD is reduced by 30%. In total, the annual lighting load drops from 82,550 eKwh to 57,760 eKwhr, equivalent to a 30% reduction.

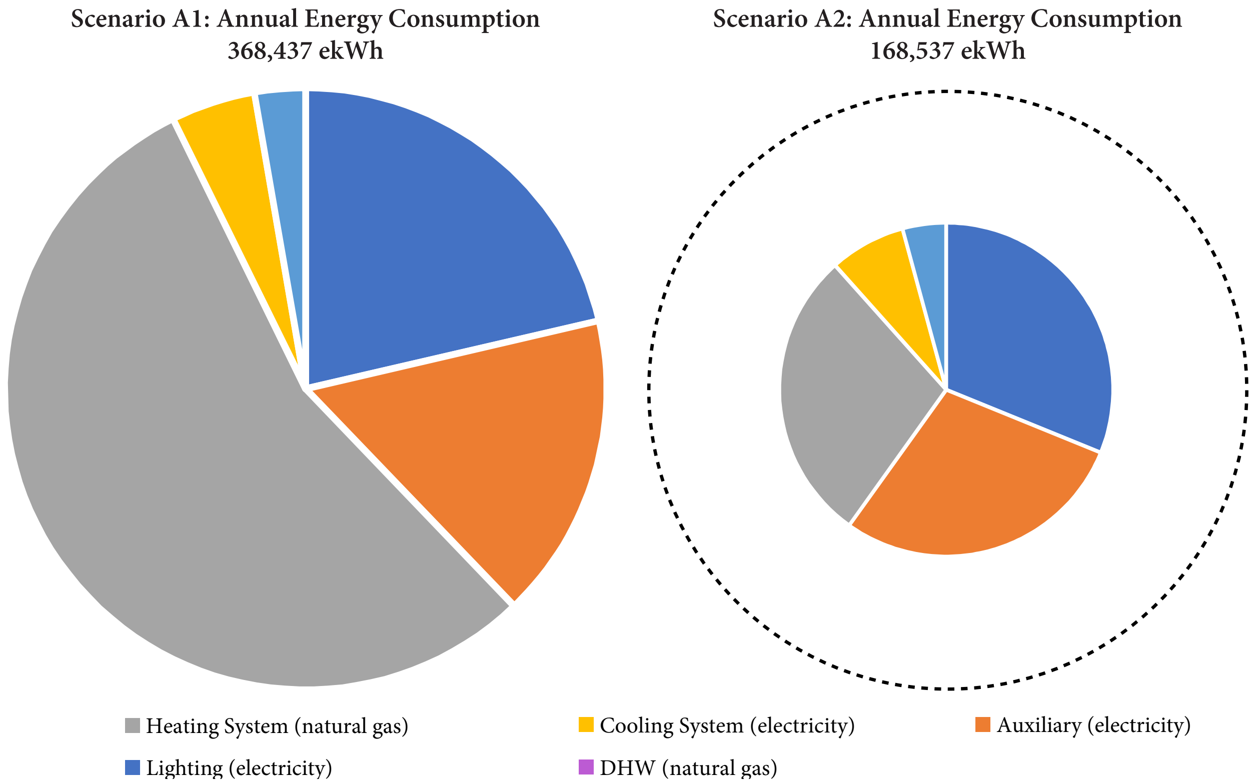


Fig. 6.20 (above)
Annual Energy Consumption Comparison of A1 Baseline and A2 2°C Mitigation Scenarios

Scenario A2, Internal Load Measure 2 - Introduce Daylight Harvesting:
Daylight harvesting is introduced as a key measure. A daylight autonomy simulation of the A2 scenario suggests that 300lux can be achieved in most regularly occupied spaces 90% of the time on an annual basis. The ground floor still achieves a high level of daylight autonomy with the overshadowing of the surrounding urban context because it is situated at a corner and is relatively exposed compared to the mid-block building. The east-west orientation of the rectangular floorplate keeps service spaces and circulation against the blank south wall while regularly occupied spaces, including the open office and staff spaces on the upper floors and the sales floor and support offices on the ground level, are arranged along the exposed facades. The relatively narrow aspect ratio ensures that regularly occupied spaces are within 9.0m of an exposed facade and is in keeping with the daylighting rule of thumb where daylight can be reasonably expected within 2.5x the height of the space[18], which in this case is 10.0m. A continuous dimming ballast set to 5% increments has been selected and is in-line with many of the case studies.

Scenario A2, Internal Load Measure 3 - Reduce Plug Loads and Elevator:
The NREL Assessment of the Technical Potential for Achieving Net-Zero Energy Buildings in the Commercial Sector[19] suggests that plug loads can be reduced by 25% and the Advanced Energy Design Guidelines for office buildings produced by ASHRAE[20] both suggest that plug and equipment loads can be reduced by up to 33% in the office . With the proliferation of electronic devices, this load component is expected to continue to increase[21]. Based on these studies, plug and auxiliary loads in the A2 scenario are reduced by 25%. This is achieved by assuming that best-in-class Energy Star office equipment is specified, personal printing devices are limited, and measures are taken to provide shut-offs to reduce or eliminate parasitic loads. In retail spaces, this would include requiring retail displays, third-party in paricular, on the sales floor to meet the reduced plug-load standard and

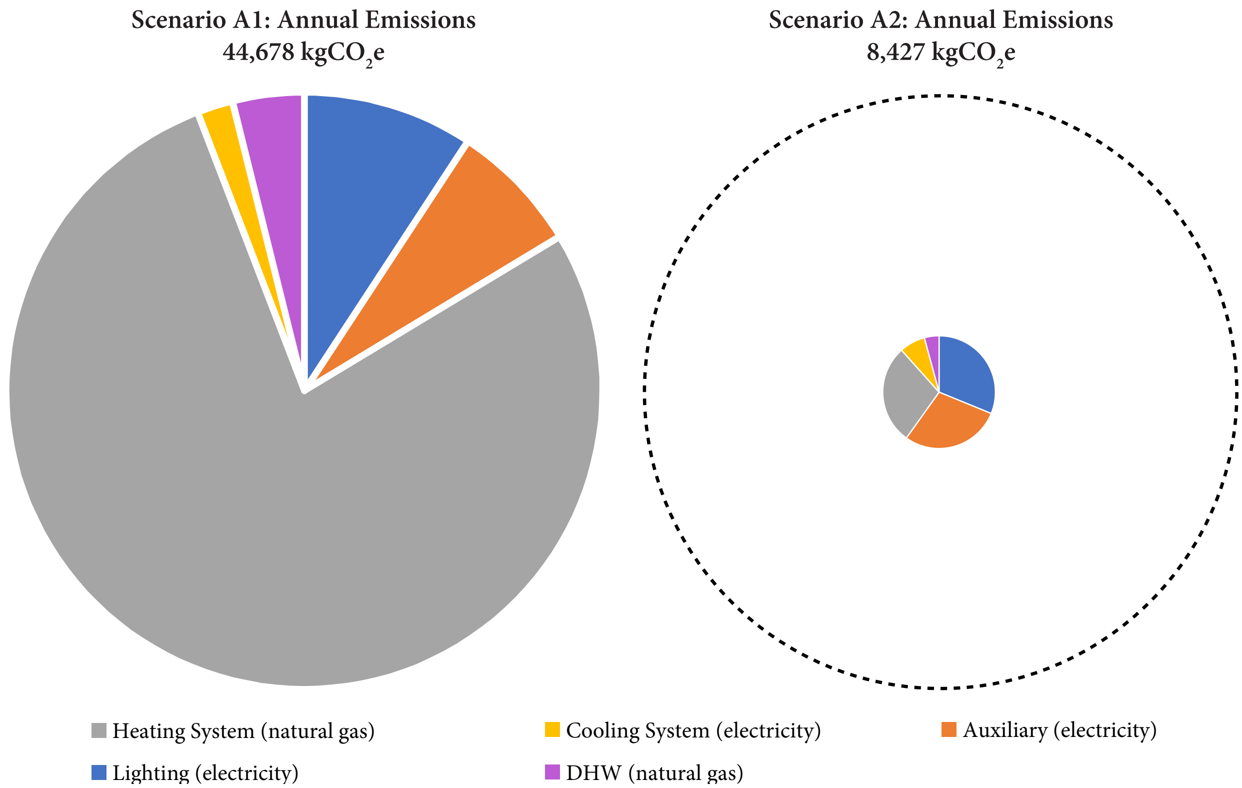


Fig. 6.21 (above)
Annual Emissions Comparison of A1 Baseline and A2 2°C Mitigation Scenarios

the use of LED over neon or other technologies for signage. The plug loads would be reduced by 25% throughout to 1.91 W/m^2 for the retail and 6.05 W/m^2 for the office. The annual energy consumption of the elevator is reduced by introducing a more energy efficient technology. The cable system is replaced with a regenerative elevator with LED lighting in the cab, leading to a reduction of 68%, equivalent to 4,205 ekWh to 1,360 eKwh.

Scenario A2, Category 3 - Fuel Switch and System Efficiency:
The third category of measures increases the mechanical system efficiencies, changes the system types, and introduces a fuel switch to an all-electric building. With the loads optimized through envelope measures, daylight harvesting, and reduced internal loads, the mechanical system has a much lower load to meet compared to the A1 baseline scenario. The following three measures reduce not only the total amount of energy required to satisfy building loads, but also reduce the emissions intensity (E_i) for the heating and domestic hot water systems from 0.164 kgCO_2e/ekWh to 0.05 kgCO_2e/ekWh, a reduction of over 70%. Given that heating is by far the dominant load in both the A1 baseline and A2 Mitigation scenarios, the potential to reduce emissions through fuel switching is substantial. When all three measures in this category are implemented, the model suggests that an EUI of 78.9 ekWh/m^2/yr can be achieved with an E_i of 3.9 kgCO_2e/m^2/yr; a reduction of 56.4% and 81.1% respectively that is well in excess of the 2°C Median Mitigation Scenario target 15.3 kg/m^2/yr.

Scenario A2, Fuel Switch and System Efficiency 1 - Fuel Switch to Electric Heating:
The A1 baseline scenario assumes a natural gas heating with a COP of 0.85 and an electric cooling system with a COP of 2.0. These approximate a high-quality system performance based on current standards. The A2 scenario replaces the natural gas system with a unitary electric heating and cooling rooftop system with integrated heat recovery. The system switch has two effects. First, the heating

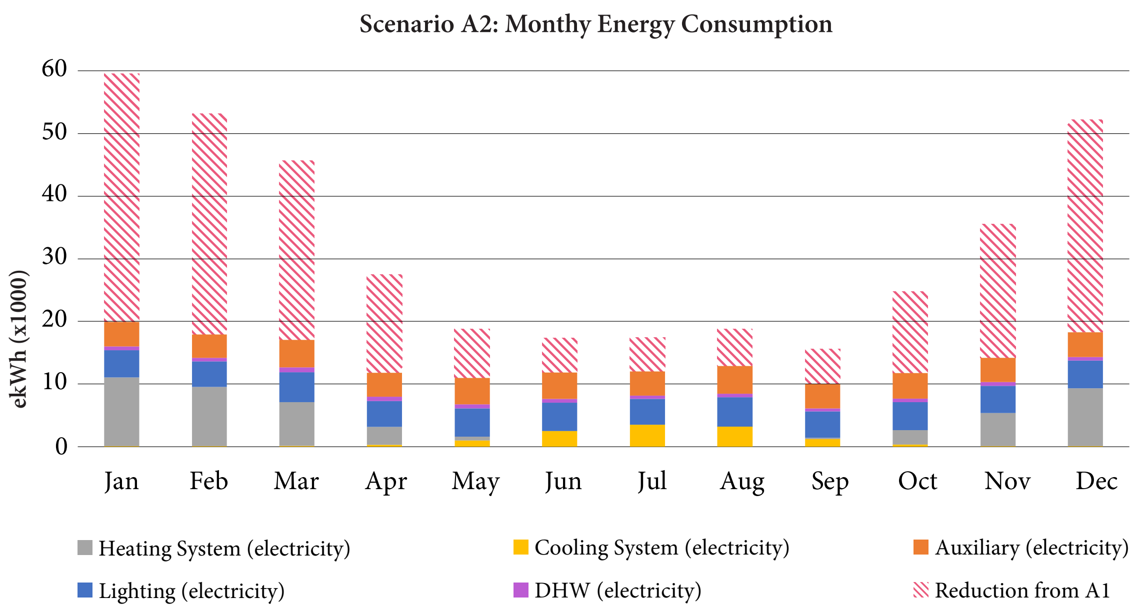


Fig. 6.22 (above)
Monthly Energy Consumption and Breakdown of the A2 2°C Mitigation Scenario

system COP improves from 0.85 to 2.0, a dramatic increase in system efficiency. Secondly, the emissions intensity of electricity in Ontario, the region where the study is located, is nearly 70% lower than natural gas. Incrementally applying this system to the envelope and internal load measures, the energy required to satisfy the annual heating load is reduced from 158,305 ekWh to 67,280 ekWh and the associated emissions are reduced from 25,936 kgCO_2e to 3,364 kgCO_2e. The share of emissions associated with heating compared to the annual total is reduced from 77% to 29% and becomes the second-highest end-use rather than the first.

Scenario A2, Fuel Switch and System Efficiency 2 - Ground Source Heat Pump
A ground-source heat pump can further improve the efficiency. Rather than generating heat and cold the system pulls it from storage in earth and makes use of heat-pumps to add or take away heat. The Clockshadow Building in Milwaukee, Wisconsin, USA makes use of this type of system and demonstrates that it can be applied to a building in a constrained urban site context similar to the demonstration projects. The system coefficient of performance (COP) for heating increases from 2.0 to 2.8 and cooling increases from 3.0 to 4.0 to approximate a well designed and high quality system. The EUI, compared to the unitary rooftop system represented in Measure One is reduced by 12%, from 91.2 ekWh/m^2/yr to to 80.2 ekWh/m^2/yr while E_i is reduced by 10%, from 5.1 kgCO_2e/m^2/yr to 4.6 kgCO_2e/m^2/yr.

Scenario A2, Fuel Switch and System Efficiency 2 - Electric Hot Water
The final measure proposes a fully electric building. Eliminating on-site combustion is required to achieve carbon-neutrality and this final measure anticipates that further improvements could be made to achieve this metric. In addition to eliminating on-site combustion, electric hot-water systems consume less energy. The model suggests that is reduced by 33%, from 10,582 ekWh per annum to 7,110 ekWh.

Scenario A2: Annual Energy and Emissions Predictions

The annual secondary (site) energy consumption and greenhouse gas emissions for the A2 north-facing end block scenario are summarized in Table 6.1.5, below, and the results suggest that the emissions cap suggested by the 2°C Median Mitigation Scenario can be exceeded. The annual energy consumption can be reduced by 56.4% compared to the A1 Scenario, from 386,437 ekWh to 168,537 kWh of electricity, an EUI of 78.9 ekWh/m^2/yr for the A2 scenario. Lighting consumes marginally the largest share use at 31% with heating the next highest at 29% share. This contrasts to the A1 scenario where heating is the largest by a large margin with lighting second. The energy consumption by season is also much less variable than the A1 scenario. This is in-line with comparable high-performance buildings with low window-wall ratios and robust envelopes where internal loads become dominant as low-energy design measures significantly reduce heating and cooling loads to dampen the impact of solar stress and climate.

Annual emissions are suggested to be 8,247 CO_2e, 81.1% lower than the 44,678 CO_2e of the A1 baseline scenario. The building's E_i is 3.9 kgCO_2e/m^2/yr, 74% lower than the emissions budget of 15.3 kgCO_2e/m^2/yr. The switch to electricity for heating, with an E_i of 0.05 kgCO_2e/ekWh,[10] is 1/3 that of natural gas and significantly lowers equivalent emissions over and above the reduction in energy use. With a single fuel source, the allocation of emissions by end-use matches energy consumption.

Table 6.1.5: Scenario A2 Energy and Emissions Summary

Category	Energy (ekWh)	Allocation	Emissions (kgCO_2e)	Allocation
Heating	48,057	29%	2,403	29%
Lighting	52,530	31%	2,627	31%
Auxiliary	48,390	29%	2,420	29%
Cooling	12,450	7%	623	7%
DHW	7,110	4%	356	4%
Total	168,537		8,427	
Intensity	78.9 ekWh/m^2		3.9 kgCO_2e/m^2	

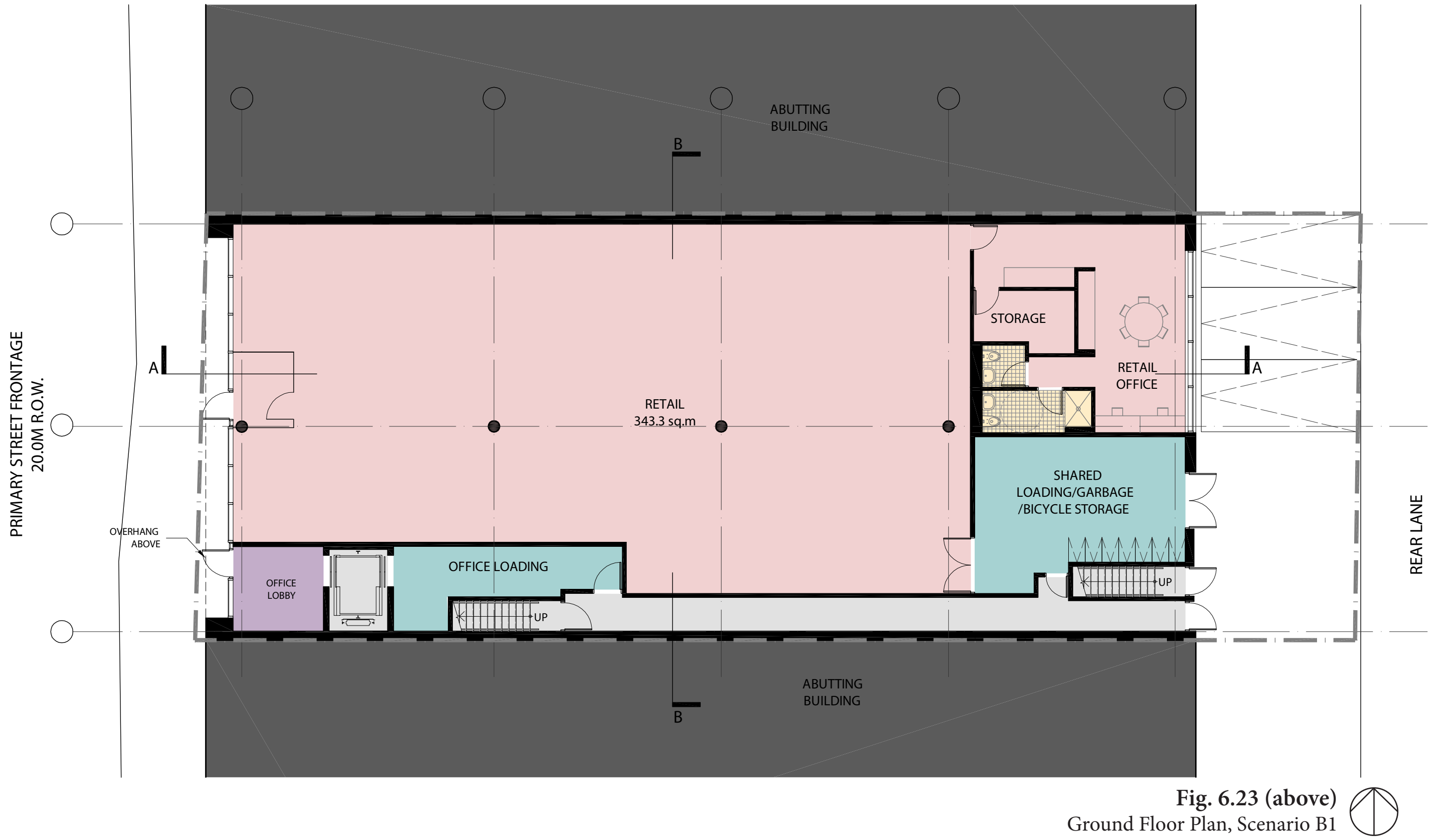


Fig. 6.23 (above)
Ground Floor Plan, Scenario B1

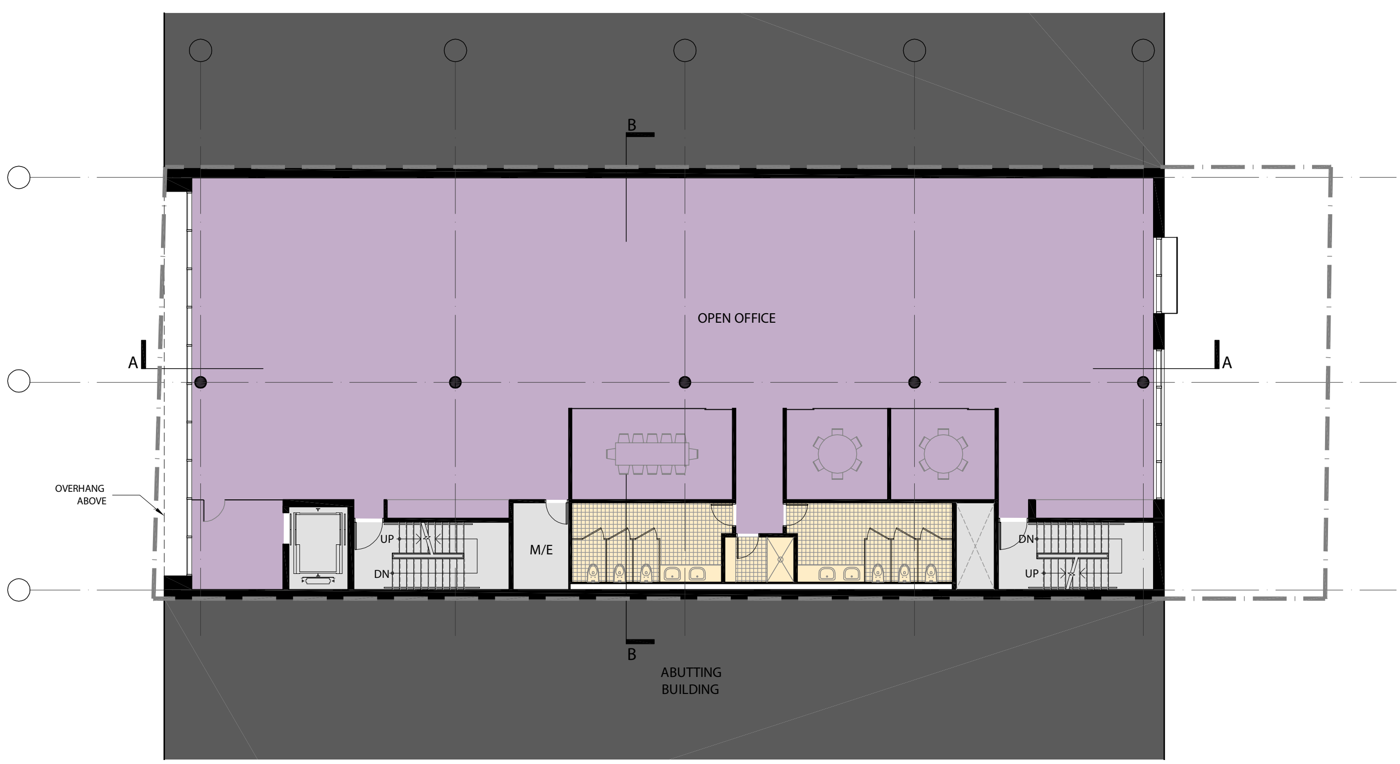
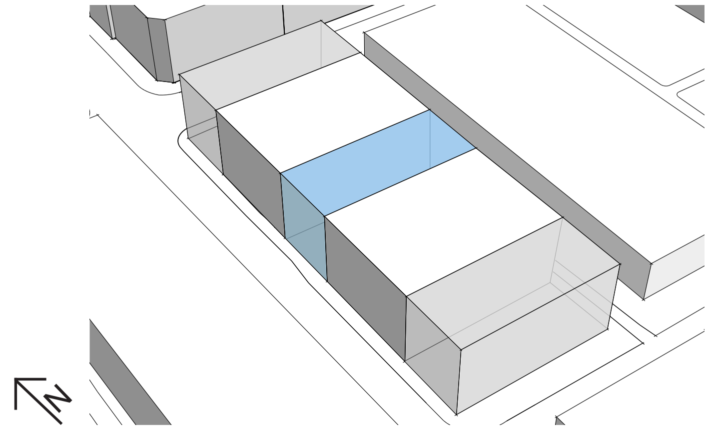


Fig. 6.24 (above)
Typical Upper Floor Plan (Levels 02-04), Scenario B1



6.2 Scenario B: MidBlock Lot

Fig. 6.25 (above)
Location of Scenario B in the prototypical block

Scenario B investigates the mid-block condition of the prototypical block. The building occupies the entire site and is built out to the property line on all sides except the laneway where it is pulled back to accommodate four parking stalls. ***Scenario B1*** analyses the energy and emission implications of a design solution that meets current building codes. A daylighting, solar insolation, and solar access analysis is then conducted to determine the impact of the surrounding urban fabric and suggest passive strategies to improve energy efficiency. ***Scenario B2*** follows and makes adjustments to the building configuration, systems, and components that bring the building energy performance within the 15.3 kg/m^2/yr emissions cap suggested by the 2°C Scenario.

Scenario B1: Current Code Standard, Building Description
This site is located on an interior lot within the prototypical block. This condition has only two exposed facades, compared to the three available on an end-block condition. Like the end-block site, the building is 17.5m and four storeys in height to the top of the roof. A 2,135m^2 (22,980ft^2), four-storey building that is 17.5m in height to the top of the roof is proposed. The building footprint is oriented along the east-west axis and each floorplate is 534m^2. The long sides, facing the north and south, abut adjacent buildings in the block, leaving the east and west facades exposed. The primary entrances are located on the west facade as it fronts onto the main Avenue with a 20.0m right-of-way. Service access, bike storage, and vehicular parking is to the east and faces a 7.5m right-of-way and laneway. The typical plans are illustrated in Figures 6.22 and 6.23, opposite, and full building drawings can be found in Appendix B.

The mixed-use program in Scenario B1 is consistent with the other demonstration buildings. The ground floor is predominantly retail. A modest 12.3m^2 (132ft^2) elevator lobby fronts onto the main avenue and provides access to the upper three floors. The floor-to-floor height of 5.0m yields high ceilings and allows for drops from the office uses above. The at-grade retail is varies slightly from the end-block buildings and the facade along the flanking street does not cut-back under the floors above. The retail sales floor is therefore slightly larger at 343m^2 (3,488ft^2) and has glazing fronting only the main avenue. This west facade features the entry doors and is fully glazed to provide views into to animate the street-front. A 63.8m^2 (687ft^2) support area at the rear includes office space, staff room, washrooms, and storage. A 40.0m^2 (433ft^2) shared loading area is accessed from the laneway and includes wall-mounted bicycle racks, storage for garbage and recycling, and a corridor connecting the elevator to the upper floors. The total leasable area for the retail is 384.8m^2.

The upper three floors are office and accommodate one tenant each. The floor plans are typical and include a 319m^2 open office area, print-copy room, and kitchenette. A glazed vestibule separates the lobby from the main space while meeting rooms are located in the core and face towards the open office. Bathrooms, exit stairs, and service shafts are arranged along the blank south wall. The site constraints allow only the west and east facades to be glazed. The floor-to-floor height of 4.0m allows for a 12-foot clear ceiling height below lights and services and the leasable area for the office is 439.5m^2 per floor, for a total of 1,318.5m^2.

The building is articulated in response to the urban context and program uses to continue the mass and presence of the streetwall while, at the same time, juxtaposing a contemporary intervention into the heritage fabric. Rather than mimic a historic facade, the modern language creates variety in the block while respecting the established height, massing, and street relationships. The glazed west facade creates a break in the streetwall and a black charred cedar surround encloses the upper three floors. This breaks up the west facade and responds to both the pedestrian scale along the street where the entrances are located, and the established facade lines of the buildings to the north and south. The east facade features more glazing than either end-block site due to the limited number of exposed faces. Black masonry at grade provides a durable envelope adjacent to vehicular parking and loading. With the two long facades abutting adjacent buildings, the overall Window-Wall-Ratio (WWR) of 19% is significantly lower than either of the end-block buildings. The WWR on the west facade is 85% while the east facade is 42%. The maximum permitted by the SB-10 prescriptive requirements is 40%. An intensive green roof manages stormwater and mitigate the urban heat island effect. This site condition is similar to the EpiCentre Artists for Humanity case study where the two long faces are blank with the only location for glazing on the two short end-faces.

The glazing percentage on these exposed facades is high to allow deep daylight penetration. Combined with a high floor-to-floor height, a multi-storey space in the centre of the plan, and daylight harvesting, achieves a low LPD of 0.15 W/m^2 without the use of an atrium or lightwell.

The requirements of the Ontario Building Code (OBC) change slightly for the B1 Scenario. The first is the limiting distance of the exposing building faces and the resulting maximum area of unprotected glazing permitted. The south and north facades abut another building and thus, cannot have any glazing. In the case of any elements that pop-up above the roof of an adjacent building, the glazing must face inwards as the outward facing exposure is on the property line. The limiting distance of the remaining exposing building faces permits the area of unprotected glazing to be 100% west (primary) facade; 64% at grade and 100% for the upper floors of the north (side street) facade; and 79% at grade and 91% for the upper floors of the east facade (rear laneway). Foam plastic insulation is permitted, provided it is separated by a continuous thermal barrier from the interior, such as 12.7mm Gypsum Board, and a non-combustible cladding is provided. On the other hand, if no foam plastics are used, a combustible cladding is permitted given that the building is sprinklered. This later condition is proposed for Scenario B1. Please refer to Appendix A for the full OBC Matrix.

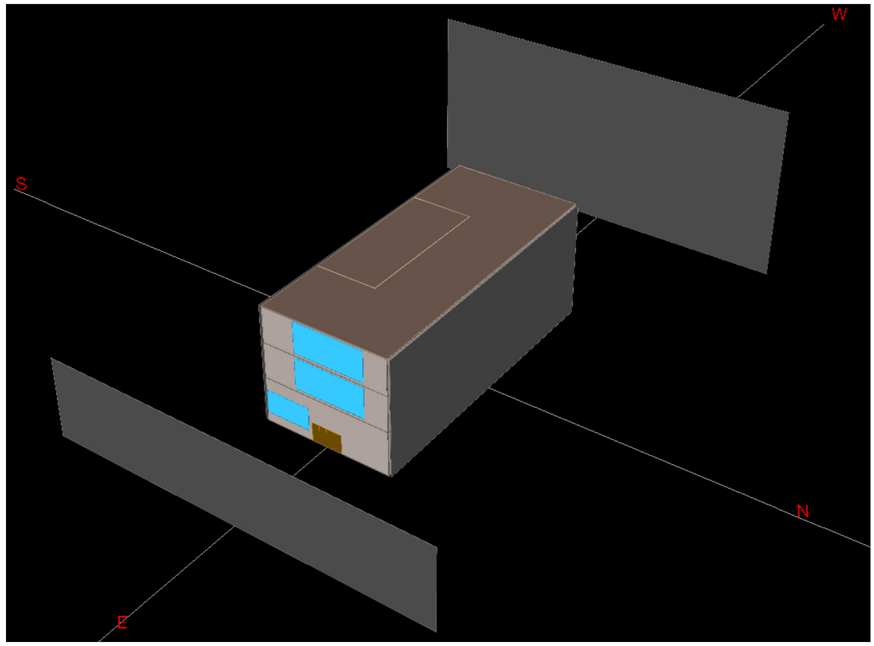


Fig. 6.26 (above)
Scenario B1 EQuest Model Screenshot

Scenario B1: Current Code Standard, Energy Model Attributes

The annual energy consumption and greenhouse gas emissions for Scenario B1 are based on detailed architectural inputs, such as building area, Window-Wall-Ratio, and glazing and envelope characteristics. To approximate the predicted annual results, the prescriptive requirements of the OBC SB-10 energy supplement are used. The model assumes the details set out in this standard for envelope design, mechanical and electrical system efficiency, and detailing for continuity of insulation and air-tightness are adhered to. Where the supplement and the base code provide different requirements, such as the maximum area of unprotected openings allowed by the Code relative to the maximum window-wall ratio allowed by the supplement, the most stringent is used. Table 6.2.1, following, summarizes the building and energy model attributes that define this scenario.

The building envelope has been modelled based on three key attributes. The first is the use of THERM to calculate a two-dimensional assembly U-Value for each building envelope component and, in turn, use this in EQuest rather than using the layer-by-layer method. This better accounts for thermal bridges within the envelope design. The second is the treatment of the two abutting walls to the north and the south. A common practice is to model this surface as adiabatic with no heat transfer and is based on the assumption that the effect of the adjacent buildings is thermally balanced compared to an exposed building face. When using energy models for comparison purposes, as long as this is consistent, it has become an accepted practice. However, when creating a model to understand absolute heating and cooling loads, this method has been shown to be inaccurate. Using measurements of as-built conditions, Lowe, Wingfield, Bell, and Bell suggest that, when the space between zero property line walls is neither insulated nor sealed, the facade has a U_{si}-value 0.5 W/m^2-k, equivalent to an R_{si}-value of 2.0 k-m^2/W[4]. For the windows and curtainwall, double-glazed insulated glazing units with metal spacers are selected from the DOE Glazing Library and match the prescriptive requirements of the SB-10. These are set into aluminum frames. Finally, the surrounding urban context has been modelled using building shades. A view of the EQuest model is shown in Figure 6.25, above.

The cooling and heating systems have been specified as a through-wall air conditioner and electric baseboard heating. Outdoor Air ventilation rates match

Table 6.2.1: Scenario B1 Energy Model Inputs and Building Attributes		
Building Description		
Building Height	Total Height: 17.5m, Four Storeys Floor-to-Floor L01: 5.0m, L02-L04: 4.0m	
Building Area	2,135m^2 \ Floorplates: Approx 534m^2 each	
L01 Program Allocation	Retail Sales: 63.0% Conditioned Storage: 2.2% General Office: 8.7% Washroom: 1.5% Mechanical/Electrical: 2.0% Office Elevator Lobby: 3.8% Corridor: 18.8%	
L02-L04 Program Allocation	Open Office: 65.0% Conference Room: 8.4% Kitchen: 2.8% Washroom: 8.5% Mechanical/Electrical: 2.0% Office Elevator Lobby: 3.7% Corridor: 7.7% Print/Copy: 2.0%	
Site Coverage (FAR)	Site Area: 639.5m^2 / FAR: 3.3x	
Retail Plannable Gross Area[4]	384.8m^2	
Office Plannable Gross Area[4]	439.5m^2 / floor, 1,318.5m^2 total	
Building Envelope Attributes		
Exterior Wall - Typical (calculated with THERM)	W1: Charred Cedar / W2: Black Masonry	R: 18.4 / U: 0.0545 R_{si}: 3.23 / U_{si}: 0.31
Exterior Wall - Abutting Zero Property line Wall[5]	W3: Masonry, unsealed.	R: 11.4 / U: 0.088 R_{si}: 2.0 / U_{si}: 0.5
Roof (calculated with THERM)	R: Inverted, Intensive Green	R: 26.2 / U: 0.038 Rsi: 4.6 / Usi: 0.217
Glazing - Curtainwall	DOE Glass Library 6458: (Guardian SunGuard LE40/Clr-12.7mm Air/Clr 6mm Aluminium C/W Frame, Thermally Broken, Metal Spacer	Centre-Glass U_{si}: 1.87 Centre-Glass U: 0.33 SHGC: 0.37 VT: 0.67
Glazing - Ribbon/Punched	DOE Glass Library 6458: Guardian SunGuard LE40/Clr-12.7mm Air/Clr 6mm Aluminium Frame, Thermally Broken, Metal Spacer	Centre-Glass U_{si}: 1.87 Centre-Glass U: 0.33 SHGC: 0.37 VT: 0.67
Daylight Settings	Off - no daylight harvesting	
Window-Wall Ratio (WWR)	West (primary street frontage): 85% North (abutting building frontage): 0% East (rear laneway frontage): 42% South (abutting building frontage): 0%	Max Permitted: 40% Overall: 19%
Air-Tightness	0.04 cfm/ft^2	

Table 6.2.1 Continued: Scenario B1 Energy Model Inputs and Building Attributes		
HVAC Systems		
Hours of Operation	Retail-Monday to Saturday: 9am - 8pm, Sunday Closed Office-Monday to Friday: 8am - 7pm, Saturday/Sunday Closed Statutory Holidays Closed	
Temperature Set-Points	Cooling Setpoint: 24°C Heating Sepoint: 22°C	
Heating System	Modelled as Electric Baseboard to determine load. Proposed system: Natural Gas, COP of 0.85 applied to heating load, resulting converted to kBTU to calculate emissions. (Table 6.8.1E, ASHRAE 900.1-2007)	Load / COP = heating system demand
Cooling System	Modelled as PTAC Through-Wall A/C. COP of 3.0 applied to approximate system-wide efficiency. Converted to cooling EIR of 0.28025.	Load = Demand
Ventilation[6]	ASHRAE 62.1 Table 6.1: Ventilation Rates for Outdoor Air Retail: 0.25cfm/ft2 outdoor air (combined occupancy + area rate) Office: 0.11cfm/ft (combined occupancy+area rate) Airflow (general): 0.5cfm/ft2	
Heat Recovery	None	
Domestic Hot Water	Natural Gas	
Electrical, Plug Loads, and Lighting		
Lighting Loads[7]	SB-10 Table 4.3.3.4: LPD Using the Space-by-Space Method Retail Sales: 18 W/m^2 Storage: 9 W/m^2 Office/Open Office: 12 W/m^2 Washroom: 10 W/m^2 M/E: 16 W/m^2 Lobby: 14 W/m^2 Corridors: 5 W/m^2 Conference Room: 14 W/m^2 Kitchen: 13 W/m^2 Print/Copy: 14 W/m^2	
Equipment Loads[8]	SB-10 Table 5-4: Equipmennt Power Density Retail Level: 2.69 W/m^2 Office: 8.07 W/m^2	
Exterior Lighting	Not Considered	
Elevator[9]	Thyssen-Krupp hydrolic elevator with a 3500kg capacity and incandescent bulbs. Annual energy consumption estimate included in Auxiliary Loads.	4,205 ekWh/yr

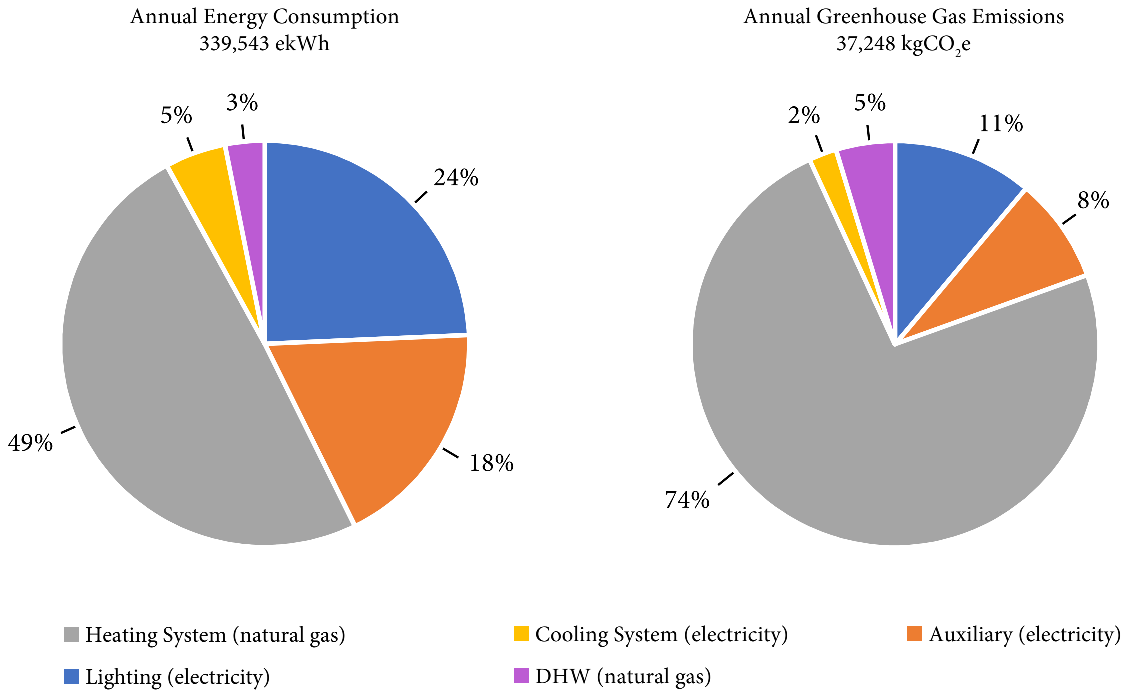


Fig. 6.27 (above)
Scenario B1 breakdown of annual energy consumption and greenhouse gas emissions.

ASHRAE Standard 62.1. This process generates a heating and cooling load in EQuest rather than a system energy consumption. A system Coefficient of Performance (COP) is then applied to these loads outside of the energy model to arrive at an approximate system energy consumption. The B1 scenario specifies natural gas as the fuel for both heating and domestic hot water while electricity is used for cooling and air-conditioning. This is representative of a packaged DX rooftop unit providing both heating with no heat recovery at a COP of 0.85 and cooling at a COP of 3.0. The lighting system meets the prescriptive requirements for Lighting Power Density (LPD) Space-by-Space method with no daylight harvesting systems. The model assumes an air-tightness of 0.04cfm/ft^2. Elevator energy consumption is added outside of the EQuest model and is based on a hydraulic, 3500kg capacity Thyssen-Krup with incandescent bulbs in the cab.

Scenario B1: Annual Energy and Emissions Predictions
The secondary energy consumption in ekWh and greenhouse gas emissions in kgCO_2e for the B1 baseline mid-block building are summarized in Table 6.2.2. The results suggest the annual energy consumption is 161,475 kWh of electricity and 559,490 kBTU of natural gas. This is equivalent to an EUI of 159.2 ekWh/m^2/yr when the fuel sources are combined. Figure 6.26, above, illustrates that, like the end-block scenarios, heating is by far the dominant load and represents 49% of the total energy use with cooling loads, representing a marginal 5% share. Lighting is the second-highest category and represents 24% of the annual total. This allocation of energy end-uses generally follow the historic measured data presented by Natural Resources Canada's Energy Use Data Handbook and is in-line with the prevailing climate where heating degree days significantly outnumber cooling degree days. Table 6.2.2, following, summarizes the results

Emissions Intensity (E_i) is calculated to be 17.4 kgCO_2e/m^2/yr. This suggests the mid-block scenario is essentially compliant with the 15.3 kgCO_2e/m^2/yr emissions budget suggested by the 2°C mitigation scenario. This calculation is based on the following consumer emission factor for Ontario:

- Electricity: 0.05 kgCO_2e/ekWh[10],
- Natural Gas: 0.164 kgCO_2e/ekWh[11].

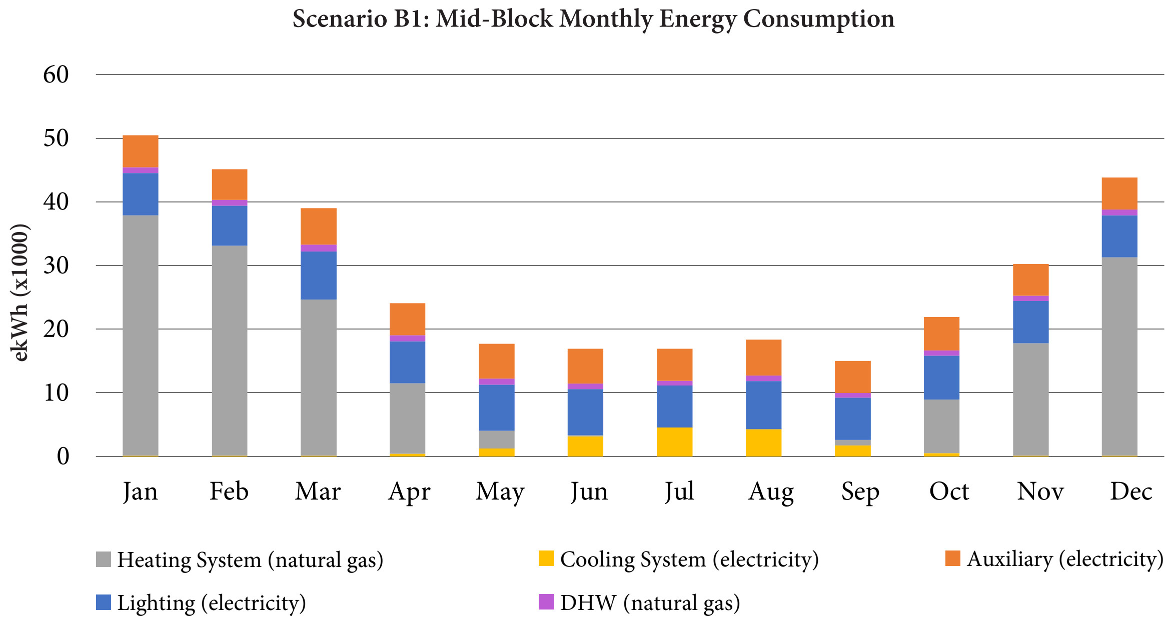


Fig. 6.28 (above)
Scenario B1 breakdown of monthly energy consumption and greenhouse gas emissions.

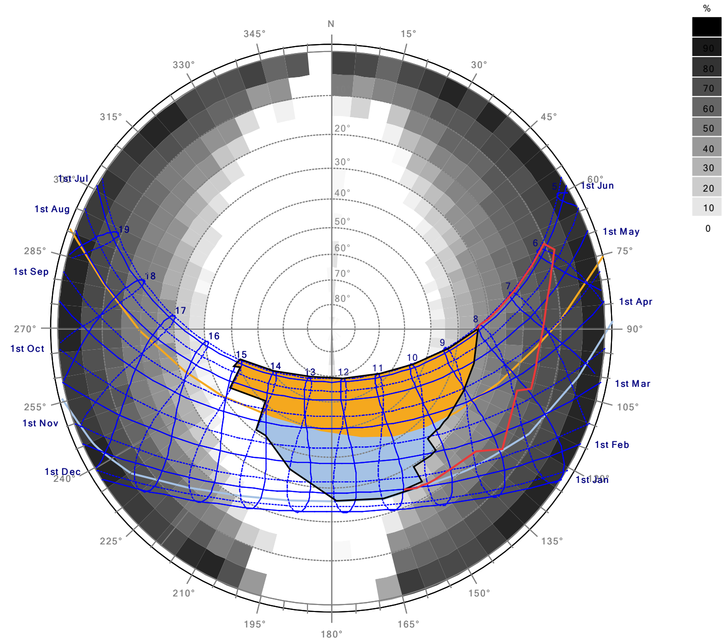
The energy use and emissions are lower compared to the end-block scenarios due to the significantly lower WWR and a minimal facade area that is fully exposed and subject to solar stress. Heating and lighting are the two highest energy use categories, representing 74% and 11% respectively, while cooling represents 3%. Although the relative allocation between energy use and emissions are the same, the fuel selection drives a change in the absolute ratios. In the case of heating load, the ratio grows from 49% to 74%, a similar ratio to the end-block conditions.

Table 6.2.2: Scenario B1 Energy and Emissions Summary

Category	Energy (ekWh)	Allocation	Emissions ($kgCO_2e$)	Allocation
Heating	167,482	49%	27,440	74%
Lighting	82,550	24%	4,218	11%
Auxiliary	62,515	18%	3,126	18%
Cooling	16,410	5%	1,734	2%
DHW	10,586	3%	821	5%
Total	339,543		37,248	
Intensity	159.0 $ekWh/m^2$		17.4 $kgCO_2e/m^2$	

Scenario B: Passive Assessment

Passive design to reduce heating, cooling, and lighting loads at the mid-block site are limited by the surrounding urban fabric more so than the end-block sites. Abutting buildings to the north and south preclude the most basic strategy of using a rectangular building shape with glazing facing south and limited glazing to the north. Considering that the heating load represents more than 50% of the building load and nearly 80% of the total emissions, this strategy would prove to be beneficial. With this site context and energy use profile in mind, a study of the overshadowing effects by the surrounding buildings, solar stress, and daylight availability will illustrate the passive opportunities.



Shading on fall and spring side of the summer equinox

Shading on fall side of summer equinox; sun required on the spring side of the summer equinox

Fig. 6.29 (above)
Scenario B east and west facade overshadowing created in Ecotect Analysis. Shading requirement overlay based on a balance-point temperature of 8.3°C and solar cutoff of 263.4 W/m². Process derived from Brown and DeKay, 2001.

Scenario B, Overshadowing + Shading:
One of the fundamental effects of a surrounding urban fabric on any particular building is with solar access. Site constraints limit orientation, contribute to overshadowing, and limit daylight access. In the case of a building where the heating load is dominant, impeded solar access on the most critical facades can significantly reduce passive design opportunities.

The B1 scenario sees building facades that are significantly overshadowed. The north and south exposures, are completely obstructed; the west exposure faces a street canyon of 20 metres in width and 17.5m in height; and finally the east facade is pulled back from the property line and has lower facing buildings for a more open condition. Using Ecotect Analysis, the average shading coefficient of the west facade, on an annual basis, is shown to be 38.1%. In the cooling season when shading is desired, it is slightly higher at 40.1%. In other words, 40.1% of the available solar radiation falling on the facade is blocked. The east facade is shaded to a lesser extent with the annual shading coefficient equal to 32.4% and 33.6% during the cooling season. The stereographic diagram above shows that this overshadowing does contribute to reducing the periods that should be covered by a shading device when the facade is overshadowed by more than 50%. In this case, the urban context helps to reduce the cooling load. However, in the heating season, it also contributes to a higher heating load. The overshadowing, on the west facade in particular, tends to happen at times of year and day when shading is not required. Table 6.1.4, below, summarizes the heating and cooling loads of the B1 Scenario with and without the urban context and suggests that the surrounding buildings create a higher total thermal load, with heating load increasing and cooling load decreasing. It can be concluded that the urban context does contribute to a comparable increase in loads by 26.2%.

Table 6.2.3: Impact of Surrounding Buildings on Annual Heating and Cooling Loads for the B1 Scenario in ekWh

	With Surrounding Buildings	Without Surrounding Buildings
Heating	167,482	148,564
Cooling	16,410	20,840
Total Thermal Loads	229,653	169,404

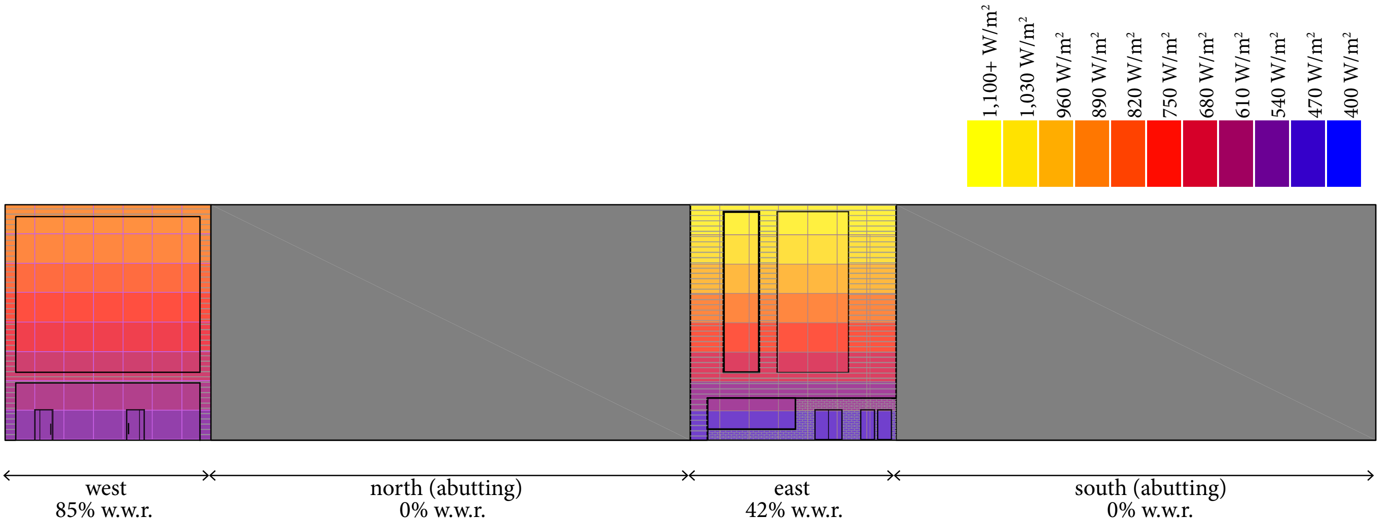
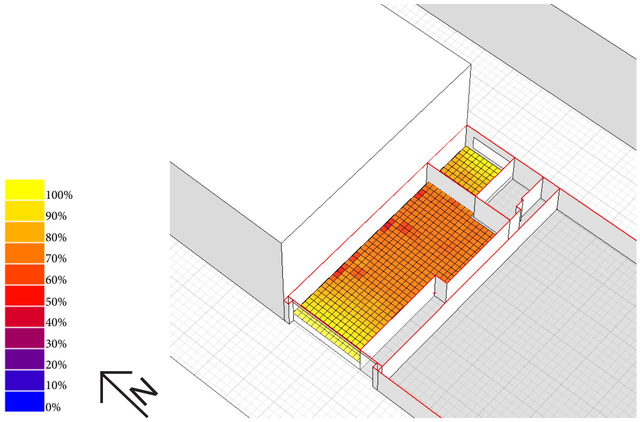


Fig. 6.30 (above)
Scenario B1 facade average daily insolation (Wh/m^2)
Calculated with Ecotect Analysis

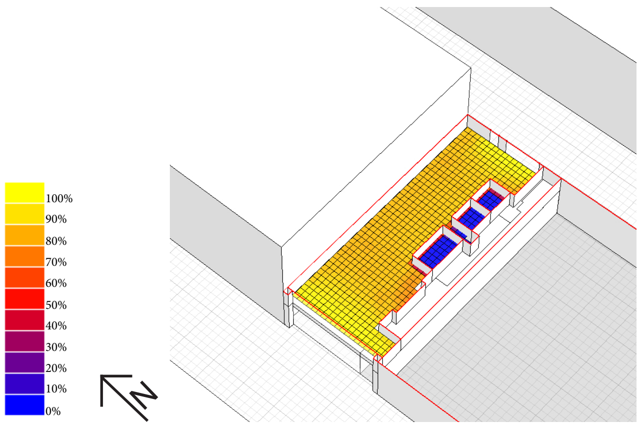
The overshadowing conditions require a careful study of solar angles to determine optimal shading. Figure 6.28 suggests that glazing on the west facade should be shaded between May 11th and August 15th using a vertical shading device that provides coverage from 12:00pm through 4:00pm. The cooling loads and overshadowing show that shoulder seasons do not need shading. Shading is not as critical towards the east except in the height of the summer cooling season between 9:30 and 11:00am. Overshadowing makes the most pronounced contribution, keeping the ground floor shaded nearly all the time early in the day. The south facade abuts an adjacent building and is not relevant in this scenario.

Scenario B, Solar Stress:
The average annual insolation striking the exposed facades is affected by the overshadowing of the surrounding buildings. Direct insolation, and the consequential solar stress leading to cooling load, is more limited. On the west facade in particular, the majority is diffuse rather than direct, leading to a relatively even distribution of solar energy across the facade and a lower solar stress than the east facade. This suggestion is supported by the heating and cooling load analysis presented in Table 6.1.3 where the overshadowing caused by nieghbouring buildings increases the heating load significantly. Figure 6.29, above, illustrates the distribution of direct and diffuse average daily insolation, on the two exposed facades.

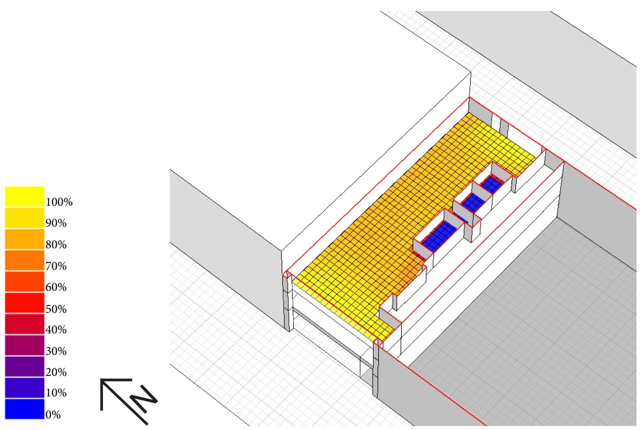
The west facade in the current code iteration is over 85% glazed. Across the entire facade, the average direct insolation does not exceed 200Wh/m^2 while the combined direct and indirect insolation ranges from 545Wh/m^2 at the ground level to 875Wh/m^2 along the top edge, reflecting the most and least overshadowed areas. The analysis suggests that glazing is a cooling liability and should be on the upper floors only. Solar gain and glare is limited as the facade is generally overshadowed from direct gain during the heating seasons and there are no "hotspots" where significant gain is expected. The east facade, on the other hand, is more exposed to direct insolation. The ground level is shaded nearly all the time while the upper floors are exposed can receive an average daily insolation in excess 1,000 Wh/m^2, creating a cooling liability. Glazing should be limited on the uppermost floor to avoid summer overheating or be shaded. In all cases, glazing should be optimized for daylighting and view only as direct solar gain is limited and is, in general, a heating liability for most of the year,



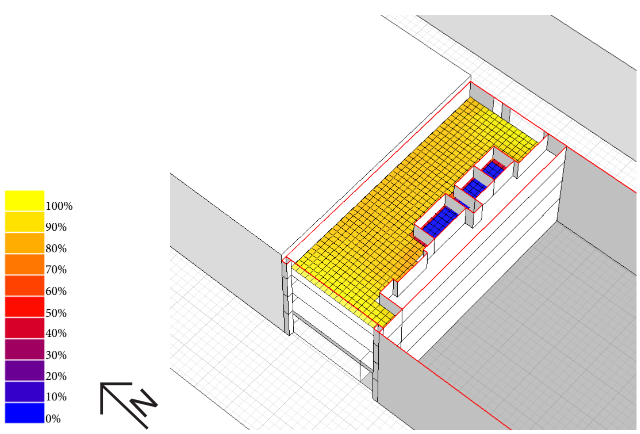
Ground



Level 02



Level 03



Level 04

Fig. 6.31 (left)
Scenario B floor-by-floor daylight autonomy based on 300lux at 762mm above the floor,
calculated in Ecotect Analysis

Scenario B, Daylight Availability:
Although the rectangular building floorplate and floor-to-floor heights are conducive to good daylighting, the abutting buildings against the north and south long facades mean there is limited daylight availability in a majority of the usable floor area. 100% daylight autonomy is possible within 4.0m of the east and west facades while the bulk of the floorplate sees less than 150lux, half of the minimum lighting level. The west facade's glazed envelope combines with the overshadowing of the surrounding buildings to create a daylighting condition similar to the north, where diffuse daylight is predominant and direct insolation and glare is limited. The depth of the daylit space is not equal to two times the height of the glazing, the rule of thumb for daylight penetration, suggesting the significant impact of the surrounding buildings. A similar condition can be found along the east facade. Here, the pattern of punched openings rather than a continuous curtainwall creates zones with less daylight adjacent to the facade.

The mid-block condition demonstrates a more substantial sensitivity to the street canyon compared to the end blocks. Figure 6.30, at left, suggests that the ground level receives significantly less daylight than the upper floor. Of the retail sales floor, 14% receives an annual average of 300lux at 762mm above the finished floor between 80% and 100% of the time. Of the open office space on the fourth level, the topmost floor, 37% receives 300lux at 762mm above the finished floor. The results suggest that daylight autonomy would be challenging to achieve with glazing available to only the short sides of the building. Four options exist to increase the effectiveness of daylight penetration. The first is a re-organization of the floor plan to place the service areas in the centre of the floorplate rather than along the south side would allow more of the regularly occupied spaces to front onto an exposed facade. Secondly, skylights could be considered for the topmost floor if the heating and cooling penalty were balanced, but the lower three floors would not be affected. A daylight shaft could be considered along one of the long facades to provide daylight to the office floors is a third option. It is important to note that, to provide daylight, the leasable floor area would be reduced by over 25% per floor and should, therefore, be considered only if other measures do not achieve the energy and emission reduction targets. Finally, light-shelves could be considered to increase daylight penetration and reduce glare immediately at the facade.

The passive analysis of Scenario B suggests opportunities to lower building loads and illustrates the constraints and challenges presented by the surrounding buildings. The urban fabric impedes the solar envelope in a significant way, driving a higher heating load and a slightly reduced cooling load that, together, generate a higher overall energy demand. The overshadowing is not always protecting the building at the right times, as a purpose-built shading device might. Therefore, during the cooling season, some shading can be added to the west and east facades to reduce solar gain during specific times of year. A re-organization of the floor plan and use of light shelves could increase daylight penetration while glazing distribution can also be adjusted by level as the available daylight on lower floors does not justify over-glazing. With the heating load predominant, sacrificing some daylight autonomy for a more solid envelope will have a more significant overall impact on reducing heating and cooling loads.

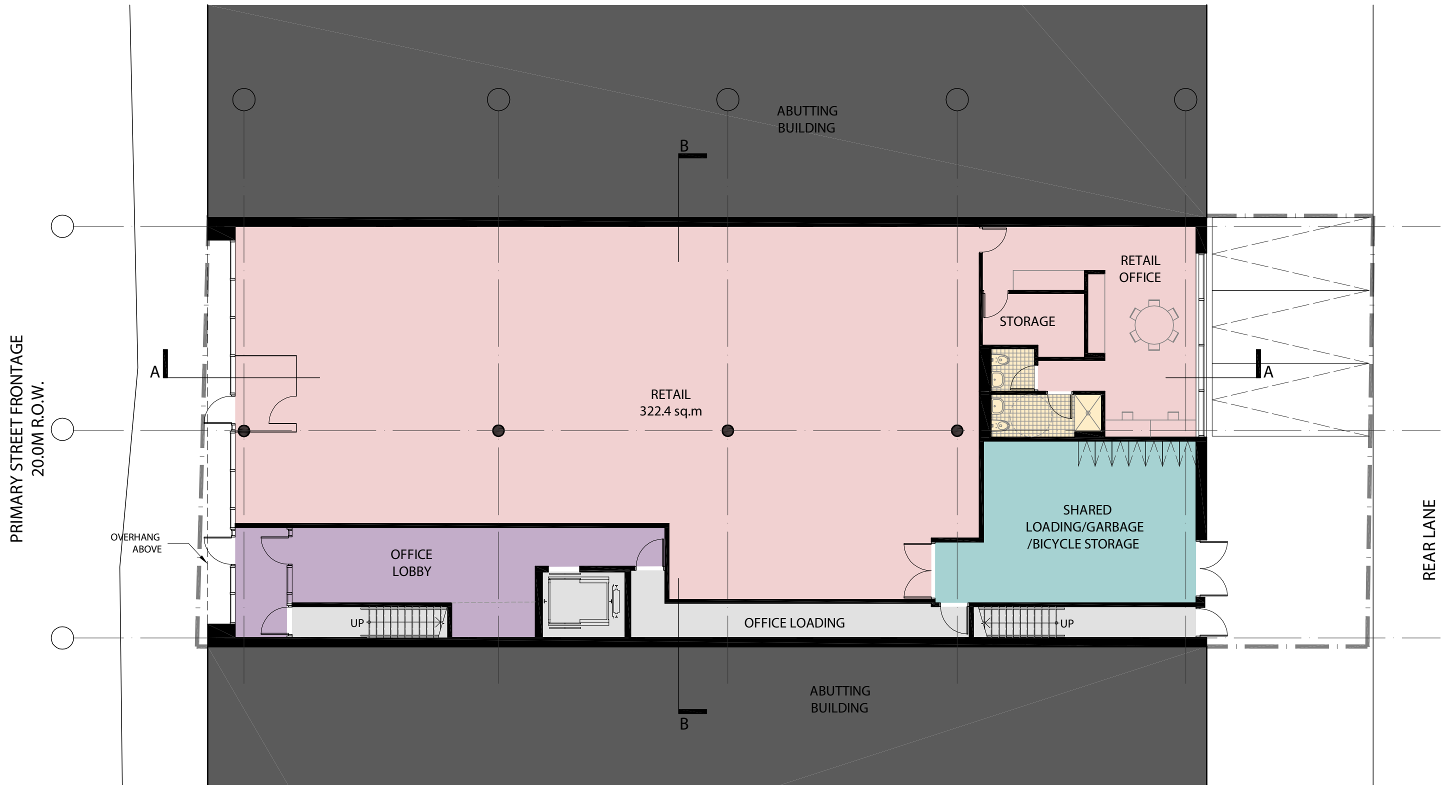


Fig. 6.32 (above)
Ground Floor Plan, Scenario B2

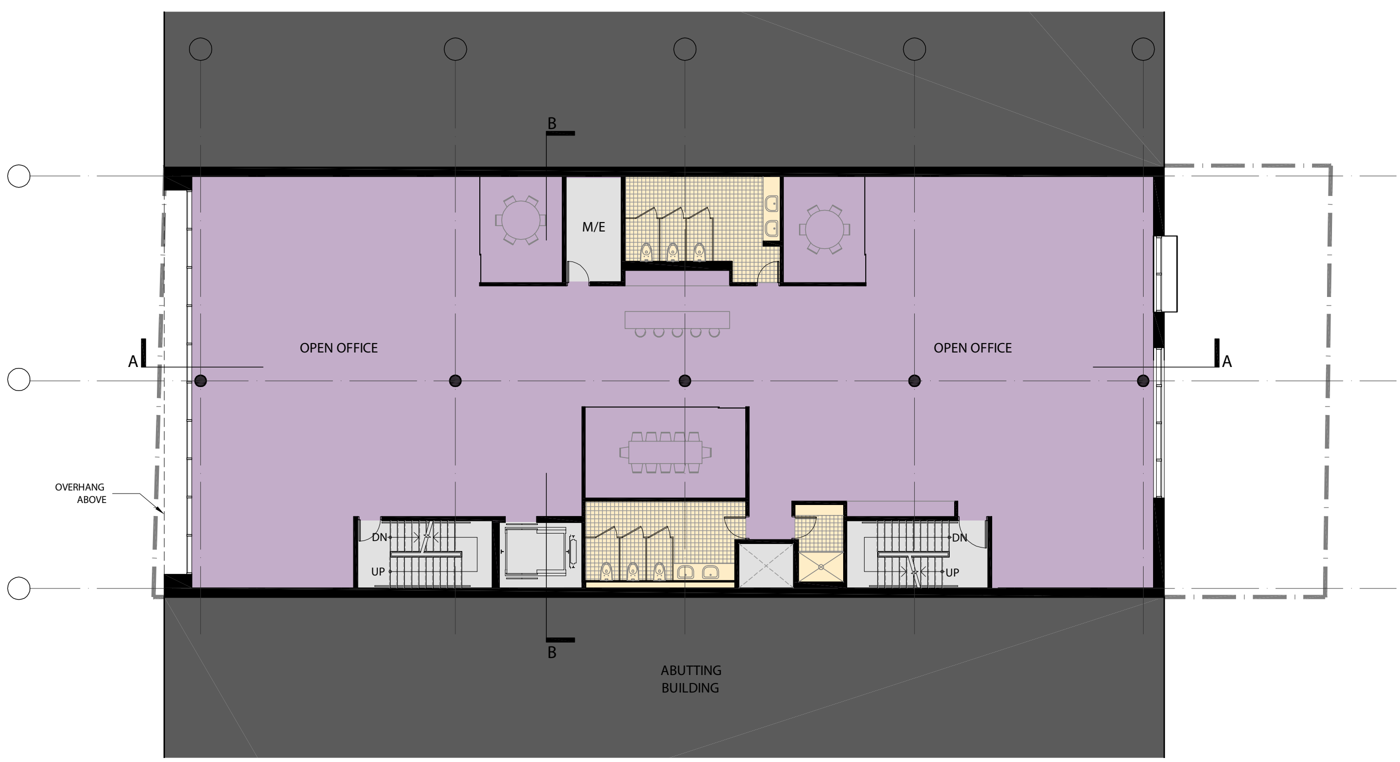


Fig. 6.33 (above)
Typical Upper Floor Plan (Levels 02-04), Scenario B2

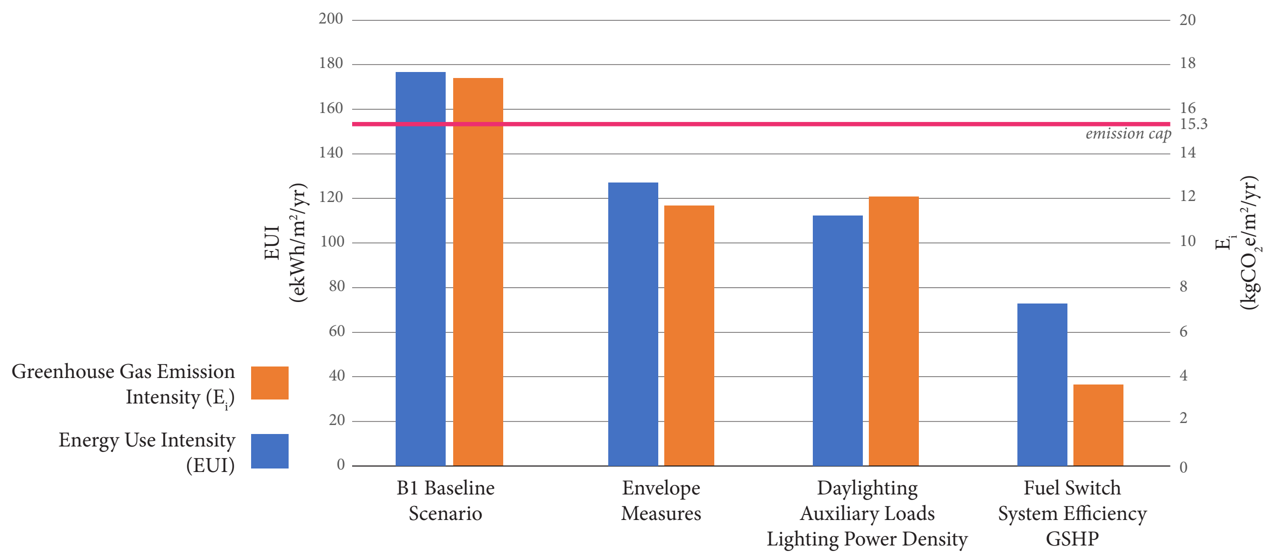


Fig. 6.34 (above)
B2 Scenario energy and emission reductions by category

<u>Scenario B2: 2°C Mitigation Scenario</u>
The annual emissions intensity (E_i) of the mid-block block scenario is 17.4 kgCO$_2$e/m^2/yr, 12% higher than the 15.3 kgCO$_2$e/m^2/yr budget suggested by the 2°C mitigation scenario. This can be reduced by addressing both the energy consumption and the emissions intensity of fuel sources used. A study of each of these two aspects of the emissions equation suggests that each can independently achieve the target and that a project has a suite of options available.

The approach taken to reducing energy and greenhouse gas emissions is based on the recommended design process for high performance buildings where energy loads are first reduced through passive design and then met using high-efficiency systems. Nine energy reducing measures are incrementally applied to the B1 Baseline Scenario and can be grouped into the following three categories. The first is comprised of four measures that improve the performance of the building envelope and re-arrange the the floorplan. The second passively reduces internal loads by incorporating high-performance lighting technology, daylight harvesting, and reduced plug-loads that represent low-consumption equipment and appliances. The third and final category incorporates fuel switching to lower emitting energy sources in conjunction with high efficiency mechanical systems. The cumulative effect of these measures suggests that achieving the emissions cap of the 2°C scenario is possible without on-site renewable energy sources and with technologies that are both proven and readily available. Table 6.2.4, following, summarizes the building attributes with all measures applied.

Scenario B2, Category 1- Building Envelope Measures:
Three measures are applied to the B1 baseline scenario to reduce heating and cooling loads driven by the building envelope. This includes re-arranging the floorplan to increase the area of regularly occupied floor area adjacent to exposed building faces. Unlike the north and south end-block scenarios, the window-wall ratio of 19% is exceptionally low. Daylight simulations showed that daylight penetration was viable but that a further reduction in glazing would make daylight harvesting a challenge and reduce the available view for occupants.

The energy model suggest that the building envelope and plan measures together reduce EUI by 20%, from 159.0 ekWh/m^2/yr to 127.2 ekWh/m^2/yr. Emissions could be reduced by 32.9% from 17.4 kgCO$_2$e/m^2/yr to 11.7 kgCO$_2$e/m^2/yr and, thus achieve the 2°C scenario. The difference in relative impact of energy consumption and emissions, although less than the end-block scenarios, illustrates the impact

Table 6.2.4: Scenario B2 Energy Model Inputs and Building Attributes		
Building Description		
Building Height	Total Height: 17.5m, Four Storeys Floor-to-Floor L01: 5.0m, L02-L04: 4.0m	
Building Area	2,135m^2 \ Floorplates: Approx 534m^2 each	
L01 Program Allocation	Retail Sales: 59.8% Conditioned Storage: 10.9% General Office: 8.7% Washroom: 2.0% Mechanical/Electrical: 2.0% Office Elevator Lobby: 8.2% Corridor: 8.4%	
L02-L04 Program Allocation	Open Office: 68.9% Conference Room: 8.3% Kitchen: 2.8% Washroom: 8.5% Mechanical/Electrical: 2.6% Office Elevator Lobby: 0.0% Corridor: 6.9% Print/Copy: 2.0%	
Site Coverage (FAR)	Site Area: 639.5m^2 / FAR: 3.3x	
Retail Plannable Gross Area[4]	364.9m^2	
Office Plannable Gross Area[4]	452.3m^2 / floor, 1,356.9m^2 total	
Building Envelope Attributes		
Exterior Wall - Typical (calculated with THERM)	W1A: Charcoal Cementitious Panel W2A: Black Masonry	R: 23.8 / U: 0.042 R_{si}: 4.19 / U_{si}: 0.24
Exterior Wall - Abutting Zero Property line Wall[5]	W3A: CMU, sealed and insulated	R: 28.6 / U: 0.035 R_{si}: 5.04 / U_{si}: 0.20
Roof (calculated with THERM)	R1A: Inverted, Intensive Green	R: 45.5 / U: 0.022 Rsi: 8.0 / Usi: 0.125
Glazing - Curtainwall	DOE Glass Library 3652: (Triple Low-E Film (77) Clear) Aluminium C/W Frame, Thermally Broken, Insulating Spacer	Centre-Glass U_{si}: 1.25 Centre-Glass U: 0.22 SHGC: 0.47 VT: 0.64
Glazing - Ribbon/Punched	DOE Glass Library 3652: (Triple Low-E Film (77) Clear) Aluminium C/W Frame, Thermally Broken, Insulating Spacer	Centre-Glass U_{si}: 1.25 Centre-Glass U: 0.22 SHGC: 0.47 VT: 0.64
Daylight Settings	On -Continuous Dimming, 5% increments	
Window-Wall Ratio (WWR)	West (primary street frontage): 85% North (abutting building frontage): 0% East (rear laneway frontage): 42% South (abutting building frontage): 0%	Max Permitted: 40% Overall: 19%
Air-Tightness	0.04 cfm/ft^2	

Table 6.2.4 Continued: Scenario B2 Energy Model Inputs and Building Attributes		
HVAC Systems		
Hours of Operation	Retail-Monday to Saturday: 9am - 8pm, Sunday Closed Office-Monday to Friday: 8am - 7pm, Saturday/Sunday Closed Statutory Holidays Closed	
Temperature Set-Points	Cooling Setpoint: 24°C Heating Sepoint: 22°C	
Heating System	Modelled as Electric Baseboard to determine load. Proposed system: Electric Ground Source Heat Pump, COP of 2.8 applied to heating load.	Load / COP = heating system demand
Cooling System	Modelled as PTAC Through-Wall A/C. COP of 4.0 applied to approximate system-wide efficiency. Converted to cooling EIR of 0.2175.	Load = Demand
Ventilation[6]	ASHRAE 62.1 Table 6.1: Ventilation Rates for Outdoor Air Retail: 0.25cfm/ft2 outdoor air (combined occupancy + area rate) Office: 0.11cfm/ft (combined occupancy+area rate) Airflow (general): 0.5cfm/ft2	
Heat Recovery	Applied; contributions taken into account with system COP	
Domestic Hot Water	Electric	
Electrical, Plug Loads, and Lighting		
Lighting Loads[7]	ASHRAE Advanced Energy Design Guideline Retail and Office Retail Floor (L01): 0.98 W/m^2 Office Floors (L02-L04): 0.75 W/m^2	
Equipment Loads[8]	SB-10 Table 5-4: Equipmennt Power Density reduced 25% Retail Level: 1.92 W/m^2 Office: 6.06 W/m^2	
Exterior Lighting	Not Considered	
Elevator[9]	Thyssen-Krupp regenerative elevator with a 3500kg capacity and LED bulbs. Annual energy consumption estimate included in Auxiliary Loads.	1,360 ekWh/yr

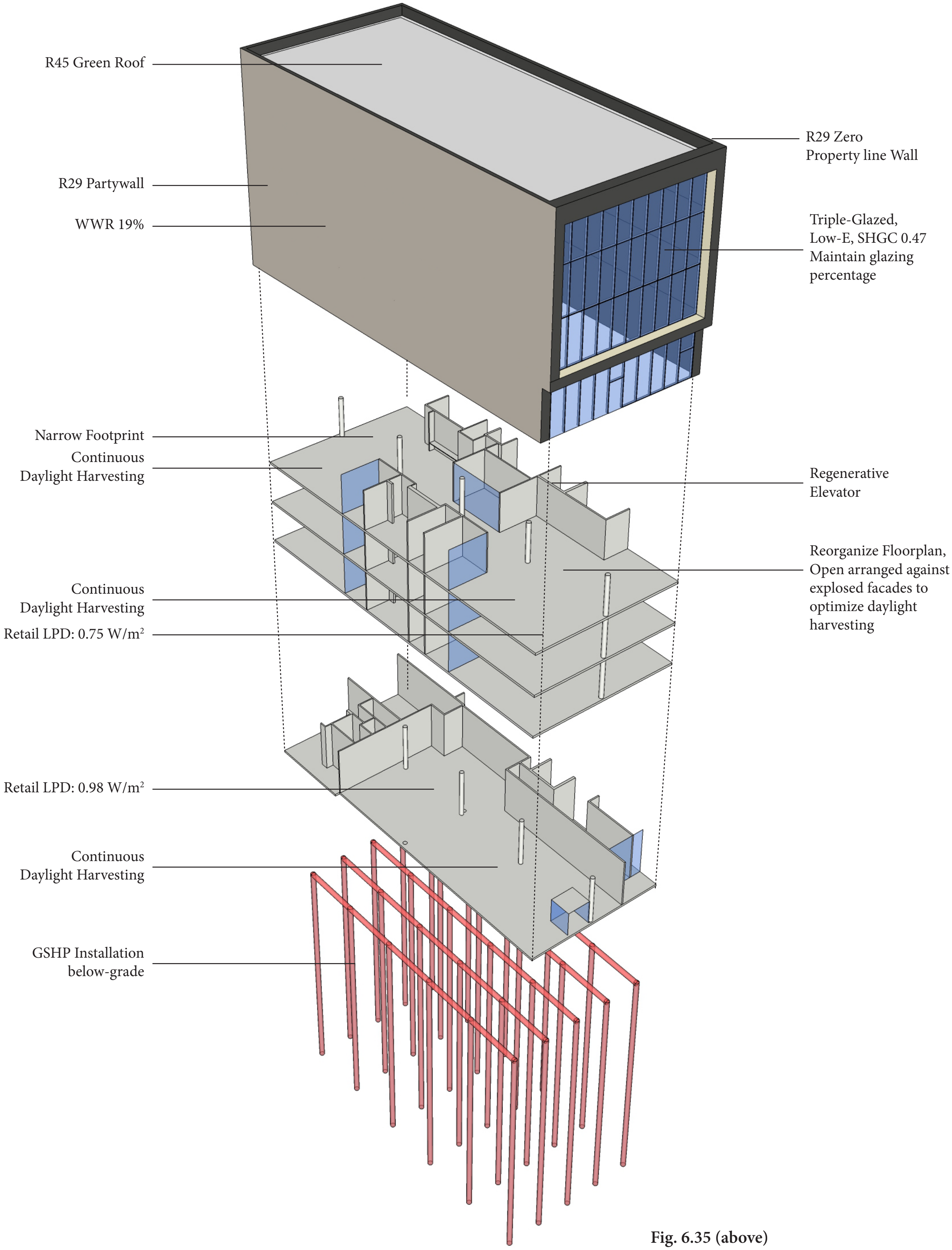
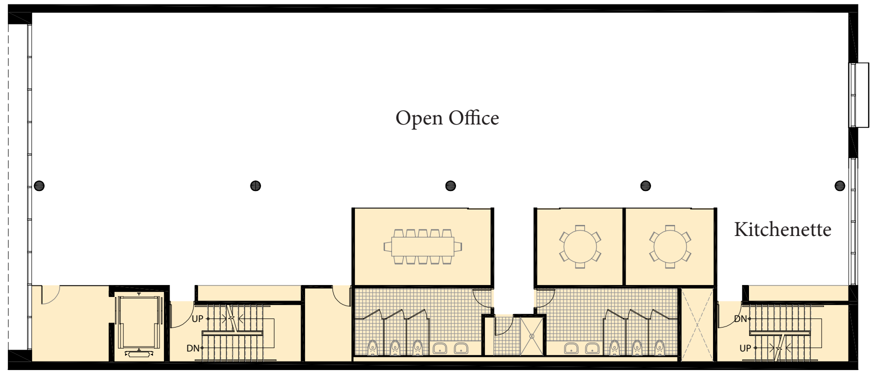
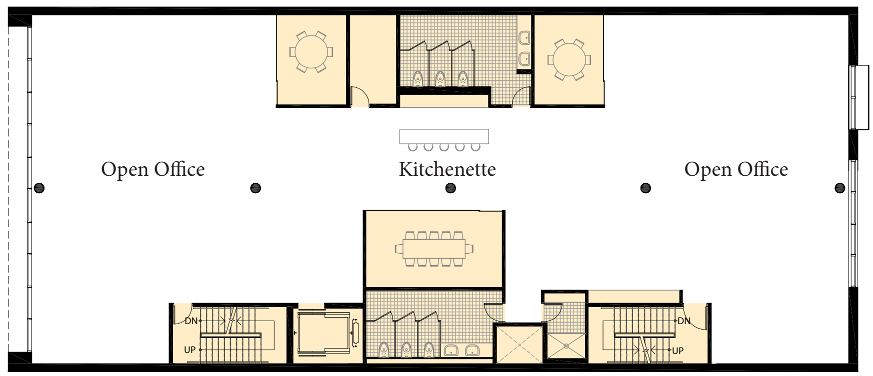


Fig. 6.35 (above)
Scenario B2 Measures Diagram



B1 Baseline Scenario: Typical Plan



B2 2°C Scenario: Typical Plan

Fig. 6.36 (above)
B1 and B2 Scenario Levels 02-04 Typical Plans

of fuel choice. In this case, the envelope measures reduce heating load somewhat more than cooling load. Natural gas is the fuel choice for heating and the system's Coefficient of Performance (COP) of 0.85 while the cooling system is electric and is much more efficient with a COP of 3.0. Therefore, reducing heating energy consumption will have a larger emissions reduction per equivalent kilowatt-hour compared to cooling. Additional incremental improvements to these measures could further improve energy efficiency and emissions to move towards a net-zero or carbon-neutral state.

Fixed shading for the west facade was investigated but did not yield overall energy savings, similar to the north facing end-block scenario. The modelling suggests that shading devices sized for the cooling dominant season also blocked solar gains for the heating season such that the heating load increased more than the cooling load decreased. This is also likely due to the overshadowing effects of the surrounding buildings and the overall lack of solar exposure with abutting buildings on the two long faces. This does suggest, however; that a dynamic shading device or thermochromatic glazing would have an effect on reducing cooling loads as they could be deployed only when needed at specific times of day. The modelling of these effects is complicated and, given that the measures selected are suggested to exceed the 2°C Scenario, could be useful to further reduce energy consumption to help achieve net-zero or carbon-neutral performance.

Scenario B2, Envelope Measure 1 - Floor Plan and HVAC Zoning Re-Arrangement: The arrangement of the floor plan in the B1 baseline scenario follows the north and south end-blocks where services are arranged along one of the blank facades adjacent to an abutting building. For the mid-block site, this is not optimized for daylight harvesting or optimizing views to the outside for occupants. The floorplan is re-arranged on the upper office floors to create two open-office spaces facing the east and west exposed facades, increasing the area of regularly occupied space within the daylit zone. Services, conference rooms, circulation and staff spaces are arranged in the centre of the floorplate. The change to the floorplate adjusts the zoning of the HVAC system to better reflect the conditioning requirements of this new arrangement. A perimeter zone extends the width of the floorplate to a depth of 9.0m on each of the east and west faces while the centre are is considered a core zone. This configuration is illustrated in Figures 6.31 and 6.32, previous.

A floorplate that is more appropriate to the site condition, and the associated changes to HVAC zoning, reduces energy consumption by 3.6% and emissions by 6.2%. The heating load is reduced to a larger degree than the cooling load. The higher emissions intensity associated with heating load results in a larger reduction in emissions relative to the reduction in energy consumption.

Scenario B2, Envelope Measure 2 - Reduce Thermal Transmittance of the Building Envelope:
The second measure increases the R-values of both the roof and exterior walls and increases the performance of the glazing system. The thermal resistance of the exterior walls with east and west exposure is increased by 22%, from R18.4 to R23.8. The cavity wall is increased from 92mm to 152mm and filled with polyurethane foam insulation while the 50mm of continuous expanded polystyrene insulation remains. The abutting north and south walls are sealed and continuously insulated at the exposing ends, increasing the equivalent R-value from R11.4 to R28.6[15]. The roof R-value increases 33%, from R26.2 to R45.5, by nearly doubling the thickness of the polyisocyanurate insulation from 112mm to 200mm. The double-glazed Low-E coated insulated glazing units (IGU) in the baseline scenario are replaced with triple-glazed Low-E coated units and the highly conductive metal spacers are upgraded to insulating spacers. The Centre-Glass U-Value decreases from 0.33 to 0.22. These measures have a significant impact in energy and emissions reduction. Energy is reduced by a further 15.9% and results in an EUI of 128.0 ekWh/m^2/yr. Emissions are reduced a further 25.4% to 11.9 kgCO$_2$e/m^2/yr. Similar to the re-arranging the floorplan, heating load is reduced to a larger extent than cooling load and results in a larger relative reduction in emissions compared to energy use.

The first two envelope measures also effect leasable area[4]. The thicker building envelope and re-arrangement of the plan reduces it by more than 1%, from 1,721.8m^2 to 1,703.3m^2. The reduction is approximately double the value on either end-block site.

Scenario B2, Envelope Measure 3 - Increase Glazing SHGC from 0.36 to 0.47
The solar heat gain coefficient of the triple-glazed IGUs is increased from 0.36 to 0.47. This measure was studied separately from the general envelope improvements to test the impact. The model suggests that, because the heating load represents 49% of the total annual heating load and is the largest end-use, the reduction of heating load by increasing the SHGC is more than the associated increase in cooling load. The overall EUI drops from 128.0 ekWh/m^2/yr to 127.2 ekWh/m^2/yr when this measure is applied to to the triple-glazed units. Furthermore, when natural gas is used as a fuel source, heating load has a higher emissions intensity than the cooling load that is met using electricity in the regional context of this study. The mid-block site has a relatively low sensitivity to solar gain because of the extent of

overshadowing by surrounding buildings and the substantial area that is abutting adjacent buildings. Therefore, internal loads have a more substantial effect than envelope loads and, given that the heating load is dominant, will contibute more to offsetting it than the consequential rise in cooling load. When lighting and equipment loads are reduced in subsequent measures, heat gain will be beneficial as the internal loads contributing to heat gain will be further reduced.

This may not always be the case. Most of the case studies in Chapter 5, with the exception of the EpiCentre building, have a lower SHGC, suggesting avoiding heat gain is preferred. In a situation where the WWR is higher, this could be the case. However, modelling results suggest a higher SHGC is more beneficial in this case.

Scenario B2, Category 2- Internal Load Measures:
The internal load category applies three strategies to the envelope measures that increase the energy efficiency of non-mechanical system loads. In some cases, such as daylight harvesting, this includes passive design. Reducing the energy consumption of these end-uses does have an effect on heating and cooling load and is why these measures are investigated separately from the mechanical systems. Energy consumption is reduced by a further 9.4% beyond the building envelope measures and the EUI is reduced to 112.3 ekWh/m^2/yr. However, emissions increase by 0.4 kgCO$_2$e/m^2/yr above the threshold achieved by the building envelope measure to 12.1 kgCO$_2$e/m^2/yr. Nevertheless, emissions are still 21% lower than the 2°C emissions cap. The heating load required during colder months is not offset to the same degree as less heat is generated by lights, appliances, computers and other auxiliary equipment. Given that the heating season is so much longer and more significant that the cooling season, heating load increases more than cooling load is decreased. With the higher emissions intensity associated with the natural gas system used to provide heat, 0.164 kgCO$_2$e/ekWh versus 0.05 kgCO$_2$e/ekWh for electricity used by the cooling system, the emission savings from lower plug and lighting loads are offset even though overall energy use decreases. It should be noted that if electricity was the fuel source for heating, the emissions decrease rather than increase. This demonstrates the interconnected relationship of building loads, system selection and performance, and fuel selection when energy consumption and greenhouse gas emissions are considered together.

Scenario B2, Internal Load Measure 1 - Reduce Lighting Power Density
The ASHRAE Advanced Energy Design Guidelines for retail and office spaces suggest a suite of technologies and design practices to achieve a 50% reduction in energy consumption. This guideline includes a Lighting Power Density (LPD) recommendation of 0.98 W/m^2 for retail uses and 0.75W/m^2 for office uses. These numbers take into account all program types within a typical retail or office building, such as washrooms and support spaces, and are applied to the entire floor area of the primary occupancy of each respective floor. The reduced LPD is the product of a combination of different technologies including high-efficiency lighting equipment, occupancy sensors, and design techniques to reduce the overall number of fixtures required are considered[16,17]. Compared to the B1 baseline scenario, retail LPD is reduced by 29% and office LPD is reduced by 30%. In total, the annual energy requirement for lighting drops from 82,110 eKwh to 57,760 ekWh, equivalent to an overall reduction of 29.6%.

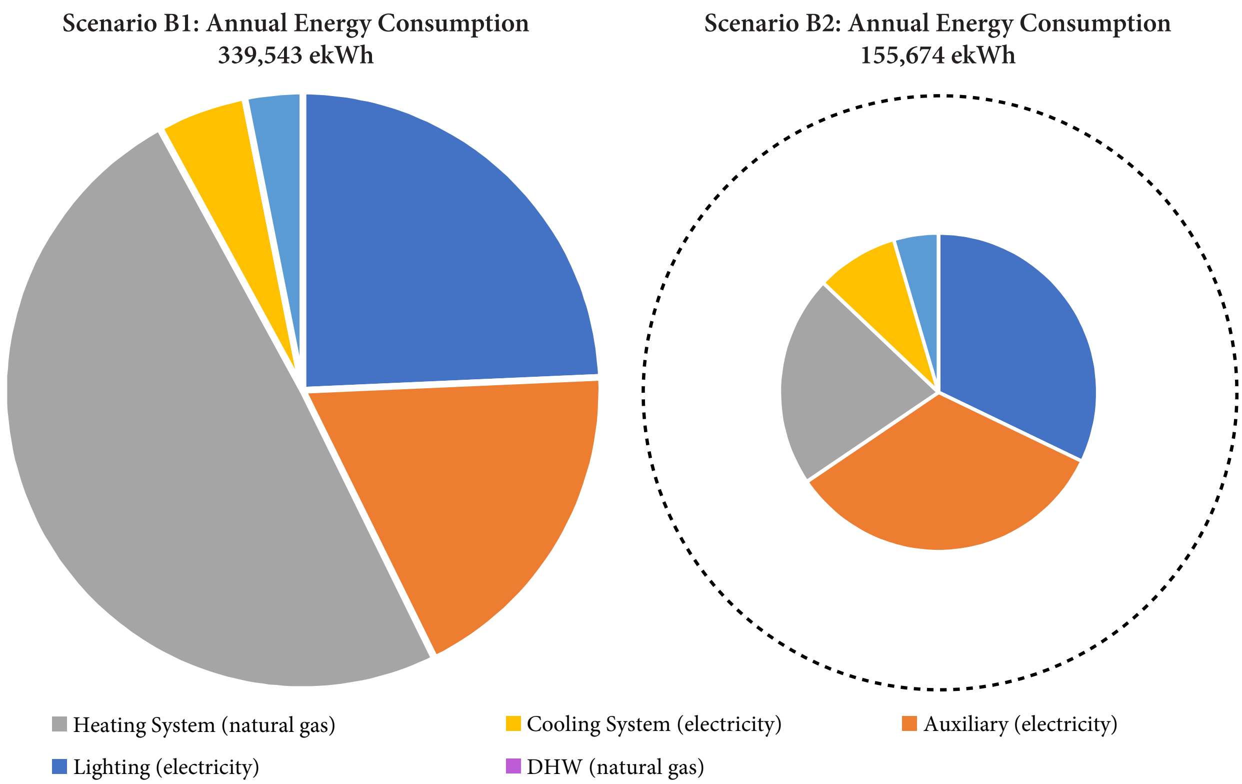


Fig. 6.37 (above)
Annual Energy Consumption Comparison of B1 Baseline and B2 2°C Mitigation Scenarios

Scenario B2, Internal Load Measure 2 - Introduce Daylight Harvesting:
Daylight harvesting is introduced as a key measure. A daylight autonomy simulation of the B2 scenario suggests that between 240 and 270 lux can be achieved in most regularly occupied spaces on an annual basis, with 300lux and above achieved within 5.0m on the lower office floors and 8.0m on the top office floor of the east and west facades. The re-organized floorplan allows a greater area of regularly occupied space within the daylit zone of between 5.0 and 8.0m of the facade compared to the B1 floorplan. The ground floor still achieves some of daylight autonomy with the overshadowing of the surrounding urban context having a substantial impact. 300 lux can be achieved within 4.0m of the west facade while a majority of the sales floor receives between 150 and 210 lux. A continuous dimming system with a 5% increment is specified throughout. Energy for lighting can be reduced by 13%, from 57,760 ekWh to 50,020 ekWh.

Scenario B2, Internal Load Measure 3 - Reduce Plug Loads and Elevator:
The NREL Assessment of the Technical Potential for Achieving Net-Zero Energy Buildings in the Commercial Sector[19] suggests that plug loads can be reduced by 25% and the Advanced Energy Design Guidelines for office buildings produced by ASHRAE[20] suggest that plug and equipment loads can be reduced by up to 33% in office spaces. With the proliferation of electronic devices, this load component is expected to continue to increase[21]. In the B2 scenario, plug and auxiliary loads in are reduced by 25%, following the recommendations in the NREL study. This is achieved by specifying best-in-class Energy Star office equipment, limiting personal printing devices, and implementing measures and providing shut-offs to reduce or eliminate parasitic loads during unoccupied hours. In retail spaces,

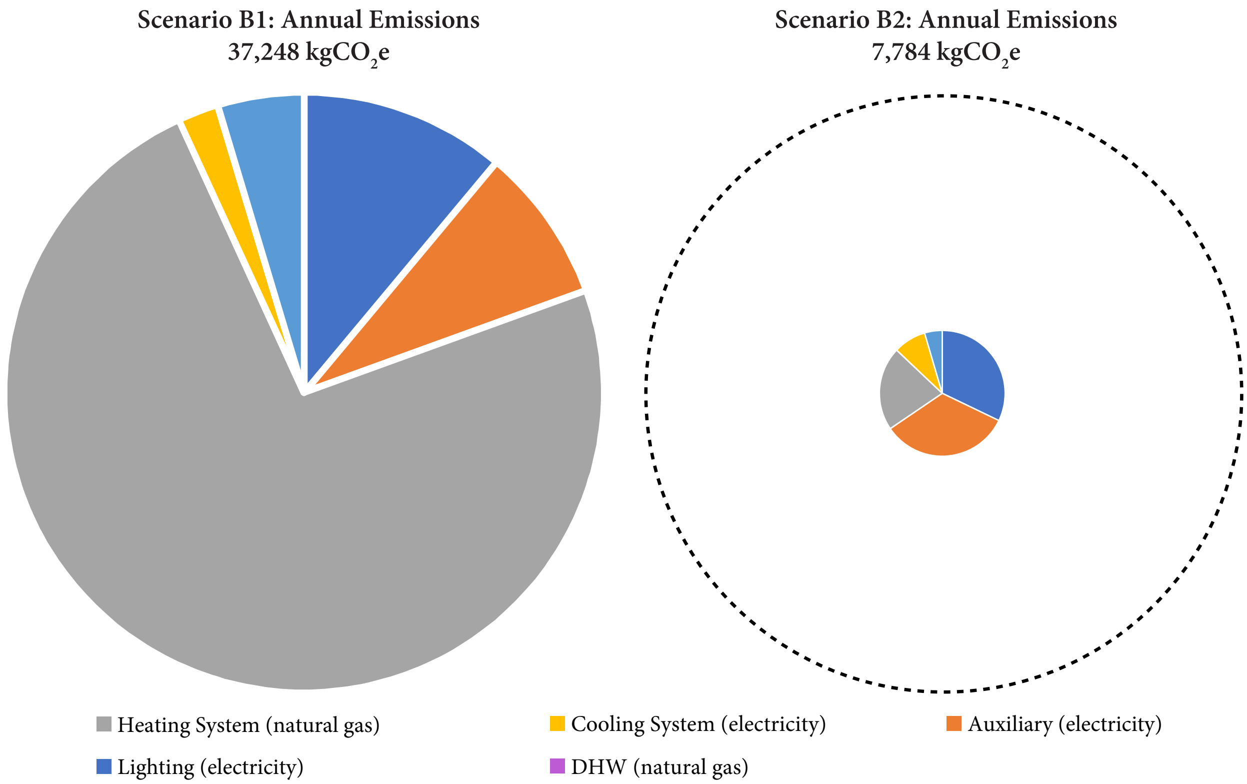


Fig. 6.38 (above)
Annual Emissions Comparison of B1 Baseline and B2 2°C Mitigation Scenarios

this would include requiring retail displays on the sales floor to meet the reduced plug-load standard, third-party installations in particular, and the use of LED over neon or other technologies for signage. The plug loads would be reduced to 1.91 W/m^2 in the Level 01 retail occupancy and 6.05 W/m^2 for the office occupancy on Levels 02 through 04. The energy efficiency of the elevator is also improved. The more typical cable system is replaced with a regenerative elevator and LED lighting in the cab, reducing the annual energy consumption by 68%, from 4,205 ekWh to 1,360 eKwh.

Scenario B2, Category 3 - Fuel Switch and System Efficiency:
The third category of measures increases the mechanical system efficiencies, changes the system types, and introduces a fuel switch to an all-electric building. With the heating, cooling, and internal loads optimized through envelope measures, daylight harvesting, and efficient equipment, the mechanical system has a much lower load to meet compared to the B1 baseline scenario. The following measures reduce not only the total amount of energy required to satisfy building loads, but replacing natural gas with electricity for heating and domestic hot water reduces the emission intensity (E_i) by over 70%, from 0.164 kgCO$_2$e/ekWh to 0.05 kgCO$_2$e/ekWh. With the heating load by far the dominant energy end-use in both the B1 Baseline and B2 Mitigation scenarios, the potential to reduce emissions through fuel switching is substantial. When all three measures in this category are implemented, the model suggests the B2 scenario achieves an EUI of 72.9 ekWh/m^2/yr, a reduction of 54.2%. The emissions intensity of 3.6 kgCO$_2$e/m^2/yr is 79.1% lower than the B1 baseline and exceeds the 2°C Mitigation cap of 15.3 kg/m^2/yr.

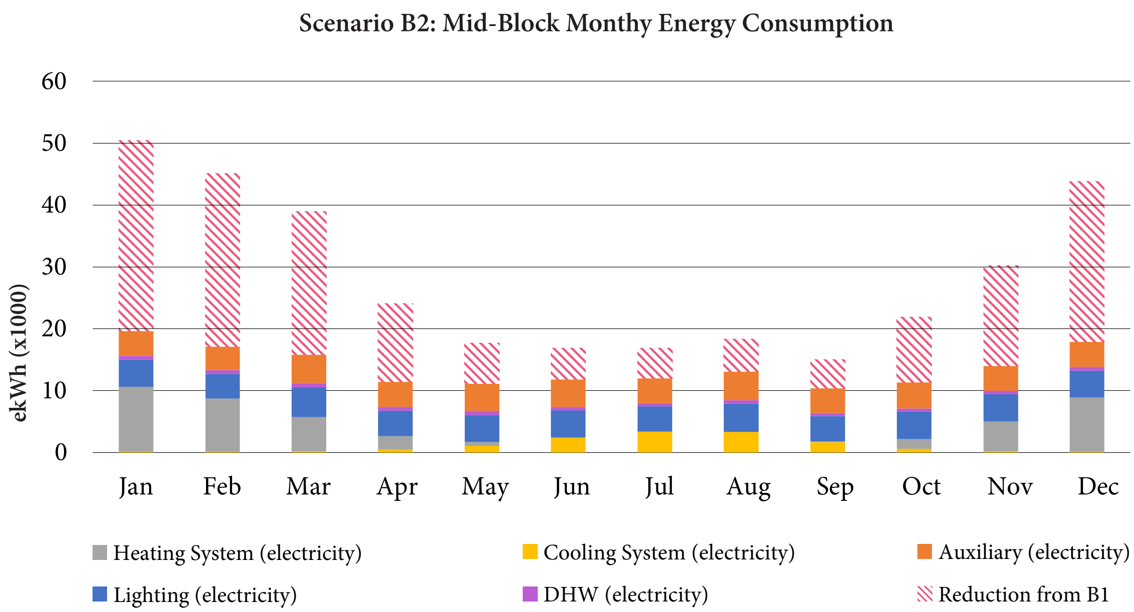


Fig. 6.39 (above)
Monthly Energy Consumption and Breakdown of the B2 2°C Mitigation Scenario

Scenario B2, Fuel Switch and System Efficiency 1 - Fuel Switch to Electric Heating: The B1 baseline scenario specifies a natural gas combustion heating system with a coefficient of performance (COP) of 0.85 and an electric cooling system with a COP of 2.0. These approximate a high-quality system based on current standards and seasonal performance. The B2 scenario replaces the natural gas system and specifies a unitary electric heating and cooling rooftop unit with integrated heat recovery. This change has two positive effects. First, the heating system COP increases dramatically from 0.85 to 2.0. Secondly, the emissions intensity of electricty in Ontario, the region where the study is located, is nearly 70% lower than natural gas. Applying this system to the B2 scenario envelope and interal load measures reduces the annual heating requirement from 110,564 ekWh to 46,990 ekWh while the associated emissions are reduced from 18,115 kgCO_2e to 2,350 kgCO_2e. The share of emissions associated with heating compared to the annual total is reduced from 70% to 23%, suggesting the dramatic impact both fuel switching and system efficiency can have.

Scenario B2, Fuel Switch and System Efficiency 2 - Ground Source Heat Pump
The use of a ground-source heat pump can further improve the efficiency of the HVAC systems. The Clockshadow Building in Milwaukee, Wisconsin, USA makes use of this type of system and demonstrates that it can be applied to a building in a constrained urban site context. The COP for heating further increases from 2.0 to 2.8 and cooling COP increases to 4.0 to approximate a well designed and high quality system. The resulting EUI, is 74.5 ekWh/m^2/yr, a 9.6% improvement compared to the unitary rooftop system specified in measure one, above. The reduction of annual emissions follows suit and is reduced by 8.5% from 4.7 kgCO_2e/m^2/yr to 4.2 kgCO_2e/m^2/yr.

Scenario B2, Fuel Switch and System Efficiency 2 - Electric Hot Water
The final measure proposes a fully electric building. Eliminating on-site combustion is required to achieve carbon-neutrality and this final measure anticipates that further improvements could be made to achieve this metric. In addition to eliminating on-site combustion, electric systems consume less energy. In the B2 scenario, the domestic hot water system energy consumption is reduced by 33% from 10,528 ekWh per annum to 7,080 ekWh.

<u>*Scenario B2: Annual Energy and Emissions Predictions*</u>
The annual secondary (site) energy consumption and greenhouse gas emissions for the B2 mid-block scenario are summarized in Table 6.2.5 below and suggests that the threshold of the 2°C emission cap can be exceeded. The model results show that annual energy consumption can be reduced by 56.4% compared to the B1 Baseline Scenario, from 339,543 ekWh to 155,674 kWh. The equivalent EUI is reduced from 159.0 ekWh/m^2/yr to 72.9 ekWh/m^2/yr. In the mid-block site context, heating load is dramatically reduced and is no longer the dominant end-use. Rather, auxiliary loads and lighting consume the first and second most energy at 33% and 32% respectively while heating represents only 22% of the total. This is in contrast to the B1 scenario where heating represents 49% of the total, with lighting representing 24% and auxiliary loads 18%. The energy consumption by season is also much less variable than either the baseline scenario or the end-block sites. This is in-line with comparable high-performance buildings that have low window-wall ratios and robust envelopes where internal loads become dominant as low-energy design measures significantly reduce heating and cooling loads.

Annual emissions are suggested to be 7,784 CO_2e, 78.7% lower than the 37,248 CO_2e of the B1 baseline scenario. The equivalent energy intensity is 3.6 kgCO_2e/m^2/yr, 76.4% lower than the emissions budget of 15.3 kgCO_2e/m^2/yr suggested by the 2°C mitigation scenario. The switch to electricity, with an E_i of 0.05 kgCO_2e/ekWh that is 1/3 that of natural gas, significantly lowers the annual emissions over and above those associated with the reduction in energy use. With a single fuel source, the allocation of emissions by end-use matches energy consumption.

Table 6.2.5: Scenario B2 Energy and Emissions Summary				
Category	Energy (ekWh)	Allocation	Emissions (kgCO_2e)	Allocation
Heating	33,564	22%	1,678	22%
Lighting	50,020	32%	2,501	32%
Auxiliary	51,970	33%	2,599	22%
Cooling	13,040	8%	652	8%
DHW	7,080	5%	354	5%
Total	155,674		7,784	
Intensity	72.9 ekWh/m^2		3.6 kgCO_2e/m^2	

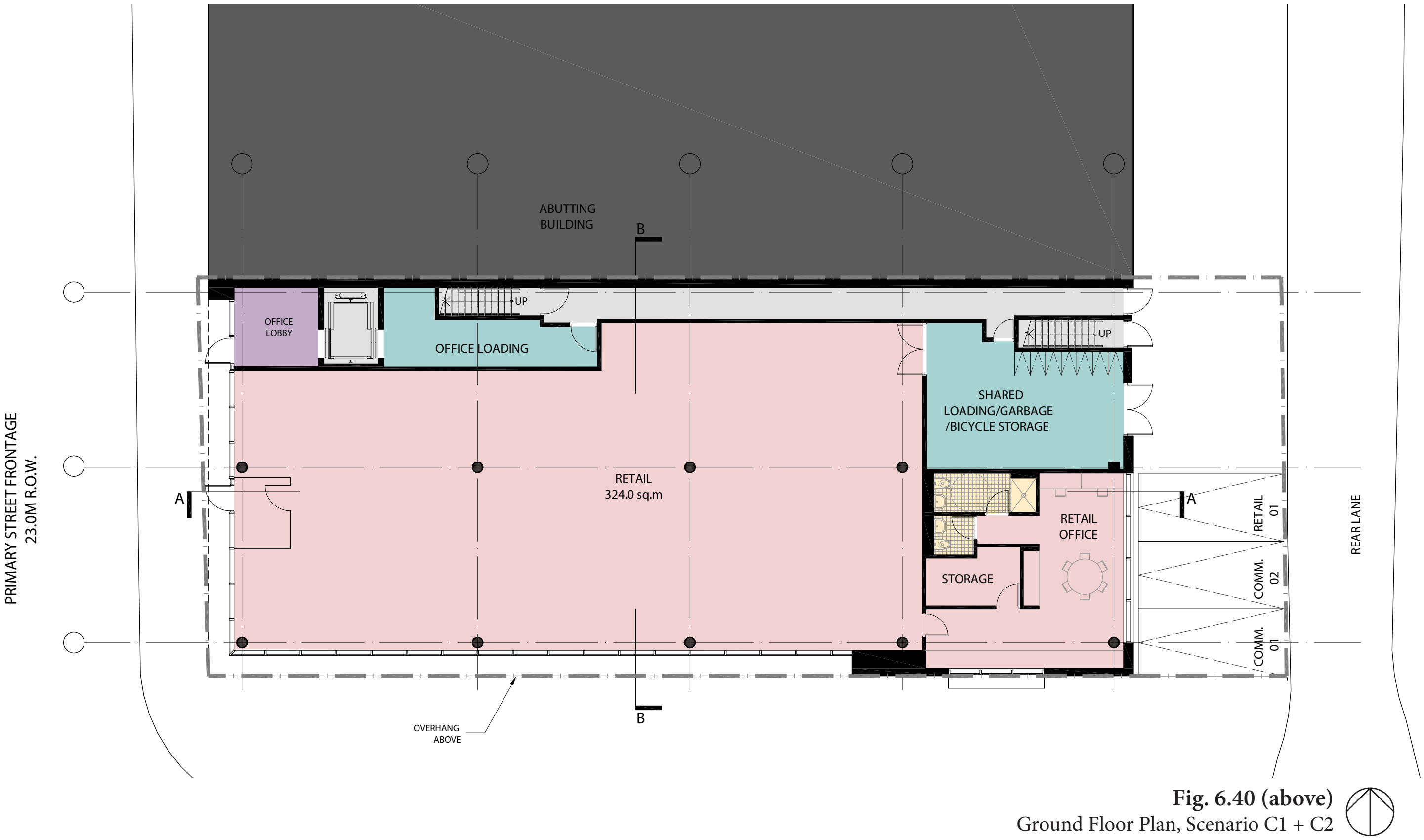
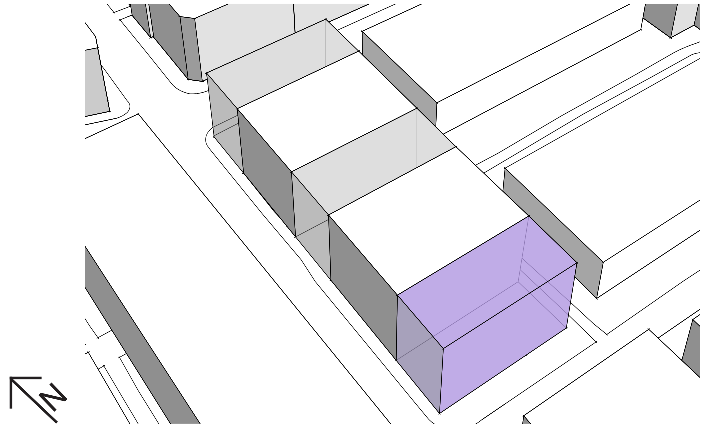


Fig. 6.40 (above)
Ground Floor Plan, Scenario C1 + C2

Fig. 6.41 (above)
Typical Upper Floor Plan (Levels 02-04), Scenario C1 + C2



6.3 Scenario C: South-Facing End-Lot

Fig. 6.42 (above)
Location of Scenario C in the prototypical block

Scenario C investigates the south-facing end-lot condition of the prototypical block. With the east-west orientation of the rectangular mass with the long south-facing exposure most closely follows the recommended building form and articulation for a low-energy building in this climate region than the other two sites. It is a mirror of the north-facing end-lot and essentially shares the same attributes, including site coverage. ***Scenario C1*** analyses the energy and emission implications of a design solution that meets current building codes. A daylighting, solar insolation, and solar access analysis is then conducted to determine the impact of the surrounding urban fabric and suggest passive strategies to improve energy efficiency. ***Scenario C2*** follows and makes adjustments to the building configuration, systems, and components that bring the building energy performance within the 15.3 kg/m^2/yr emissions cap suggested by the 2°C Scenario.

Scenario C1: Current Code Standard, Building Description
The site located on the south end lot of the prototypical block. This condition has three exposed facades, similar to north-facing lot of Scenario A. The building is 2,135m^2 (22,980ft^2) in area, four-storeys, and 17.5m in height to the top of the roof. The footprint is oriented along the east-west axis and each floorplate is 534m^2. With the north facade abutting the adjacent building in the block and the east, south, and west facades exposed, this is the only site in the block configuration that can achieve the ideal massing and orientation characteristics of a low-energy building. The primary entrances are located on the west facade and fronts onto the main Avenue with a 20.0m right-of-way. Service access, bike storage, and vehicular parking is to the east and faces a 7.5m right-of-way and laneway. The typical plans are illustrated in Figures 6.39 and 6.40, opposite, and full building drawings can be found in Appendix C.

The mixed-use program in Scenario C1 matches the A1 Scenario. The ground floor is predominantly retail. A modest 12.3m^2 (132ft^2) elevator lobby fronts onto the main avenue and provides access to the upper three floors with office uses. The floor-to-floor height of 5.0m yields high ceilings and allows for drops from the office uses above. The at-grade retail fronts onto both the main avenue and flanking street, also with a 20.0m Right-of-Way. The retail sales floor is 324m^2 (3,488ft^2) with the public entry from the main avenue to the west. A 63.8m^2 (687ft^2) support area at the rear includes office space, staff room, washrooms, and storage. A 40.0m^2 (433ft^2) shared loading area is accessed from the laneway and includes wall-mounted bicycle racks, storage for for garbage and recycling, and a corridor connecting the elevator to the upper floors. The total leasable area for the retail is 367.2m^2.

Table 6.3.1: Scenario C1 Energy Model Inputs and Building Attributes		
Building Description		
Building Height	Total Height: 17.5m, Four Storeys Floor-to-Floor L01: 5.0m, L02-L04: 4.0m	
Building Area	2,135m² \ Floorplates: Approx 534m² each	
L01 Program Allocation	Retail Sales: 63.0% Conditioned Storage: 2.2% General Office: 8.7% Washroom: 1.5% Mechanical/Electrical: 2.0% Office Elevator Lobby: 3.8% Corridor: 18.8%	
L02-L04 Program Allocation	Open Office: 65.0% Conference Room: 8.4% Kitchen: 2.8% Washroom: 8.5% Mechanical/Electrical: 2.0% Office Elevator Lobby: 3.7% Corridor: 7.7% Print/Copy: 2.0%	
Site Coverage (FAR)	Site Area: 639.5m² / FAR: 3.3x	
Retail Plannable Gross Area[4]	367.2m²	
Office Plannable Gross Area[4]	439.5m² / floor, 1,318.5m² total	
Building Envelope Attributes		
Exterior Wall - Typical (calculated with THERM)	W1: Charred Cedar / W2: Black Masonry	R: 18.4 / U: 0.0545 R_{si}: 3.23 / U_{si}: 0.31
Exterior Wall - Abutting Zero Property line Wall[5]	W3: Masonry, unsealed.	R: 11.4 / U: 0.088 R_{si}: 2.0 / U_{si}: 0.5
Roof (calculated with THERM)	R: Inverted, Intensive Green	R: 26.2 / U: 0.038 Rsi: 4.6 / Usi: 0.217
Glazing - Curtainwall	DOE Glass Library 6458: (Guardian SunGuard LE40/Clr-12.7mm Air/Clr 6mm Aluminium C/W Frame, Thermally Broken, Metal Spacer	Centre-Glass U_{si}: 1.87 Centre-Glass U: 0.33 SHGC: 0.37 VT: 0.67
Glazing - Ribbon/Punched	DOE Glass Library 6458: Guardian SunGuard LE40/Clr-12.7mm Air/Clr 6mm Aluminium Frame, Thermally Broken, Metal Spacer	Centre-Glass U_{si}: 1.87 Centre-Glass U: 0.33 SHGC: 0.37 VT: 0.67
Daylight Settings	Off - no daylight harvesting	
Window-Wall Ratio (WWR)	West (primary street frontage): 85% North (flanking street frontage): 0% East (rear laneway frontage): 36% South (abutting building frontage): 54%	Max Permitted: 40% Overall: 37%
Air-Tightness	0.04 cfm/ft²	

Table 6.3.1 Continued: Scenario C1 Energy Model Inputs and Building Attributes		
HVAC Systems		
Hours of Operation	Retail-Monday to Saturday: 9am - 8pm, Sunday Closed Office-Monday to Friday: 8am - 7pm, Saturday/Sunday Closed Statutory Holidays Closed	
Temperature Set-Points	Cooling Setpoint: 24°C Heating Sepoint: 22°C	
Heating System	Modelled as Electric Baseboard to determine load. Proposed system: Natural Gas, COP of 0.85 applied to heating load, resulting converted to kBTU to calculate emissions. (Table 6.8.1E, ASHRAE 900.1-2007)	Load / COP = heating system demand
Cooling System	Modelled as PTAC Through-Wall A/C. COP of 3.0 applied to approximate system-wide efficiency. Converted to cooling EIR of 0.28025 to approximate a system-wide energy consumption.	Load = Demand
Ventilation[6]	ASHRAE 62.1 Table 6.1: Ventilation Rates for Outdoor Air Retail: 0.25cfm/ft2 outdoor air (combined occupancy + area rate) Office: 0.11cfm/ft (combined occupancy+area rate) Airflow (general): 0.5cfm/ft2	
Heat Recovery	None	
Domestic Hot Water	Natural Gas	
Electrical, Plug Loads, and Lighting		
Lighting Loads[7]	SB-10 Table 4.3.3.4: LPD Using the Space-by-Space Method Retail Sales: 18 W/m^2 Storage: 9 W/m^2 Office/Open Office: 12 W/m^2 Washroom: 10 W/m^2 M/E: 16 W/m^2 Lobby: 14 W/m^2 Corridors: 5 W/m^2 Conference Room: 14 W/m^2 Kitchen: 13 W/m^2 Print/Copy: 14 W/m^2	
Equipment Loads[8]	SB-10 Table 5-4: Equipmennt Power Density Retail Level: 2.69 W/m^2 Office: 8.07 W/m^2	
Exterior Lighting	Not Considered	
Elevator[9]	Thyssen-Krupp hydrolic elevator with a 3500kg capacity and incandescent bulbs. Annual energy consumption estimate included in Auxiliary Loads.	4,205 ekWh/yr

The upper three floors are office and accommodate one tenant each. The floor plans are typical and include a 319m^2 open office area, print-copy room, and kitchenette. A glazed vestibule at the north-west corner separates the lobby from the main space while meeting rooms are located in the core and face south towards the open office. Bathrooms, exit stairs, and service shafts are arranged along the blank north wall to keep a contiguous space for the open office to have exposure on the three exposed facades which feature glazing. The floor-to-floor height of 4.0m allows for a 12-foot clear ceiling height below lights and services. The leasable area for the office is 439.5m^2 per floor, for a total of 1,318.5m^2.

The building is articulated in response to the urban context to continue the mass and presence of the streetwall while, at the same time, juxtaposing a contemporary intervention into the heritage fabric. Rather than mimic a historic facade, the modern language creates variety in the block while respecting the established height, massing, and street relationships. The facades are articulated in response to the building program as well. The facade of the four-storey rectangular mass is expressed as a crisp volume of charred cedar that is punctuated by glazing. The south facade is broken into a series of linear glazed strips that are randomly defined by stainless steel box projections to break up the mass of the facade. The west facade features the entries to the office lobby and retail and is predominantly glazed. The corner is dissolved to promote a transparent at-grade expression to animate the street. As one turns the corner and moves along the side street, the black cladding above plunges down at a sharp angle to meet the ground. A black surround on the upper floors of west face defines the office and retail uses while bringing the scale down to the pedestrian level along the sidewalk. Glazing is limited along the east and black masonry at grade provides a durable envelope adjacent to vehicular parking and loading. An overall Window-Wall-Ratio (WWR) of 37% is achieved, primary because the entire north facade is blank. Along the south facade, the WWR is 54%, roughly equivalent to the maximum permitted glazing at grade by code while the west facade is 85% and the east facade is 37%. The maximum permitted is 40%. An intensive green roof manages stormwater and helps to mitigate the urban heat island effect.

The limitations placed on the building by the OBC are similar to Scenario A1. The north facade abuts another building and thus, cannot have any glazing. The limiting distance of the remaining three building faces permits the area of unprotected glazing to be 100% on the west (primary) facade; 64% at grade and 100% for the upper floors of the south (flanking street) facade; and 79% at grade and 91% for the upper floors of the east facade (rear laneway). Foam plastic insulation is permitted if it is separated by a thermal barrier, equivalent to 12.7mm Gypsum Board, and if a non-combustible cladding is used. On the other hand, if no foam plastics are used, a combustible cladding is permitted given that the building is sprinklered. This later condition is proposed for the C1 iteration. Please refer to Appendix C for the full OBC Matrix.

Scenario C1: Current Code Standard, Energy Model Attributes
The forecast annual heating, cooling, and system loads for Scenario A1 are based on detailed architectural and general system inputs, including building area, window wall ratio, envelope characteristics, lighting power density, and HVAC system COP.

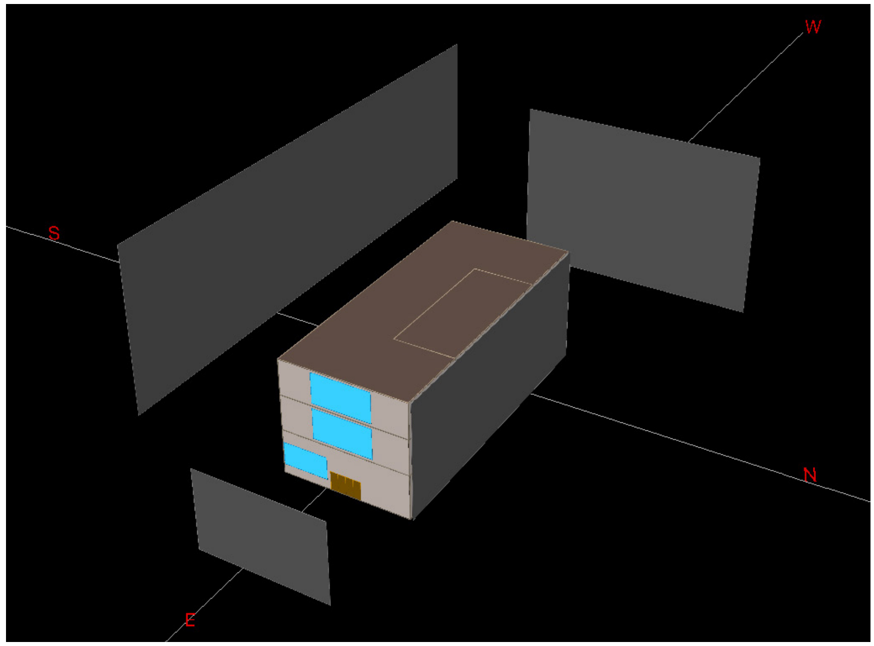


Fig. 6.43 (above)
Scenario C EQuest model screenshot

The prescriptive requirements of the OBC SB-10 energy supplement are used for each input. The details set out in this standard for envelope design, mechanical and electrical system efficiency, and detailing for continuity of insulation and air-tightness are assumed to be implemented. Where the supplement and the Code conflict, such as area of unprotected openings allowed relative to the maximum window-wall ratio in the supplement, the most stringent is used. Table 6.3.1, opposite, summarizes the characteristics.

The building envelope inputs are based on three key attributes. The first is the use of THERM to calculate a two-dimensional assembly U-Value for each building envelope component that is, in turn, used this in EQuest rather than using the layer-by-layer method. This better represents and accounts for thermal bridges within the envelope design. The second is the treatment of the two abutting walls to the north and the south. A common practice is to model this surface as adiabatic with no heat transfer. This is based on the assumption that the effect of the adjacent buildings creates a relatively thermally balanced condition compared to an exposed building face. When using energy models for comparison purposes, it has become an accepted practice as long as this is consistent for both cases. However, when creating a model to understand absolute heating and cooling loads, this method has been shown to be inaccurate. Using measurements of as-built conditions, Lowe, Wingfield, Bell, and Bell suggest that, when the space between zero property line walls is neither insulated nor sealed, the facade has a U_{si}-value 0.5 W/m^2-k, equivalent to an R_{si}-value of 2.0 k-m^2/W[4]. For the windows and curtainwall, double-glazed insulated glazing units with metal spacers are selected from the DOE Glazing Library and match the prescriptive requirements of the SB-10. These are set into aluminum frames. Finally, the surrounding urban context has been modelled using building shades. A view of the EQuest model is shown in Figure 6.42, above.

The cooling and heating systems have been specified as a through-wall air conditioner and electric baseboard heating. Outdoor Air ventilation rates match ASHRAE Standard 62.1. This process generates a heating and cooling load in EQuest rather than a system energy consumption. A system Coefficient of Performance (COP) is then applied to these loads outside of the energy model to arrive at an approximate system energy consumption. The B1 scenario specifies

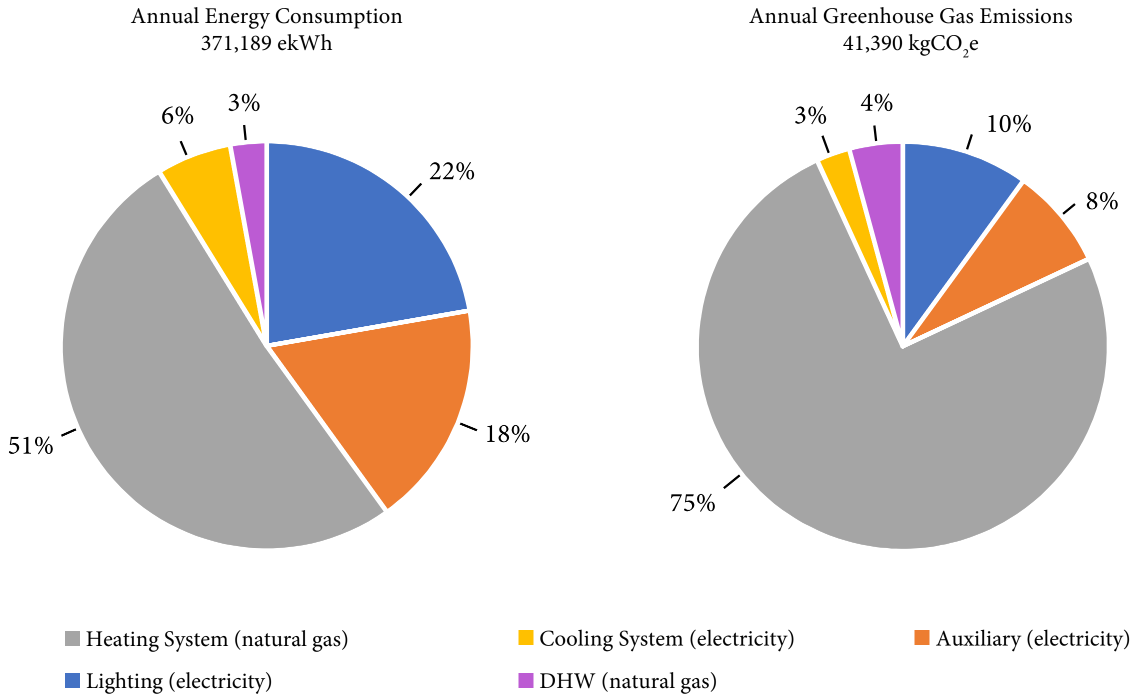


Fig. 6.44 (above)
Scenario C1 breakdown of annual energy consumption and greenhouse gas emissions.

natural gas as the fuel for both heating and domestic hot water while electricity is used for cooling and air-conditioning. This is representative of a packaged DX rooftop unit providing both heating with no heat recovery at a COP of 0.85 and cooling at a COP of 3.0. The lighting system meets the prescriptive requirements for Lighting Power Density (LPD) Space-by-Space method with no daylight harvesting systems. The model assumes an air-tightness of 0.04cfm/ft^2. Elevator energy consumption is added outside of the EQuest model and is based on a hydraulic, 3500kg capacity Thyssen-Krup with incandescent bulbs in the cab.

Scenario C1: Annual Energy and Emissions Predictions

The annual secondary (site) energy consumption in ekWh and greenhouse gas emissions in kgCO_2e for the code compliant south-facing end-lot building are summarized in Table 6.3.2. The results suggest the annual energy consumption is 170,635 kWh of electricity and 630,139 kBTU of natural gas, equivalent to an Energy Use Intensity (EUI) of 173.8 ekWh/m^2/yr when the fuel sources are combined. Figure 6.42, above, illustrates that, like the other two scenarios, heating is by far the dominant load and represents 51% of the total energy use with cooling loads representing a marginal 6% share. Lighting is the second-highest category and represents 22%. This allocation of energy end-uses generally follow the historic measured data presented by Natural Resources Canada's Energy Use Data Handbook. It is also in-line with the prevailing climate where heating degree days significantly outnumer cooling degree days by a large margin. Table 6.3.2, following, summarizes the energy consumption allocation and values.

The Emissions Intensity (E_i) for the C1 iteration is calculated to be 19.4 kgCO_2e/m^2/yr, 27% higher than the emissions budget of 15.3 kgCO_2e/m2/yr suggested by the 2°C mitigation scenario. This calculation is based on the following consumer emission factors for Ontario:

- Electricity: 0.05 kgCO_2e/ekWh[10],
- Natural Gas: 0.164 kgCO_2e/ekWh[11].

Scenario C1: South-Facing End Block Monthly Energy Consumption

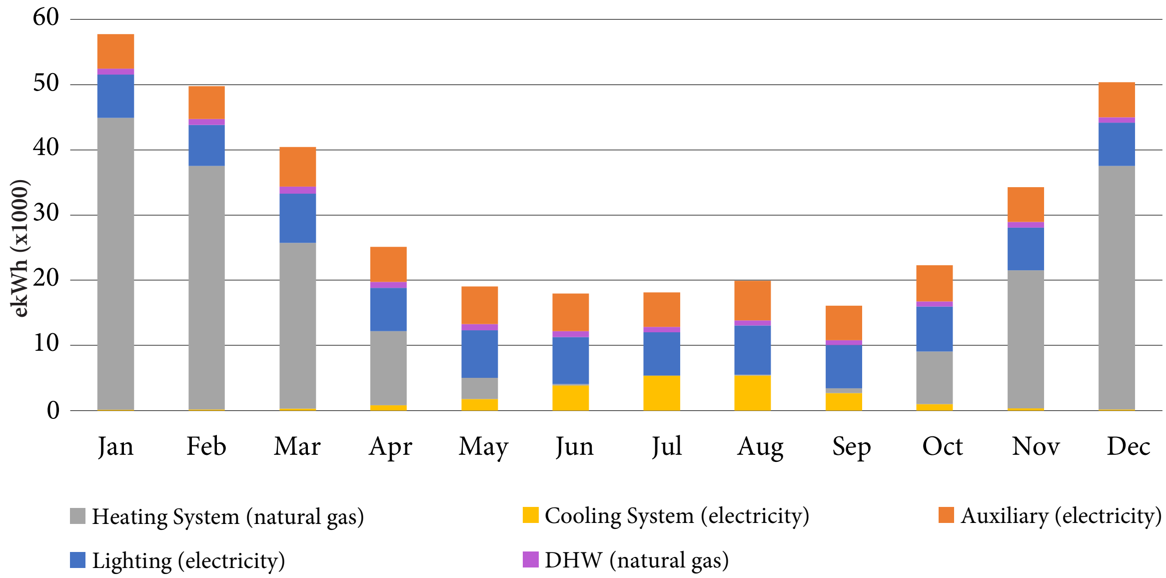


Fig. 6.45 (above)
Scenario C1 breakdown of monthly energy consumption and greenhouse gas emissions.

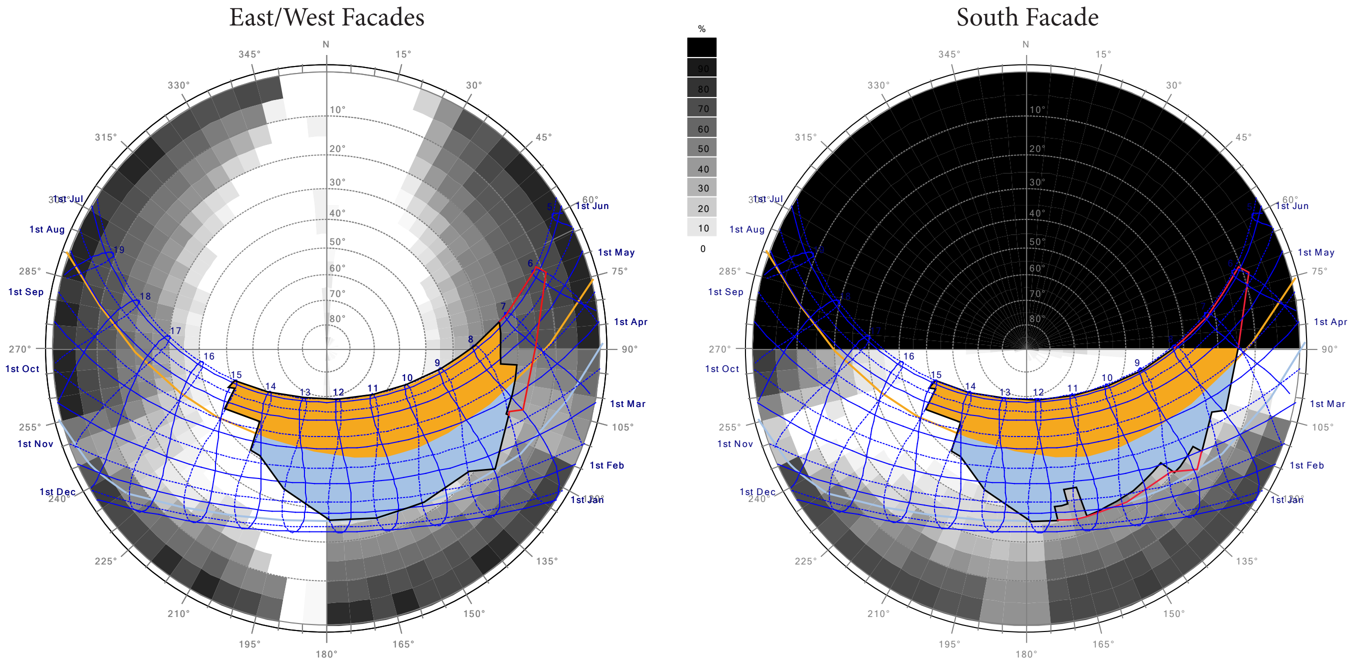
Similarly, emissions are lower than the north-facing block and higher than the mid-block. Heating and lighting are the two highest categories, representing 75% and 10% respectively, while cooling represents 3%. Although the relative allocation between energy use and emissions are the same, the fuel selection drives a change in the absolute ratios. This is reflected in the change in the relative share of each end-use category. In the case of heating load, the ratio grows from 51% to 75%.

Table 6.3.2: Scenario C1 Energy and Emissions Summary

Category	Energy (ekWh)	Allocation	Emissions ($kgCO_2e$)	Allocation
Heating	189,965	51%	31,123	75%
Lighting	82,550	22%	4,128	10%
Auxiliary	62,515	18%	3,126	8%
Cooling	21,180	6%	1,094	3%
DHW	10,59	3%	1,735	4%
Total	371,189		41,390	
Intensity	173.8 $ekWh/m^2$		19.4 $kgCO_2e/m^2$	

Scenario C: Passive Assessment

Passive design to reduce heating, cooling, and lighting loads at the south-facing end-block site, although limited by the surrounding buildings, is more effective compared to the other two scenarios. The use of a rectangular building shape with glazing facing south and the north facade abutting an adjacent building is possible. With ideal exposures and the ability to control solar stress and allow daylight, both heating and cooling loads can be reduced. With this site context and energy use profile in mind, a study of the overshadowing by the surrounding buildings, solar stress, and daylight availability will illustrate the passive opportunities.



Scenario C: Overshadowing + Shading:
One of the fundamental effects of a surrounding urban fabric on any particular building is on the solar envelope. Site constraints limit orientation, contribute to overshadowing, and limit daylight access. In a heating dominated climate, impeded solar access can reduce passive heating design opportunities.

Scenario C represents a more ideal passive design arrangement than the other two sites. The rectangular floorplate is oriented east-west with the north facade completely obstructed while the south facade has good solar exposure. The street canyons 20 metres in width and 17.5m in height to the west and south provide some overshadowing while the east facade is pulled back from the property line and has lower facing buildings that create a more open condition. Using Ecotect Analysis, the average shading coefficient of the south facade is calculated to be 70.6%, with the winter more shaded that the summer when the sun is lower in the sky. However, solar gain is generally above 274 Wh and shading should still be considered. The west facade, on an annual basis, is shaded 38.1% and 37.9% in the summer. The east facade is shaded to a similar extent with the average annual shading coefficient equal to 35.4% and 34.3% during the cooling season. The stereographic diagrams above show that overshadowing does contribute to reducing the periods when shading is needed, although more on the east and west than the south. In all three cases, a shading device should be used. On the west facade in particular, overshadowing tends to happen at times of year and day when shading is not required. Like the other sites, the surrounding buildings contribute to a higher overall energy demand. Table 6.3.3, below, summarizes the heating and cooling loads with and without the urban context. When surrounding buildings are considered, the total thermal loads are higher, with heating load increased and cooling load decreased, with the overall combined loads increasing 21.8%.

Table 6.3.3: Impact of Surrounding Buildings on Annual Heating and Cooling Loads for the C1 Scenario in ekWh

	With Surrounding Buildings	Without Surrounding Buildings
Heating	189,965	138,020
Cooling	21,180	27,200
Total Thermal Loads	211,145	165,220

Shading on fall and spring side of the summer equinox

Shading on fall side of summer equinox; sun required on the spring side of the summer equinox

Fig. 6.46 (above)
C Scenario east/west and south facade overshadowing created in Ecotect Analysis. Shading requirement overlay based on a balance-point temperature of 8.3°C and solar cutoff of 263.4 W/m². Process derived from Brown and DeKay, 2001.

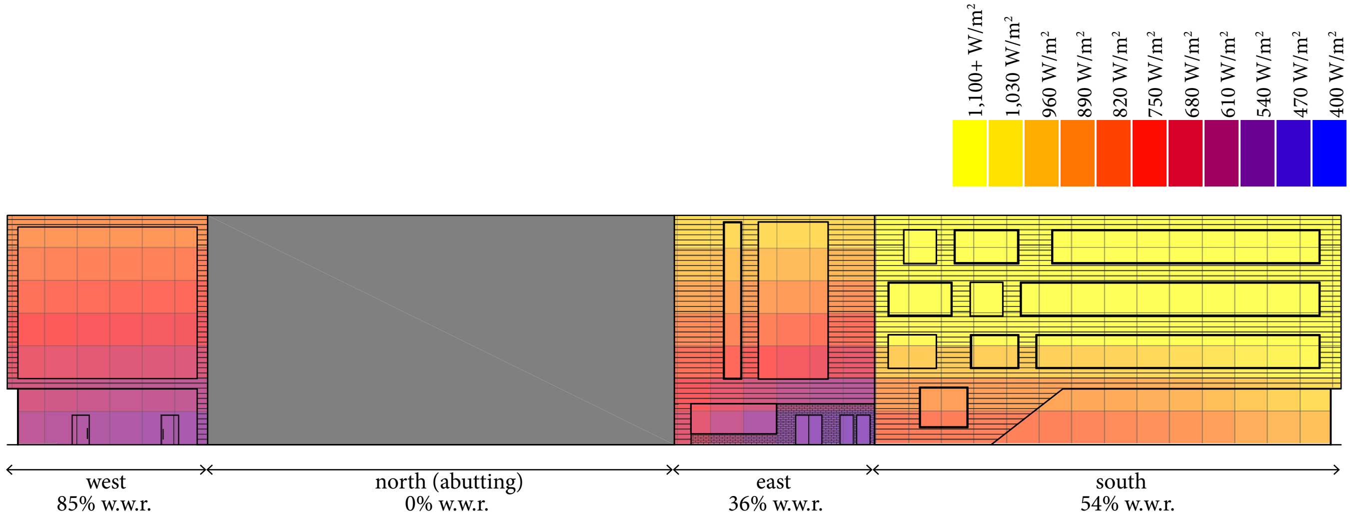


Fig. 6.47 (above)
Scenario C facade average daily insolation (Wh/m^2)
Calculated with Ecotect Analysis

The overshadowing conditions require a careful study of solar angles to determine optimal shading. The diagrams suggest that glazing on the west facade should be shaded between April 16th and September 10th using a vertical shading device that provides coverage from 1:00pm through 4:00pm. On the south facade, shading should be provided from April 1st through September 1st between 11am and 2:30pm. Shading is not as critical towards the east except in the height of the summer cooling season until 11:00am. Overshadowing makes the most pronounced contribution by keeping the ground floor shaded nearly all the time early on all facades. Unlike the other two scenarios, the shading requirements extend into the shoulder seasons.

Scenario C: Solar Stress:
The average annual insolation striking the three exposed facades is affected by the surrounding context, although to a lesser degree than the north facing and mid-block scenarios. On the west facade in particular, the majority of the solar insolation is diffuse rather than direct, leading to a relatively even distribution of solar energy across the facade and a lower solar stress than the east facade with the ground floor nearly completely shaded with the upper floor more exposed. The south facade is overshadowed, but nevertheless requires shading in the cooling season while, during the heating season, the surrounding buildings obstruct useful solar gain. This suggestion is supported by the heating and cooling load analysis presented in Table 6.3.3 where the heating load is significantly higher compared to the same building without any obstructions to the solar envelope. Figure 6.49m above, illustrates the distribution of direct and diffuse average daily insolation on the three exposed facades and illustrates how solar exposure increases as one moves higher on the building.

The west facade in the current code iteration is over 85% glazed. Across the entire facade, the average direct insolation does not exceed 200Wh/m^2 while the combined direct and indirect insolation ranges from 563Wh/m^2 on the northwest corner of the ground floor to 858Wh/m^2 on the southwest corner, reflecting the most and least overshadowed areas. The analysis suggests that glazing is a cooling liability and should be shaded as required. Solar gain and glare is limited as the facade is generally overshadowed from direct gain during the heating seasons and there are no "hotspots" where significant gain is expected. The east facade, on the other hand, is more more exposed to direct insolation. The ground level is shaded

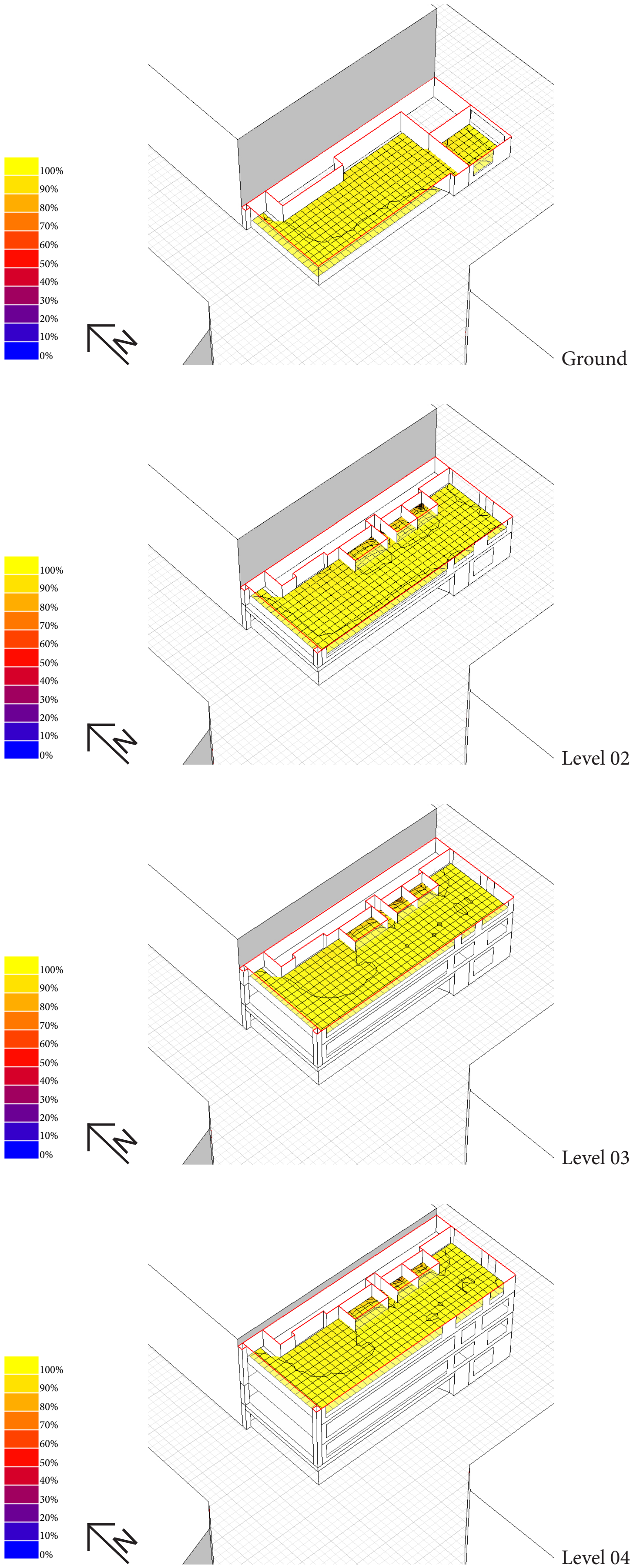


Fig. 6.48 (left)
Scenario C1 floor-by-floor daylight autonomy based on 300lux at 762mm above the floor, calculated in Ecotect Analysis

nearly all the time while the upper floors can receive an average daily insolation in excess 900Wh/m^2, creating a cooling liability. Glazing should be limited on the top floor to avoid summer overheating. The south facade receives both direct and diffuse radiation and, requires shading to avoid overheating. Average daily insolation ranges from over 800Wh/m^2 on the ground floor to 1,100Wh/m^2 on the upper floor. Glazing should be optimized for daylighting and view only due to overshadowing in the heating season and shading in the cooling season.

Scenario C: Daylight Availability:

The rectangular building floorplate, orientation, and floor-to-floor heights are conducive to good daylighting. The depth of the retail sales floor and office spaces are, generally, within 8.5m to 9.0m of any facade while service spaces, elevator, exit stairs, mechanical shafts and washrooms are arranged along the blank north side. The orientation of the building along the east-west axis allows the south elevation to be the primary face for daylight harvesting, where glazing should be shaded to avoid heat gain in the summer and fall shoulder seasons. The west facade's glazed envelope, combined with the overshadowing of surrounding buildings, creates a daylighting similar to a north-facing condition, where diffuse insolation is predominant and direct insolation is limited. However, the depth of daylit space from this facade falls off more quickly than the rest of the space, suggesting the significant shading impacts of the surrounding buildings. The east has more limited glazing where direct insolation is more prevalent. Similar to the west facade, daylight autonomy is marginally affected by overshadowing. In general, all floors can be nearly 100% daylit in regularly occupied spaces and the distribution is even across the floorplate.

The daylight autonomy analysis, illustrated in Figure 6.47, suggests that the occupied spaces receive 300lux at 762mm above the finished floor nearly 100% of the time. The entire occupied floorplate is daylight autonomous and suggests there is a significant potential to reduce lighting energy. Unlike the other two site scenarios, all floors receive ample daylight and could be subject to glare. The results also suggest that glazing could be reduced and while maintaining daylight autonomy. The depth for regularly occupied spaces follows the rule of thumb where a daylit zone exists for a depth of 2.5x the height of the glazing.

Scenario C presents a number of opportunities to passively lower building loads. The urban fabric does impede on the solar envelope in a measurable way, driving a significantly higher heating load and a slightly reduced cooling load that, together, generate a higher overall energy demand. The overshadowing is not always protecting the building at the right times, as a purpose-built shading device might.

Nevertheless, during the cooling season, shading can be added to the east, west and south facades to reduce solar gain. The daylight distribution suggests that the plan configuration of the floor levels supports daylight autonomy and that the amount of glazing can be reduced. With heating being such a dominant load, reduced glazing to increase the overall thermal resistance of the envelope should be considered. It may be true where sacrificing daylight autonomy for a more solid envelope will have a more significant overall impact on reducing heating and cooling loads.

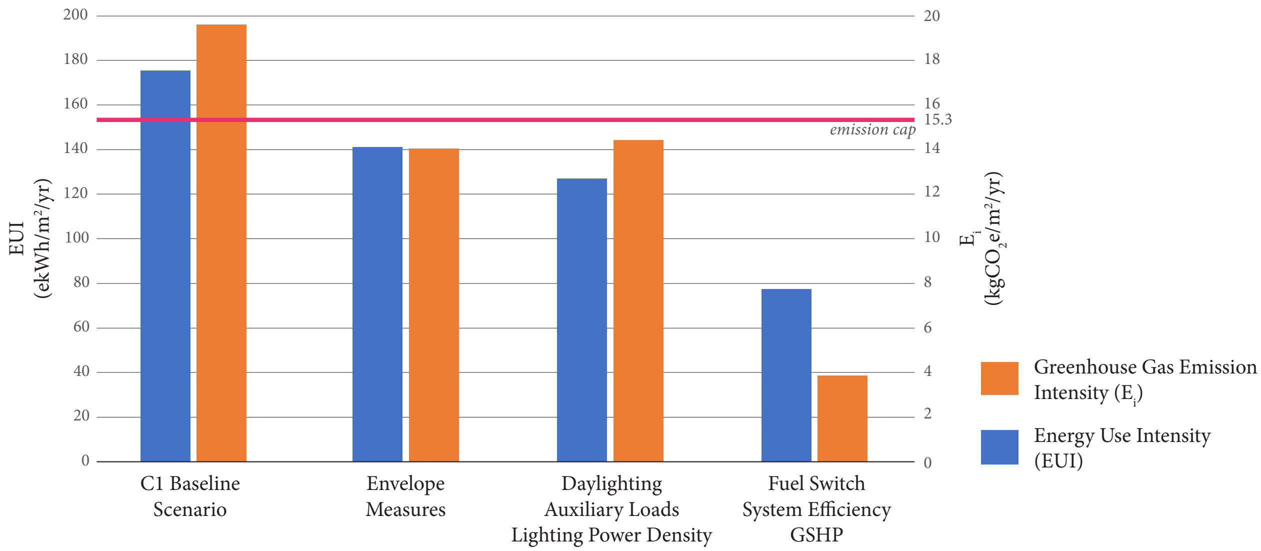


Fig. 6.49 (above)
C2 Scenario energy and emission reductions by category

<u>Scenario C2: 2°C Mitigation Scenario:</u>
The annual emissions intensity (E_i) of the baseline south-facing end block scenario is 19.6 $kgCO_2e/m^2/yr$, 28% higher than the 15.3 $kgCO_2e/m^2/yr$ budget suggested by the 2°C Median Mitigation Scenario. This can be reduced by addressing both the energy consumption and the emissions intensity of fuel sources used. A study of these two aspects of the emissions equation suggests that each can independently achieve the target and that a project has a number of avenues available.

The approach taken to reducing energy and greenhouse gas emissions is based on the recommended design process for high performance buildings where energy loads are first reduced through passive design and then met using high-efficiency systems. Ten energy reducing measures are incrementally applied to the baseline C1 scenario and can be grouped into the following three categories. The first is comprised of four measures that improve the performance of the buildng envelope. The second passively reduces internal loads by incorporating high-performance lighting technology, daylight harvesting, and reduced plug-loads that represent low-consumption equipment and appliances. The third and final category incorporates fuel switching to lower emitting energy sources in conjuntion with high efficiency mechanical systems. The cumulative effect of these measures suggests that on-site renewable energy is not required to meet the emissions cap of the 2°C scenario and that it can be done using technologies that are both proven and readily available.

Scenario C2, Category 1- Building Envelope Measures:
Four measures that improve the building envelope are applied to the C1 scenario to reduce heating and cooling loads. The results suggest that the EUI can be reduced by 19.5%, from 175.5 $ekWh/m^2/yr$ to 141.2 $ekWh/m^2/yr$. Emissions can be reduced by 28.3% from 19.6 $kgCO_2e/m^2/yr$ to 14.1 $kgCO_2e/m^2/yr$, beating the emission cap. The difference in relative impact of energy consumption and emissions illustrates the impact of fuel choice. In this case, the envelope measures reduce heating load significantly more than cooling load. The heating system is fueled by natural gas and has a system COP of 0.85 compared to the electric cooling system COP of 3.0. Therefore, reducing heating energy consumption will have a larger emissions reduction per equivalent kilowatt-hour compared to reducing the cooling load. There are additional incremental improvements to these measures that could further improve energy efficiency and reduce emissions to move towards a net-zero or carbon-neutral performance level. With the exception of adding shading devices to the south facade, the measures are similar to the A2 scenario.

Scenario C2, Envelope Measure 1 - Reduce Window-to-Wall Ratio (WWR):
The window-wall ratio in the C2 scenario is reduced by 9%, from 37% to 28%. The most substantial reduction is on the west facade, where the curtainwall facade is transformed into a strip-window composition on the upper floors. Along the south elevation, pieces of the strip windows are filled in with opaque wall to create a punched expression. The east facade remains unchanged as the WWR is already low and both daylight availability and view are optimized along this frontage. This measure reduces both heating and cooling loads without sacrificing daylight availability. Analysis suggests that an annual average of 300lux across the regularly occupied floor areas can be achieved and, thus, not impede daylight availability.

Scenario C2, Envelope Measure 2 - Reduce Thermal Transmittance of the Building Envelope:
R-values of both the roof and exterior walls and the performance of the glazing system are increased. The exterior walls with south, east, and west exposure are increased by 22%, from R18.4 to R23.8. This is achieved by increasing the cavity wall from 92mm to 152mm and using polyurethane foam insulation while retaining the 50mm of continuous expanded polystyrene insulation to limit thermal bridging. The abutting north wall is sealed and continuously insulated at the exposing ends, increasing the equivalent R-value from R11.4 to R28.6[15]. The roof R-value increases 33%, from R26.2 to R45.5, by nearly doubling the thickness of the polyisocyanurate insulation from 112mm to 200mm. The double-glazed Low-E coated insulated glazing units (IGU) in the baseline scenario are replaced with triple-glazed Low-E coated units and the metal spacers are upgraded to insulating spacers. The Centre-Glass U-Value decreases from 0.33 to 0.22. The envelope measures also effect plannable area as defined by the ASTM *Standard Practice for Building Floor Area Measurements for Facility Management*[4]. The thicker building envelope reduces it by less than 1%, from 1,685.7m^2 to 1,678m^2.

Scenario C2, Envelope Measure 3 - Increase Glazing SHGC from 0.36 to 0.47:
The solar heat gain coefficient of the triple-glazed IGUs is increased from 0.36 to 0.47. This measure was studied separately from the general envelope improvements to test the impact individually. The model suggests that, because the heating load represents 51% of the total annual heating load in the baseline scenario, the reduction of heating load by increasing the SHGC is more than the associated increase in cooling load, thus reducing the overall energy use intensity. The overall EUI drops from 142.4 ekWh/m^2/yr to 141.6 ekWh/m^2/yr when this measure is applied to the triple-glazed units. When natural gas is used as a fuel source, heating load has a higher emissions intensity than cooling load and, therefore; it is advantageous from both an energy efficiency and emissions intensity point of view to increase the SHGC. The emissions intensity is reduced from 14.2 kgCO_2e/m^2/yr to 13.8 kgCO_2e/m^2/yr, a reduction of 2.8% while the EUI is reduced by only 0.5%. This may not always be the case. Most of the case studies in Chapter 5, with the exception of the EpiCentre building, have a lower SHGC, suggesting avoiding heat gain is preferred. In a situation where the WWR is higher, this could be the case. However, results suggest a higher SHGC is more beneficial here.

Table 6.3.4: Scenario C2 Energy Model Inputs and Building Attributes		
Building Description		
Building Height	Total Height: 17.5m, Four Storeys Floor-to-Floor L01: 5.0m, L02-L04: 4.0m	
Building Area	2,135m^2 \ Floorplates: Approx 534m^2 each	
L01 Program Allocation	Retail Sales: 63.0% Conditioned Storage: 2.2% General Office: 8.7% Washroom: 1.5% Mechanical/Electrical: 2.0% Office Elevator Lobby: 3.8% Corridor: 18.8%	
L02-L04 Program Allocation	Open Office: 65.0% Conference Room: 8.4% Kitchen: 2.8% Washroom: 8.5% Mechanical/Electrical: 2.0% Office Elevator Lobby: 3.7% Corridor: 7.7% Print/Copy: 2.0%	
Site Coverage (FAR)	Site Area: 639.5m^2 / FAR: 3.3x	
Retail Plannable Gross Area[4]	366.4m^2	
Office Plannable Gross Area[4]	437.2m^2 / floor, 1,311.6m^2 total	
Building Envelope Attributes		
Exterior Wall - Typical (calculated with THERM)	W1A: Charcoal Cementitious Panel W2A: Black Masonry	R: 23.8 / U: 0.042 R_{si}: 4.19 / U_{si}: 0.24
Exterior Wall - Abutting Zero Property Line Wall[5]	W3A: CMU, sealed and insulated	R: 28.6 / U: 0.035 R_{si}: 5.04 / U_{si}: 0.20
Roof (calculated with THERM)	R1A: Inverted, Intensive Green	R: 45.5 / U: 0.022 Rsi: 8.0 / Usi: 0.125
Glazing - Curtainwall	DOE Glass Library 3652: (Triple Low-E Film (77) Clear) Aluminium C/W Frame, Thermally Broken, Insulating Spacer	Centre-Glass U_{si}: 1.25 Centre-Glass U: 0.22 SHGC: 0.47 VT: 0.64
Glazing - Ribbon/Punched	DOE Glass Library 3652: (Triple Low-E Film (77) Clear) Aluminium C/W Frame, Thermally Broken, Insulating Spacer, 610mm shading device on south facing glazing	Centre-Glass U_{si}: 1.25 Centre-Glass U: 0.22 SHGC: 0.47 VT: 0.64
Daylight Settings	On -Continuous Dimming	
Window-Wall Ratio (WWR)	West (primary street frontage): 57% North (abutting building): 0% East (rear laneway frontage): 36% South (flanking street): 40%	Max Permitted: 40% Overall: 29%
Air-Tightness	0.04 cfm/ft^2	

Table 6.3.4 Continued: Scenario C2 Energy Model Inputs and Building Attributes		
HVAC Systems		
Hours of Operation	Retail-Monday to Saturday: 9am - 8pm, Sunday Closed Office-Monday to Friday: 8am - 7pm, Saturday/Sunday Closed Statutory Holidays Closed	
Temperature Set-Points	Cooling Setpoint: 24°C Heating Sepoint: 22° C	
Heating System	Modelled as Electric Baseboard to determine load. Proposed system: Electric Ground Source Heat Pump, COP of 2.8 applied to heating load.	Load / COP = heating system demand
Cooling System	Modelled as PTAC Through-Wall A/C. COP of 4.0 applied to approximate system-wide efficiency. Converted to cooling EIR of 0.2175.	Load = Demand
Ventilation[6]	ASHRAE 62.1 Table 6.1: Ventilation Rates for Outdoor Air Retail: 0.25cfm/ft2 outdoor air (combined occupancy + area rate) Office: 0.11cfm/ft (combined occupancy+area rate) Airflow (general): 0.5cfm/ft2	
Heat Recovery	Applied; contributions taken into account with system COP	
Domestic Hot Water	Electric	
Electrical, Plug Loads, and Lighting		
Lighting Loads[7]	ASHRAE Advanced Energy Design Guideline Retail and Office Retail Floor (L01): 0.98 W/m^2 Office Floors (L02-L04): 0.75 W/m^2	
Equipment Loads[8]	SB-10 Table 5-4: Equipmennt Power Density reduced 25% Retail Level: 1.92 W/m^2 Office: 6.06 W/m^2	
Exterior Lighting	Not Considered	
Elevator[9]	Thyssen-Krupp regenerative elevator with a 3500kg capacity and LED bulbs. Annual energy consumption estimate included in Auxiliary Loads.	1,360 ekWh/yr

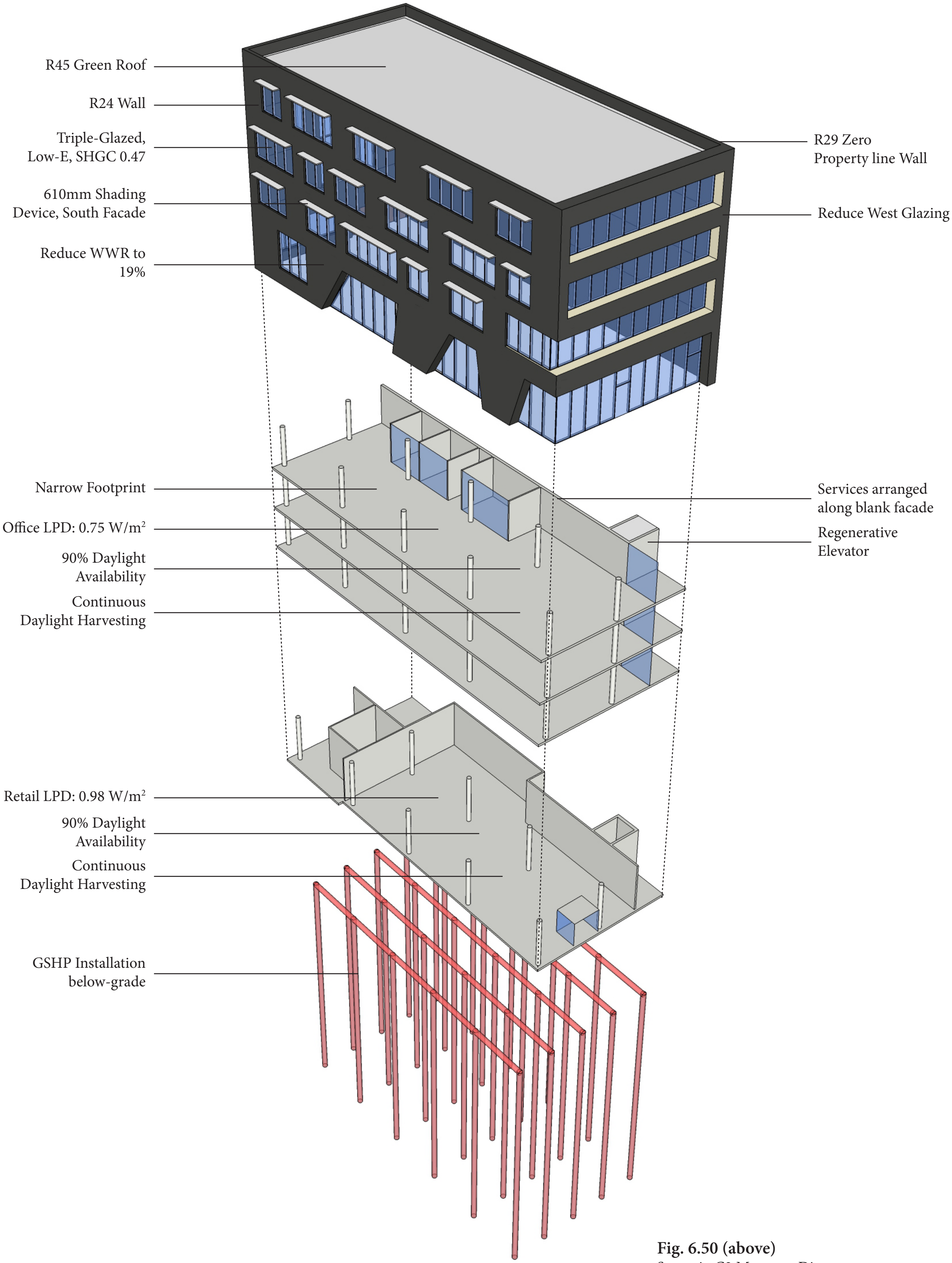


Fig. 6.50 (above)
Scenario C2 Measures Diagram

Scenario C2, Envelope Measure 4 - Add South Shading Devices
The south facade receives enough incident solar energy to warrant shading devices, particularly the upper floors while the ground level is largely shaded by the adjacent context. Shading devices are particularly important as the SHGC is relatively high. A 610mm horizontal device is proposed above each window to provide shade during the cooling seasons while still permitting passive solar gain during the heating season. The heating load is reduced to a larger extent than the increase in cooling load, leading to an overall reduction in EUI. Fixed vertical shading devices were investigated for the west facade as well, but were not implemented as, unlike the effect on the south facade, the shading devices block more passive heat than is saved by reducing the cooling load. However, a dynamic shading system or thermochromatic glazing would avoid this interference and be able to provide shading and allow heating when required.

Scenario C2, Category 2- Internal Load Measures:
The internal load category involves three strategies that are applied to the envelope measures. In some cases, such as daylight harvesting, this involves passive design strategies. Reducing the energy consumption of these systems does effect heating and cooling loads and is the primary reason why these measures are investigated separately from the mechanical systems. The EUI is reduced to 126.9 ekWh/m^2/yr, 8.2% lower than the building envelope measures. However, the emissions intensity increases by 0.3 $kgCO_2e/m^2$/yr to 14.4 $kgCO_2e/m^2$/yr. This is due to an increase in heating load as a result of less heat generated by lights, appliances, computers and other auxiliary equipment. With the higher emissions intensity associated with heating load, 0.164 $kgCO_2e$/ekWh for natural gas versus 0.05 $kgCO_2e$/ekWh for electricity, the emission savings from lower plug and lighting loads are offset. Nevertheless, the emissions intensity is still below the 2°C Scenario cap of 15.3 $kgCO_2e/m^2$/yr. However, emissions decrease rather than increase if electricity was the fuel source for heating. This demonstrates the interconnected nature of building loads, systems, and fuel selection when energy consumption and greenhouse gas emissions are considered holistically.

Scenario C2, Internal Load Measure 1 - Reduce Lighting Power Density
The ASHRAE Advanced Energy Design Guidelines for retail and office buildings suggest technologies and design practices to reduce energy consumption by 50%. This guideline provides a Lighting Power Density (LPD) recommendation of 0.98 W/m^2 for retail uses and 0.75W/m^2 for office uses. These numbers take into account all program types within a typical retail or office building, such as washrooms and support spaces, and are applied to the entire floor area of the primary occupancy of each respective floor. The reduced LPD involves a combination of different technologies and includes high-efficiency lighting systems, occupancy sensors, and design techniques that reduce the overall number of fixtures required[16,17]. Compared to the baseline C1 scenario, retail LPD is reduced by 29% and office LPD is reduced by 30%. In total, the annual lighting load drops from 82,550 ekWh to 57,800 ekWhr, equivalent to a 30% reduction.

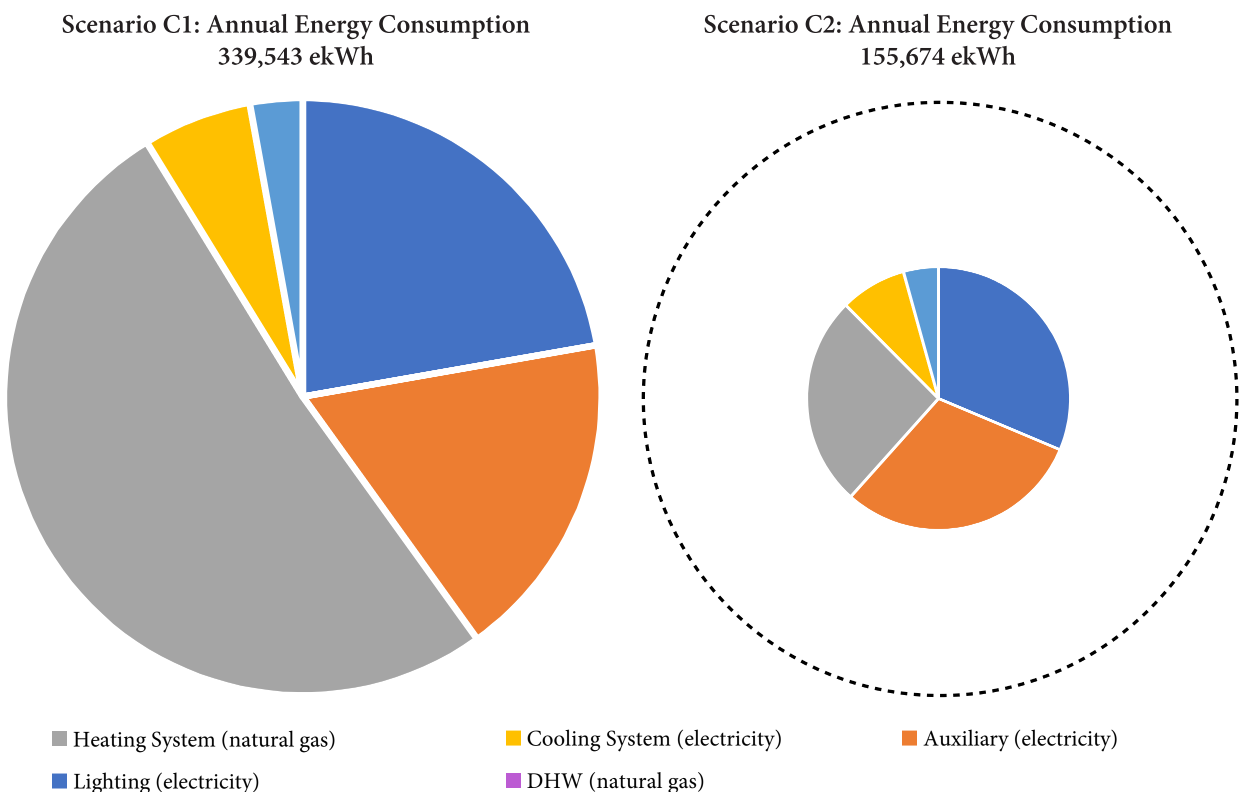


Fig 6.51 (above)
Annual energy consumption comparison of C1 Baseline and C2 2°C Mitigation Scenarios

Scenario C2, Internal Load Measure 2 - Daylight Harvesting:
Daylight harvesting is a key passive design strategy. A daylight autonomy simulation of the C2 scenario suggests that 300lux can be achieved in most regularly occupied spaces 90% of the time on an annual basis. The ground floor still achieves a high level of daylight autonomy regardless of the overshadowing effects of the surrounding urban fabric because it is situated at a corner and is relatively exposed compared to the mid-block building. The east-west orientation of the rectangular floorplate keeps service spaces and circulation against the blank north wall while regularly occupied spaces, including the open office and staff spaces on the upper floors and the sales floor and support offices on the ground level, are arranged along the exposed facades. The relatively narrow aspect ratio ensures that regularly occupied spaces are within 9.0m of an exposed facade and is in keeping with the daylighting rule of thumb where daylight can be reasonably expected within 2.5x the height of the space[18], which in this case is 10.0m. A continuous dimming ballast set to 5% increments has been selected and is in-line with many of the case studies. Daylight harvesting reduces lighting energy by over 10%, from 57,800 ekWh to 51,830 ekWh.

Scenario C2, Internal Load Measure 3 - Reduce Plug Loads and Elevator:
The NREL Assessment of the Technical Potential for Achieving Net-Zero Energy Buildings in the Commercial Sector[19] suggests that plug loads can be reduced by 25% and the Advanced Energy Design Guidelines for office buildings produced by ASHRAE[20] suggests that plug and equipment loads can be reduced by up to 33% in office occupancies. With the proliferation of electronic devices, this load

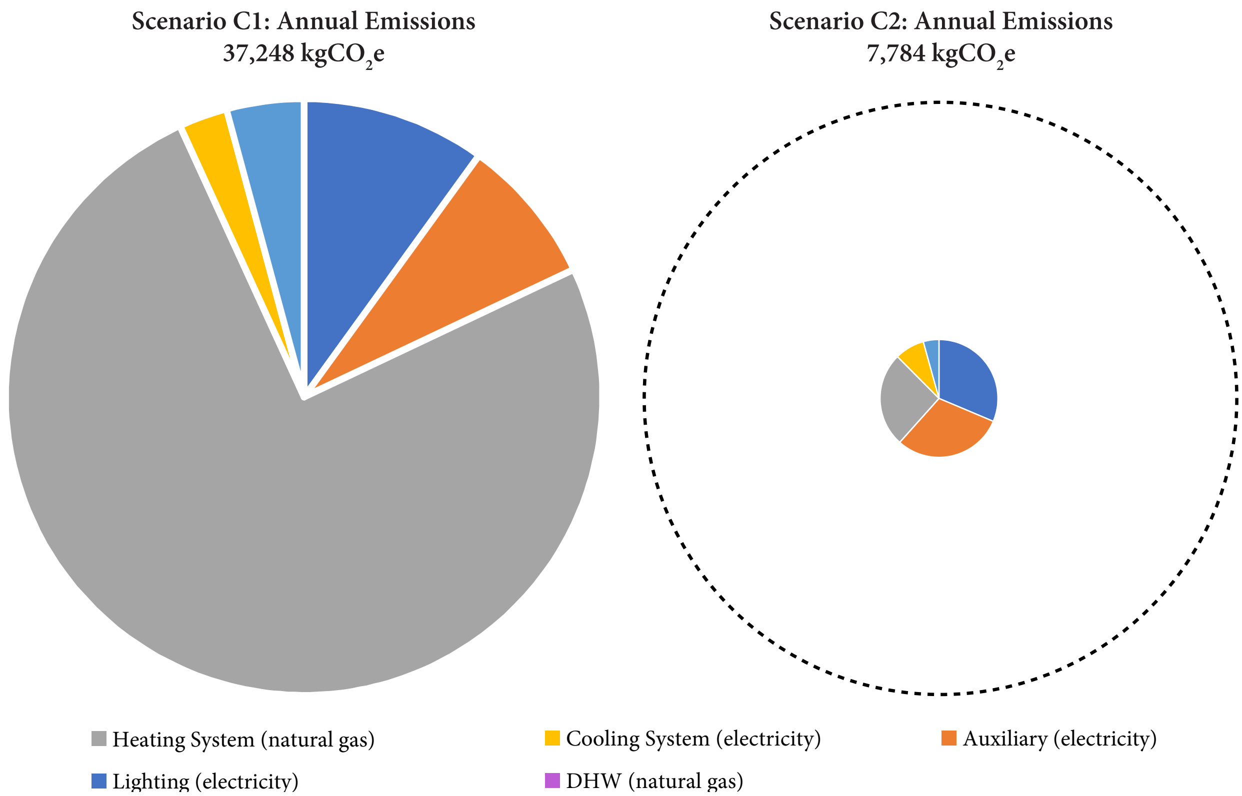


Fig 6.52 (above)
Annual emissions comparison of C1 Baseline and C2 2°C Mitigation Scenarios

component is expected to continue to increase[21]. The C2 scenario follows the NREL recommendations. This 25% plug load reduction requires that best-in-class Energy Star office equipment is specified, personal printing devices are limited, and measures are taken to provide shut-offs to reduce or eliminate parasitic loads. In retail spaces, reductions can be made by requiring retail displays on the sales floor to meet the reduced plug-load standard and the use of LED over neon or other technologies for signage. This is particularly important when considering third-party retail displays and advertisements. Applying this reduction percentage to the C1 baseline yields an equipment intensity of 1.91 W/m^2 for the retail occupancy and 6.05 W/m^2 for the office occupancy. The annual energy consumption of the elevator is also addressed. The more typical cable system is upgraded to a regenerative elevator with LED lighting in the cab to reduce the annual energy consumption by 68%, from 4,205 ekWh to 1,360 eKwh.

Scenario C2, Category 3 - Fuel Switch and System Efficiency:
This last category increases HVAC system efficiencies, changes the system types, and switches the natural gas system for an all-electric building. The optimized envelope, daylight harvesting, low-consumption equipment and shading systems reduce the heating and cooling loads the mechanical system meet compared to the C1 baseline scenario. The following three measures reduce not only the total amount of energy required to satisfy building loads, but also reduce the emissions intensity (E_i) for the heating and domestic hot water systems by 70%, from 0.164 $kgCO_2e/ekWh$ to 0.05 $kgCO_2e/ekWh$. Given that heating represents 51% of the total load and 75% of total annual emissions in the C1 baseline scenario,

Scenario C2: Monthly Energy Consumption

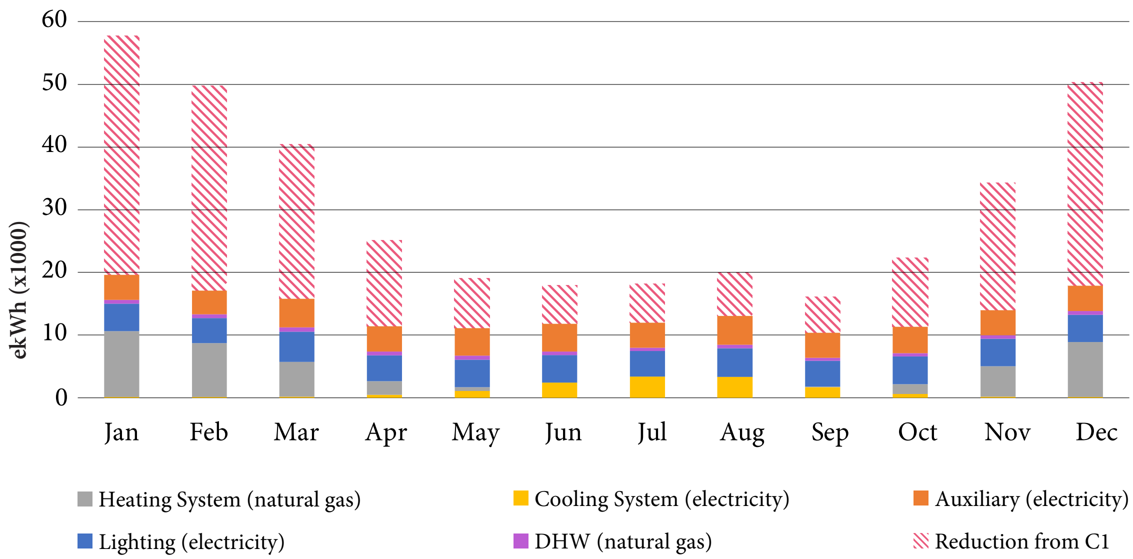


Fig 6.53 (above)
Monthly energy consumption and breakdown of the C2 2°C Mitigation Scenario

the potential to reduce emissions through switching the heating and domestic hot water from natural gas to electricity is substantial. When all measures are implemented, the results suggest that EUI can be reduced by 55.9% to 77.4 ekWh/m^2/yr. E_i can be reduced by 80.3% to 3.9 $kgCO_2e/m^2$/yr greatly exceeding the 15.3 kg/m^2/yr cap.

Scenario C2, Fuel Switch and System Efficiency 1 - Fuel Switch to Electric Heating:
The south-facing end-block baseline scenario assumes a natural gas system with a COP of 0.85 for heating and an electric system with a COP of 2.0 for cooling. These approximate a high-quality system in line with current standards and seasonal performance. In this measure, the natural gas system is replaced with a unitary electric heating and cooling rooftop unit with integrated heat recovery. This has two effects. First, the heating system is much more efficient and the COP improves from 0.85 to 2.0. Secondly, the emissions intensity of electricity in Ontario, the region where the study is located, is nearly 70% lower than natural gas. Applying this system to the C2 scenario envelope and internal load measures reduces the annual heating requirement from 141,247 ekWh to 60,030 ekWh while the associated emissions are reduced from 23,142 $kgCO_2e$ to 3,002 $kgCO_2e$. The share of emissions associated with heating compared to the annual total is reduced from 75% to 28%, suggesting that both fuel switching and system efficiency can have a dramatic effect.

Scenario C2, Fuel Switch and System Efficiency 2 - Ground Source Heat Pump
A ground-source heat pump is applied to further improve the system efficiency. The Clockshadow Building in Milwaukee, Wisconsin, USA makes use of this type of system and demonstrates that it can be applied to a building in a constrained urban site context similar to the demonstration projects. The system coefficient of performance (COP) for heating increases from 2.0 to 2.8 and cooling increases

from 3.0 to 4.0, approximating a well designed and high quality GSHP system. The EUI is reduced by 11.1%, from 88.9 ekWh/m^2/yr to to79.0 ekWh/m^2/yr compared to the unitary rooftop system. Similarly, E_i is reduced by 10%, from 5.0 kgCO_2e/m^2/yr to 4.5 kgCO_2e/m^2/yr.

Scenario C2, Fuel Switch and System Efficiency 2 - Electric Hot Water
The final measure proposes a fully electric building. Eliminating on-site combustion is required to achieve carbon-neutrality and this final measure anticipates that further improvements could be made to achieve this standard. In addition to eliminating on-site combustion, electric domestic hot water (DHW) systems consume less energy compared to natural gas. Here, energy for DHW is reduced by 33%, from 10,582 ekWh per annum to 7,110 ekWh.

Scenario C2: Annual Energy and Emissions Predictions
The annual secondary (site) energy consumption and greenhouse gas emissions for the C2 south-facing end block scenario are summarized in Table 6.3.5. below. The results suggest that the emissions cap required by the 2°C Mitigation scenario can be exceeded. The model predicts that annual energy consumption can be reduced by 55.9% compared to the C1 baseline, from 374,812 ekWh to 165,319 ekWh, equivalent to an EUI of 77.4 ekWh/m^2/yr for the C2 scenario. Lighting represents 31% of the total annual energy footprint, followed by auxiliary loads at 30%. This contrasts with the C1 scenario where heating represents 51%, the largest end-use category by a large margin. The energy consumption by season is also much less variable than the baseline scenario. This is in-line with comparable high-performance buildings with low window-wall ratios and robust envelopes where internal loads become more dominant as low-energy design measures significantly reduce heating and cooling loads and sensitivity to weather and solar insolation is reduced.

Annual emissions are suggested to be 8,266 CO_2e, 81.3% lower than the 41,844 CO_2e of the C1 baseline scenario. The building's E_i is 3.9 kgCO_2e/m^2/yr, 75% lower than the 15.3 kgCO_2e/m^2/yr emission cap required by the 2°C mitigation scenario. The switch to electricity, with an E_i of 0.05 kgCO_2e/ekWh that is 1/3 that of natural gas, significantly lowers the annual emissions over and above those associated with the reduction in energy use. With a single fuel source, the allocation of emissions by end-use matches energy consumption.

Table 6.3.5: Scenario C2 Energy and Emissions Summary

Category	Energy (ekWh)	Allocation	Emissions (kgCO_2e)	Allocation
Heating	42,879	26%	2,144	26%
Lighting	51,830	31%	2,592	31%
Auxiliary	50,030	30%	2,502	30%
Cooling	13,470	8%	674	8%
DHW	7,110	4%	356	4%
Total	165,319		8,266	
Intensity	77.4 ekWh/m^2		3.9 kgCO_2e/m^2	

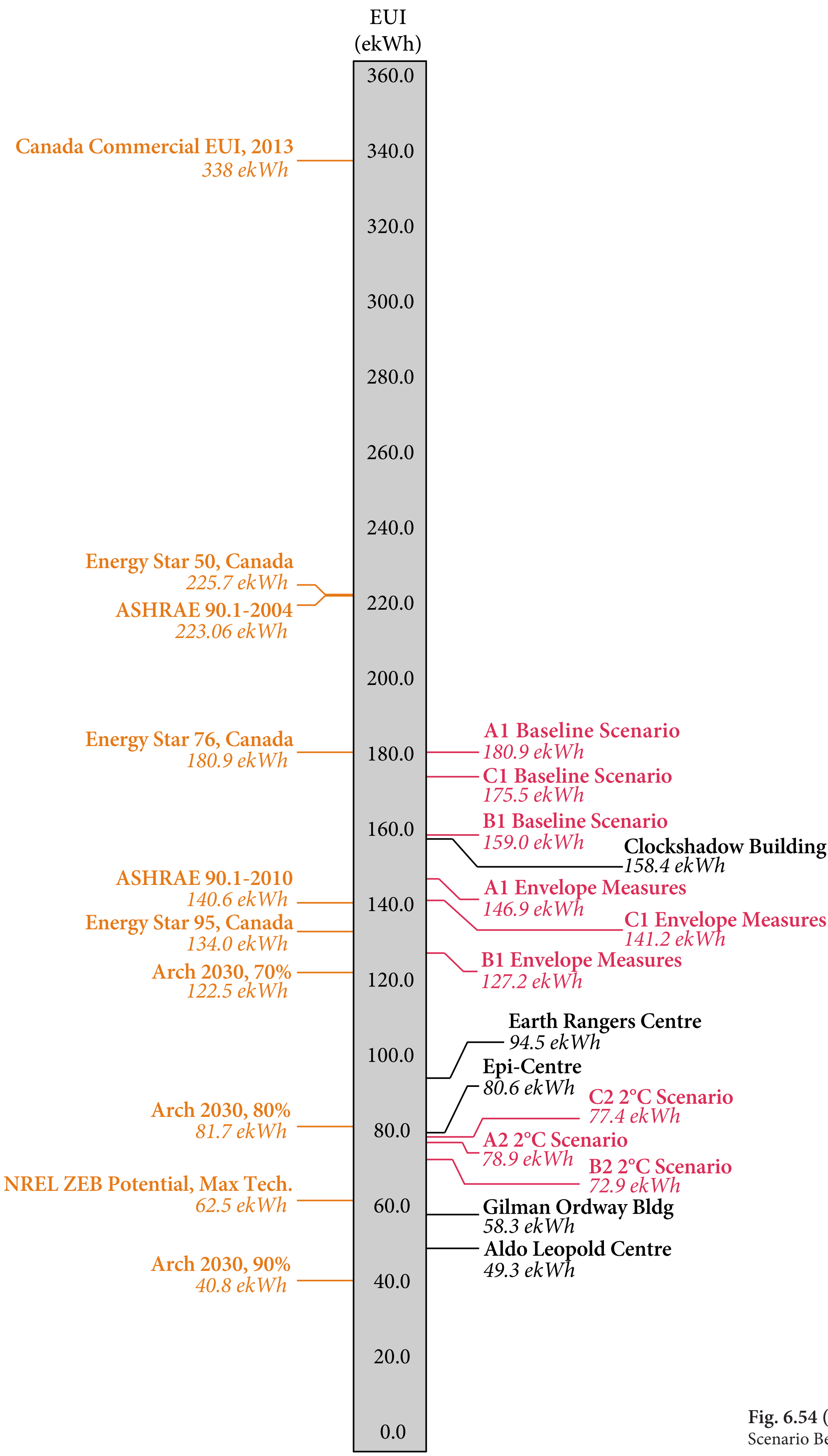
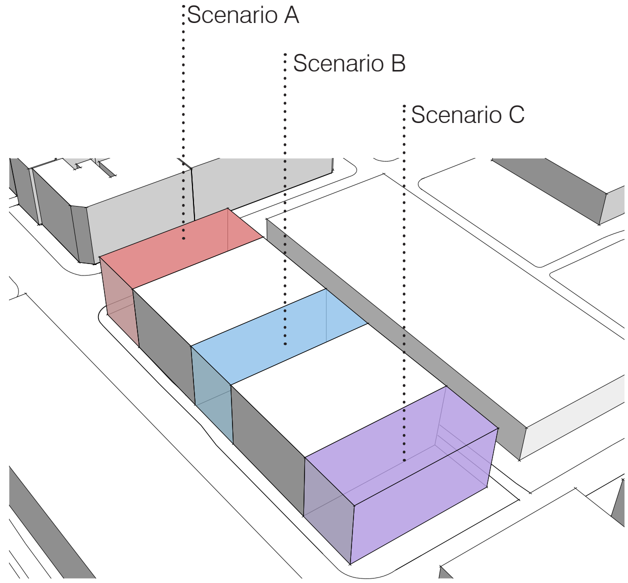


Fig. 6.54 (above)
Scenario Benchmark Diagram



6.4 Scenario Comparisons + Analysis

Fig. 6.55 (above)
Scenarios A, B and C located in the prototypical block

The analysis of the prototypical block suggests that the 2°C Mitigation emissions cap of 15.3 $kgCO_2e/m^2/yr$ can be met in each of the three site condition scenarios. Reducing building loads through passive design, internal load reduction, system efficiency, and switching the fuel type away from on-site combustion using natural gas to electricity both singly and in combination achieve the performance standard. Comparing the results against the benchmark of the case studies introduced in Chapter 5 and current standards suggests the performance threshold predicted by the models is possible with current and available technologies and on-site renewable energy installations are not necessarily required. Nevertheless, at least a 50% improvement beyond the energy and emission rates suggested by current practice are required.

Within the prototypical block, each site context performs differently and the effect and applicability of each measure varies. For example, fixed shading is recommended on the south facade of Scenario C while fixed shading on the west facade of all three blocks may increase overall energy use and emissions. Although this demonstrates the very important fact that each project is unique and must be investigated in its own right using the emissions cap formula, general conclusions and attributes can be drawn for the block as a whole and its constituent individual buildings represented by the three scenarios.

These conclusions are based on simulation results rather than the measured performance of an as-built and operating condition. Models are a prediction of performance. The true energy consumption and emissions are subject to a number of variables that include, amongst others, weather, accuracy of installation and commissioning of equipment, model assumptions reasonably representing the true built condition, and occupant behaviour. In *Benchmarking for Sustainable Buildings,* Susan Roaf suggests that modelling results can be up to three times better than the actual built reality[22]. At the Aldo Leopold Centre, modelled energy demand was 36% less than measured energy demand[23]. The difference between simulation and reality, though it will always vary from real performance no matter how refined the model, is an important consideration when placing simulated building results into the larger real-world context. This raises the importance of energy labelling and the fundamental fact that achieving emission targets are based on how a project actually performs over time.

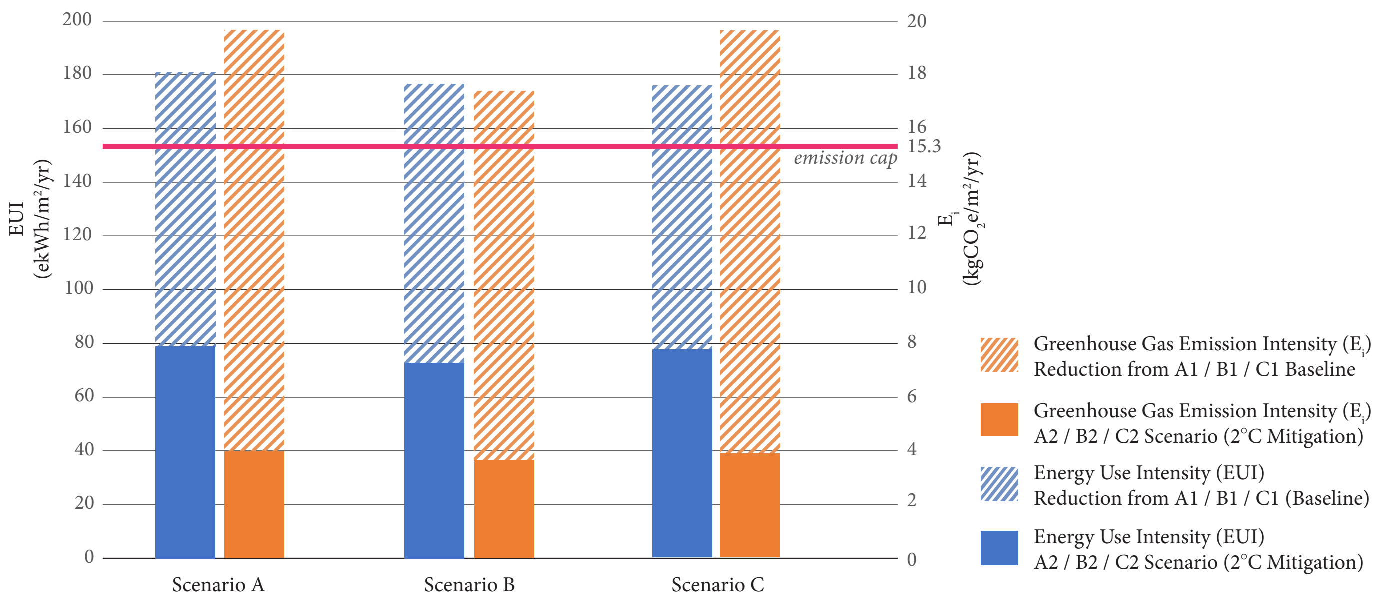


Fig. 6.56 (above)
Comparison of A2, B2, and C2 Scenario Energy Use Intensity and Greenhouse Gas Emission Intensity

Benchmarking and the Gap in Current Practice:
Benchmarking the demonstration projects with both the Case Studies identified in Chapter 5 and existing reference standards provides the basis for identifying the gap between current practice and the proposed 2°C Median Mitigation Scenario. The results demonstrate an urban building need not be net-zero or carbon neutral achieve the 2°C Scenario. The proposed building envelope measures that are over and above the mandatory requirements in the local standard are enough to achieve the minium threshold in all three site scenarios, albeit just and are equivalent to achieving a minimum Energy Star Rating of 96[24].

The EnergyStar benchmarking tool suggests that all three baseline scenarios are within the 76th percentile of buildings. Indeed, if fully and properly applied, the mandatory requirements in the local code do suggest that new construction is substantially better than the stock of existing buildings. This EUI benchmark, when combined with the low emissions intensity of electricity of the local grid, suggests that current code standards should yield urban commercial buildings that are relatively close to achieving the 2°C mitigation scenario. The 20.9 $kgCO_2e/m^2/yr$ emissions intensity of the A1 baseline scenario is 36.4% above the emission cap and has the highest EUI and emissions of the demonstration projects. The B1 mid-block site has the lowest value and is only 13.8% above the minimum while the C1 south-facing end-block site is over by 27.8%. Improving the building envelope of each scenario to the thresholds suggested in this study could achieve the emission target of the 2°C Median Mitigation Scenario. **The limitations of the urban and site context clearly have a measurable effect on EUI, emissions, and present different challenges for each site condition to achieve the emissions cap.**

"The limitations of the urban and site context clearly have a measurable effect on EUI, emissions, and present different challenges for each site condition to achieve the emissions cap."

When all envelope, design, equipment, and system measures are implemented, the results suggest that each scenario can achieve an Energy Use Intensity (EUI) within the range of the case studies and achieve an Energy Star score greater than 100. When considering the maximum technology potential suggested by the NREL Technical Potential for Net Zero Energy Buildings study, the level of energy efficiency demonstrated by these examples approach r net-zero or carbon-neutral examples. The EUI ranges of between 78.9 and 72.9 compare to EpiCentre Artists for Humanity building in Boston at 80.6 and the Gilman Ordway Building at 58.3, both of which use on-site renewable energy to achieve net-zero. They are also between the 80% and 90% EUI targets suggested by Architecture 2030 Initiative.

Table 6.4.1: Demonstration Project Scenarios A, B, and C Energy and Emissions Summary						
Measure Category	Scenario A		Scenario B		Scenario C	
	EUI (ekWh/m²/yr)	E_i ($kgCO_2e/m^2/yr$)	EUI (ekWh/m²/yr)	E_i ($kgCO_2e/m^2/yr$)	EUI (ekWh/m²/yr)	E_i ($kgCO_2e/m^2/yr$)
Baseline (A1, B1, C1)	180.9	20.9	159.0	17.4	175.5	19.6
Envelope Measures	146.9	15.2	127.2	11.7	141.2	14.1
Internal Load Measures	133.9	15.7	112.3	12.1	126.9	14.4
System + Fuel Switch (A2, B2, C2)	78.9	3.9	72.9	3.6	77.4	3.9

The full suite of measures presented not only exceed the minimum emissions, but demonstrate an EUI with net-zero and carbon-neutral potential. The energy and emission factors of the A2, B2, and C2 scenarios are much more similar than in the respective baseline scenarios. This pattern suggests the measures implemented reduce the relative effect of the urban context. The more robust envelope and internal load measures create an energy use and emission profile that is driven more by internal loads than skin-loads and the challenges presented by different site conditions, although still variable, are less pronounced. The A2 and C2 emissions intensity are the same at 3.9 $kgCO_2e/m^2/yr$ while the B2 3.6 $kgCO_2e/m^2/yr$ is the lowest of the three. The mitigation scenarios exceed the emissions cap by between 74% and 76%.

In all three sites the leasable area for the 2°C Scenario iterations is lower than the baseline scenarios. The thicker building envelope reduces it by approximately 0.5%. In the mid-block scenario, the re-organization of the floorplan to achieve better daylight autonomy reduced floor area by an additional 0.5%.

Effect of Site on Energy Performance:
A comparison of the energy and emissions, summarized in Table 6.4.1 above, illustrates the how the constraints posed by the site context and various energy efficiency and emission reduction measures vary amongst the three scenarios. At the scale of the block, the pattern of energy use between each scenario converges as energy efficiency increases. The difference between the baseline A1 scenario, which consumes the most energy, and the B1 baseline scenario, which consumes the least energy, is 12.1%. This gap is reduced to 7.6% in the A2 and B2 scenarios while the C2 scenario energy consumption nearly matches A2. This suggests that the energy efficiency measures are driven more by internal than external loads and, consequently, the impact of variation in the site context is reduced.

It is not surprising that the mid-block scenario consumes less energy than the end-block sites. With the two long facades abutting adjacent buildings, the skin-load due to the sun and exposure is drastically reduced and the adjacent buildings create a more thermally stable condition. A low window-wall ratio of 19% also ensures that heat gain and loss is comparatively minimized. On the other hand, there are less available measures to reduce energy consumption and emissions. For example, the window-wall ratio is already very low, the abutting walls are generally thermally stable and, thus, increasing the R-value will have little effect, and daylight harvesting is limited with no opportunity to introduce more apertures without dramatically reducing the salable floor area.

Conversely, the north-facing A scenario has the highest energy footprint of the three. The north facade of any building in a cold climate is a heating liability. Although the reduction in window-wall-ratio and the improvement in the R-values allows the site to achieve the 2°C emission cap, reducing the internal loads and their associated offset of heating load throughout most of the year drives up heating load with little opportunity to offset it with solar gains. The emissions intensity and efficiency of the heating system generates enough emissions that it is offset by greater heating load. At the other two sites the overall heating load is much lower in both the baseline and low-emission scenarios. Like the A site scenario, heating load does also increase when internal loads are reduced, however the overall load is low enough that emissions remain below the 2°C threshold. Heating system efficiency and emissions intensity is thus a more important end-use to address than the other two sites.

The south facing C Scenario more closely reflects the ideal massing, orientation, and configuration for passive design. It features south facing glazing, a blank northern facade, and regularly occupied spaces arranged along the east, west and south faces with service spaces buried against the blank north elevation. This is the only site where 610mm deep fixed shading devices on the south facade reduced overall energy use and emissions such that the lower cooling load is not offset by an increase in heating load. The south and west facades receive enough solar radiation to create a much higher cooling load than the other two sites. The overshadowing of the east elevation by the surrounding building context is such that any fixed shading blocks more useful heat gain than cooling is reduced. However, dynamic shading or thermochromatic glazing would be a very useful strategy to employ for additional energy savings.

It is important to note that the Row, Wingfield, Bell, and Bell suggestion for the effective R-value of zero-property line walls was conducted in England and studied row housing. The climate zone of the subject site in this research is colder and the non-residential use of the demonstration projects would behave differently. However, the study does suggest that zero-property walls are not adiabatic and are, indeed, subject to heat transfer. This study demonstrates the impact of this particular condition on building energy performance and suggests that further study into the thermal behaviour of this condition should be conducted. The R-values taken from the aforementioned study suggest a substantial heat loss and, therefore; the results presented are suggested to be conservative.

"The relationship between fuel choice and energy efficiency strategies reveal that a holistic approach must be taken where energy and emissions are measured together."

Measures Relative to the 2°C Emission Cap:
Applying the measures incrementally demonstrates a progressive improvement in energy efficiency, but not always a reduction in emissions. This is due to the change in each energy end use relative to the emissions intensity of the associated fuel. **The relationship between fuel choice and energy efficiency strategies reveal that a holistic approach must be taken where energy and emissions are measured together.** For example, if the internal load measures are implemented alone, emissions may increase. With the emission intensity of grid-supplied electricity fixed by large-scale infrastructure and a large variation in the cost of different fuel types, a project may not be able to choose the cleanest mix. In Ontario for example, electricity rates per kWh, not including distribution and other fees, ranges from 6.5 to 13.2 ¢/kWh while natural gas is ranges from 1.2 to 1.8 ¢/ekWh.

Table 6.4.2, opposite, summarizes each of the measures and their relative impact on energy consumption and emissions. In all three scenarios, the 2°C emissions cap of 15.3 $kgCO_2e/m^2/yr$ can be achieved by introducing the suite of envelope measures. The north-facing end-block just meets the requirement, with an emissions intensity of 15.2 $kgCO_2e/m^2/yr$ while the mid-block and south-facing end-block sites achieve 11.7 $kgCO_2e/m^2/yr$ and 14.1 $kgCO_2e/m^2/yr$ respectively. The typical exterior walls are increased to R24, the roof nearly doubles the amount of insulation to achieve R45, and the abutting walls are air-sealed and insulated across the facade between the two buildings leading to an increase in thermal resistance from R11 to R29. In the B2 scenario, improving the abutting wall has a substantial effect as the two long facades are this type and is equivalent to the envelope improvements and reduction in WWR made on the two end blocks. Insulated Glazing Units (IGUs) are upgraded to triple-glazed units with low-E coatings and insulating spacers. The SHGC is increased to 0.47 to admit more heat, an important measure when the heat contributed by internal equipment is reduced in later measures. Fixed shading was found to decrease overall EUI when applied to the south facade of the south-facing end-block site only.

On all three site conditions, the internal load measures reduce overall energy consumption, but increase emissions. Reducing the lighting and plug-load power densities cause heat load to increase. In this particular project, the natural gas heating system has both a higher emissions intensity and lower COP than electricity and, as a result, emissions savings associated with electricity is less than the corresponding increase caused by a higher demand on the heating system. Without other actions, introducing this set of measures alone could cause the baseline cases to see emissions rise and energy use decrease only marginally. However, should these be introduced in a building using only electricity, emissions would likely decrease, while the opposite may be true in a region like Alberta where natural gas is cleaner than electricity. The effect is most pronounced on the north-facing end-block site where emissions intensity increases by 0.5 $kgCO_2e/m^2/yr$, and least on the south-facing end block site where the increase is 0.3 $kgCO_2e/m^2/yr$. This is likely due to solar gains being available to the south exposure. EUI nevertheless does decrease by 7.2% and 8.2% respectively.

"Improving the system efficiencies and replacing the natural gas heating system with a unitary rooftop electric heating and cooling unit makes the most substantial contribution to reducing energy consumption and, to a larger degree, emissions, with the relative impact similar across all three sites."

Improving the system efficiencies and replacing the natural gas heating system with a unitary rooftop electric heating and cooling unit makes the most substantial contribution to reducing energy consumption and, to a larger degree, emissions, with the relative impact similar across all three sites. This system reduces the EUI from 133.9 $ekWh/m^2/yr$ to 91.2 $ekWh/m^2/yr$ for the A scenario, 112.3 $ekWh/m^2/yr$ to 82.6 $ekWh/m^2/yr$ for the B scenario, and 126.9 $ekWh/m^2/yr$ to 88.9 $ekWh/m^2/yr$ for the C scenario, equivalent to a 32%, 26%, and 30% respectively, and represents the single most effective strategy of all measures. With the north-facing site having a higher heating load, the increased efficiency and reduced emission intensity will have a larger relative effect compared to the other two sites. The remaining HVAC measures provide additional efficiencies in the order of approximately 10%.

Table 6.4.2: Energy and Emission Saving Measures													
Measures		Scenario A (north-facing end-block)				Scenario B (mid-block)				Scenario C (south-facing end-block)			
		EUI	Δ%	GHG	Δ%	EUI	Δ%	GHG	Δ%	EUI	Δ%	GHG	Δ%
Baseline (A1, B1, C1)		*180.9*	*0.0%*	*20.9*	*0.0%*	*159.0*	*0.0%*	*17.4*	*0.0%*	*175.5*	*0.0%*	*19.6*	*0.0%*
Building Envelope	Re-arrange Floorplan and HVAC zoning					153.2	-3.6%	16.3	-6.2%				
	Reduce WWR by 9%	172.5	-4.6%	19.6	-6.0%					166.4	-5.2%	18.3	-6.6%
	Increase Exposing Wall R-Value to R24 (+28%) Increase Roof R-Value to R45 (+71%) Increase Abutting Wall R-Value to R29 (+150%) Improve to Triple-Glazed Low-E, insulated IGU spacer	147.9	-18.3%	15.5	-26.0%	128.0	-19.5%	11.9	-31.6%	142.4	-18.9%	14.2	-27.4%
	Increase SHGC from 0.36 to 0.47	146.9	-18.8%	15.2	-27.5%	127.2	-20.0%	11.7	-32.9%	141.6	-19.3%	13.8	-29.5%
	610mm Fixed Shading on South Elevation									141.2	-19.5%	14.1	-28.3%
	Measure Subtotal	*146.9*	*-18.8%*	*15.2*	*-27.5%*	*127.2*	*-20.0%*	*11.7*	*-32.9%*	*141.2*	*-19.5%*	*14.1*	*-28.3%*
Internal Loads	Reduce LPD by 29% in Retail, 30% in Office	140.0	-22.6%	15.5	-25.7%	120.0	-24.5%	12.0	-31.2%	133.8	-23.8%	14.3	-26.8%
	Add daylight harvesting continuous dimming	132.9	-26.5%	15.3	-26.8%	117.1	-26.4%	12.0	-31.1%	126.3	-28.1%	14.1	-28.1%
	Reduce Plug Loads by 25% and elevator by 68%	133.9	-26.0%	15.7	-24.9%	112.3	-29.4%	12.1	-30.6%	126.9	-27.7%	14.4	-26.3%
	Measure Subtotal	*133.9*	*-26.0*	*15.7*	*-24.9%*	*112.3*	*-29.4%*	*12.1*	*-30.6%*	*126.9*	*-27.7%*	*14.4*	*-26.3%*
System +Fuel Switch	Switch to electric unitary rooftop unit for heating and cooling, COP for heating from 0.85 to 2.0	91.2	-49.6%	5.1	-75.5%	82.6	-48.1%	4.7	-73.1%	88.9	-49.4%	5.0	-74.5%
	Ground Source Heat Pump, COP cooling from 3.0 to 4.0, heating COP from 2.0 to 2.8	80.5	-55.5%	4.6	-78.3%	74.5	-53.1%	4.3	-75.4%	79.0	-55.0%	4.5	-77.0%
	Electric Hot Water	78.9	-56.4%	3.9	-81.1%	72.9	-54.2%	3.6	-79.1%	77.4	-55.9%	3.9	-80.3%
2°C Mitigation (A2, B2, C2)		*78.9*	*-56.4%*	*3.9*	*-81.1%*	*72.9*	*-54.2%*	*3.6*	*-79.1%*	*77.4*	*-55.9%*	*3.9*	*-80.3%*

Although internal load measures decrease energy but increase emissions, ... a more robust envelope, improved HVAC system efficiency, and making use of fuels with the lowest emission intensity will always have a positive impact deployed either singly or together. When deployed holistically, all measures make a positive impact.

Comparing the results suggests the surrounding urban fabric and site constraints do create a unique energy and emissions context for each site. The north-facing site has a higher heating load, fixed shading is only effective on the south-facing site, and the mid-block site is driven more by internal loads and has the lowest energy footprint. Nevertheless, not only can the 2°C Scenario be achieved in all cases, the energy and emissions in the final A2, B2, and C2 iterations have an EUI consistent with the high-performance case studies that, in some cases, achieve net-zero or carbon neutral. Although internal load measures decrease energy but increase emissions, the results nevertheless suggest a more robust envelope, improved HVAC system efficiency, and making use of fuels with the lowest emission intensity will always have a positive impact deployed either singly or together. When deployed holistically, all measures make a positive impact.

The 2°C Target Relative to Net-Zero and Carbon-Neutral:

Renewable energy is not proposed for the 2°C iteration for each site for a number of reasons. The first is that the results suggest that the measures achieve emissions well below the 2°C emissions cap. Secondly, overshadowing by rooftop projections, trees, and adjacent buildings can result in low yields for PV and Solar Hot Water while the sites are not suitable for wind turbines of a size or scale that can make a measurable difference in offsetting electricity demand. Thirdly, the mitigation studies upon which the emission target is based allocate renewable energy to the power generation sector, regardless of location or size. Fourthly, and most importantly, the urban fabric is continually developing. Lots are routinely redeveloped for higher densities and heights that can completely overshadow adjacent buildings. The timing and impact of future construction cannot be anticipated. Currently, there is no policy that could be found at the time of writing that addresses the replacement or relocation of affected renewable energy installations. For example, the 109OZ condominium is currently under construction on Ossington Avenue in Toronto, Ontario, a street that represents the built form and street Right-of-Way in this study. The proposed building is twice the height of the surrounding buildings and is higher than the width of the R.O.W. and, consequently, adjacent buildings will now be overshadowed.

Nevertheless, the case studies in Chapter 5 and other technical reports suggest the demonstration project buildings could achieve even lower EUI and annual emissions that approach net-zero or carbon-neutral. The proposed measures have a technical potential that can be improved, in some cases substantially. For example, lighting technology and design has been demonstrated to successfully achieve a further 20% reduction with an LPD of 0.6 W/ft^2 (6.45 Wm^2). The building envelopes of the best-performing study buildings in Climate Zone 6 feature walls and roofs with R-values nearly twice those proposed in the 2°C Scenario and techniques such as offset framing and Structurally Insulated Panels can dramatically improve performance by reducing thermal bridging. The Aldo Leopold Centre, for example, has an overall envelope R-value of 64 and the Passivehaus standard for Climate Zone 6 is between R-39 and R-51 for walls and R-70 for the roof[25]. The A2, B2, and C2 scenarios propose a wall R-value of R24 and a roof R-value of R45. Although less than some examples, it is nevertheless comparable to some of the case studies, including the Gilman Ordway Building and the Earth Rangers Centre.

Fig. 6.57 (above)
109OZ condominium proposal

Fig. 6.58 (right)
Ossington Avenue, Toronto, Ontario

Attaining net-zero or carbon-neutrality would require on-site renewable energy. With the building footprint occupying nearly the entire site, roof-mounted PV panels would be a suitable technology. If the overshadowing potential of future development, roof pop-ups and equipment, and mature street-tress are not considered, the available roof area for PV is 290m^2. Using the PVWatts tool[26] to calculate energy production, a 17% efficient array could produce 57,675 kWh of electricity per annum. With the annual energy requirement for the A2, B2, and C2 scenarios ranging from 155,674 kWh to 168,537 kWh, the array would satisfy less than 40% of the annual energy requirement at the performance level currently proposed and suggests that net-zero would be very difficult to achieve.

The 2°C Target and On-Site Renewable Energy:
Of the selected case studies, net-zero or carbon-neutral performance is a stated goal that has, in many of these examples, been achieved. On-site renewable energy arrays, green energy purchase credits and, the case of the Aldo Leopold Centre, a managed stand of trees are used to offset greenhouse gas emissions. **However, in the context of the emission reductions outlined in the mitigation studies that form the basis of the proposed emission cap, renewable energy installations are allocated to the power sector.** Emission reductions required by the building sector are to be achieved by reducing energy demand and limiting on-site combustion. In each scenario, a global or regional share of electricity generation from renewable energy is proposed. In other words, to use renewable energy credits or on-site renewable energy as a means to achieve the proposed emission cap of 15.3 kg/m^2/yr is considered "double-counting". The World Resources Institute *Guidelines for Quantifying GHG Reductions from Grid Connected Electricity Projects* cautions against this double-counting and requires that GHG reductions must be resolved through legal or policy measures[32].

"When considering emission reductions from the building sector to achieve the climate change targets as required by the core mitigation scenarios, it is building energy consumption that must be reduced."

When considering emission reductions from the building sector to achieve the climate change targets as required by the core mitigation scenarios, it is building energy consumption that must be reduced. In the World Energy Outlook 2012 450-ppm Scenario, it is energy demand reduction that is largest potential of emission reduction in the short term[33]. With the window for peak emissions suggested to close by 2020[34], this fact cannot be ignored. Therefore, achieving net-zero, carbon-neutral, or purchasing green power credits, can be considered a layer of concern over and above the energy consumption threshold required by the 15.3 kgCO_2e/m^2/yr cap. In other words, the methodology proposed by the Architecture 2030 Initiative aligns with international standards where a minimum reduction in building EUI be achieved across the building sector regardless of on-site renewables or GHG removals.

The 2°C Threshold Relative to Existing and Upcoming Building Code Improvements: The A1, A2, and A3 baseline scenarios follow the mandatory requirements of the prevailing local code, the Ontario Building Code Supplementary Bulletin 10 - Energy Efficiency Requirements. The improvements to the building envelope just achieve the Energy Use Intensity thresholds to achieve the 2°C Scenario. The thermal transmittance of the walls increased 29%, the roof 73%, and the glazing by 50%, by using triple glazed IGUs, and the Window-Wall Ratio is reduced by 9% on the end-block sites while it remains already 52% lower on the mid-block site. Improving heating system COP from 0.85 to 2.8 and the cooling system COP from 3.0 to 4.0 further improve EUI to achieve emissions below the 15.3 $kgCO2e/m^2/yr$ threshold. These combined improvements suggest urban projects can achieve energy efficiency similar to the case studies presented, assuming that measured energy consumption and emissions can consistently achieve the design ambitions.

The results suggest that the mandatory compliance path requirements in the local code require improvement to achieve climate change requirements. This study was based on the 2011 edition that was in effect until December 31st, 2016. **As of 2017, an update was published that increased these mandatory requirements by a further 13%[35]. This trend demonstrates a continued improvement towards lower energy consumption over time. Given that envelope measures meet the 2dC requirement with an EUI between 18.% and 20.0% lower than the prescriptive path minimum standard, achieving climate change goals are easily achievable. Peak emissions are required by 2020, however, and the pace of regulatory change suggests that efforts to close this gap should be accelerated.**

The 2°C Target Emission Boundary:

The emission boundary of the 2°C Median scenario presented here follows the IPCC sectoral emission allocation. The emissions accounted for are secondary energy from Scope One Energy Direct and Scope Two Energy In-Direct emission sources. This is equivalent to on-site combustion of natural gas, wood, and other heating fuels and imported electricity measured in kWhr at the meter. Primary emissions related to energy generation and transportation is allocated to the power sector. Scope Three emissions in the form of embodied energy of materials over the building's lifecycle or other operational emissions, such as employee commuting, are not included. In these two instances, emissions are allocated to the industrial and transportation sectors, respectively. Emission reductions from off-site renewable energy credits, GHG reductions that meet the definition of additionality and on-site renewable energy arrays are also excluded.

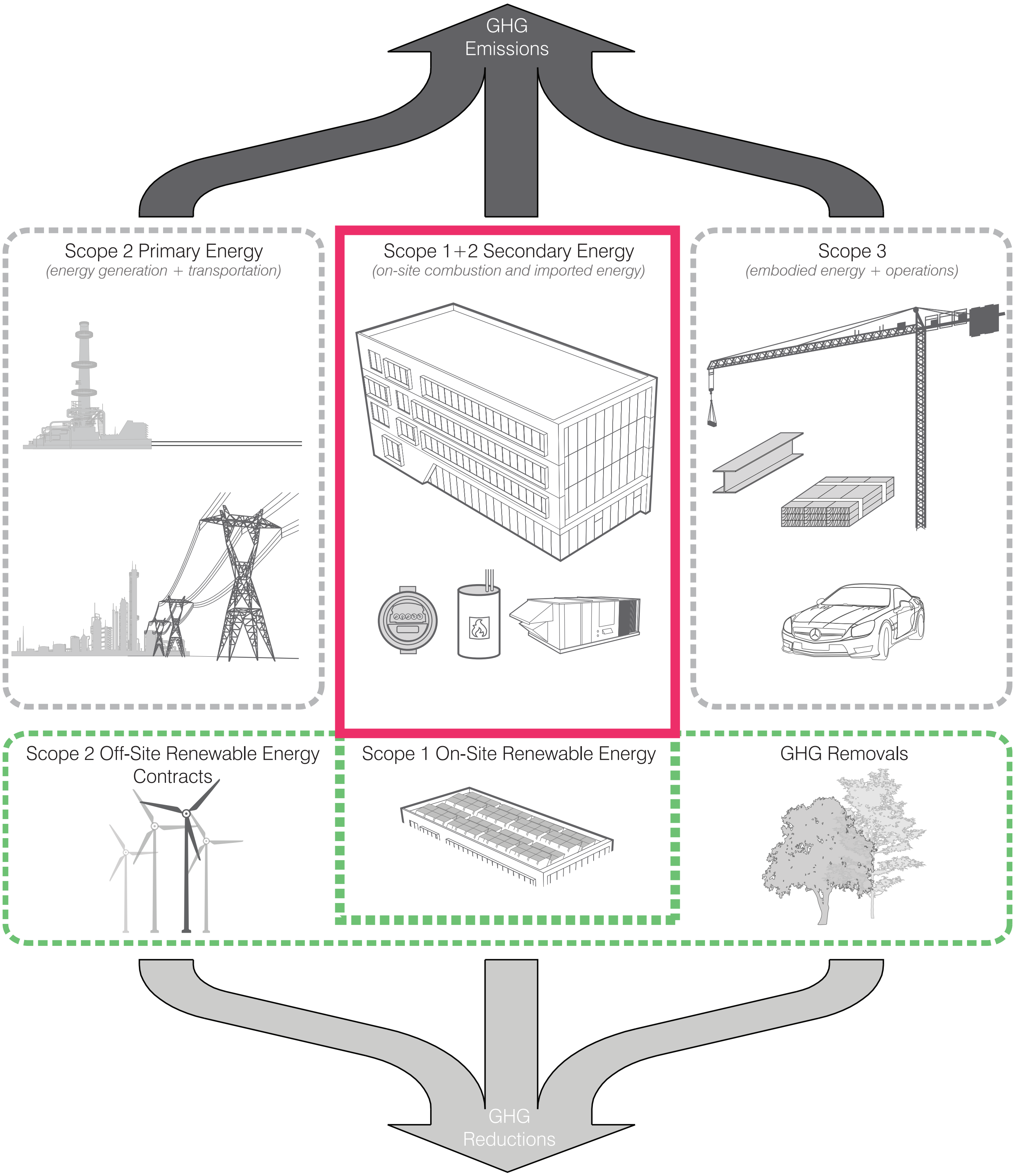
Fig. 6.59 (right)
2°C Scenario Emission Scope

The Scope Diagram, presented in Figure 6.59, illustrates the emission sources from all scopes that feed into the total lifecycle emissions of a building and the limited boundary that is assigned to the building sector. Many methodologies that investigate building emissions and energy consumption have expanded scopes. Achieving Net-Zero Energy, the Architecture 2030 Initiative, and the UNEP Common Carbon Metric for Measuring Greenhouse Gas Emission in Buildings, for example, all include Scope One On-Site renewable energy. The Living Building Challenge accounts for Scope Three Embodied Energy, and the Aldo Leopold Centre demonstrated additionally with a managed tree stand within the boundary of its rural site to successfully apply GHG reductions. Clearly, the greenhouse gas emissions from a building are varied, extensive, and involve sources beyond those allocated using the international sectoral standards. The McKinsey and Company Pathways to a Low Carbon Economy suggest that cross-sectoral opportunities in the building sector are larger than any other sector[36]. **When considering GHG emissions, all scopes should be taken into account.**

Given the expanded nature of emissions that can be positively effected by careful design and operation of buildings, the 2°C can be placed in the larger context by considering it a layer of concern amongst the larger discussion of sustainable buildings and emissions. The thresholds presented by the 2°C Scenario require a minimum energy performance from buildings in order to achieve climate change targets over and above on-site renewable energy installations, optimized material selections, and off-site green energy credits. This conclusion is similar to the methodology of the Architecture 2030 Initiative where minium energy efficiency is required. A holistic approach to sustainability is required when approaching building design and the 2°C Scenario targets are one aspect of a larger equation.

"A holistic approach to sustainability is required when approaching building design and the 2°C Scenario targets are one aspect of a larger equation.

The limited nature of emission studied here also suggest that further study in the relationship between primary and secondary emission sectors requires further study. The fuel used to create grid electricity effects building emissions and are essential to success. On the other hand, improved building efficiency is also required to achieve the lower overall energy production for the energy grid required by the power sector to achieve its climate change ambitions. Less considered is similar relationship between optimized building design for materials for the industrial sector to achieve lower emissions.


GHG
Emissions
Scope 2 Primary Energy
(energy generation + transportation)
Scope 1+2 Secondary Energy
(on-site combustion and imported energy)
Scope 3
(embodied energy + operations)
Scope 2 Off-Site Renewable Energy
Contracts
Scope 1 On-Site Renewable Energy
GHG Removals
GHG
Reductions

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7.0 Conclusions

The imperative for sustainable design as both an architectural language and a design metric is not new. Rather, it is the impetus to bring a widespread improvement in building energy performance in a technically accurate way within the larger context of looming and irreversible climate change that is. Consensus agrees that the building sector will play a vital role in achieving the emission reduction ambitions of the Paris Accord in the long term and peak emissions by 2020 in the short term, particularly as the adoption of climate change policies accelerate.

The practical discussion of buildings in this context has largely focused on net-zero and carbon-neutral performance. Although built examples demonstrate that this is technically feasible using current and proven technologies, these standards remain the exception rather than the norm. A large number of commercial urban buildings would also find it difficult to achieve them at the development densities represented by many existing city streets. With Energy Star ratings beyond 100, these ambitions represent a substantial leap forward compared to current practice.

There is, however; a middle ground. GHG emissions for commercial buildings in Canada should be approximately 40 $MtCO_2e$ by 2050, less than half the projected Business-As-Usual projection. Forecasting new construction until 2050, this goal requires that new and substantially renovated commercial buildings achieve 15.3 $kgCO_2e/m^2/yr$, suggesting that the widespread adoption of neither net-zero nor carbon-neutral buildings is required to achieve climate change goals. In fact, the energy consumption threshold implied by this cap is required whether these standards are applied or not. Benchmarking the results with current practice and low-energy case studies illustrates the importance of aligning emission and energy metrics with the goals outlined in published climate change mitigation pathways. The emission cap is not presented as an exclusive claim to achieving a sustainable building and the threshold should be considered an essential component to it; minimum efficiency should be achieved before GHG reductions, such as on-site renewable energy, power credits, or tree planting are implemented.

Since the benchmark year of 2005, more stringent measures in Building Codes and reducing the emissions intensity of the electricity grid suggest that half of the required emission reductions have been made. However, in Ontario and Quebec, the electricity grid is already one of the cleanest in the world and the Ontario Building Code Energy Supplement SB-10 prescriptive requirements, as of the end of 2016, already improves upon the ASHRAE 90.1-2010 standards by 5% to achieve an equivalent Energy Star rating of 75. Therefore, further change in this region simply relies on better buildings and implies an even bigger gap in both standards and infrastructure elsewhere. However, the demonstration projects suggest that the required change need not rely on cutting-edge techniques or emerging technologies reserved for a select few ambitious buildings. Given that the envelope measures alone represent an Energy Star Rating of 96, they rather represent the continued incremental evolution of building codes and, perhaps more importantly, suggest the gap in current practice is driven more by a lack of craft and execution of even current standards as prescriptive compliance path measures suggested building performance exceeds the median Energy Star ratings.

Urban sites do present a challenge to achieving low energy performance. Modelling suggests that the surrounding urban fabric creates higher loads compared to rural or suburban sites and that buildings set within the typical urban morphology studied here have a higher Energy Use Intensity. Within an urban block, the constraints of the site itself also affect building performance. North-facing end-block sites require more energy, and consequently generate more emissions. The effects of abutting buildings in mid-block sites create a lower energy use intensity compared to end-block conditions and are dominated by internal loads more than skin loads. Although energy and emissions vary across the prototypical block, the emission reductions of the 2°C scenario can nevertheless be met simply by improving the envelope and exceeded by reducing internal loads and deploying high-efficiency electric HVAC systems. Although somewhat more challenging, urban sites nevertheless demonstrate a similar potential for low-energy design to suburban or rural sites with unimpeded solar envelopes.

The relationship between fuel choice and the energy efficiency strategies must be considered as lower EUI does not always correlate to lower greenhouse gas emissions. The ability to choose cleaner fuels is not always possible, particularly on tight urban sites where on-site renewable energy arrays may not be effective or appropriate or the cost of the cleaner fuel is not affordable. Although this study allows general conclusions to be drawn, each lot is distinct and the site constraints and local energy mix will yield a unique built-form and system solution.

The fuel mix in different regions in Canada suggest that the building sector cannot meet its climate change obligations on its own. Alberta and Saskatchewan, for example, currently have an electricity grid that, when the emission cap is applied, yield an annual energy budget that simply cannot be met in even the most energy efficient building. Given that fuel-switching is one of the more potent measures, the role of the larger power generation and supply infrastructure is intertwined with the ability of the built environment to meet its obligations. Nevertheless, this should not deter a move towards stringent energy efficiency. With the 50 year lifecycle of durable commercial buildings, future improvements to create cleaner electricity could bring a region's buildings within the emissions.

The bottom-up approach of using an emission cap provides a means for each project to determine its own path to achieve it. In this way, it becomes more than simply a design or policy tool or a standard, but rather a generator of form, expression, and invention that not only roots a project in its local context, but perhaps makes it at once relevant to a global one. When seen as an opportunity rather than a constraint, the emissions cap can take on a generative role where energy-efficiency is no longer a goal in and of itself, but is instead woven into the larger agency of living with the means and limits of our environment. It is a constraint, not in a negative sense, but one that allows and possibly even drives invention, imagination, and change.

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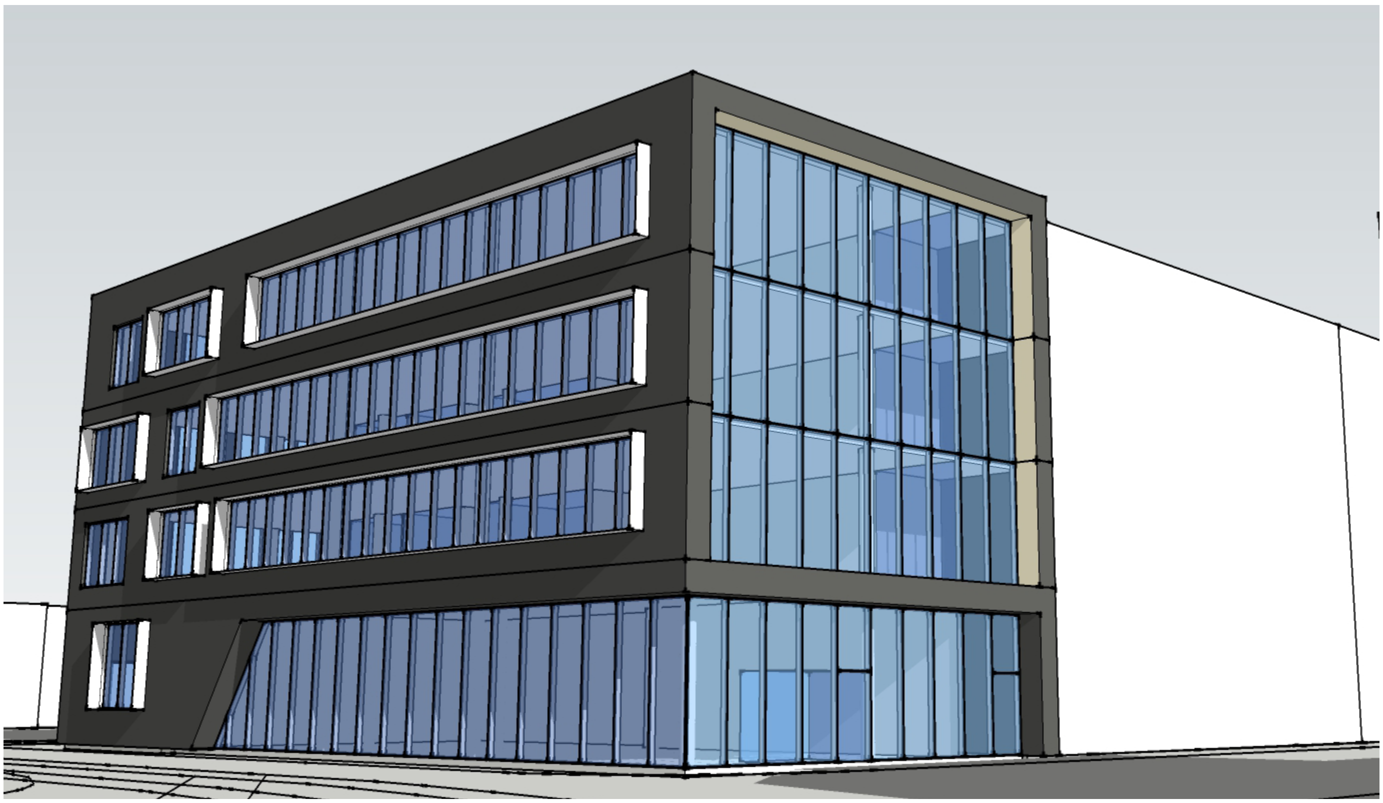
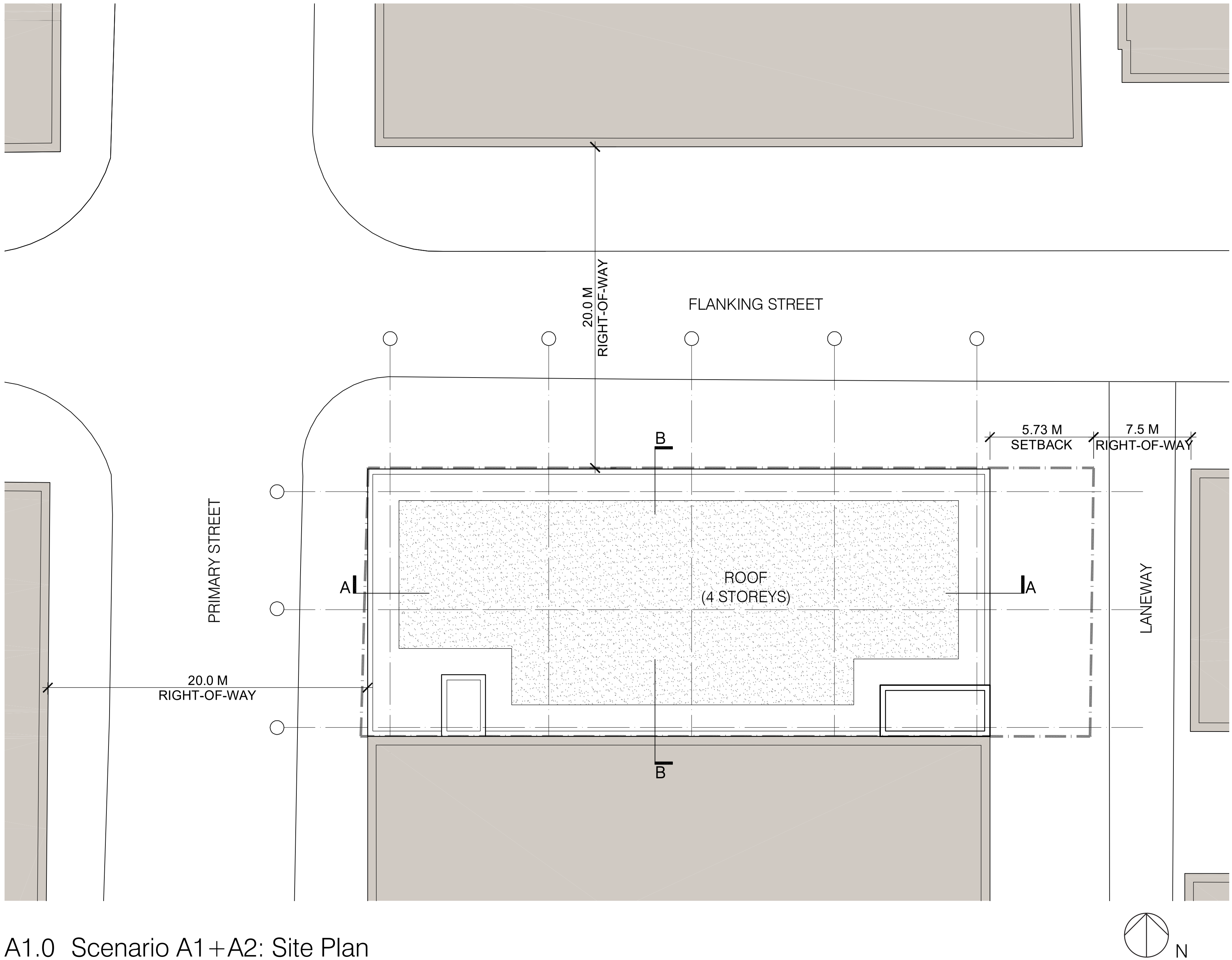
APPENDIX A:
SCENARIO A1 + A2 DRAWINGS



Drawing and Document List:



A1.0 Scenario A1+A2: Site Plan

Name of Practice:

Name of Project:
THESIS: SCENARIO A: NORTH FACING END LOT

Location:
TORONTO, ONTARIO

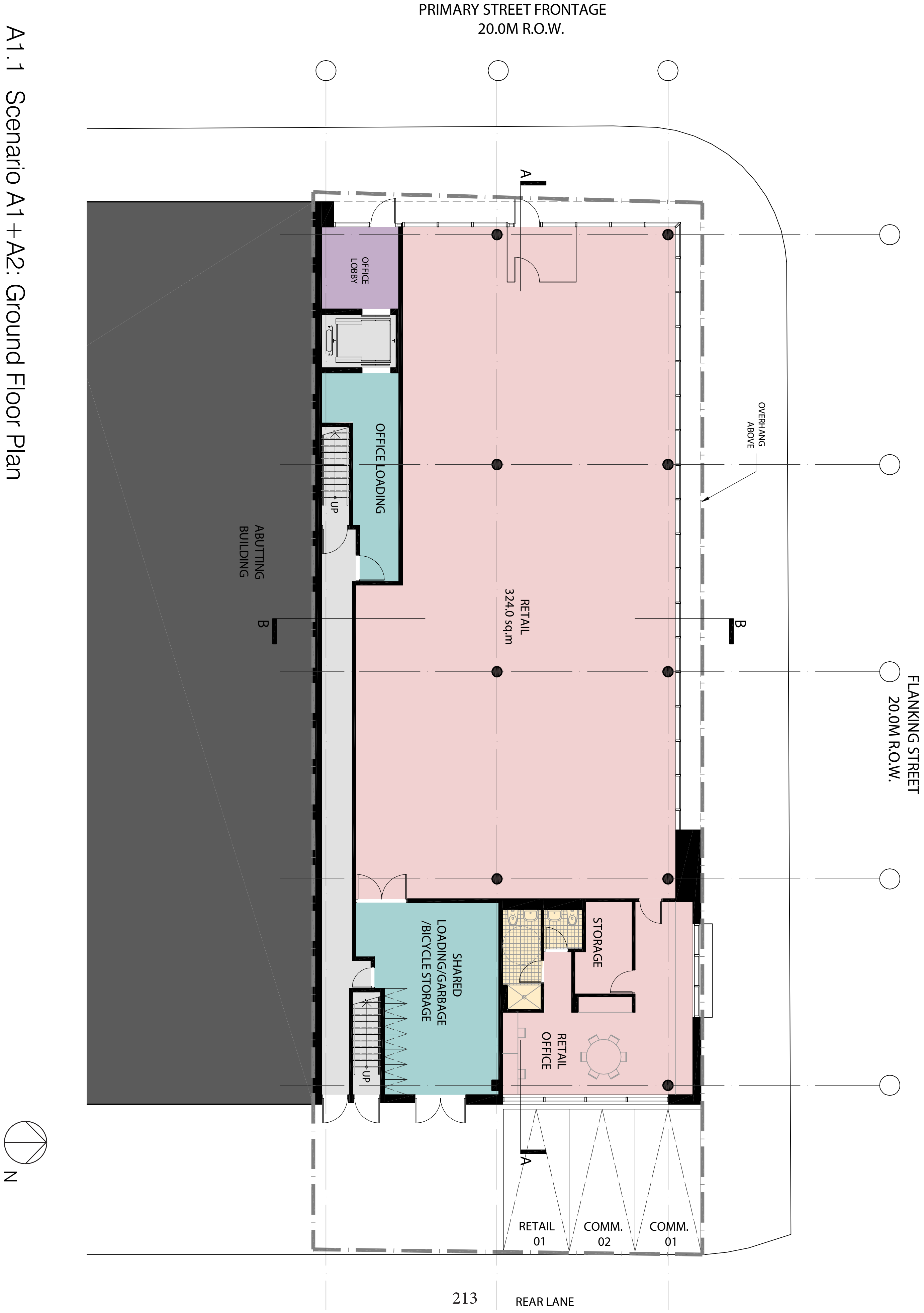
Item	Ontario's 2006 Building Code Data Matrix Part 3 or 9		BC Reference: References are to Division B unless noted [A] for Division A or [C] for Division C.	
1	Project Description: ☑ New ☐ Addition ☐ Change of Use ☐ Alteration	☐ Part 11 11.1 to 11.4	☑ Part 3 1.1.2. [A]	☐ Part 9 1.1.2. [A] & 9.10.1.3.
2	Major Occupancy(s) ***Group D: Business and Personal Services Occupancy*** ***Group E: Mercantile Occupancy***		3.1.2.1.(1)	9.10.2.
3	Building Area (m²) Existing ________ New 534.0 Total 534.0		1.4.1.2. [A]	1.4.1.2. [A]
4	Gross Area Existing ________ New 2,135.0 Total 2,135.0		1.4.1.2. [A]	1.4.1.2. [A]
5	Number of Storeys Above grade ***4*** Below grade ***1***		1.4.1.2. [A]&3.2.1.1.	1.4.1.2[A] & 9.10.4
6	Number of Streets/Fire Fighter Access ***2***		3.2.2.10. & 3.2.5.	9.10.20.
7	Building Classification ***Group D: Up to 4 Storeys, Sprinklered (3.2.2.52)*** ***Group E: Any Height, Any Area, Sprinklered (3.2.2.57)***		3.2.2.52 / 3.2.2.57 3.2.2.4 - 3.2.2.7	9.10.2.
8	Sprinkler System Proposed ☑ entire building ☐ selected compartments ☐ selected floor areas ☐ basement ☐ in lieu of roof rating ☐ not required		3.2.2.20.-.83 3.2.1.5. 3.2.2.17. INDEX	9.10.8.2. INDEX
9	Standpipe required ☑ Yes ☐ No		3.2.9.	N/A
10	Fire Alarm required ☑ Yes ☐ No		3.2.4.	9.10.18.
11	Water Service/Supply is Adequate ☑ Yes ☐ No		3.2.5.7.	N/A
12	High Building ☐ Yes ☑ No		3.2.6.	N/A
13	Construction Restrictions ☐ Combustible permitted ☐ Non-combustible required ☑ Both Actual Construction ☐ Combustible ☐ Non-combustible ☑ Both		3.2.2.52 / 3.2.2.57 3.2.2.4 - 3.2.2.7	9.10.6.
14	Mezzanine(s) Area m² ___________________________		3.2.1.1.(3)-(8)	9.10.4.1.
15	Occupant load based on ☑ m²/person ☐ design of building Basement: Occupancy: 46.0 m² / person Load 12 persons 1st Floor Occupancy: 3.70m² / person Load 138 persons 2nd Floor Occupancy: 9.30m² / person Load 47 persons 3nd Floor Occupancy: 9.30m² / person Load 47 persons 4th Floor Occupancy: 9.30m² / person Load 47 persons		3.1.17.	9.9.1.3.
16	Barrier-free Design ☑ Yes ☐ No (Explain) ______________________		3.8.	9.5.2.
17	Hazardous Substances ☐ Yes ☑ No		3.3.1.2. & 3.3.1.19.	9.10.1.3.(4)

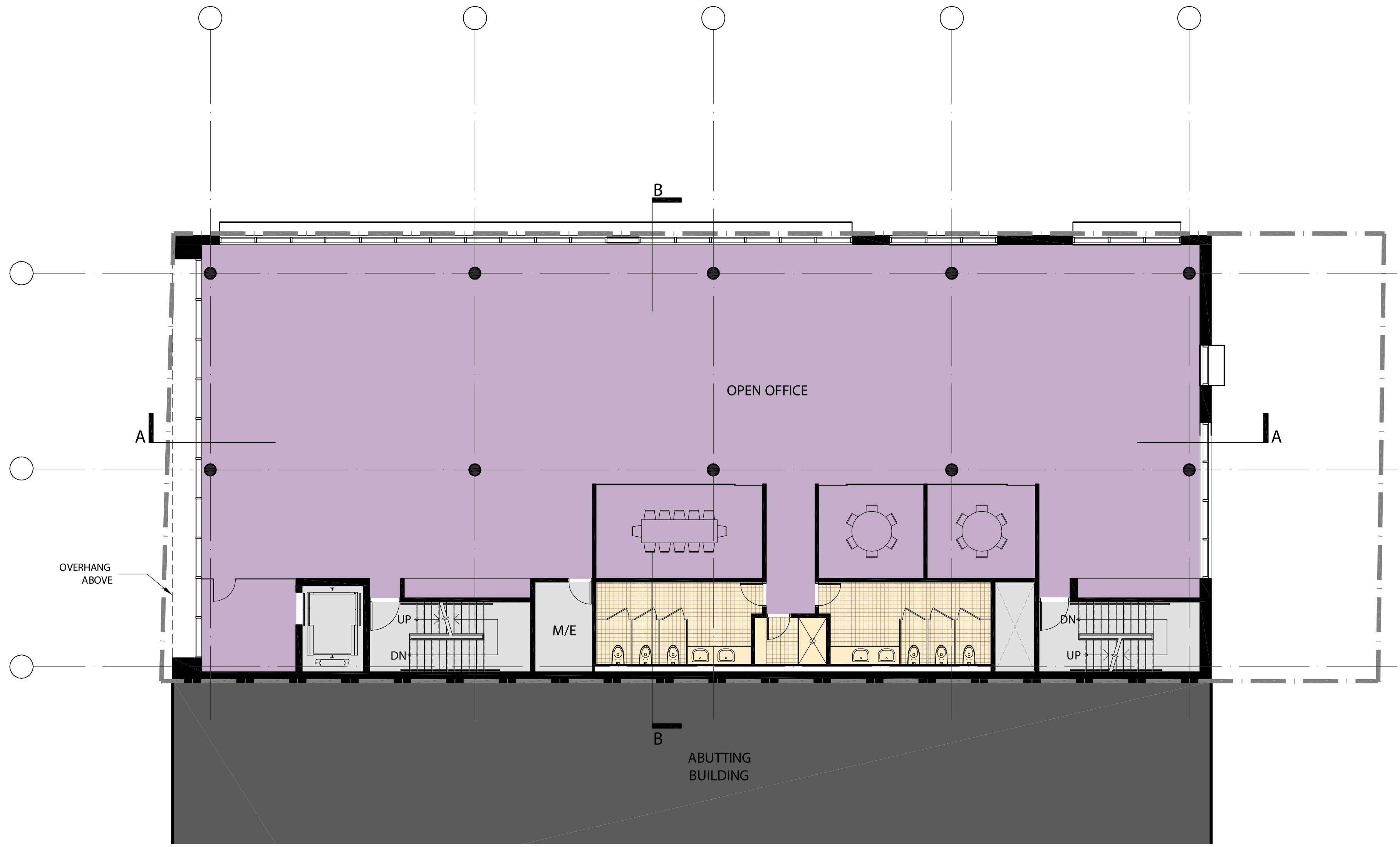
18	Required Fire Resistance Rating (FRR)	Horizontal Assemblies FRR (Hours)	Listed Design No. or Description (SG-2)	3.2.2.52 / 3.2.2.57 3.2.2.4 - 3.2.2.7	9.10.8. 9.10.9.
		Floors L01-02: 2.0 Hours Floors L03-04: 1.0 Hours			
		Roof: 1.0 Hours			
		Mezzanine: N/A			
		FRR of Supporting Members	Listed Design No. Or Description (SG-2)		
		Floors L01: 2.0 Hours Floors L02-04: 1.0 Hours			
		Roof: 1.0 Hours			
		Mezzanine: N/A			

19	Spatial Separation – Construction of Exterior Walls										3.2.3.	9.10.14.
	Wall	Area of EBF (m²)	L.D. (m)	L/H or H/L	Permitted Max. % of Openings	Proposed % of Openings	FRR (Hours)	Listed Design or Description	Comb Const	Comb. Constr. Nonc. Cladding	Non-comb. Constr.	
	North (L01)	187.0	9.60	N/A	64%	A1: 63% A2: 42%	1.0		Yes	No	No	
	North (L02-04)	427.5	9.60	N/A	100%	A1: 53% A2: 42%	45 min		Yes	No	No	
	South (L01)	190.6	0.0	N/A	64%	A1: 0% A2: 0%	4.0		No	No	Yes	
	South (L02-04)	446.6	0.0	N/A	100%	A1: 0% A2: 0%	4.0		No	No	Yes	
	East (L01)	77.3	8.75	N/A	80%	A1: 20% A2: 20%	1.0		Yes	No	No	
	East (L02-04)	190.5	8.75	N/A	80%	A1: 43% A2: 43%	45 min		Yes	No	No	
	West (L01)	73.8	9.14	N/A	100%	A1: 78% A2: 78%	1.0		Yes	No	No	
	West (L02-04)	196.5	9.14	N/A	100%	A1: 83% A2: 49%	45 min		Yes	No	No	

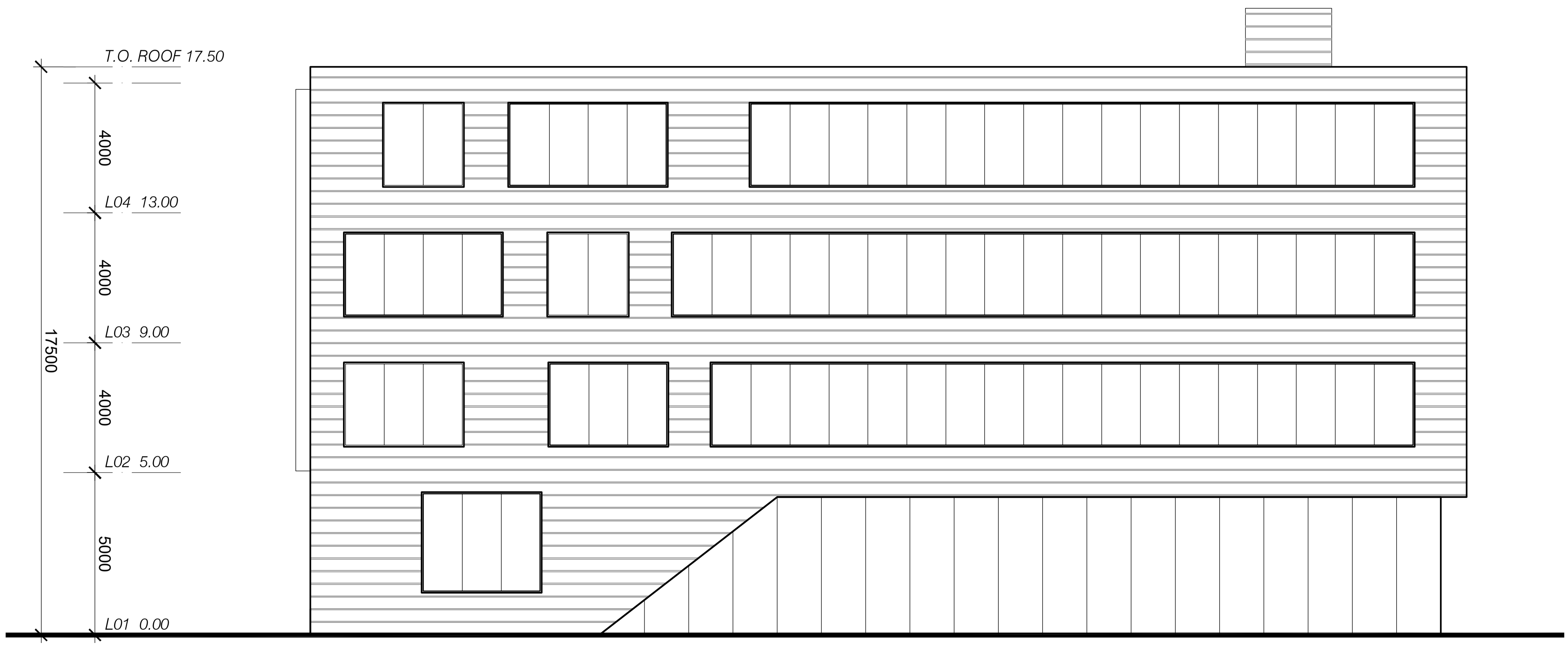
20	Plumbing Fixture Requirements						
						BC Reference	
						☑ Part 3	☐ Part 9
	Male/Female Count @ _____% / _____%, except as noted otherwise	Occupant Load	BC Table Number	Fixtures Required	Fixtures Provided		
	Basement: Occupancy: Storage	12	3.7.4.8	0	0	3.7.4.1 (3)	
	1st Floor: Occupancy: Mercantile	37	3.7.4.8	2	2	3.7.4.8 (2)	
	2nd Floor: Occupancy: Business / Personal Serv.	47	3.7.4.7	6	6	3.7.4.7 (X)	
	3rd Floor: Occupancy: Business / Personal Serv.	47	3.7.4.7	6	6	3.7.4.7 (X)	
	4th Floor: Occupancy: Business / Personal Serv._	47	3.7.4.7	6	6	3.7.4.7 (X)	

A1.1 Scenario A1+A2: Ground Floor Plan

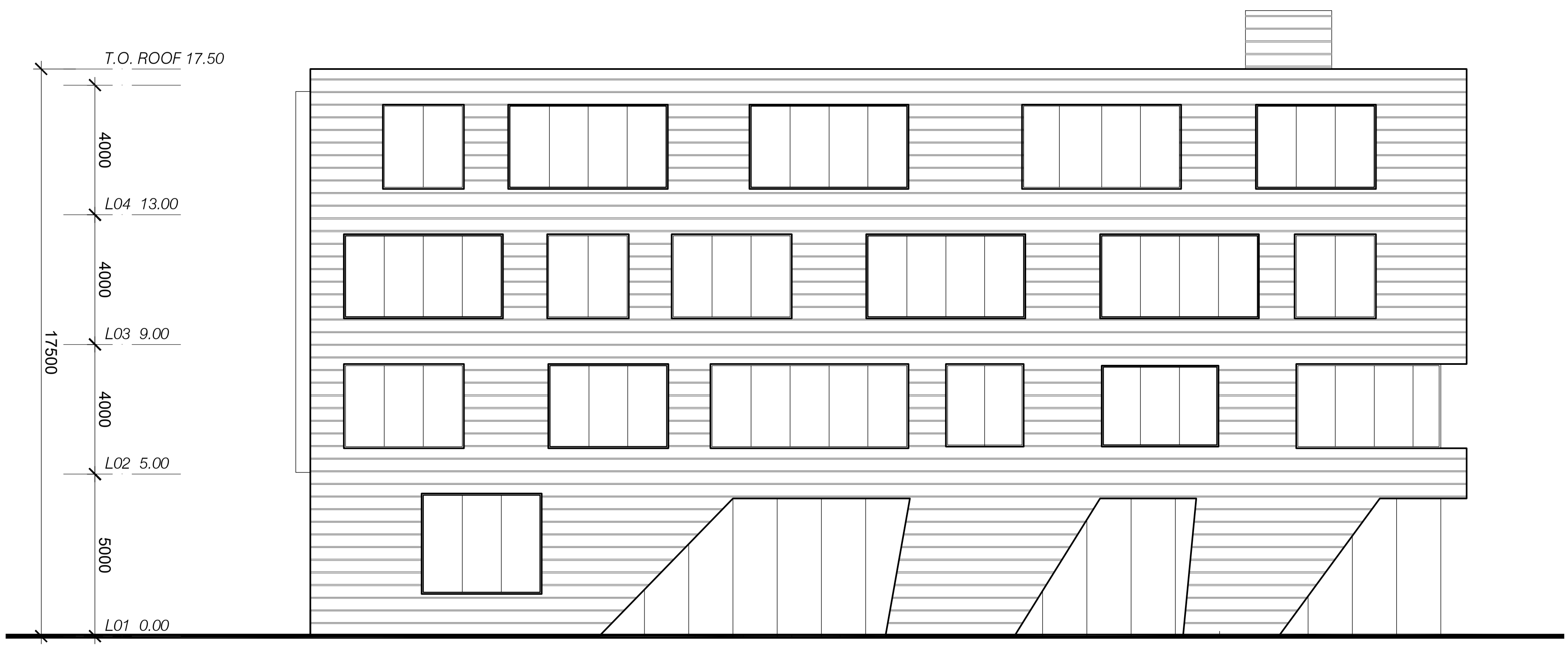




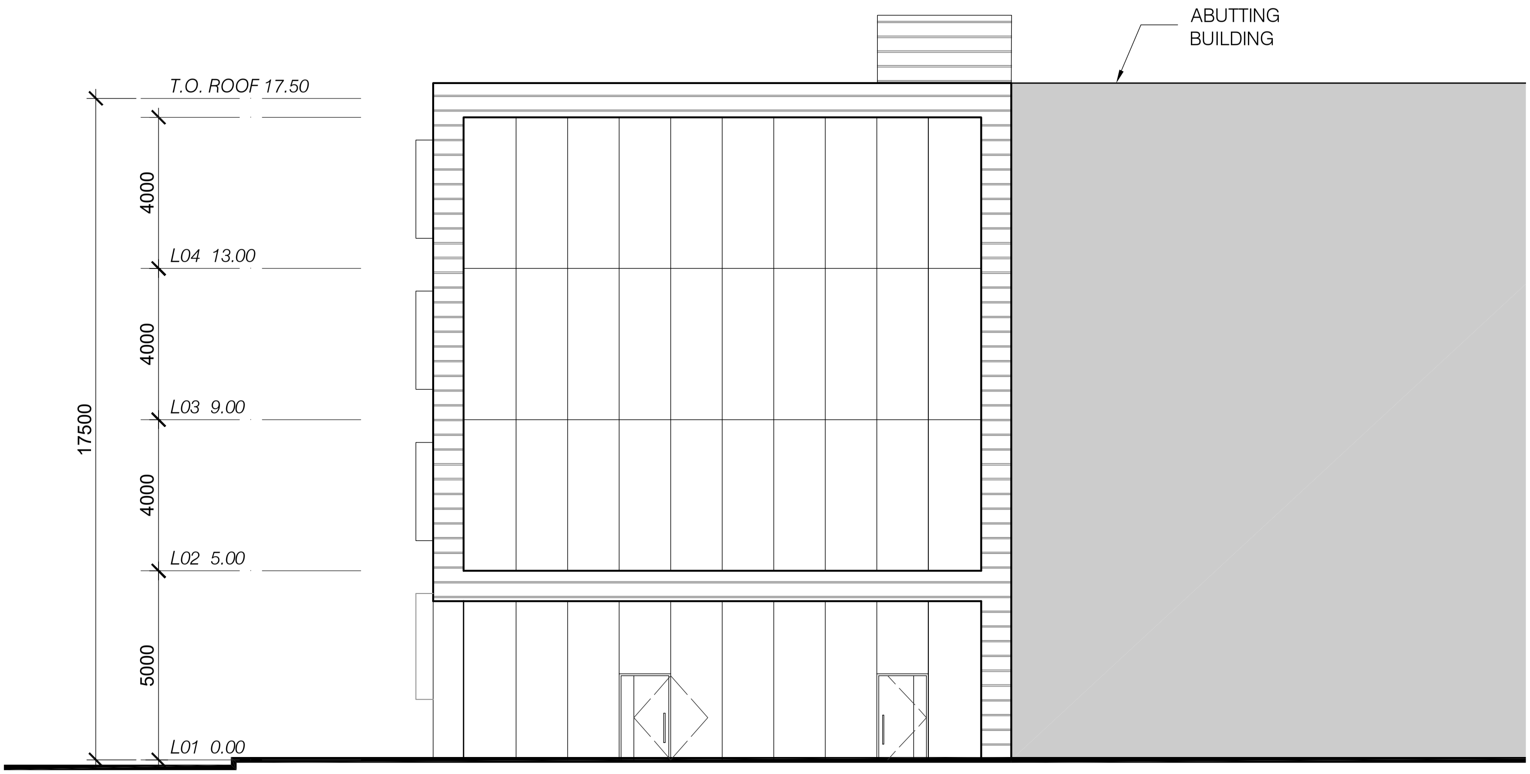
A1.2 Scenario A1+A2: Levels 02-04 Plan



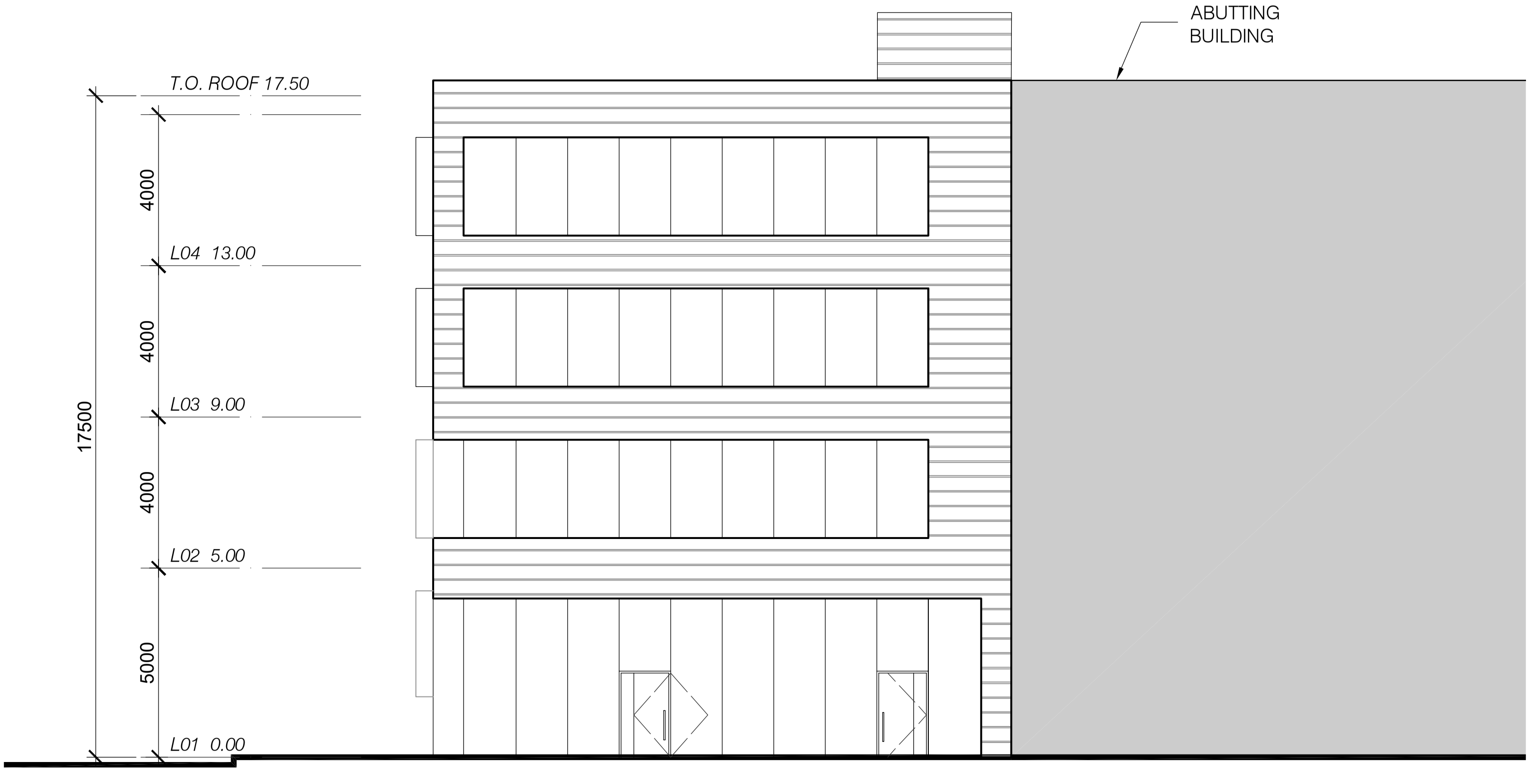
A1.3 Scenario A1: North Elevation (flanking street)



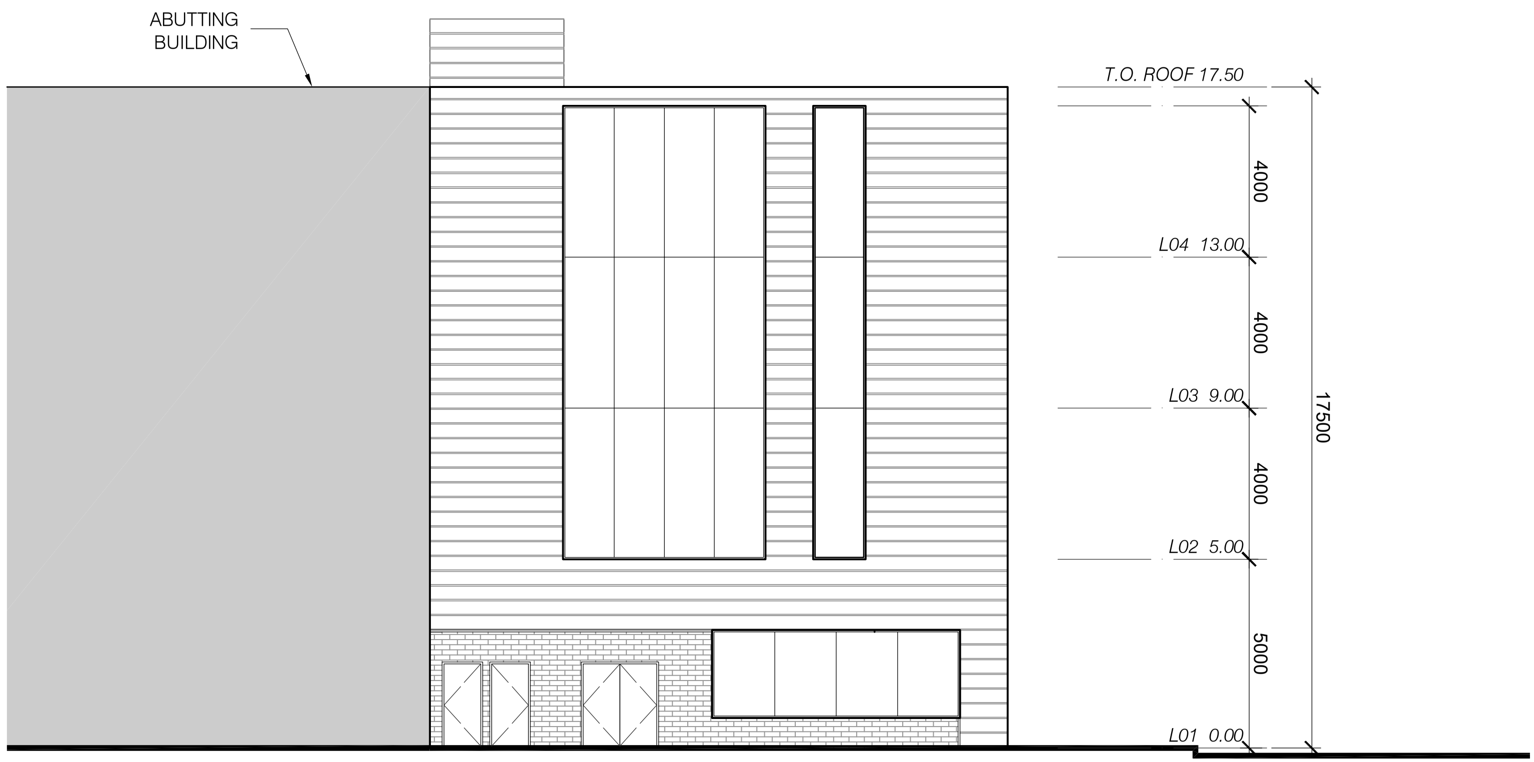
A1.4 Scenario A2:North Elevation (flanking street)



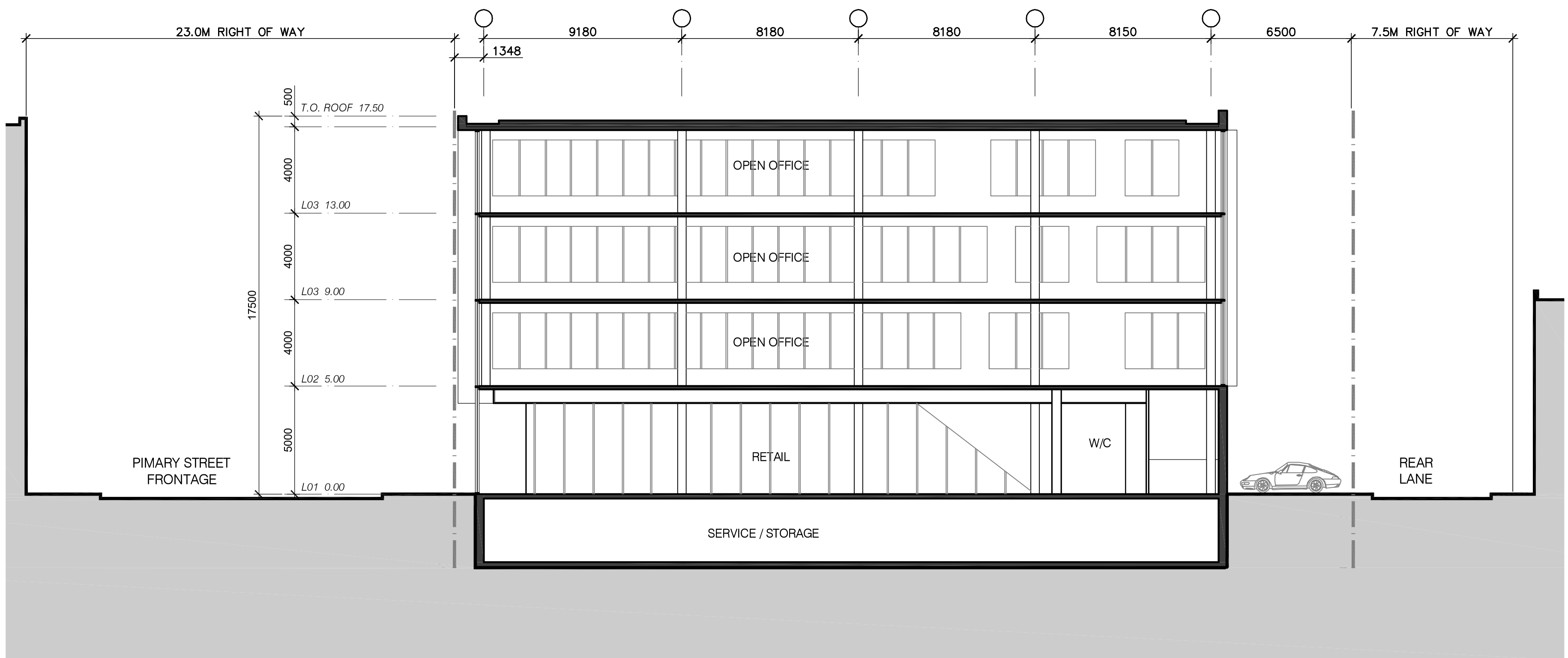
A1.5 Scenario A1: West Elevation (primary street)



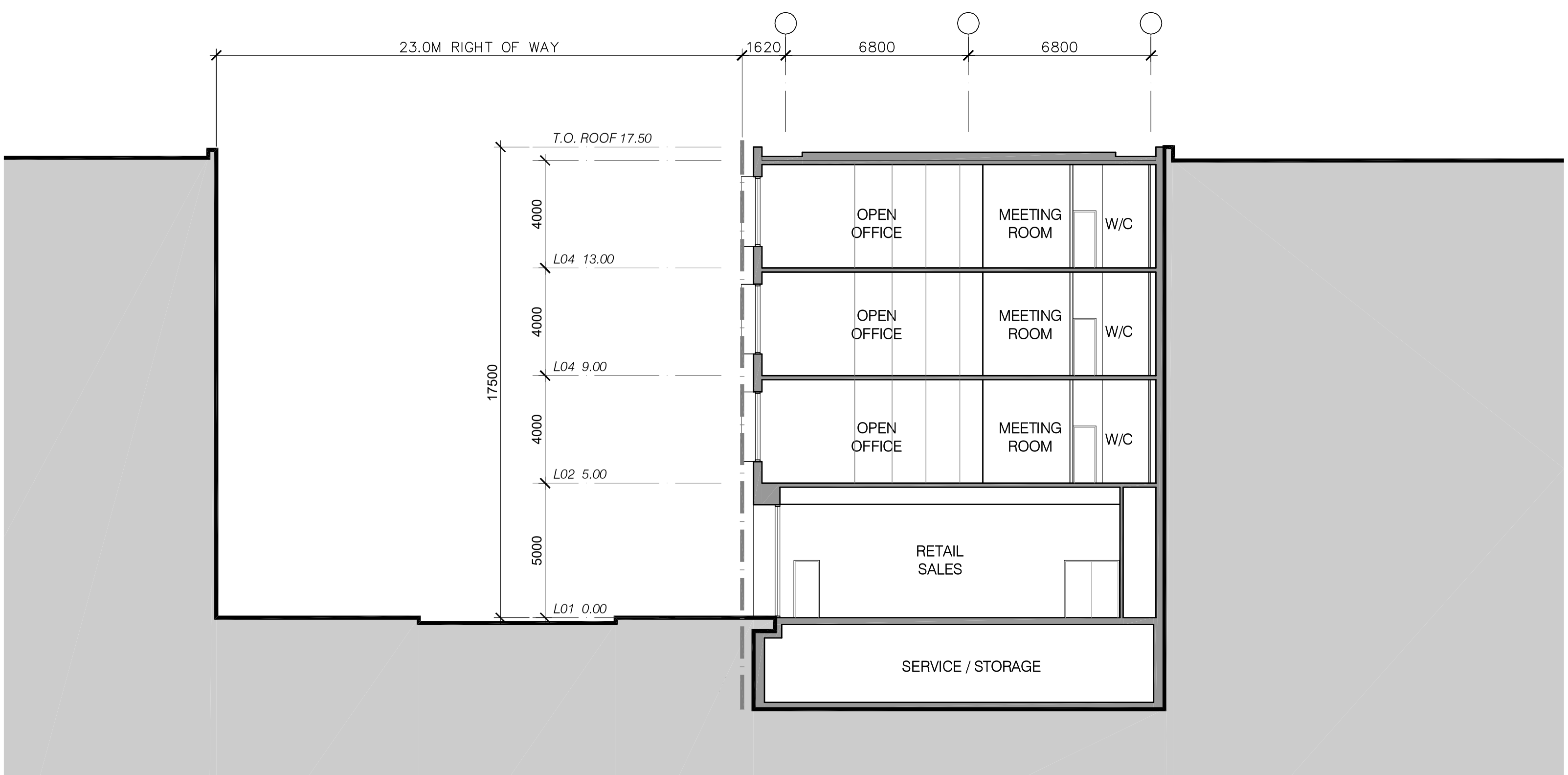
A1.6 Scenario A2: West Elevation (primary street)



A1.7 Scenario A1+A2: East Elevation (rear laneway)

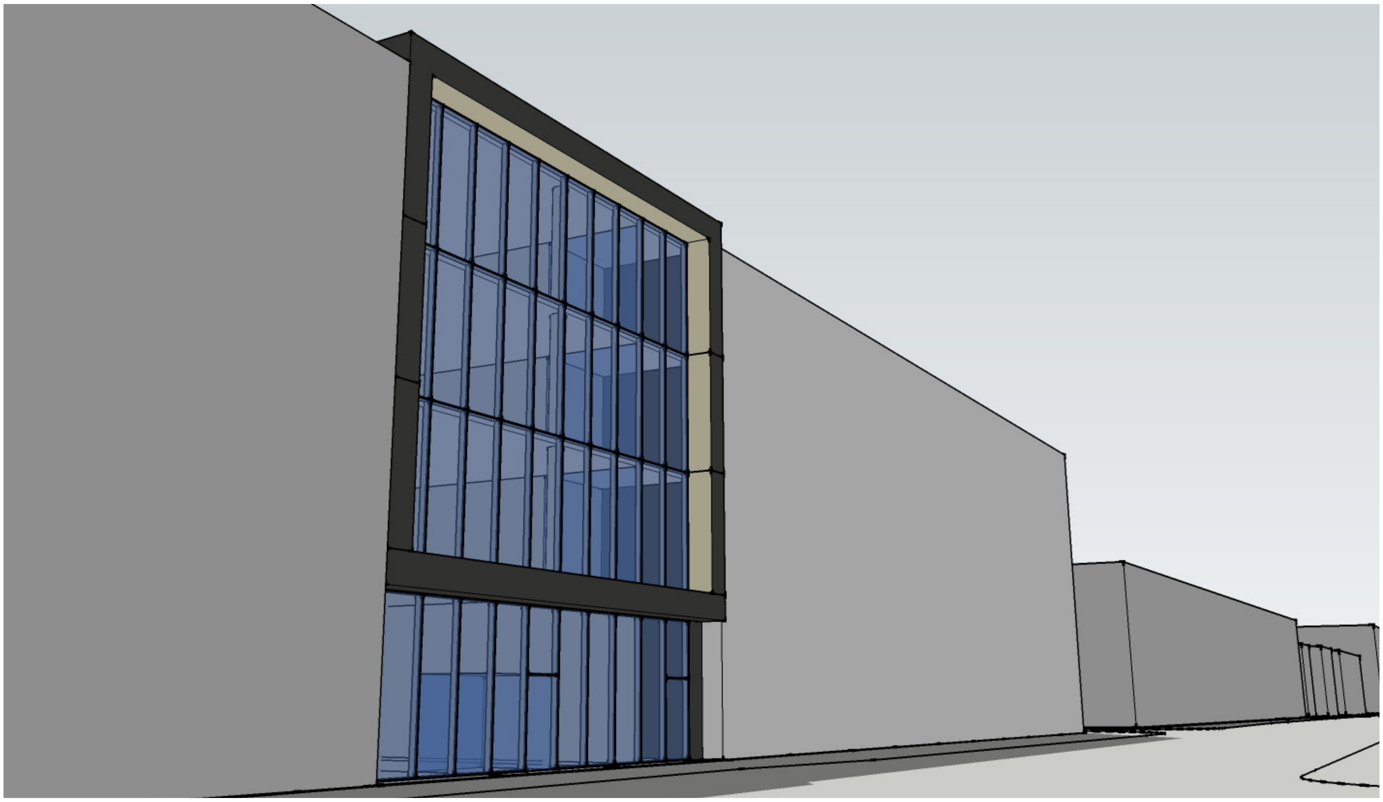


A1.8 Scenario A1+A2: Section A-A

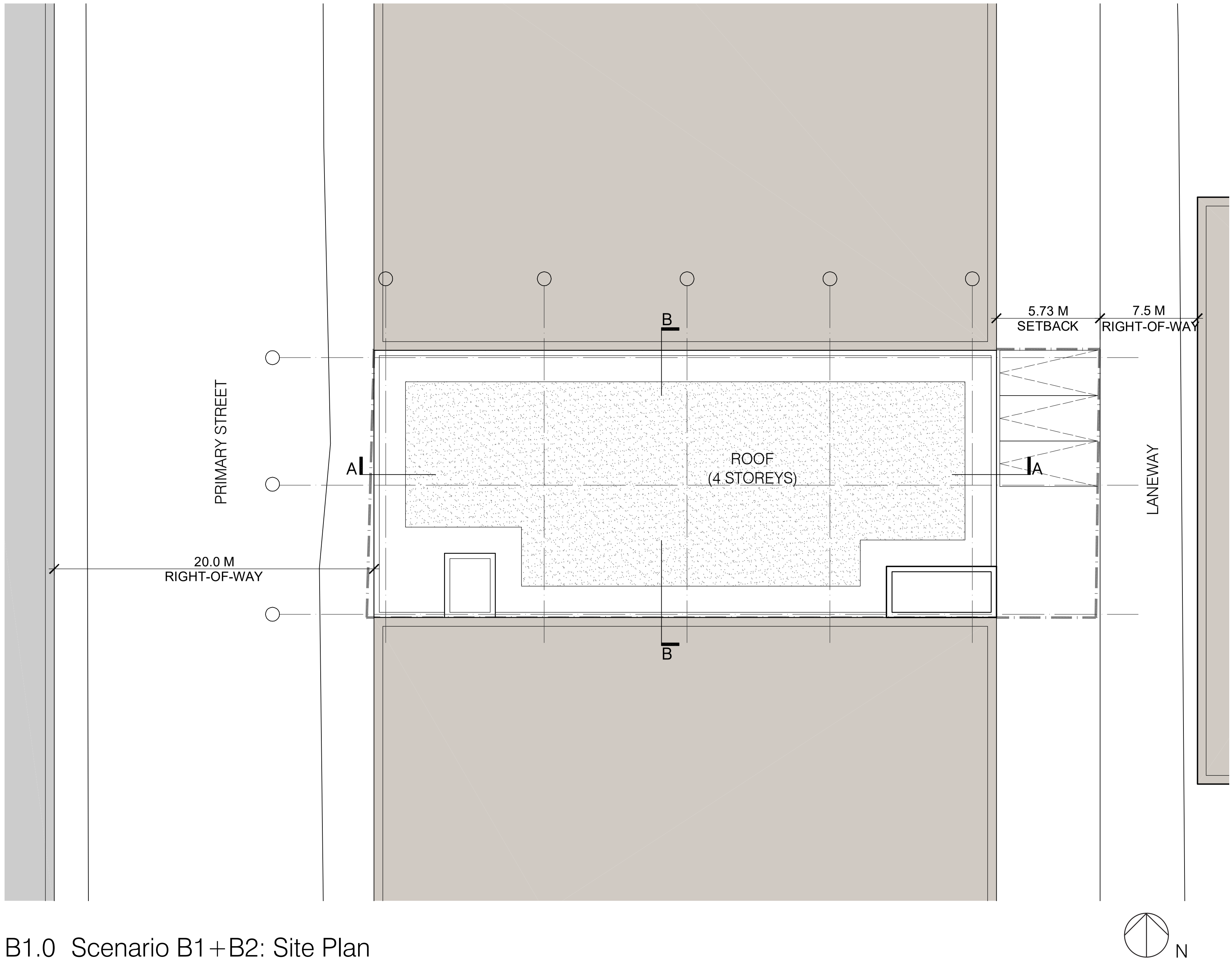


A1.9 Scenario A1+A2: Section B-B

APPENDIX B:
SCENARIO B1 AND B2 DRAWINGS



Drawing and Document List:



B1.0 Scenario B1+B2: Site Plan

Name of Practice:

Name of Project:
THESIS: SCENARIO B: MID-BLOCK LOT

Location:
TORONTO, ONTARIO

Item	Ontario's 2006 Building Code Data Matrix Part 3 or 9		BC Reference (References are to Division B unless noted [A] for Division A or [C] for Division C.)	
1	Project Description: ☑ New ☐ Addition ☐ Change of Use ☐ Alteration	☐ Part 11 11.1 to 11.4	☑ Part 3 1.1.2. [A]	☐ Part 9 1.1.2. [A] & 9.10.1.3.
2	Major Occupancy(s) ***Group D: Business and Personal Services Occupancy*** ***Group E: Mercantile Occupancy***		3.1.2.1.(1)	9.10.2.
3	Building Area (m^2) Existing ________ New 534.0 Total 534.0		1.4.1.2. [A]	1.4.1.2. [A]
4	Gross Area Existing ________ New 2,135.0 Total 2,135.0		1.4.1.2. [A]	1.4.1.2. [A]
5	Number of Storeys Above grade ***4*** Below grade ***1***		1.4.1.2. [A]&3.2.1.1.	1.4.1.2[A] & 9.10.4
6	Number of Streets/Fire Fighter Access ***1***		3.2.2.10. & 3.2.5.	9.10.20.
7	Building Classification ***Group D: Up to 4 Storeys, Sprinklered (3.2.2.52)*** ***Group E: Any Height, Any Area, Sprinklered (3.2.2.57)***		3.2.2.52 / 3.2.2.57 3.2.2.4 - 3.2.2.7	9.10.2.
8	Sprinkler System Proposed ☑ entire building ☐ selected compartments ☐ selected floor areas ☐ basement ☐ in lieu of roof rating ☐ not required		3.2.2.20.-.83 3.2.1.5. 3.2.2.17. INDEX	9.10.8.2. INDEX
9	Standpipe required ☑ Yes ☐ No		3.2.9.	N/A
10	Fire Alarm required ☑ Yes ☐ No		3.2.4.	9.10.18.
11	Water Service/Supply is Adequate ☑ Yes ☐ No		3.2.5.7.	N/A
12	High Building ☐ Yes ☑ No		3.2.6.	N/A
13	Construction Restrictions ☐ Combustible permitted ☐ Non-combustible required ☑ Both Actual Construction ☐ Combustible ☐ Non-combustible ☑ Both		3.2.2.52 / 3.2.2.57 3.2.2.4 - 3.2.2.7	9.10.6.
14	Mezzanine(s) Area m^2 ________________________		3.2.1.1.(3)-(8)	9.10.4.1.
15	Occupant load based on ☑ m^2/person ☐ design of building Basement: Occupancy: 46.0 m^2 / person Load 12 persons 1st Floor Occupancy: 3.70m^2 / person Load 138 persons 2nd Floor Occupancy: 9.30m^2 / person Load 47 persons 3nd Floor Occupancy: 9.30m^2 / person Load 47 persons 4th Floor Occupancy: 9.30m^2 / person Load 47 persons		3.1.17.	9.9.1.3.
16	Barrier-free Design ☑ Yes ☐ No (Explain) ____________________		3.8.	9.5.2.
17	Hazardous Substances ☐ Yes ☑ No		3.3.1.2. & 3.3.1.19.	9.10.1.3.(4)

18	Required Fire Resistance Rating (FRR)	Horizontal Assemblies FRR (Hours)	Listed Design No. or Description (SG-2)	3.2.2.52 / 3.2.2.57 3.2.2.4 - 3.2.2.7	9.10.8. 9.10.9.
		Floors L01-02: 2.0 Hours Floors L03-04: 1.0 Hours			
		Roof: 1.0 Hours			
		Mezzanine: N/A			
		FRR of Supporting Members	Listed Design No. Or Description (SG-2)		
		Floors L01: 2.0 Hours Floors L02-04: 1.0 Hours			
		Roof: 1.0 Hours			
		Mezzanine: N/A			

19 Spatial Separation – Construction of Exterior Walls — 3.2.3. — 9.10.14.

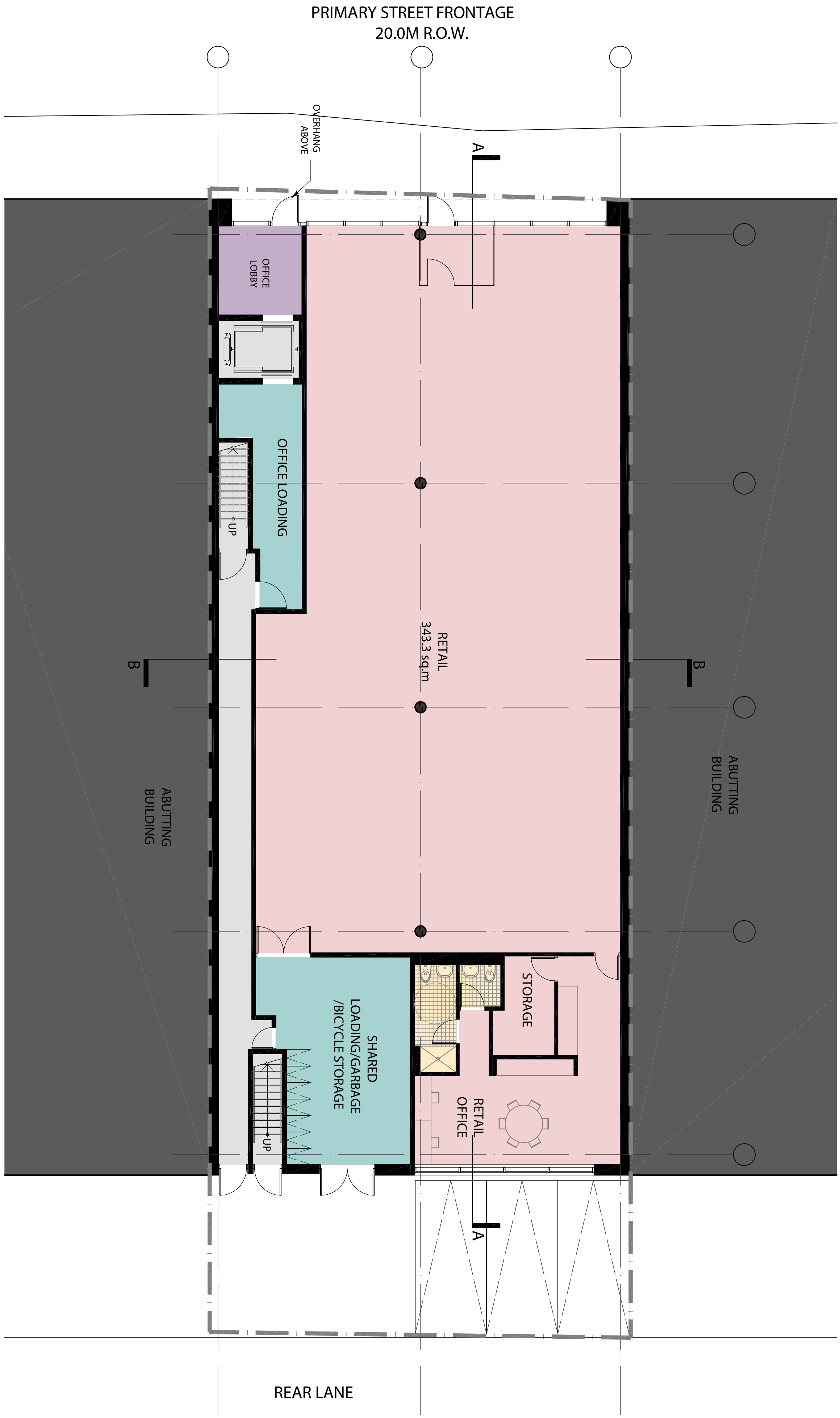
Wall	Area of EBF (m^2)	L.D. (m)	L/H or H/L	Permitted Max. % of Openings	Proposed % of Openings	FRR (Hours)	Listed Design or Description	Comb Const	Comb. Constr. Nonc. Cladding	Non-comb. Constr.
North (L01)	187.0	9.60	N/A	0%	B1: 0% B2: 0%	1.0		Yes	No	No
North (L02-04)	427.5	9.60	N/A	0%	B1: 0% B2: 0%	45 min		Yes	No	No
South (L01)	190.6	0.0	N/A	0%	B1: 0% B2: 0%	4.0		No	No	Yes
South (L02-04)	446.6	0.0	N/A	0%	B1: 0% B2: 0%	4.0		No	No	Yes
East (L01)	77.3	8.75	N/A	80%	B1: 20% B2: 20%	1.0		Yes	No	No
East (L02-04)	190.5	8.75	N/A	80%	B1: 43% B2: 43%	45 min		Yes	No	No
West (L01)	73.8	9.14	N/A	100%	B1: 78% B2: 78%	1.0		Yes	No	No
West (L02-04)	196.5	9.14	N/A	100%	B1: 83% B2: 83%	45 min		Yes	No	No

20 Plumbing Fixture Requirements

Male/Female Count @ _____% / _____%, except as noted otherwise

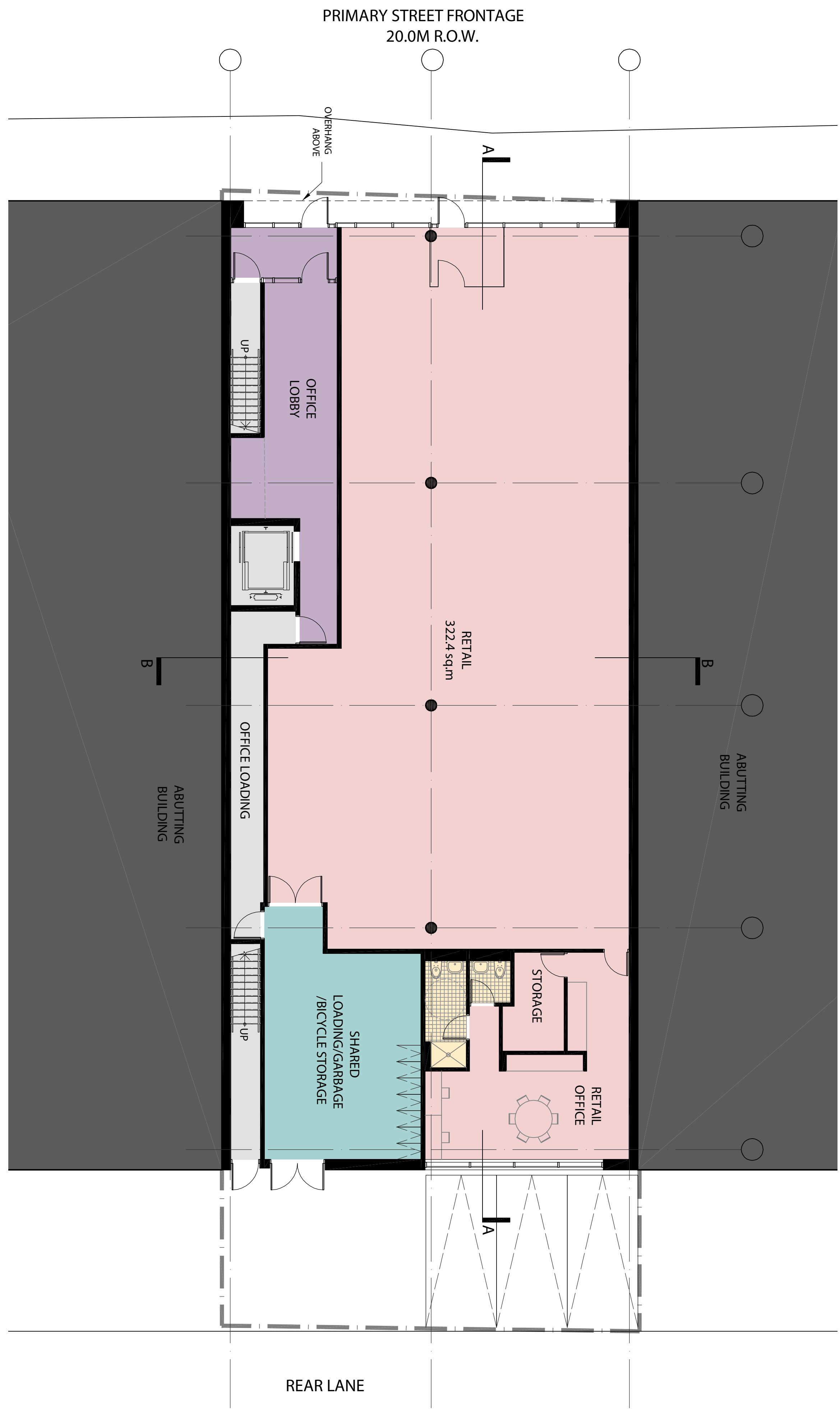
	Occupant Load	BC Table Number	Fixtures Required	Fixtures Provided	BC Reference ☑ Part 3	BC Reference ☐ Part 9
Basement: Occupancy: Storage	12	3.7.4.8	0	0	3.7.4.1 (3)	
1st Floor: Occupancy: Mercantile	37	3.7.4.8	2	2	3.7.4.8 (2)	
2nd Floor: Occupancy: Business / Personal Serv.	47	3.7.4.7	6	6	3.7.4.7 (X)	
3rd Floor: Occupancy: Business / Personal Serv.	47	3.7.4.7	6	6	3.7.4.7 (X)	
4th Floor: Occupancy: Business / Personal Serv._	47	3.7.4.7	6	6	3.7.4.7 (X)	

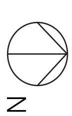
B1.1 Scenario B1, Current Code: Ground Floor Plan



N

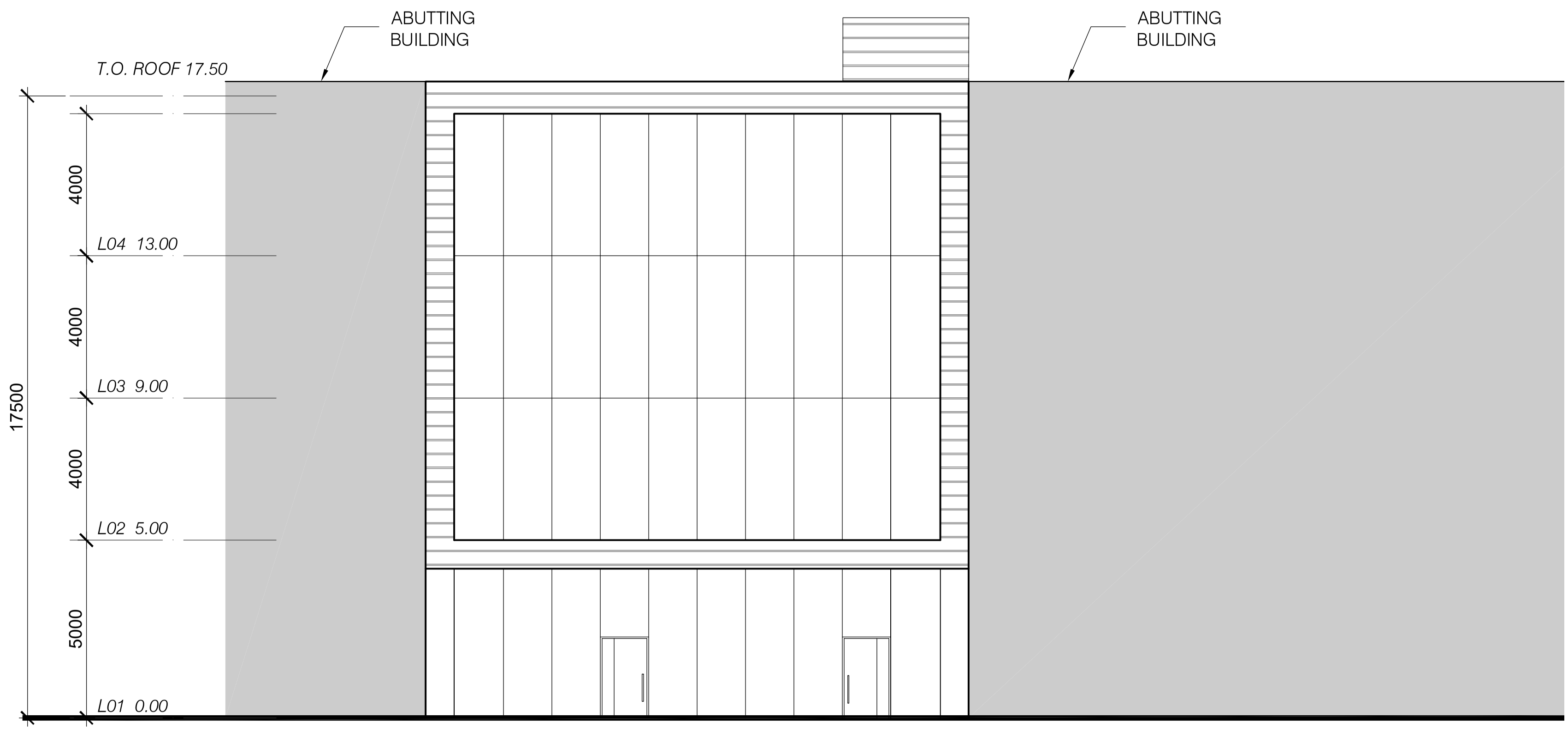
B1.2 Scenario B2, 2°C: Ground Floor Plan



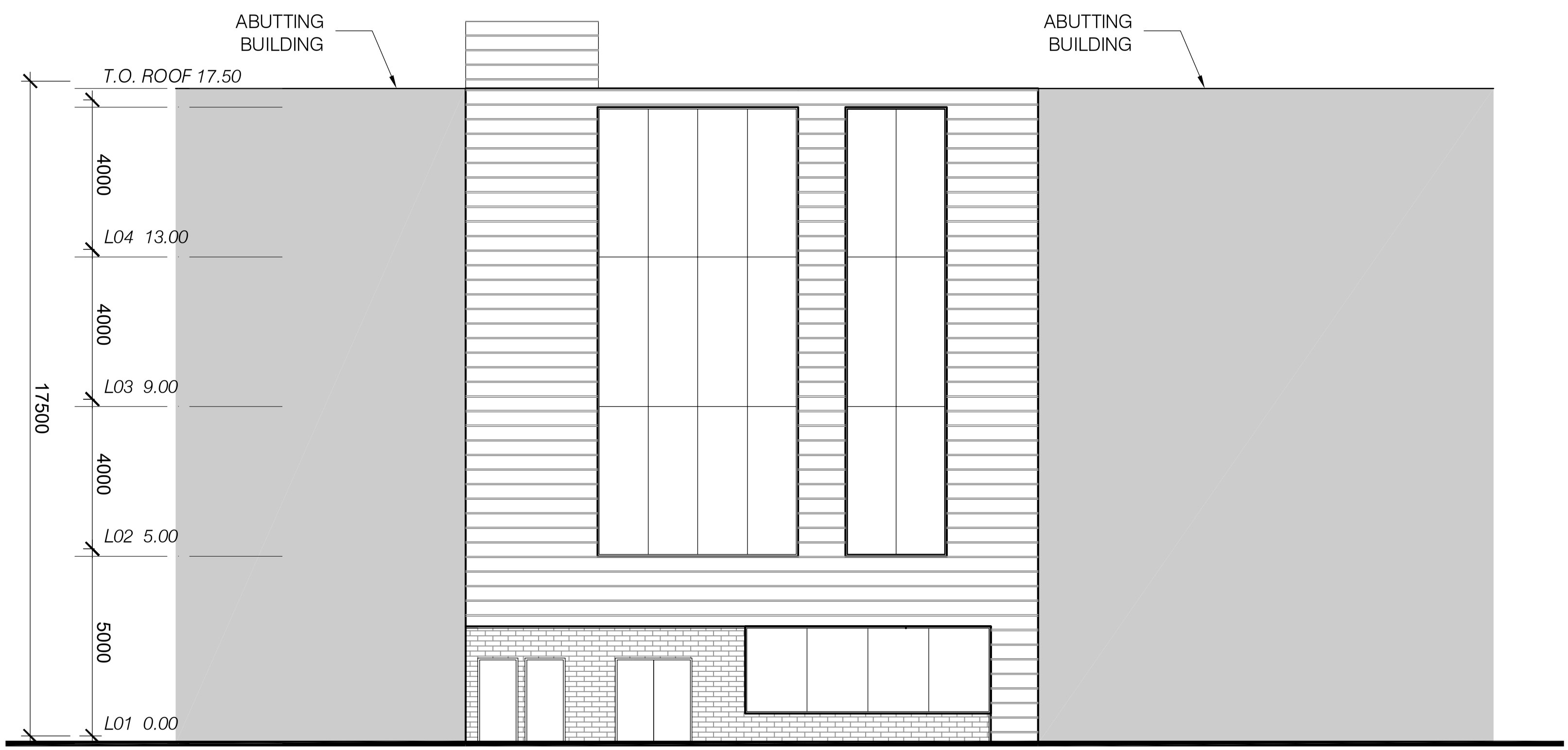


B1.3 Scenario B1: Levels 02-04 Plan

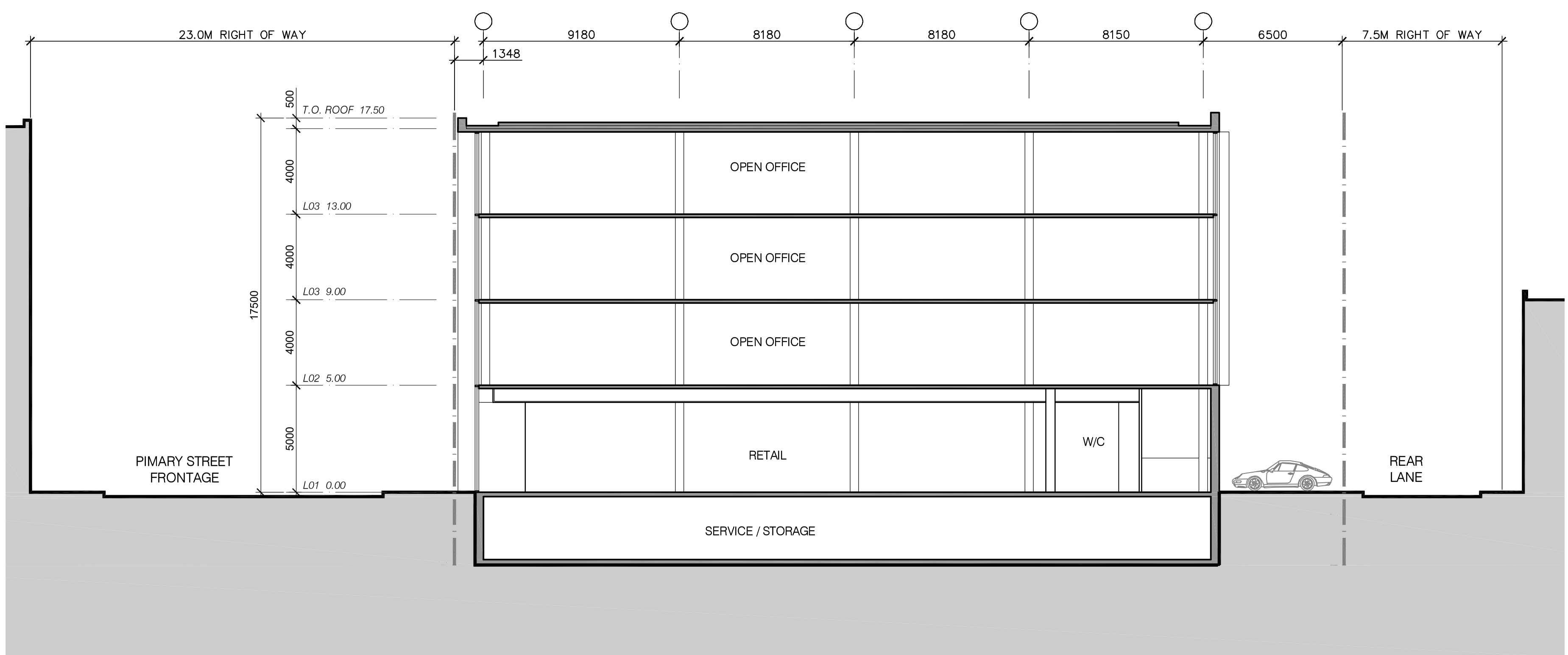
B1.4 Scenario B2, 2°C: Levels 02-04 Plan



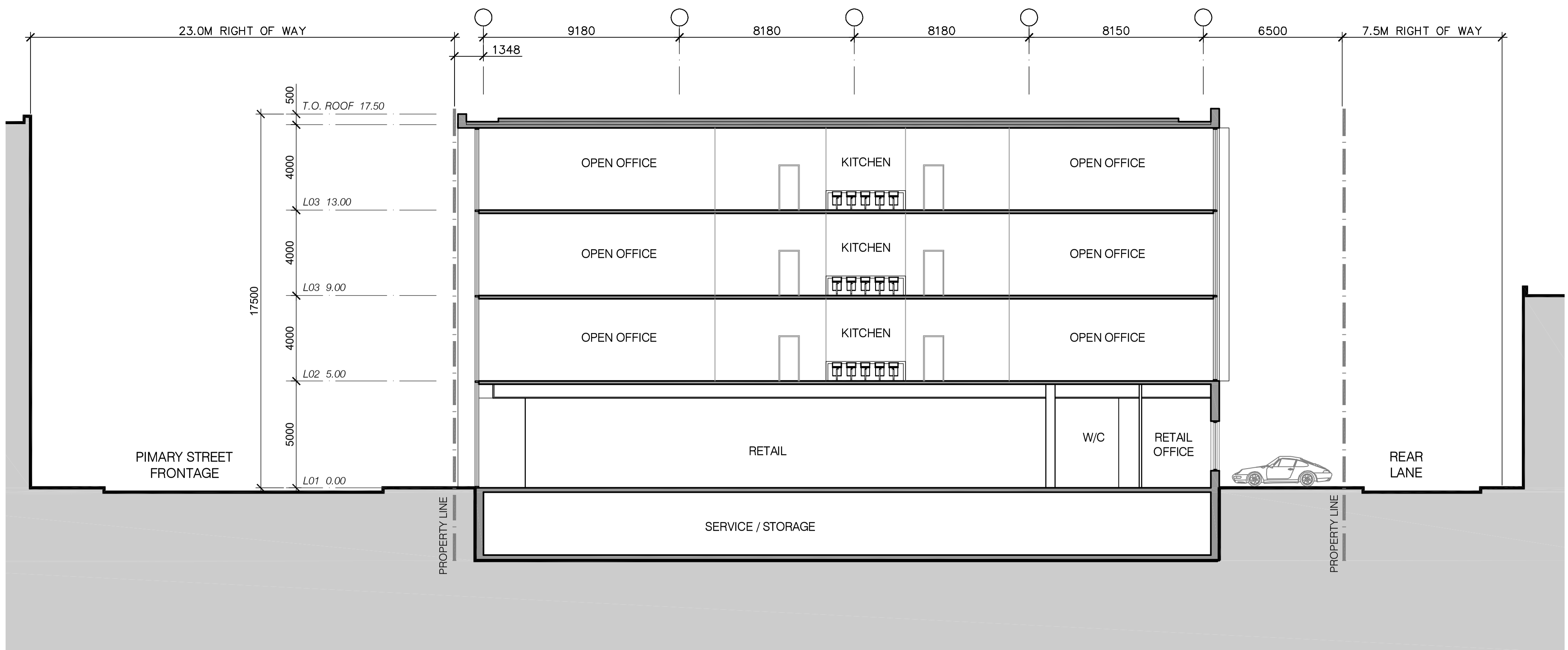
B1.5 Scenario B1+B2: West Elevation (primary street)



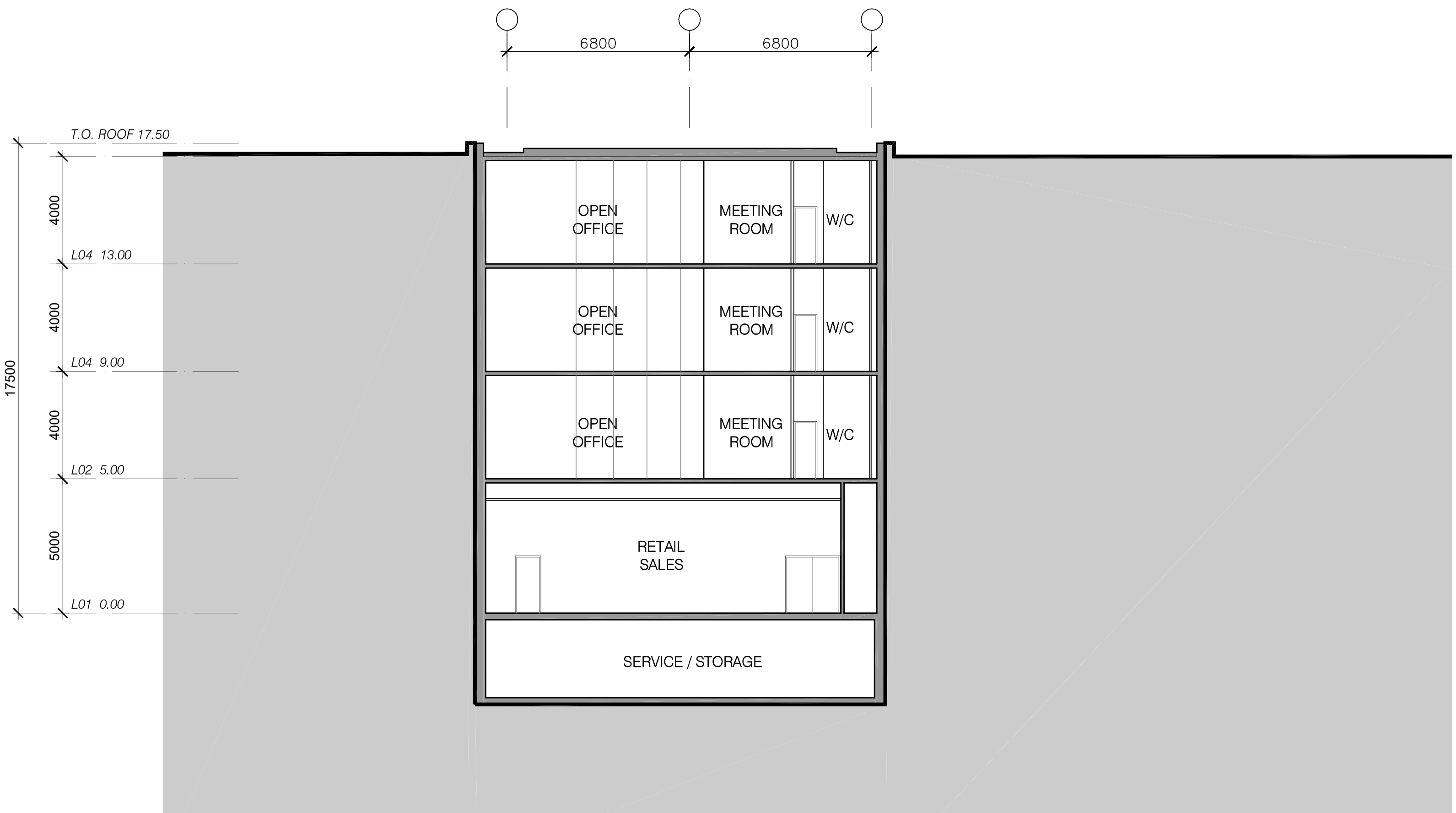
B1.6 Scenario B1+B2: East Elevation (rear laneway)



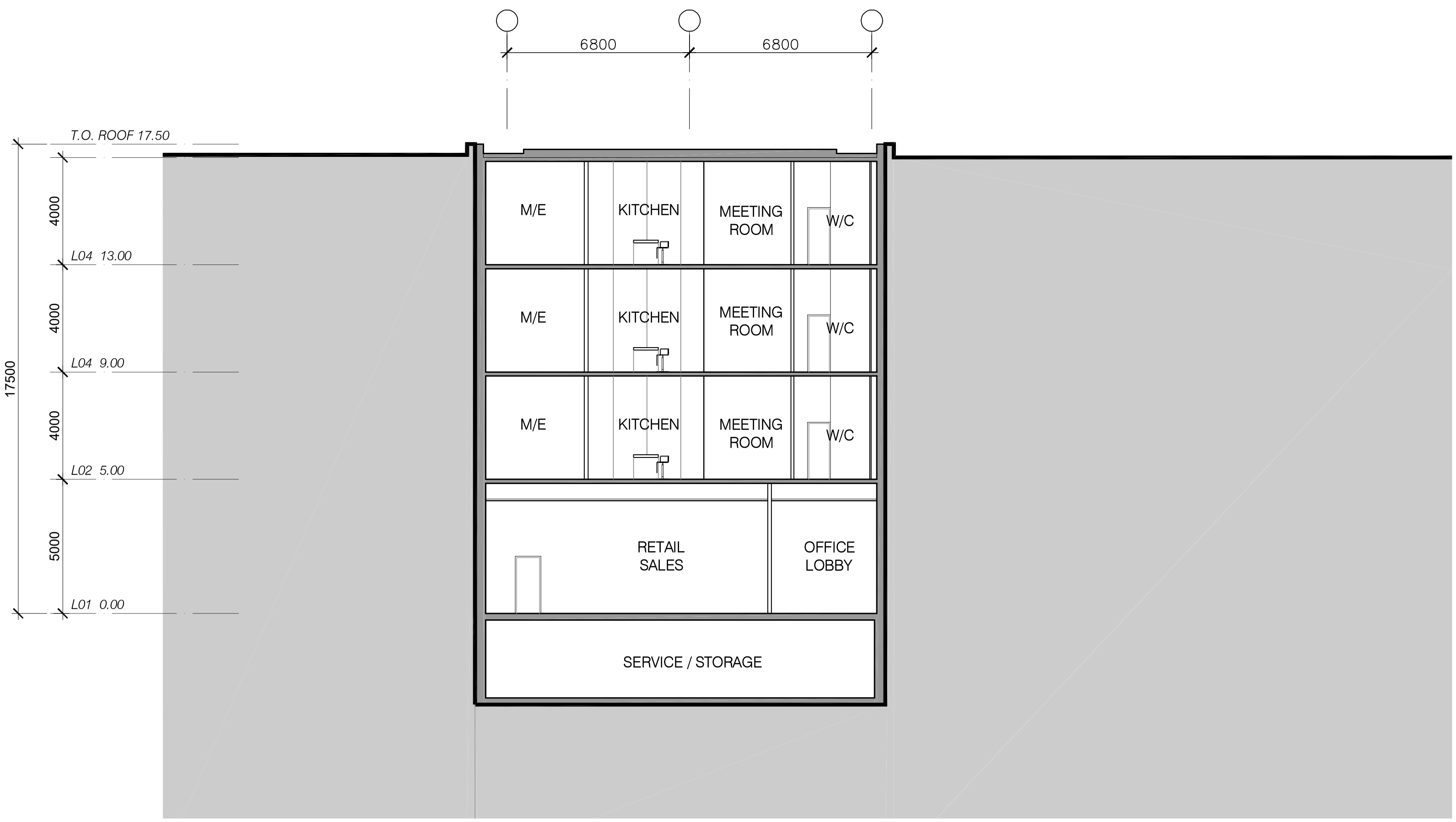
B1.7 Scenario B1, Current Code: Section A-A



B1.8 Scenario B2, 2°C: Section A-A

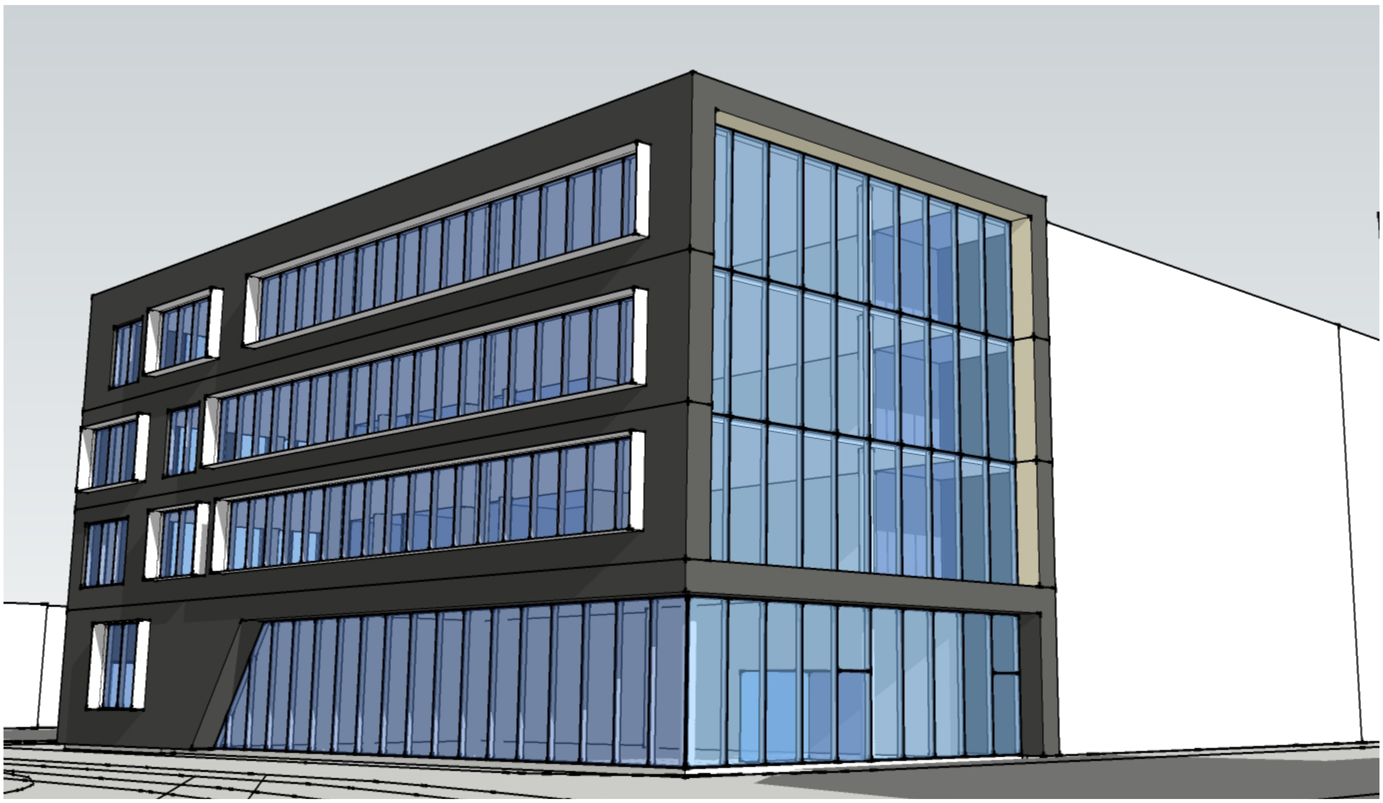


B1.9 Scenario B1, Current Code: Section B-B

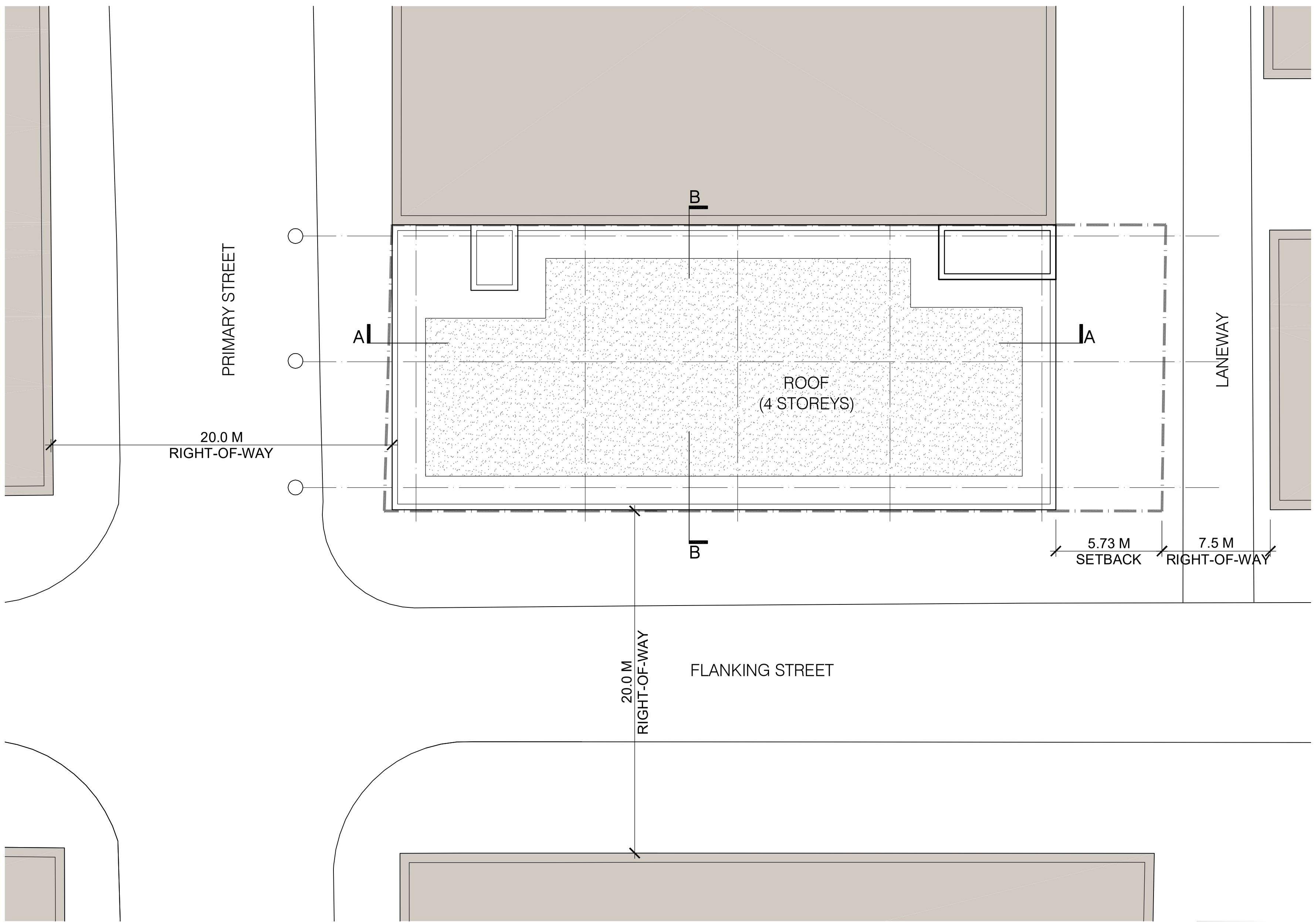


B1.10 Scenario B2, 2°C: Section B-B

APPENDIX C:
SCENARIO C1 + C2 DRAWINGS



Drawing and Document List:



C1.0 Scenario C1+C2: Site Plan

Name of Practice:

Name of Project:
THESIS: SCENARIO C: SOUTH FACING END LOT

Location:
TORONTO, ONTARIO

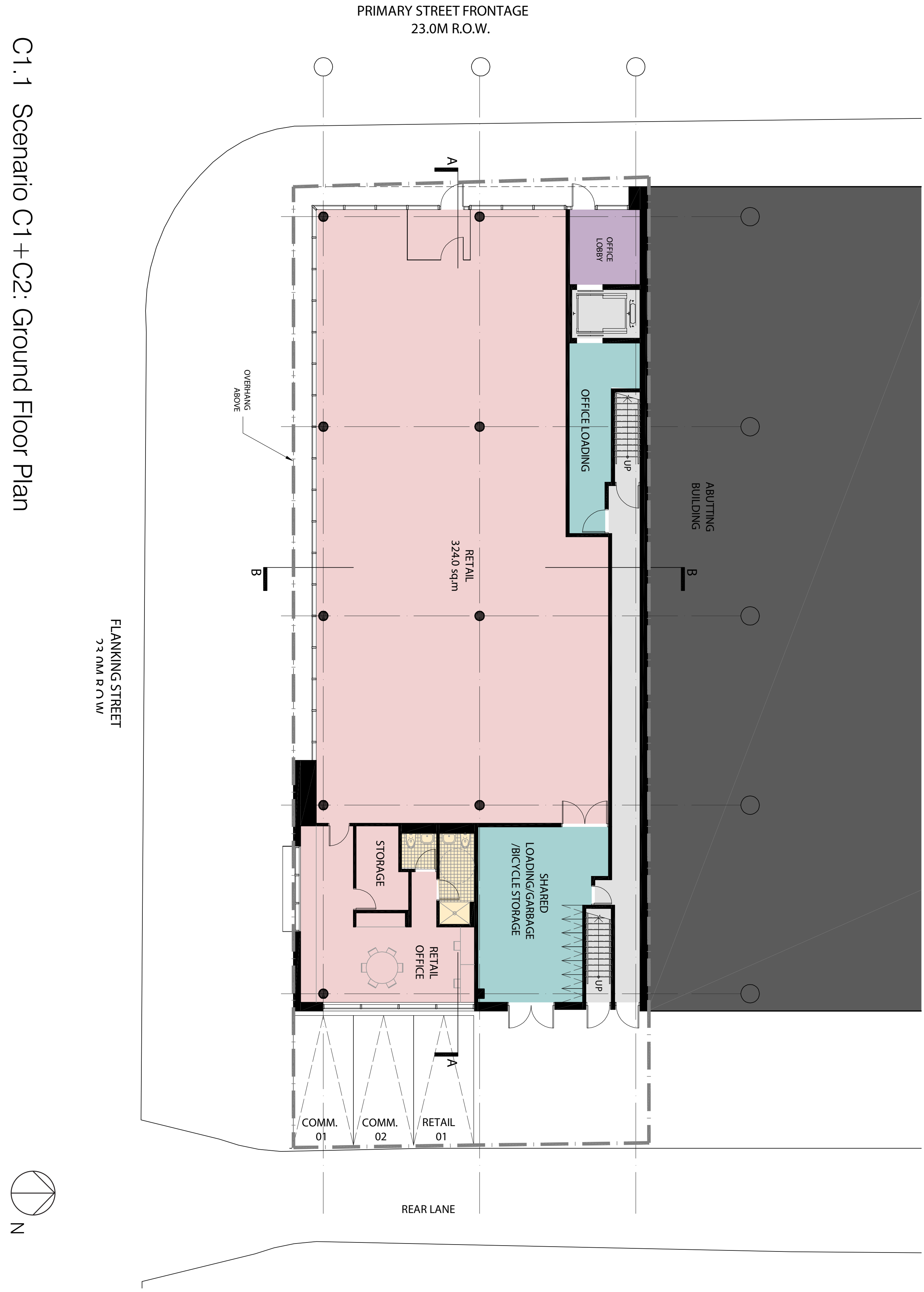
Item	Ontario's 2006 Building Code Data Matrix Part 3 or 9		BC Reference (References are to Division B unless noted [A] for Division A or [C] for Division C.)	
1	Project Description: ☑ New ☐ Addition ☐ Change of Use ☐ Alteration	☐ Part 11 11.1 to 11.4	☑ Part 3 1.1.2. [A]	☐ Part 9 1.1.2. [A] & 9.10.1.3.
2	Major Occupancy(s) ***Group D: Business and Personal Services Occupancy*** ***Group E: Mercantile Occupancy***		3.1.2.1.(1)	9.10.2.
3	Building Area (m²) Existing ________ New 534.0 Total 534.0		1.4.1.2. [A]	1.4.1.2. [A]
4	Gross Area Existing ________ New 2,135.0 Total 2,135.0		1.4.1.2. [A]	1.4.1.2. [A]
5	Number of Storeys Above grade ***4*** Below grade ***1***		1.4.1.2. [A]&3.2.1.1.	1.4.1.2[A] & 9.10.4
6	Number of Streets/Fire Fighter Access ***2***		3.2.2.10. & 3.2.5.	9.10.20.
7	Building Classification ***Group D: Up to 4 Storeys, Sprinklered (3.2.2.52)*** ***Group E: Any Height, Any Area, Sprinklered (3.2.2.57)***		3.2.2.52 / 3.2.2.57 3.2.2.4 - 3.2.2.7	9.10.2.
8	Sprinkler System Proposed ☑ entire building ☐ selected compartments ☐ selected floor areas ☐ basement ☐ in lieu of roof rating ☐ not required		3.2.2.20.-.83 3.2.1.5. 3.2.2.17. INDEX	9.10.8.2. INDEX
9	Standpipe required ☑ Yes ☐ No		3.2.9.	N/A
10	Fire Alarm required ☑ Yes ☐ No		3.2.4.	9.10.18.
11	Water Service/Supply is Adequate ☑ Yes ☐ No		3.2.5.7.	N/A
12	High Building ☐ Yes ☑ No		3.2.6.	N/A
13	Construction Restrictions ☐ Combustible permitted ☐ Non-combustible required ☑ Both Actual Construction ☐ Combustible ☐ Non-combustible ☑ Both		3.2.2.52 / 3.2.2.57 3.2.2.4 - 3.2.2.7	9.10.6.
14	Mezzanine(s) Area m² ________________________		3.2.1.1.(3)-(8)	9.10.4.1.
15	Occupant load based on ☑ m²/person ☐ design of building Basement: Occupancy: 46.0 m² / person Load 12 persons 1st Floor Occupancy: 3.70m² / person Load 138 persons 2nd Floor Occupancy: 9.30m² / person Load 47 persons 3nd Floor Occupancy: 9.30m² / person Load 47 persons 4th Floor Occupancy: 9.30m² / person Load 47 persons		3.1.17.	9.9.1.3.
16	Barrier-free Design ☑ Yes ☐ No (Explain) ____________________		3.8.	9.5.2.
17	Hazardous Substances ☐ Yes ☑ No		3.3.1.2. & 3.3.1.19.	9.10.1.3.(4)

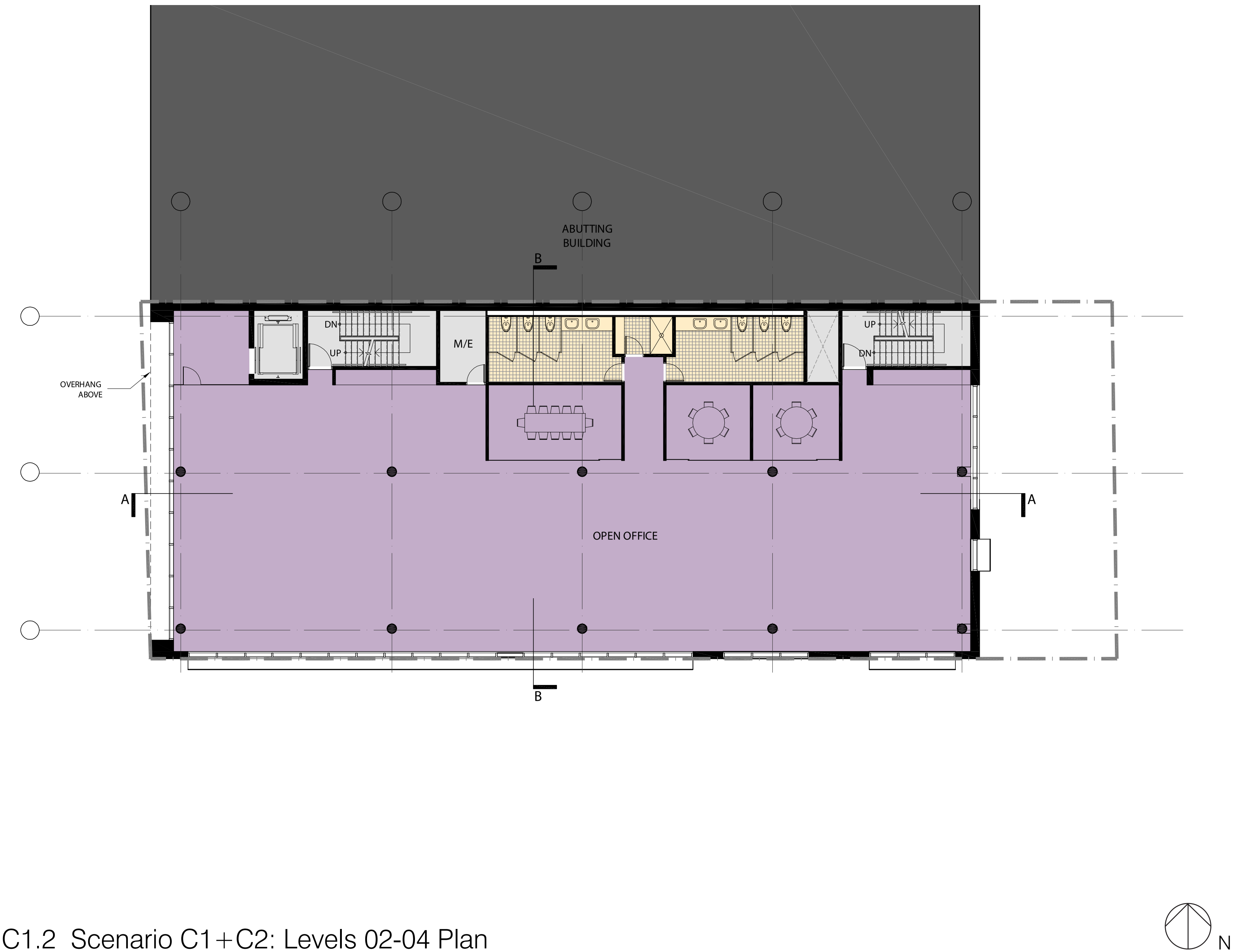
18	Required Fire Resistance Rating (FRR)	Horizontal Assemblies FRR (Hours)	Listed Design No. or Description (SG-2)	3.2.2.52 / 3.2.2.57 3.2.2.4 - 3.2.2.7	9.10.8. 9.10.9.
		Floors L01-02: 2.0 Hours Floors L03-04: 1.0 Hours			
		Roof: 1.0 Hours			
		Mezzanine: N/A			
		FRR of Supporting Members	Listed Design No. Or Description (SG-2)		
		Floors L01: 2.0 Hours Floors L02-04: 1.0 Hours			
		Roof: 1.0 Hours			
		Mezzanine: N/A			

19	Spatial Separation – Construction of Exterior Walls							3.2.3.		9.10.14.	
	Wall	Area of EBF (m^2)	L.D. (m)	L/H or H/L	Permitted Max. % of Openings	Proposed % of Openings	FRR (Hours)	Listed Design or Description	Comb Const	Comb. Constr. Nonc. Cladding	Non-comb. Constr.
	North (L01)	187.0	9.60	N/A	0%	C1: 0% C2: 0%:	1.0		Yes	No	No
	North (L02-04)	427.5	9.60	N/A	0%	C1: 0% C2: 0%	45 min		Yes	No	No
	South (L01)	190.6	0.0	N/A	64%	C1: 63% C2: 42%	4.0		No	No	Yes
	South (L02-04)	446.6	0.0	N/A	100%	C1: 53% C2: 40%	4.0		No	No	Yes
	East (L01)	77.3	8.75	N/A	80%	C1: 20% C2: 20%	1.0		Yes	No	No
	East (L02-04)	190.5	8.75	N/A	80%	C1: 43% C2: 43%	45 min		Yes	No	No
	West (L01)	73.8	9.14	N/A	100%	C1: 78% C2: 78%	1.0		Yes	No	No
	West (L02-04)	196.5	9.14	N/A	100%	C1: 83% C2: 49%	45 min		Yes	No	No

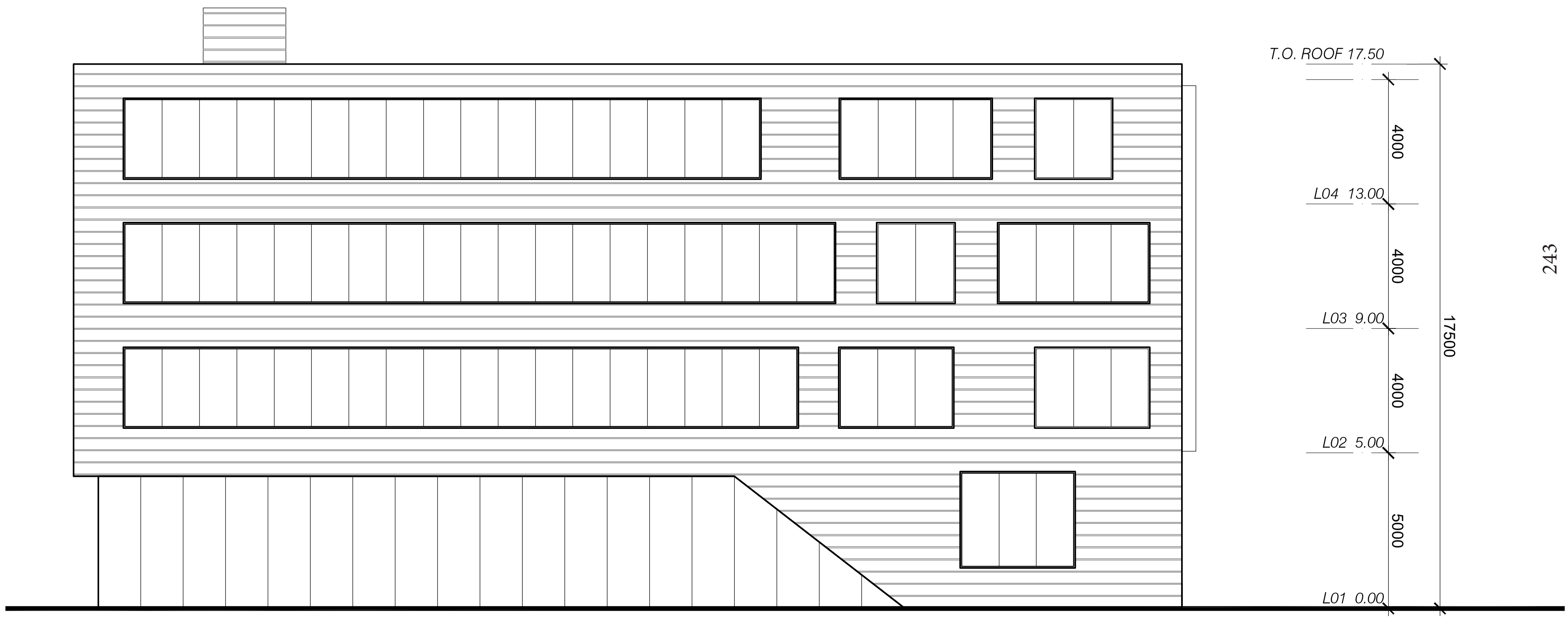
20	Plumbing Fixture Requirements						
						BC Reference	
						☑ Part 3	☐ Part 9
	Male/Female Count @ _____% / _____%, except as noted otherwise	Occupant Load	BC Table Number	Fixtures Required	Fixtures Provided		
	Basement: Occupancy: Storage	12	3.7.4.8	0	0	3.7.4.1 (3)	
	1st Floor: Occupancy: Mercantile	37	3.7.4.8	2	2	3.7.4.8 (2)	
	2nd Floor: Occupancy: Business / Personal Serv.	47	3.7.4.7	6	6	3.7.4.7 (X)	
	3rd Floor: Occupancy: Business / Personal Serv.	47	3.7.4.7	6	6	3.7.4.7 (X)	
	4th Floor: Occupancy: Business / Personal Serv._	47	3.7.4.7	6	6	3.7.4.7 (X)	

C1.1 Scenario C1+C2: Ground Floor Plan



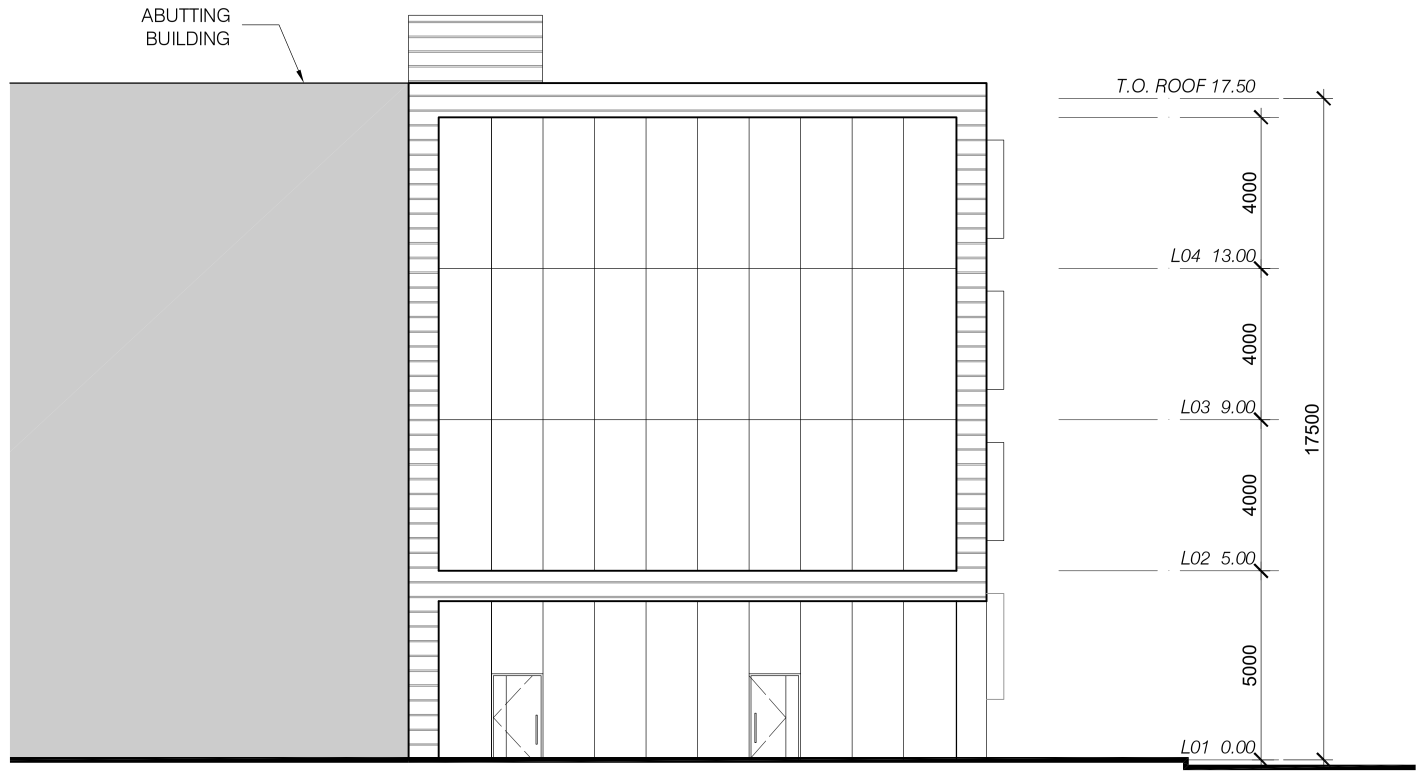


C1.2 Scenario C1+C2: Levels 02-04 Plan



C1.3 Scenario C1: South Elevation (flanking street)

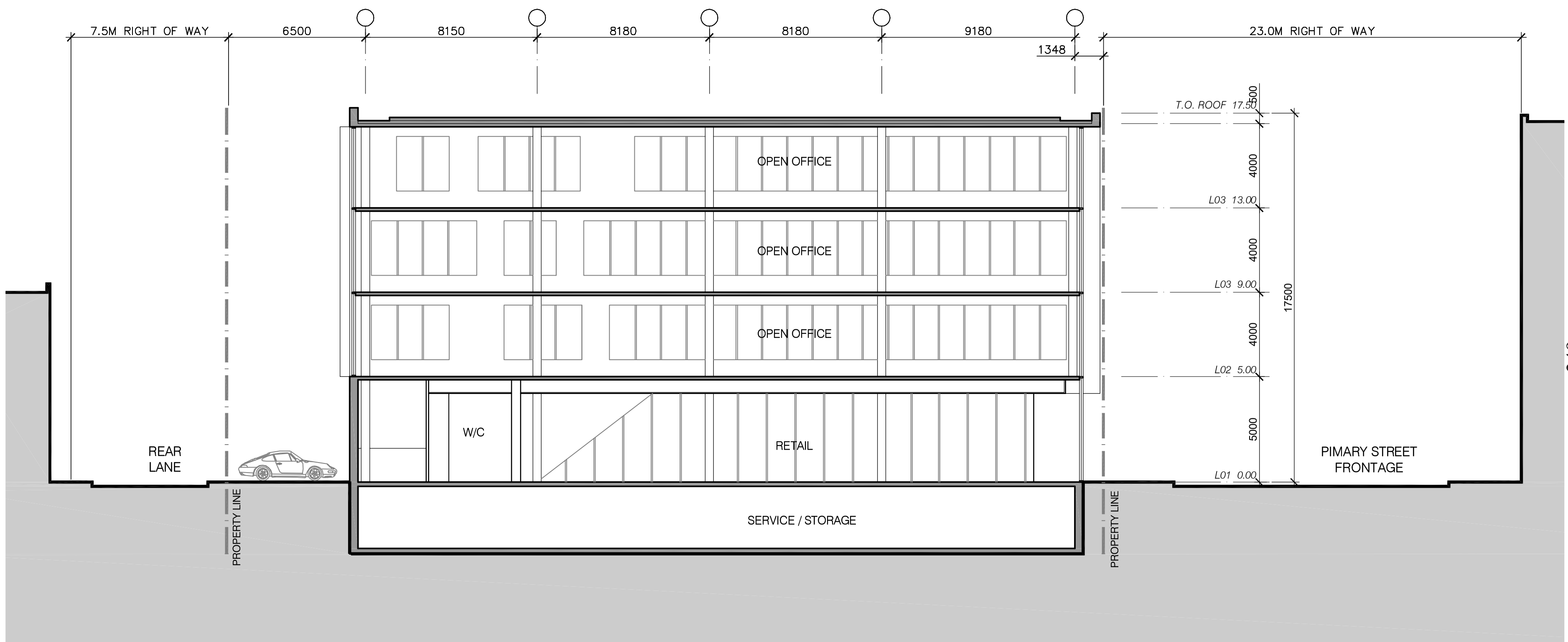
C1.4 Scenario C2: South Elevation (flanking street)



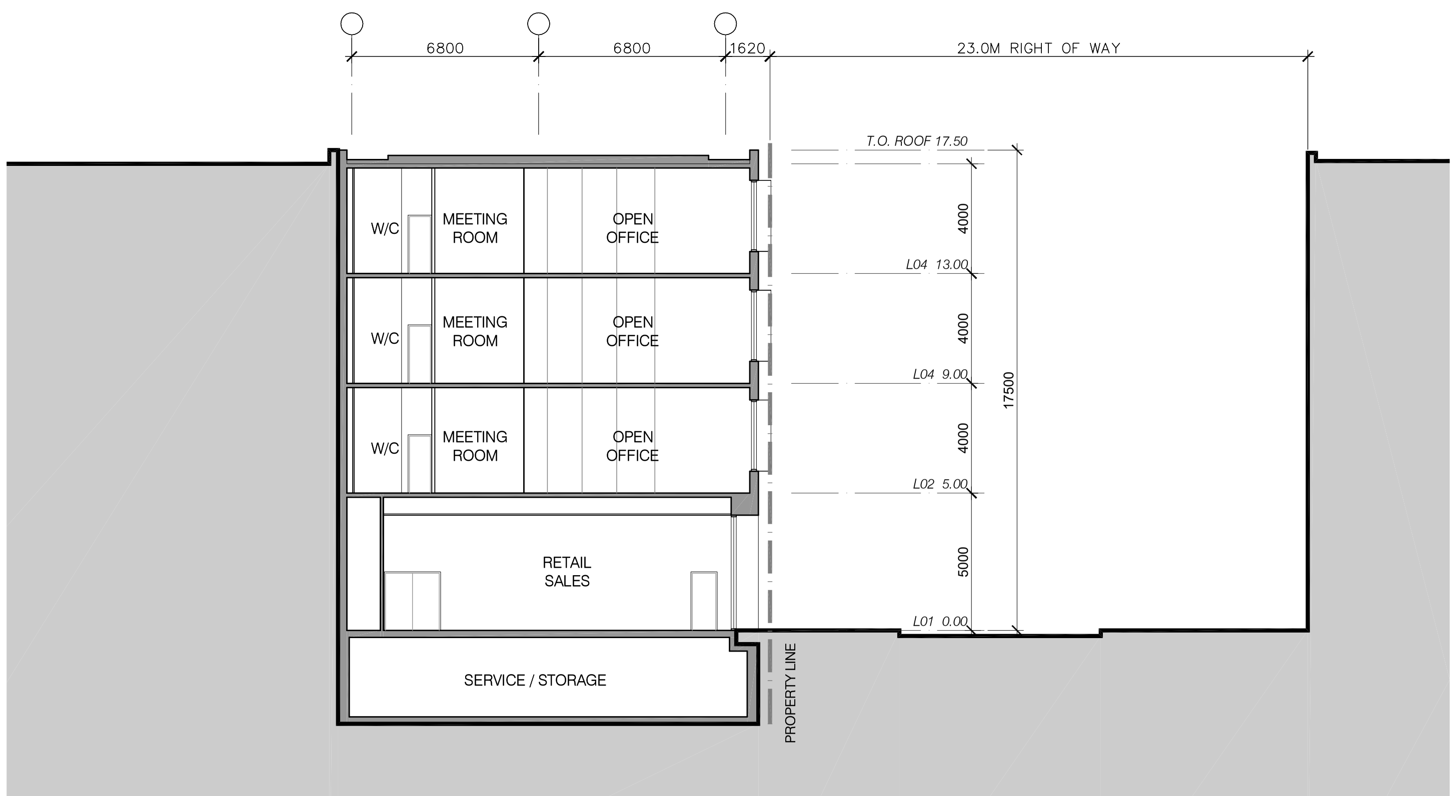
C1.6 Scenario C1+C2: West Elevation (primary street)

C1.6 Scenario C1+C2: West Elevation (primary street)

C1.8 Scenario C1+C2: East Elevation (rear laneway)



C1.6 Scenario C1+C2: Section A-A

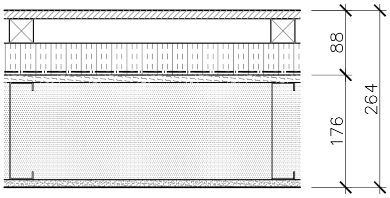


A1.7 Scenario A1+A2: Section B-B

APPENDIX D: ASSEMBLY SCHEDULES

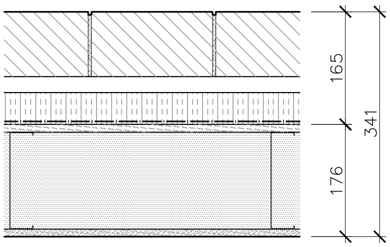
ASSEMBLY SCHEDULE: 2°C MEDIAN MITIGATION SCENARIO (A2, B2, C2)

W1A



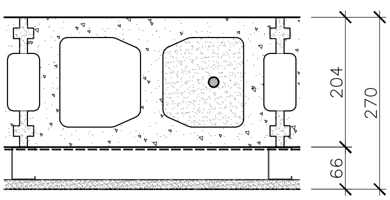
EXTERIOR WALL, WOOD
OUTSIDE
13x180mm CHARCOAL CEMENTITIOUS PANEL SIDING
25mm AIRSPACE
50mm EXTRUDED POLYSTYRENE RIGID INSULATION
SPRAY-APPLIED VAPOUR-PERMEABLE AIR BARRIER / DRAINAGE PLANE
12mm FIBREGLASS FACED GYPSUM SHEATHING
38x152 STEEL STUD c/w POLYURETHANE SPRAY-FOAM INSULATION
12mm TYPE X GYPSUM BOARD, JOINTS FULLY TAPED (THERMAL BARRIER)
INSIDE

W2A



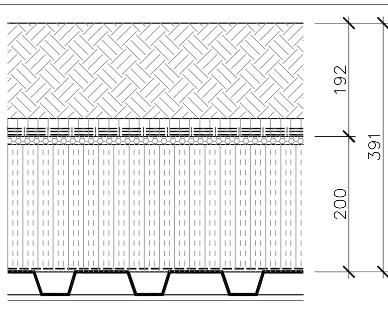
EXTERIOR WALL, MASONRY
OUTSIDE
90mm CLAY BRICK
25mm AIRSPACE
50mm EXTRUDED POLYSTYRENE RIGID INSULATION
SPRAY-APPLIED VAPOUR-PERMEABLE AIR BARRIER
12mm FIBREGLASS FACED GYPSUM SHEATHING
38X152 STEEL STUD c/w POLYURETHANE SPRAY-FOAM INSULATION
12mm TYPE X GYPSUM BOARD, JOINTS FULLY TAPED (THERMAL BARRIER)
INSIDE

W3A



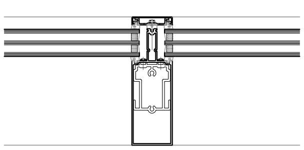
2 HOUR WALL ABUTTING ADJACENT BUILDING
OUTSIDE
204x390 CMU, JOINTS FULLY GROUTED C/W #15M BAR AND GROUT AT 400mm O.C.
(100mm EQUIVALENT THICKNESS)
SELF-ADHERING AIR-VAPOUR BARRIER
51mm FURRING
15mm GYPSUM BOARD
EXPOSING ENDS IN GAP FILLED WITH 50mm MINERAL WOOL INSULATION AND SEALED WITH SELF-ADHERING AIR/VAPOUR BARRIER
INSIDE

R1A



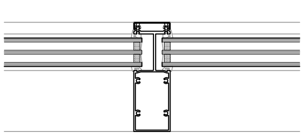
ROOF, GREEN
OUTSIDE
150mm GROWING MEDIUM
28mm MOISTURE-RETENTION AND DRAINAGE LAYER
40mil POLY ROOT BARRIER
150mil PROTECTION FABRIC
90mil SINGLE-PLY EPDM ROOF MEMBRANE
13mm INSULATING COVERBOARD
187mm POLYISOCYANURATE INSULATION. MECHANICALLY FASTENED
AIR/VARPOUR BARRIER
38mm 22-ga. CORRUGATED METAL DECK
INSIDE

G1



ALUMINUM CURTAINWALL
THERMALLY-BROKEN ALUMINUM CURTAINWALL
TRIPLE-GLAZED c/w LOW-E COATING (CLEAR 77)
INSULATING SPACER
CENTRE-GLASS Usi: 1.25, SHGC: 0.47, VT: 0.64
DOE GLAZING REFERENCE 3652

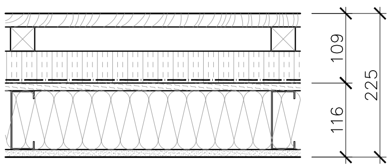
G2



PUNCHED OPENING (RIBBON)
THERMALLY-BROKEN ALUMINUM RIBBON WINDOW
TRIPLE-GLAZED c/w LOW-E COATING (CLEAR 77)
INSULATING SPACER
CENTRE-GLASS Usi: 1.25, SHGC: 0.47, VT: 0.64
DOE GLAZING REFERENCE 3652

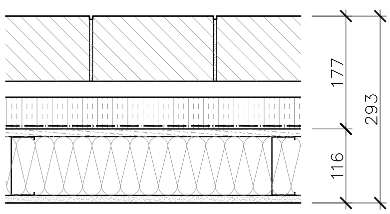
ASSEMBLY SCHEDULE: BASELINE (A1, B1, C1)

W1



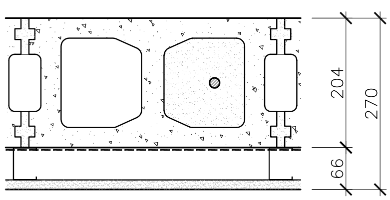
EXTERIOR WALL, WOOD
<u>*OUTSIDE*</u>
21 x 180 CHARRED LINEAR WOOD CLADDING
38x38 (MIN.) WOOD BATTEN AND AIRSPACE
50mm EXTRUDED POLYSTYRENE RIGID INSULATION
SPRAY-APPLIED OR TROWEL APPLIED A/V BARRIER (CLASS 1 VAPOUR-RETARDER, AND AIR BARRIER), DRAINAGE PLANE
12mm FIBREGLASS-FACED GYPSUM SHEATHING
38X92 STEEL STUD c/w BATT INSULATION
12mm GYPSUM BOARD WITH LATEX PAINT FINISH
<u>*INSIDE*</u>

W2



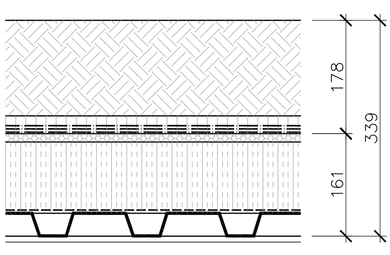
EXTERIOR WALL, MASONRY
<u>*OUTSIDE*</u>
90mm CLAY BRICK
25mm AIRSPACE
50mm EXTRUDED POLYSTYRENE RIGID INSULATION
SPRAY-APPLIED OR TROWEL APPLIED A/V BARRIER (CLASS 1 VAPOUR-RETARDER, AND AIR BARRIER), DRAINAGE PLANE
12mm FIBREGLASS FACED GYPSUM SHEATHING
38X92 STEEL STUD c/w BATT INSULATION
12mm GYPSUM BOARD WITH LATEX PAINT FINISH
<u>*INSIDE*</u>

W3



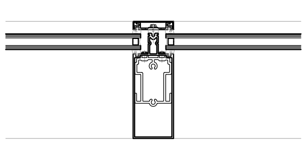
2 HOUR WALL ABUTTING ADJACENT BUILDING
<u>*OUTSIDE*</u>
204x390 CMU, ALL JOINTS FULLY GROUTED C/W #15M BAR AND GROUT AT 400mm O.C.
(100mm EQUIVALENT THICKNESS)
SELF-ADHERING A/V MEMBRANE (CLASS 1 VAPOUR-RETARDER AND AIR BARRIER
51mm FURRING
16mm GYPSUM BOARD WITH LATEX PAINT FINISH
<u>*INSIDE*</u>

R1



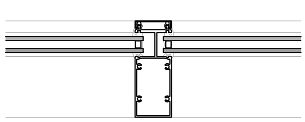
ROOF, GREEN
<u>*OUTSIDE*</u>
150mm GROWING MEDIUM
28mm MOISTURE-RETENTION AND DRAINAGE LAYER
40mil POLY ROOT BARRIER
150mil PROTECTION FABRIC
90mil SINGLE-PLY EPDM ROOF MEMBRANE
13mm INSULATING COVERBOARD
112mm POLYISOCYANURATE INSULATION. MECHANICALLY FASTENED
AIR/VARPOUR BARRIER
38mm 22-ga. CORRUGATED METAL DECK
<u>*INSIDE*</u>

G1



ALUMINUM CURTAINWALL
THERMALLY-BROKEN ALUMINUM CURTAINWALL
DOUBLE-GLAZED c/w LOW-E COATING
ALUMINUM SPACER
CENTRE-GLASS Usi: 1.87, SHGC: 0.37, VT: 0.67
DOE GLAZING REFERENCE 6458

G2



PUNCHED OPENING (RIBBON)
THERMALLY-BROKEN ALUMINUM RIBBON WINDOW
DOUBLE-GLAZED c/w LOW-E COATING
ALUMINUM SPACER
CENTRE-GLASS Usi: 1.87, SHGC: 0.37, VT: 0.67
DOE GLAZING REFERENCE 6458

Glossary

Business As Usual (BAU): McKinsey and Co.	Business-As-Usual refers to a baseline GHG emissions projection of a scenario to which an abatement or mitigation potential is applied.
Carbon Dioxide Equivalency (CO_2e)	Used to express Global Warming Potential, carbon dioxide equivalency is a measure of the amount of CO_2e that would cause the same value of radiative forcing as a given mixture of CO_2 and other GHGs in the Earth's atmosphere. CO_2e must be measured over a consistent time-frame owing to the varying persistence of GHGs and is generally taken to be 100 years. The most common units used for statistical reporting are megatonnes carbon dioxide equivalent, $MtCO_2e$.
Climate Change: **(United Nations Framework on Climate Change Article 1)**	Climate Change a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. It is important to note that this definition makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability which is attributable to natural causes.
Embodied Energy:	The amount of non-renewable energy that is consumed with respect to the building materials in terms of the acquisition of raw materials, their processing, manufacturing, transportation, construction, repair/replacement, and demolition/removal. It is sub-divided into initial embodied energy expended during the construction phase and recurring expended for renovations, repairs or upgrades over operational phase.
Emission Intensity (E_i)	Similar to Energy Use Intensity, Greenhouse Gas Intensity is a measure of the Global Warming Potential per unit of activity. In the case of a building, the term refers to megatonnes carbon dioxide equivalent per square metre of gross building area and is expressed as $MtCO2_e/m^2$.
Emissions Scenario: **(IPCC 4th Assessment Report on Climate Change, Working Group 1 Glossary)**	A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships. Most contain both a Business-As-Usual emission projection based upon the defined driving forces and an intervention emission projection based on specific changes made to them.
Energy-Indirect ISO 14064	Energy-Indirect is electricity, heat, steam, or other energy that is imported to a site or organizational boundary and includes grid-supplied electricity.
Energy Use Intensity (EUI) Natural Resources Canada Website Glossary http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/glossary_e.cfm?attr=0	Also known as energy intensity, EUI is a measure of energy used per unit of activity. In the case of a building, the term refers to energy use in kilowatt-hours (kWhr) or gigajoules (GJ) per square metre of gross building area and is expressed as $kWhr/m^2$ or $GJ/m^2/yr$ respectively..

Floor Area (OBC)	The Ontario Building Code defines Floor area as the space on a storey of a building between exterior walls and required firewalls, including the space occupied by interior walls and partitions, but not including exits, vertical service spaces, and their enclosing assemblies. It is important to note that Floor Area is defined differently by many organizations, standards, and local authorities. For the purposes of this study, Floor Area will be defined in accordance with the OBC, with any notable exceptions discussed where appropriate.
Global Warming Potential (GWP) **(IPCC 4th Assessment Report on Climate Change, Working Group 1 Glossary)**	An index, based upon radiative properties of well-mixed greenhouse gases, measuring the radiative forcing of a unit mass of a given well-mixed greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation. The Kyoto Protocol is based on GWPs from pulse emissions over a 100-year time frame.
Green Building Assessment (GBA)	A green building assessment tool uses qualitative and quantitative to attempt to measure the "greenness". They typically feature a series of credits or points that set the minimum threshold to meet the criteria of the various measures. Most feature a graduated series of achievement based on the number of points, with the most stringent requiring all measures. It is important to note that not all GBAs require the measurement or verification of performance in order to be awarded a credit.
Greenhouse Gas (GHG): **(IPCC 4th Assessment Report on Climate Change, Working Group 1 Glossary)**	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6),hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).
Greenhouse Gas Sink: **(IPCC 4th Assessment Report on Climate Change, Working Group 1 Glossary)**	A GHG Sink is any process, activity or mechanism that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol from the atmosphere. A GHG Removal within a greenhouse gas accounting project involves the introduction of a GHG sink.
Lifecycle Assessment (LCA): **ISO 14040**	A study that addresses the environmental aspects and potential environmental impacts throughout a product's lifecycle from raw material acquisition through production, use, end-of-life treatment, recycling, and final disposal within a defined system boundary.
Operating Energy:	The amount of energy that is consumed by building to satisfy the demand for operation that includes, but is not limited to, heating, cooling, ventilation, lighting, auxiliary equipment such as computers and appliances, mechanical equipment, and electrical equipment. Operating energy is sub-divided into two categories:

Primary Operating Energy:	The total requirement for all energy including energy used "at the meter" by the final consumer (see secondary operating energy), non-energy uses, intermediate uses of energy, used to generate or transform electricity from one form to another (eg coal to electricity), and energy used by suppliers in transporting energy to the end user or providing it to the market (eg pipeline fuel or transmission losses over power lines).
Radiative Forcing: **(IPCC 4th Assessment Report on Climate Change, Working Group 1 Glossary)**	Radiative forcing is the change in the net, downward minus upward, irradiance (expressed in W/m^2) due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun. Radiative forcing is computed with all tropospheric properties held fixed at their unperturbed values, and after allowing for stratospheric temperatures, if perturbed, to readjust to radiative-dynamical equilibrium. Radiative forcing is called instantaneous if no change in stratospheric temperature is accounted for. For the purposes of this report, radiative forcing is further defined as the change relative to the year 1750 and, unless otherwise noted, refers to a global and annual average value. Radiative forcing is not to be confused with cloud radiative forcing, a similar terminology for describing an unrelated measure of the impact of clouds on the irradiance at the top of the atmosphere.
Secondary Operating Energy:	The energy used "at the meter" for final end-use consumers including the building, transportation, agricultural, and industrial end-use sectors. Within the specific context of the building sector, this includes energy used for space heating and cooling, ventilation, lighting, appliances and electronics, fans and pumps etc. It does not include generation, transformation, or transportation energy use and is thus only concerned with the final end-use within the boundaries of the site.
SRES Marker Scenario: **(IPCC 4th Assessment Report on Climate Change, Working Group 1 Glossary)**	SRES emission scenarios were developed by Nakićenović and Swart (2000) and continue to be used as a basis for climate projections in IPCC 4th Assessment Reports and National Emission projections. There are a number of scenarios that are grouped into families that share a similar demographic, societal, economic and technical change storyline. There three families known as the A2, B1 and B2 with the fourth family subdivided into A1B, A1F1, and A1B. Within each family, a single marker scenario has been chosen to represent a given scenario family. The choice of markers was based on the initial quantifications that best reflected the storyline. They are no more or less likely than other scenarios, but are considered by the writing team as the most illustrative and have received the closest scrutiny. Many climate change mitigation studies make use of SRES marker scenarios for Business-As-Usual or mitigation projections.