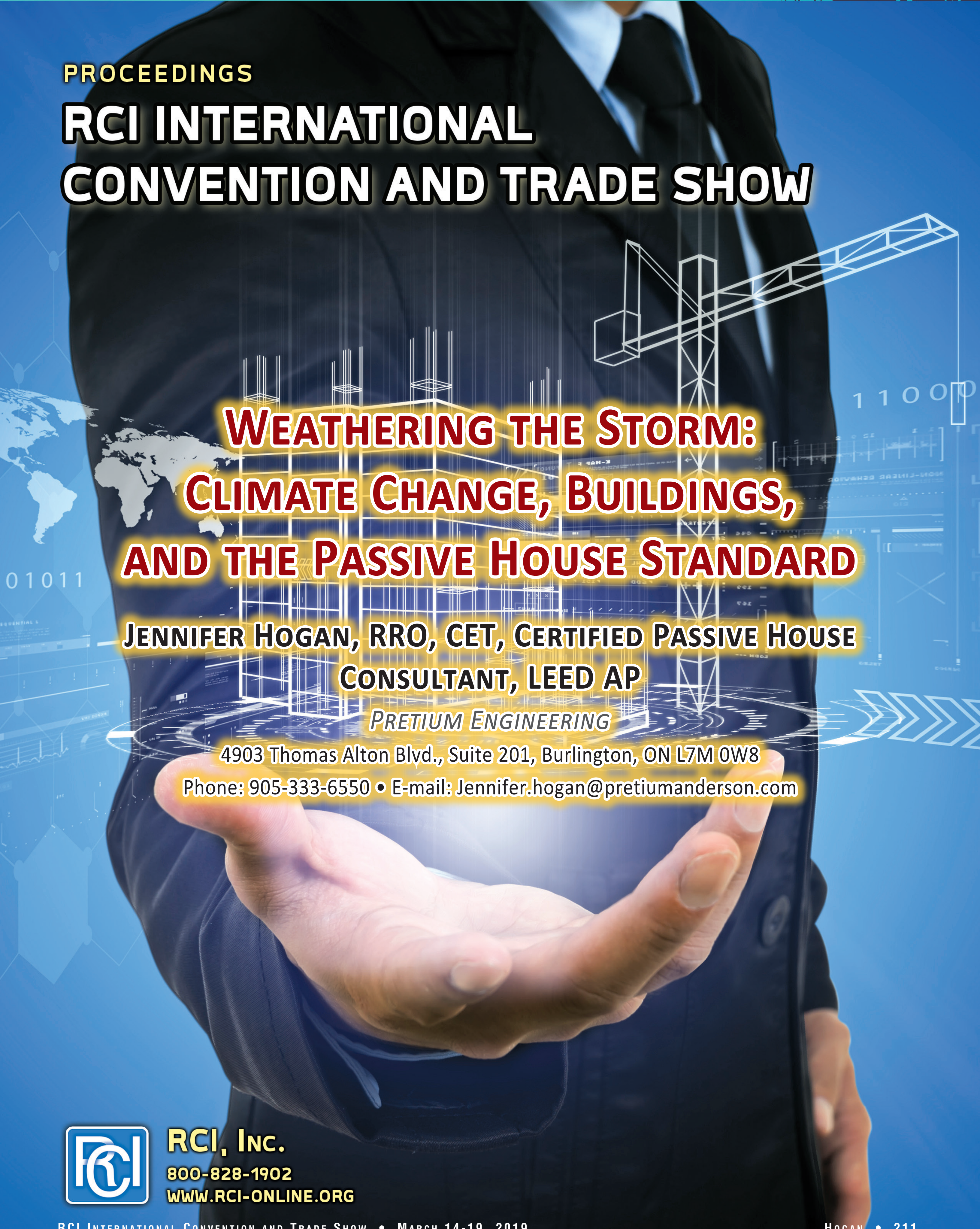

PROCEEDINGS

RCI INTERNATIONAL CONVENTION AND TRADE SHOW

# Weathering the Storm: Climate Change, Buildings, and the Passive House Standard

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## Abstract

The climate data are clear: climate change is happening. As the severity and frequency of storms and other extreme weather events increase, it becomes more and more critical that we achieve the targets set out in the Paris Agreement. While limiting our global temperature rise to 2°C (3.6°F) may seem like an easy target, how we design, construct, and operate buildings will need to change dramatically.

There are many sustainable building initiatives/programs, but Passive House is the most rigorous voluntary energy-based standard in the design and construction industry today. Passive House buildings:

- Achieve up to a 90% reduction in energy required for space heating and cooling
- Maintain a habitable interior temperature for weeks without power
- Have excellent indoor environmental quality
- Allow design flexibility

Through the course of this paper, actual project examples will be used to reinforce each of the five key principles of the Passive House standard and how quality assurance is carried out for each:

- Low U-value and continuous insulation
- Continuous air barrier layer
- Elimination of thermal bridges
- Use of high-performance glazing
- Optimization of mechanical ventilation with heat recovery

We will conclude with a discussion on how the standard is being implemented in codes and standards at the local level using the Toronto Green Standard as an example, and discuss the potential impact of widespread adoption of the standard.

## Speaker

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JENNIFER HOGAN is the branch operations director for her firm and has 11 years of experience in the building science industry. She is a member of RCI, the Canadian Green Building Council (CaGBC), and the Building Commissioning Association (BCxA). In addition to her extensive experience in the investigation of building envelope failures, building condition assessments, specification writing, contract administration, field review of building condition rehabilitation projects, and capital planning studies, Hogan also has experience in energy and green retrofit analysis, Passive Houses, hygrothermal modelling, building envelope commissioning, and artistic renderings.

# Weathering the Storm: Climate Change, Buildings, and the Passive House Standard

## CLIMATE CHANGE

### The Science...

The argument over the validity of climate change is one that frequently makes headlines on a global scale. With staunch supporters on each side of the argument, it can be difficult to decipher truth from propaganda, particularly when the definition of climate change is made malleable to suit the desired message. Misuse of the term "global warming" often has climate change deniers pointing to rising temperatures as the only measure of a changing climate.

However, the science is quite clear. Our climate is, in no uncertain terms, changing, and it is our fault.

Environment and Climate Change Canada (ECCC) has been collaborating with similar agencies worldwide as part of the Intergovernmental Panel on Climate Change (IPCC). The IPCC has been collecting data on greenhouse gas (GHG) emissions, temperature, precipitation, and a host of other factors to create predictive climate models. Using direct measurements starting in the mid-20th century and data from air bubbles trapped in glacial ice prior to that, they have found that human-related GHG emissions have increased to unprecedented atmospheric levels in at least the last 800,000 years. *Figure 1* shows their data for carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$).[1] The exponential increase in emissions starting in the mid-1900s is a clear indication of the effects our progress has had on the environment.

What impact does this increase in emissions have on our climate? Well, the National Oceanic and Atmospheric Administration (NOAA) in the U.S. has tracked the global land temperature anomalies[2] since 1880. *Figure 2* shows that the average surface temperature has risen exponentially, in a curve that closely reflects that of emissions since the mid-1900s.[3] From 2015–2017, the average increase in global land temperature was 1.38°C (2.48°F).

The Paris Agreement, which was signed by the parties of the UNFCCC in 2015, aims to keep the global temperature rise to

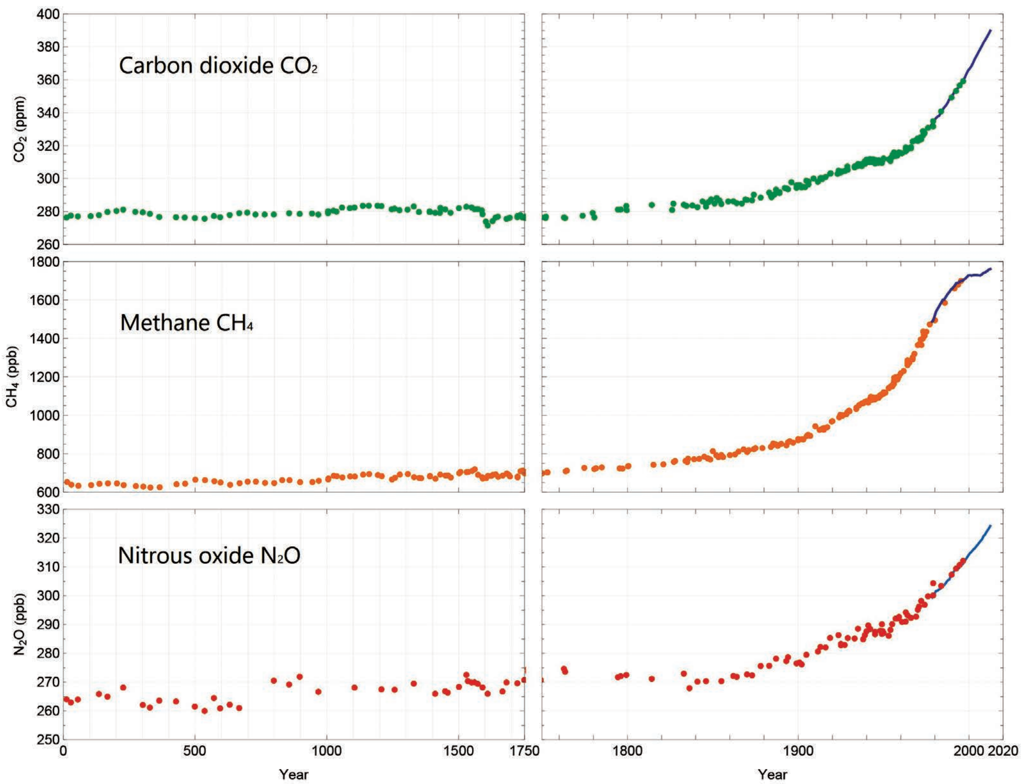


*Figure 1 – GHG emissions data from ECCC.*

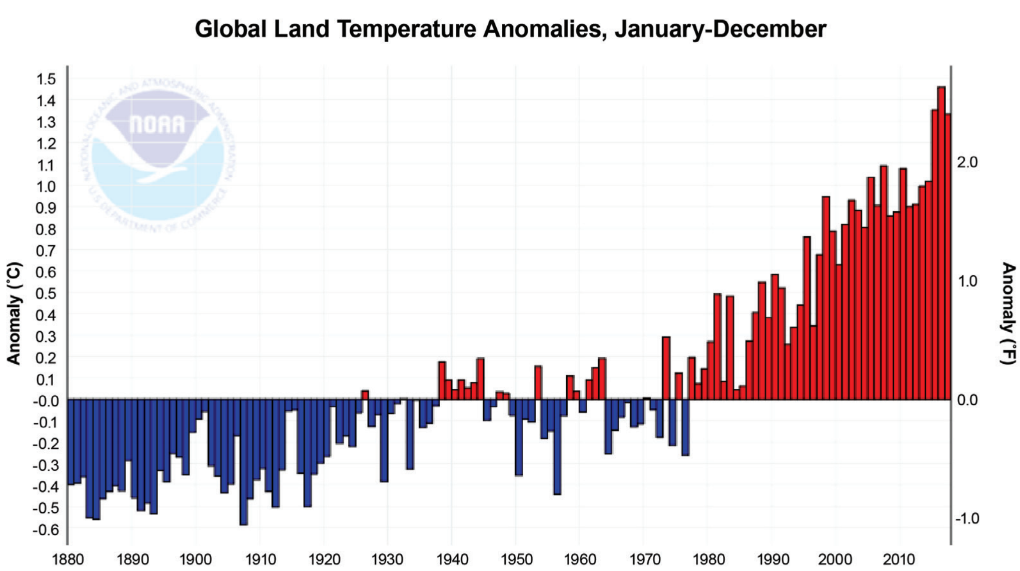


*Figure 2 – Global land temperature anomalies as recorded by the NOAA.*

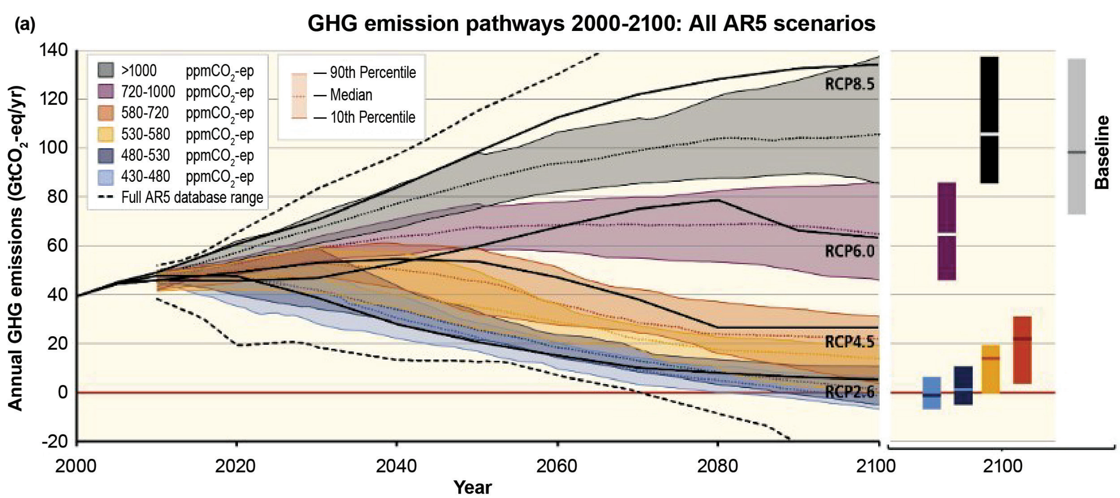


*Figure 3 – RCP for all AR5 scenarios as prepared by IPCC. Each RCP corresponds to the following global temperature increase:*
*RCP 8.5: 3.2 – 5.4°C*
*RCP 6.0: 2.0 – 3.7°C*
*RCP 4.5: 1.7 – 3.2°C*
*RCP 2.6: 0.9 – 2.3°C*

2.0°C (3.6°F) this century and includes an extra effort to limit the temperature rise to 1.5°C (2.7°F). This does not really give us a lot of wiggle room. In generating their predictive models, IPCC has confirmed that sadly, if we continue our current trajectory, achieving the targets of the Paris Agreement is a pipe dream.

The models they have generated include approximately 900 mitigation scenarios with atmospheric concentration levels of GHG emissions ranging from 2100 ppm $CO_2eq$[4] to 430 ppm $CO_2eq$. *Figure 3* shows the data grouped into four representative concentration pathways (RCPs), and only the very lowest of the scenarios (shown in blue) is likely to limit the global temperature rise to below 2°C.[5] In this RCP, emissions begin to decline by 2020 and then decline rapidly thereafter until they achieve net negative $CO_2$ emissions in the second half of the century.

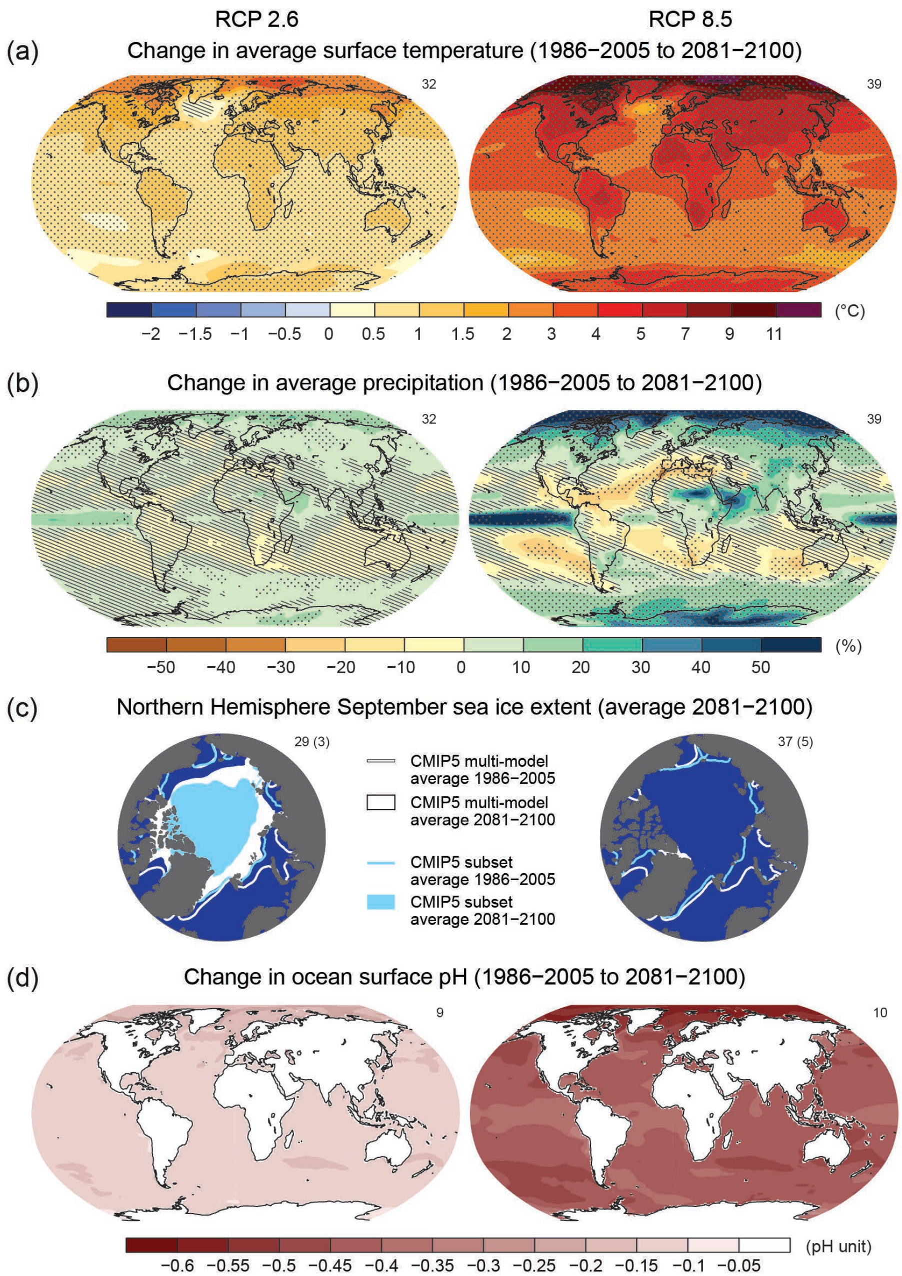


*Figure 4 – Comparison of RCP 2.6 and RCP 8.5 for temperature, precipitation, sea ice, and ocean pH by IPCC.*

## ... And Its Effect on Our Buildings

The effects of an increase to the global temperature anomaly is a nebulous concept for most. What does this really mean for us? IPCC has looked at the modelling for RCP 2.6 and RCP 8.5 and made some predictions about four key factors that affect our environment: surface temperature, precipitation, sea ice, and ocean surface pH. The results of the modelling are shown graphically in *Figure 4*.[6] The future of our planet under RCP 8.5 is an uncertain one. With the average surface temperature increasing by as much as 11°C (19.8°F), precipitation becoming more polarized (30% increase in some areas with a 30% reduction in others), minimal to no sea ice, and extreme acidification of the oceans, the one thing we can be sure of is that the world will be a different place.

Even if we achieve the Paris Agreement, or near to it, at RCP 2.6 there are now, and will continue to be, changes to our climate that will impact our buildings. Some of the changes we can expect to see include:

- Increased frequency and intensity of temperature extremes (e.g., heat waves), with 1:20 year events becoming 1:5 year events
- Increased precipitation in most areas, with 1:20 events becoming 1:10 by 2050
- Snow season lengths and snow depths are likely to decrease; however, the maximum snow depths resulting from extreme snow storms could increase because of the increased precipitation.
- Double the number of wind gusts that exceed 90 km/h (25 m/s)

Each of these points corresponds to a design load for buildings. The problem is that the codes base most of their loads on historical data. While ECCC is working to have codes in Canada updated to include load requirements based on predictive modelling, all of our building designs have been based on out-of-date information.

### So Where Do We Go From Here?

Mandated government codes are likely not enough to ensure our buildings can withstand the coming storm. For that reason, many designers are looking to other voluntary standards to aid them in designing high-performing buildings that have long-term durability in mind. There are many different standards that can be used, each with a focus or strength. Some examples include Energy Star, Leadership in Energy and Environmental Design (LEED), Green Globes, Zero Energy Certification, the WELL Building Standard, and Passive House.

## THE PASSIVE HOUSE STANDARD

### Introduction

What is a Passive House (Passivhaus)? For those of you not familiar with it, there are three very common misconceptions. First, Passive House does not mean the use of only passive building systems. While the buildings do take advantage of passive systems, they do not rely solely on them to condition the space. Second, Passive House is not just for "houses." It can apply to all building types, including high-rise residential, commercial, and institutional buildings. Finally, Passive House is not just for new construction. Through the EnerPHit standard, existing buildings can take advantage of slightly relaxed targets for existing conditions that cannot be easily changed, while still benefiting from significant energy savings. While this paper is not intended to discuss the differences between Passive House and EnerPHit in detail, it should be noted that EnerPHit offers two compliance paths: the Component Method (meeting targets specific to each component) or the Energy Demand Method (meeting demand targets, which is the method most similar to Passive House).

The first Passive House building was constructed in Darmstadt, Germany, in 1991 by founders Wolfgang Feist and Bo Adamson with the help of architects Bott, Ridder, and Westermeyer. The building was a row of houses consisting of four flats, each with 156 m$^2$ of living space. The design was based on research aimed at combining energy efficiency with comfort, affordability, and good indoor air quality (many of the principles applied were based on a previous project located in Canada in 1977 called the Saskatchewan Conservation House). It was equipped with a highly precise data measurement and acquisition system to allow for analysis of its performance versus the objectives/targets.

Since the success of that inaugural project, the standard has continued to gain momentum, with buildings being certified across the globe, achieving energy savings as high as 90%. While at the time of the writing of this paper there were only 17 certified projects within Canada, more than 35 projects were in some stage of design and development, with more on the way. Internationally there have been over 60,000 projects completed.

Passive House is the most rigorous voluntary energy standard, and it produces buildings with both unmatched comfort and very low energy consumption.

Because Passive House is a performance-based standard, there are several specific targets that must be met for any building hoping to achieve certification. These targets are validated both by using the Passive House Planning Package (PHPP) energy modelling software and by physical

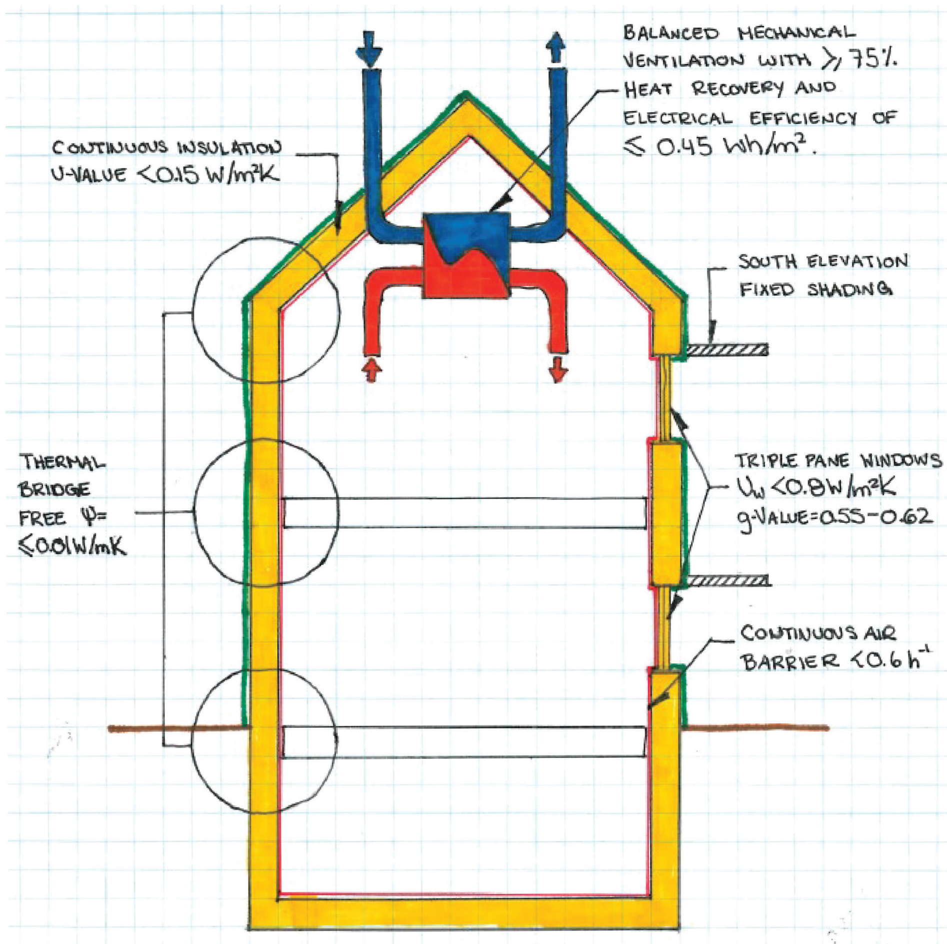


*Figure 5 – Illustration of some of the key Passive House principles: low-U-value and continuous insulation layer, continuous air barrier, elimination of thermal bridges, high-performance glazing, and mechanical heat recovery.*

testing based on a strict set of protocols. The key Passive House targets are:

- **Space Heating Demand:** 15 kWh/$m^2$a (or 10 W/$m^2$ peak demand)
- **Space Cooling Demand:** 15 kWh/$m^2$a plus a regionally determined dehumidification allowance (calculation in the PHPP)
- **Primary Energy (PE) Demand:** 120 kWh/$m^2$a annually

OR

- **Primary Energy Renewable (PER) Demand:** 60 kWh/$m^2$a (Classic), 45 kWh/$m^2$a (Plus), or 30 kWh/$m^2$a (Premium), and renewable energy generation of 0 kWh/$m^2$a (Classic), 60 kWh/$m^2$a (Plus), or 120 kWh/$m^2$a (Premium)
- **Airtightness:** 0.6 ACH@50Pa
- **Thermal Comfort:** not more than 10% of the hours in any year exceeding 25°C (77°F)

While there are many things to consider with the design and construction of a Passive House building, there are five key principles that should be considered to ensure targets are met:

- Low-U-value and continuous insulation layer
- Continuous air barrier layer
- Elimination of thermal bridges
- High-performance glazing
- Mechanical ventilation with heat recovery

Each of these principles is illustrated in *Figure 5* and is discussed in greater detail below.

### Low-U-Value and Continuous Insulation Layer

A continuous layer of insulation is required for all Passive House buildings. Typically, this layer is designed such that the assembly provides a U-value of 0.15W/$m^2$K or less; however, this number is highly dependent on the climate, building form, planning restrictions, available space, and other building elements. The purpose of the insulation is to reduce heat loss in the winter months, as well as to reduce heat gains in the summer. It also ensures that interior surfaces will remain a comfortable temperature. Since occupant comfort is of the utmost importance, reducing temperature stratification both vertically and horizontally in a space is important.

A comparison of typical R-Values (1/U) for assemblies in a conventionally constructed building under Part 9 of the Ontario Building Code (OBC) and under Passive House is provided in *Table 1*.

### Continuous Air Barrier Layer

A continuous air barrier offers a number of benefits for building physics, energy efficiency, and occupant comfort. From a building physics perspective, it reduces the possibility of moisture damage to the envelope by limiting air leakage and resultant interstitial condensation. From an energy perspective, a continuous air barrier will help to reduce heat loss in the winter and humidity in the summer, thereby lowering heating and cooling loads. Finally, by reducing drafts, the barrier helps to improve occupant comfort.

Passive House requires buildings to achieve an airtightness of 0.6 ACH@50Pa with performance proven through a whole-building air leakage test. The OBC only requires that a building be designed to achieve less than or equal to 2.5 ACH@50Pa. Testing to confirm performance is not required unless the design team is taking advantage of a lower air leakage rate to achieve savings in the energy model.

Achieving such a tight envelope can be a challenge and requires each member of the construction team to be on board with the project goals. Detailing the air barrier in such a way that is it protected from damage (and putting in place a system to track intentional punctures) is critical to success.

### Eliminate Thermal Bridges

Thermal bridges typically occur at structural connections or penetrations in the continuous insulation layer,

| Assembly | OBC Part 9 Residential | Passive House |
|---|---|---|
| Roof | R-30 – R-52 | R-50 – R-100 |
| Window | R-2.8 – R-3.6 | R-6.8 – R-9.5 |
| Wall | R-13 – R-31 | R-50 – R-70 |
| Floor Slab | R-10 – R-27 | R-38 – R-50 |

***Table 1 – Comparison of OBC Part 9 typical assembly R-values and Passive House insulation levels.***

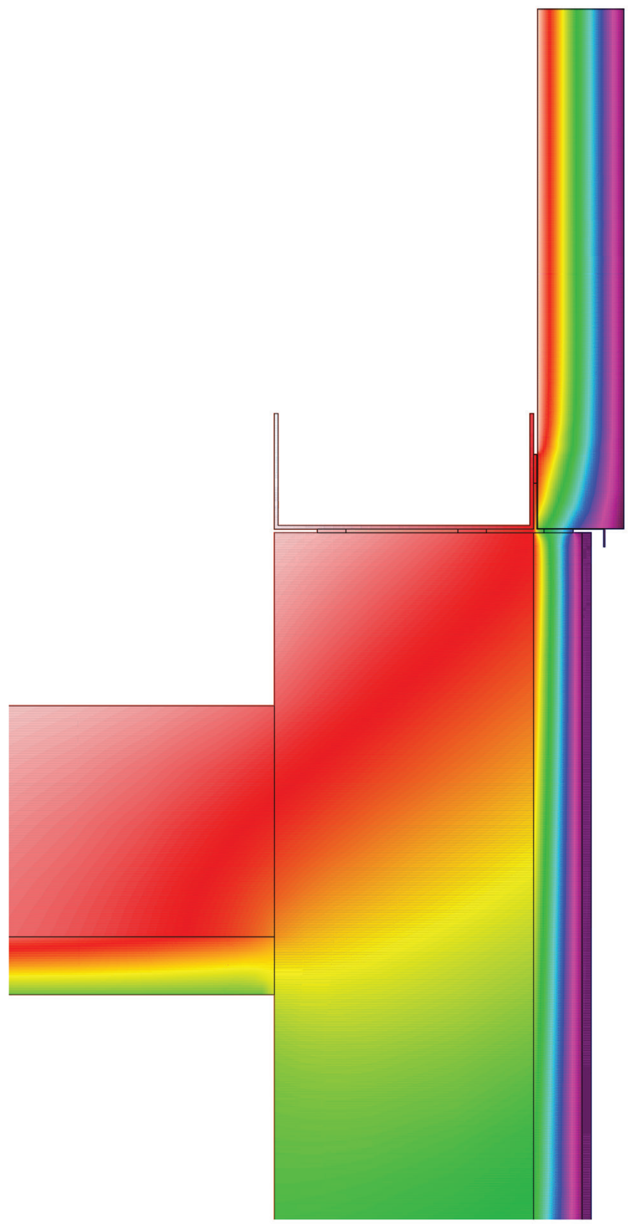

***Figure 6 – THERM modelling of a thermal bridge detail at a floor slab.***

*Figure 7 – Passive House window and balcony door installation in an existing building.*


(i.e., service penetrations, windows, and doors). Eliminating thermal bridges can be challenging, particularly when pursuing EnerPHit for existing buildings where large structural elements like foundations, on-grade slabs, and balconies are already in place. Passive House requires the design to be free of thermal bridges, meaning the heat loss through any detail in the building must be less than 0.01 W/m$^2$K. This can often only be confirmed through careful computer modelling, using 2-D or 3-D software, depending on the type and complexity of the detail being analyzed. An example of 2-D modelling is shown in *Figure 6*.

New products aimed at minimizing thermal bridging are becoming available on the market all the time. Some examples include thermal clips, ultra-thin insulation sheets, ultra-high thermal resistance materials, and other types of gaskets. Each is designed to address a specific type of thermal bridge and can be certified for use by the Passive House Institute. While it is not a requirement that only Passive House-certified products be used, it can help simplify some design decisions.

## High-Performance Glazing

High-performance glazing has similar benefits to low-U-value continuous insulation, continuous air barriers, and eliminating thermal bridges, but with a few added benefits. By using triple-pane insulated glazing units with a U-value of less than 0.8 W/m$^2$K and a solar heat gain coefficient of between 0.5 and 0.62, the window will add more energy to the building than it loses. It should be noted that the ability of the windows to add energy to the building will vary based on geographical location; however, Passive House projects have been successful in achieving a positive energy balance for windows, even in northern climates.

High-performance glazing also helps ensure that the radiant temperature difference between the area adjacent to the window and the rest of the space is below 4.2°C (7.5°F). This eliminates the need for a compensating heat source near the windows (i.e., electric baseboard heaters).

*Figure 7* shows a pilot installation of Passive House windows and balcony doors at an existing building. Note that the plane of the fenestration has been moved outwards from the original installation to bring it more in line with the insulation that will be added in a future phase of work. In an ideal Passive House design, the window would be located even further outward from the face of the brick, such that it would be centered in the insulation layer (which will be installed outboard of the existing brick). Also visible are the transition tapes and gaskets that are used to ensure an airtight assembly.

### Mechanical Ventilation With Heat Recovery

Passive House buildings are designed to supply clean, filtered air all year round. The inclusion of 75% minimum heat recovery helps reduce the heat loss in the winter. Heating and cooling can be included as part of the ventilation system, or as a separate system. The Passive House Institute certifies Heat Recovery Ventilator (HRV) and Energy Recovery Ventilator (ERV) units (as well as other building components as discussed above). Like the windows, doors, and thermal bridging products, you are not required to use certified equipment; however, particularly in the case of HVAC equipment, it helps simplify design and ensures that these more detailed Passive House requirements are met. These requirements include creating an HRV/ERV unit that is its own "mini-Passive House," since each unit must be superinsulated, airtight, thermal-bridge free, compact, quiet, and energy efficient.

In existing buildings, retrofitting ventilation air into each separate unit can be challenging, since most buildings are designed to supply fresh air through a combination of make-up air supply and in-suite exhaust fans that do not require a central duct system. Installation of a ducted system requires sufficient service space in ceilings, walls, or closets, which is not always available.

### Modelled Building Performance

At the time of the writing of this paper, the author was part of the team delivering two projects of different building types, which had reached the conclusion of the feasibility stage for achieving the EnerPHit standard in Southern Ontario. The first is a two-story residential building with 20 units, and the second is a 20-story high-rise building with 300 units. The results of the PHPP modelling (see *Figure 8*) conclude that the low-rise building will save 78% of its annual energy demand, and the high-rise will save 85%. That is an annual cost savings of $22,164 and $297,843, respectively.

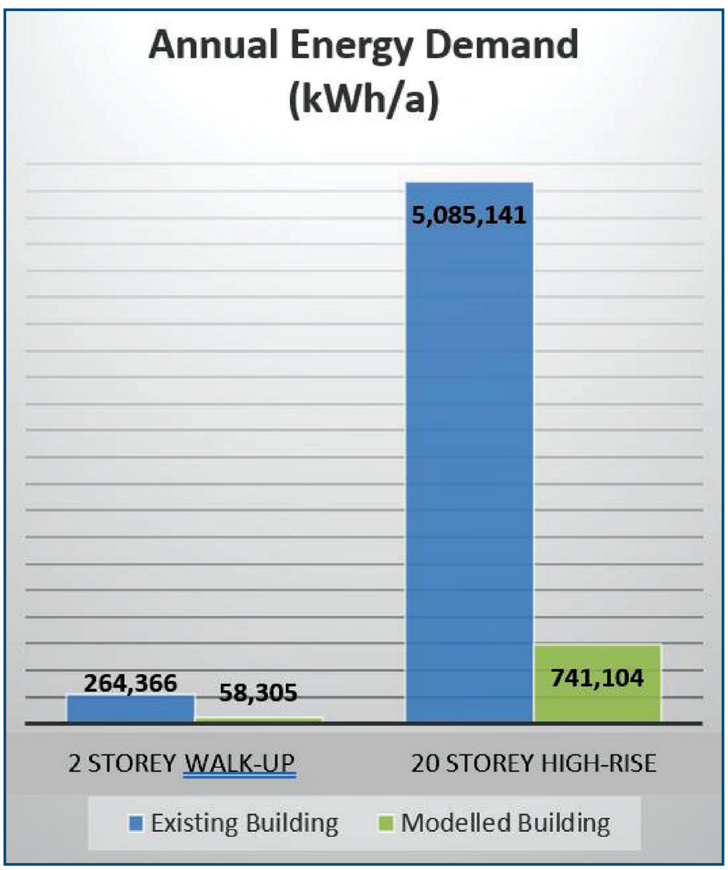


***Figure 8 – Results of the PHPP modelling for two EnerPHit projects currently underway.***

The next challenge will be to ensure that the design and subsequent construction achieve the performance levels set out in the PHPP model, addressing each of the key targets and principles discussed.

### How Can a Passive House "Weather the Storm"?

So why does Passive House make sense in the context of addressing our changing climate? As we have seen, the design principles used in a Passive House lend themselves to a few unique features. Because of the extremely tight and high-performing building envelope, the energy consumption and interior condition of a Passive House building are less susceptible to changes in the exterior climate. In fact, research by the Passive House Institute has shown that Passive Houses are able to maintain habitable interior temperatures for weeks, even with below-zero (0°C or 32°F) exterior temperatures. This would allow residents to shelter in place in the event of an extreme storm or power outage for much longer than those living in a conventionally constructed building. During the winter months, most conventional homes are uninhabitable within 72 hours of a power loss, with temperatures dropping to around 9.9°C (50°F). A Passive House building in the same environment would maintain an interior temperature of approximately 19.7°C (67.5°F). After a full two weeks without power, conventional buildings would fall to 0.9°C (33.6°F), while Passive House buildings would maintain a habitable 18.3°C (65°F).[7]

## A VIEW TO THE FUTURE

### Evolving Codes and Standards

In addition to the work currently being completed by ECCC to update the way we determine building loads for use in our codes, many municipalities are implementing programs of their own that increase the requirements for sustainability and resilient design and construction above the current code requirements.

For example, the leaders of Toronto, Montreal, Vancouver, Copenhagen, Johannesburg, London, Los Angeles, New York City, Newburyport, Paris, Portland, San Francisco, San Jose, Santa Monica, Stockholm, Sydney, Tokyo, Tshwane, and Washington, D.C. have signed an agreement called the C40 Net Zero Carbon Emissions Declaration. C40 aims to ensure that all new buildings operate at net-zero carbon by 2030 and that all buildings—old or new—will meet net-zero carbon standards by 2050.

In March of 2017, the city of Toronto published its Zero Emissions Building Framework. The Framework makes recommendations on updating the existing Toronto Green Standard (a two-tier set of performance measures for new developments that was adopted in 2010). Four tiers of performance were developed to create a stepped approach that would take buildings from today's standard practice and performance levels to a near-zero emissions level of performance by 2030. With this plan, the Toronto Green Standard will be updated every four years, with the lowest performance tier being removed in each revision. In this process, by 2030, what are now Tier 4 targets will become Tier 1 targets.

In the current proposal, the Tier 4 targets match many of the Passive House performance requirements such as thermal energy demand intensity (space heating demand) and the requirement for airtightness testing to confirm that the as-built construction meets the design. As such, the city of Toronto has confirmed that Tier 4 compliance can be granted through Passive House Certification.

## FINAL THOUGHTS

While the Passive House standard is not the only method to ensure achievement of a high-performance building, it does have a proven track record that makes it hard to ignore. The average deviation in savings from what is modelled with the PHPP and what is measured in the first year post construction is 2%. With so many design options and standards available, it is reassuring to know that by following the Passive House principles, you will not only create a building that uses, on average, 84% less energy on heating, but also creates an exceptional indoor environment, is durable, and can offer a refuge for its occupants during severe environmental events by maintaining a habitable interior climate.

While it is easy to look around and fall back on the defense that a single building's emissions are inconsequential on a global scale, the final thought for this paper is from the IPCC:

***Emissions anywhere affect the concentration everywhere.***[9]

In this, we must lead by example and pave the way for the type of global change that will ensure the continued prosperity of our planet and all its inhabitants.

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