2016 Greenest City Scholars
City of Vancouver

Window Replacement Best Practice Guide for Apartments and Condos

Prepared by: Sahar Badiei
MASLA Candidate, School of Architecture & Landscape Architecture, University of British Columbia
Mentor: Micah Lang
C40 Green Buildings Planner, City of Vancouver

This report was produced as part of the Greenest City Scholars (GCS) Program, a partnership between the City of Vancouver and The University of British Columbia, in support of the Greenest City Action Plan.

This GCS project was conducted under the mentorship of City staff. The opinions and recommendations in this report, and any errors, are those of the author, and do not necessarily reflect the views of the City of Vancouver or The University of British Columbia.

The following are the official partners and sponsors of the Greenest City Scholars Program:

CITY OF VANCOUVER | GREENEST CITY

UBC a place of mind THE UNIVERSITY OF BRITISH COLUMBIA sustainability

Acknowledgment

GREENEST CITY SCHOLAR PROJECT FOR THE CITY OF VANCOUVER

A huge thank you to Micah Lang for his guidance and support on this project.

Also a special thank you to Jennifer Wahl, Chris Higgins, Sean Pender, Patrick Enright and the Sustainability Group for their insights and knowledge.

Table of Contents

1. Introduction

"Windows can be a primary heating source… but, It is one thing to recommend something. It is another thing to get people to use it."
Guido Wimmers, founding director of the CanPHI West

The Greenest City Action Plan (GCAP), serves as the road map for the City of Vancouver becoming the greenest city in the world by 2020. The GCAP outlines ten goals as targets for 2020. [Fig.1] This project focuses on Goal 2/ Green Buildings, set to reduce energy use and GHG emissions in existing buildings by 20% over 2007 level.

Figure 1. Greenest City Action Plan 2020 Goals & Targets for City of Vancouver

Buildings use 64% of all energy in Vancouver and since natural gas is the predominant source of space heating, they produce 55% of GHG emissions. Multi-unit residential buildings (MURBs), including both rental apartment and strata condominium type buildings, make up 18% of building-related GHG emissions. Currently, many MURBs in Vancouver and other parts of BC have or are undergoing comprehensive building envelope retrofitting such as window replacement, to reduce energy costs as well as noise or moisture related problems [Energy consumption and conservation of MURBs building in BC, RDH, 2012].

The goal of this project is identifying barriers to MURBs window replacement and then, making recommendations to use high quality windows and best practice installation techniques in existing built rental buildings and condominiums.

Project Objectives

Based on the project goal, objectives of this research are:

- Define the current state of window replacement practice
- Identify the barriers to MURBs window replacement
- Make recommendations to increase accessibility of window replacement guides as well as educate strata corporations and building landlords regarding window procurement.

Methodology

Methods used to achieve the objectives includs:

background research to learn about different aspects of MURBs, windows, the window replacement process, as well as onsite or offsite interviews with practitioners in related fields, business owners, City staffs and other involved parties. This helped me to find first hand information about this market. In another word, there are a variety of opportunities that present themselves by looking at MURBs window replacement through different lenses of building owners and managers, strata building representatives, contractors, window companies as well as City of Vancouver staff.

Research Questions

Based on the objectives, the following questions were asked in our research interviews:

- What are the barriers to MURB window replacement?
- Who are the parties involved in MURBs window replacement process?
- What is the role of each party in this process?

For each user group:

- What are the main motivations of each party to invest in window replacement?
- What prevents people from replacing old inefficient windows with new ones?
- How does each group make decisions?
- How does ownership effect this process?
- What are the challenges each user group encounters in this process?
- Where do different groups obtain information about windows?

- Do existing guides effectively address window replacement considerations?
- How do people use the existing window replacement guides? Such as the one offered by Homeowner Protection Office (HPO)?
- What needs to be improved or changed in order to make existing window replacement guidelines more applicable? Is there any missing information? Is there any information that should be rephrased?

Research Questions

- Based on the City's previous research, there are three main barriers to existing building's energy retrofitting:

  - Limited owner investment in building improvements

  - Limited capacity/expertise to implement energy improvements

  - Limited awareness of energy efficiency opportunities and incentives

- How can we address these gaps in future guides?

- How do customers pay for windows? Given the current price code, is there any role for financial incentives for applying high performance windows?
- What are the financial and technical considerations window companies take into account?

- How do you make sure that the windows are installed using best practices? What happens after installation? Is there any maintenance needed for windows?
- How does building type effect the replacement method?
- What is noticeable in existing MURBs or similar buildings that already went through window replacement process successfully?

• Importance of the Project

Building Failure Study by *Canada Mortgage and Housing Corporation* (CMHC) building retrofit statistics In Canada, shows that building rehabilitation for roofing and wall system repairs and replacements cost an estimated **$7.5 billion** annually. 18% of this cost is spent on windows & doors which makes it the top six most frequent and costly problem areas in building envelop retrofitting. [2001 Building Failures Study at CMHC, Accessed May 2016]

The building envelope, windows and doors represent the second most frequent and costly source of deficiencies in Canada. In addition, almost 60% of building energy consumption is spent on space heating of which efficient windows have major role. Therefore, relative guides need to address new building envelope system solutions, as well as decision making tips for the public.

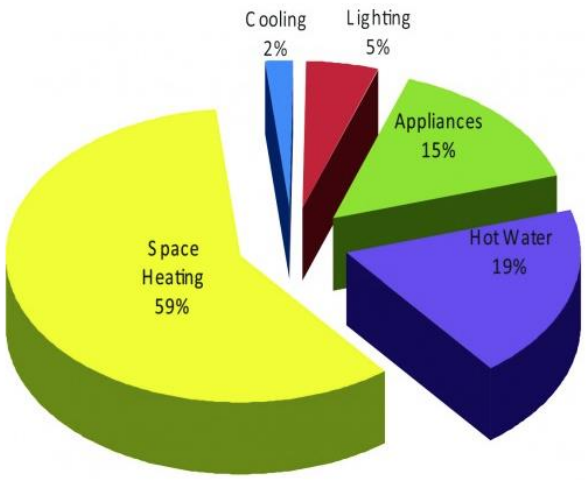


Figure 2. Space Heating Secondary Energy Use and GHG Emission by Building Type
[Natural Resources Canada (NRC), September, 2008]

"Canadians spend close to 90% of their time indoors; the buildings we live and work are a big part of our lives"
GCAP2020

• Why MURBs?

In British Columbia, particularly the Lower Mainland, there is a relatively recent trend for people to choose to live in multi-unit mid- and high-rise residential buildings (MURBs) greater than 4 stores in height. The reasons are many and varied: the shortage of suitable land, the climate, the desire to live close to populated centers, the views, etc. The developments may be private or public and tenure may be partial ownership, rental, or social housing. Preference is for individual ownership of each unit with shared ownership of the common areas. Management is by means of the elected strata council, maintenance and building operation is typically contracted to property management firms. This study focuses on these types of strata corporations or condominiums, which make-up the majority of multi-family residential housing stock.
[MURB Energy Study Report, RDH ltd, 2012.]

MURB suites account for 60% of the dwelling units and the fastest growing housing segment in Vancouver. Studies show the potential for 40% - 70% reductions in energy consumption for MURBs through energy efficiency upgrades. [Energy impact of building retrofitting, efficient MURBs, www.living-future.org, Accessed on May 2016]

Sector specific strategies designed by City of Vancouver in Energy-Retrofit Strategy for Buildings are:

1. **Focus on largest and least efficient Multi-unit Residential Buildings using Energy Bench marking** Which includes nearly all large condo buildings are managed by **8** property management firms. Considering that **46** landlords own **60%** of market rental units in Vancouver, we realize that any improvement in retrofitting or replacing guides makes a significant change.

2. **Provide targeted support to main barriers to existing building's energy retrofitting**

3. **Additional City support for voluntary energy efficiency action for MURBs**

2. Overview of Windows Current Practice

• Windows Basics

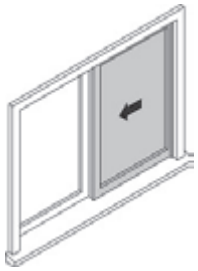
Windows can be separated in two categories based on their function.

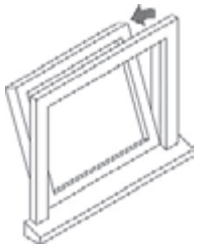
1. CURTAINWALL:
A non-load bearing wall cladding that is hung to the exterior of the building, usually spanning from floor to floor . This type is not covered in this project.

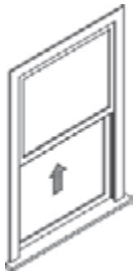
2. PUNCHED WINDOWS:
Or Punched Framing, is a type of window which is installed as a punched opening surrounded by cladding, as opposed to being arranged in vertical or horizontal strips. Punched framing like curtainwalls can accept operable units such as awnings, hopper, casements and sliding windows for air flow into a building.

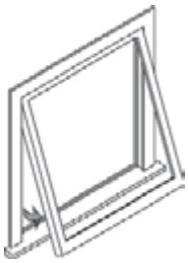
Windows can operate in many ways:

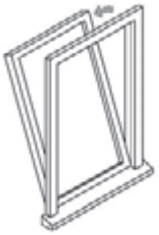
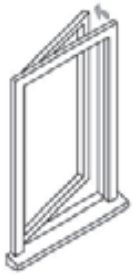

Casement

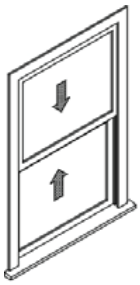

Sliding


Hopper


Single hung


Awning



Tilt & Turn (Dual Action)


Double Hung

Windows can improve homes in many ways:

- **Energy & Cost Saving:**
- **Lower HVAC Costs**
- **Improve Comfort**
- **Reduce Condensation**
- **Increase Light & View**
- **Reduce Noise**
- **Improve building's look**

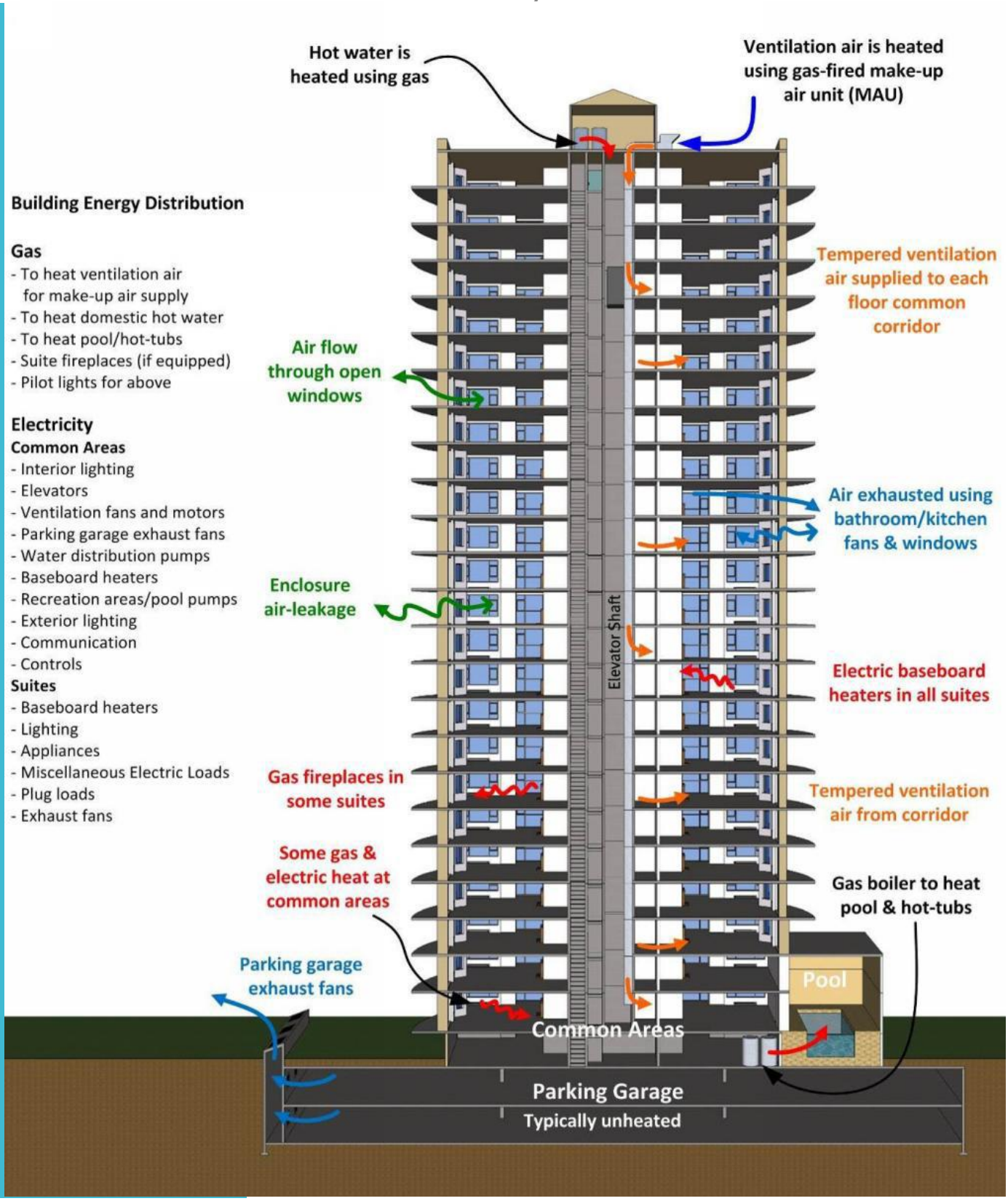
Non-energy efficient windows can represent a major source of unwanted heat loss, discomfort, and condensation problems in the heating season. Window companies are constantly improving windows to provide lower heat loss, less air leakage, and warmer window surfaces that improve comfort and minimize condensation. Depending on the condition of the old windows in an existing home, the savings can be higher if window replacement leads to long-term air leakage reduction.

In hot climate zones or seasons, non-energy efficient windows can be a major source of unwanted heat gain. In recent years, low-E coatings that reject solar heat without darkening the glass have undergone a technological revolution. It is now possible to significantly reduce solar heat gain and improve comfort while providing clear views and daylight.

The rate of heat loss is indicated in terms of the **U-factor** (U-value) of a window assembly. The lower the U-factor, the greater a window's resistance to heat flow and the better its insulating properties. While the U-factor is used to express the insulation value of windows, **R-value** is used for insulation in most other parts of the building envelope (Window frame, walls, floors, roofs) [www.efficientwindows.org, Accessed July 2016]

In terms of Structural consideration, the principal loads which windows must resist are wind loads and rain loads. [American Architectural Manufacturers Association (AAMA)

Schematic of a Typical MURB windows in association with Heating and Ventilation Systems



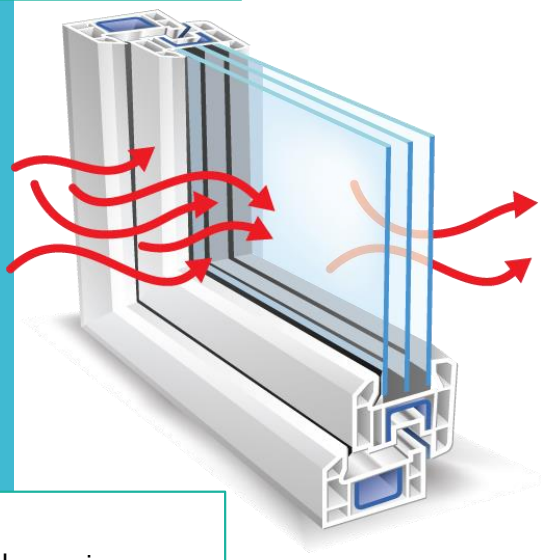
[Figure 3. MURB Energy Study Report, RDH ltd, 2012, Accessed May 2016.]

• Window Technologies

A variety of window technologies can improve window performance as a building envelope key component, including **gas fills, low-E coating** and **high-performance frame** options. How these technologies affect a window's energy performance depends on the sum of all parts. Today, manufacturers use an array of advanced technologies to make higher quality windows:

Improved Frame Materials
Wood composites, vinyl, and fiberglass frames reduce heat transfer and help insulate better

Advanced Low-E Coating glass
Special coatings reflect infrared light, keeping heat inside in winter and outside in Summer. They also reflect damaging ultraviolet light, which helps protect interior furnishings from fading.



Improved Airtightness
Improved weather-stripping

GAS Fills
Some energy-efficient windows have Argon, Krypton, or other gases between the panes. These odorless, colorless, non-toxic gases insulate better than regular air.

Multiple Panes
Two panes of glass, with an air or gas-filled space in the middle, insulate much better than a single pane of glass. Some ENERGY STAR qualified windows include three or more panes for even greater energy efficiency, increased impact resistance, and sound insulation.

Warm Edge Spacers
A spacer keeps a window's glass the correct distance apart. Today's warm edge spacers- made of steel, foam, fiberglass, or vinyl- reduce heat flow and prevent condensation.

[www.efficientwindows.org, Accessed July 2016]
Commonly used window glass material
[www.wbdg.org, Accessed July 2016]

A critical element of successful window design is integration with adjacent wall components to create a functioning wall system. Reliable wall system design generally includes a water resistant barrier behind the wall cladding, an air barrier, thermal insulation, and sometimes a vapor retarder. The "punched" window openings in the wall system threaten to create holes in the water, air, thermal, vapor barrier(s). Careful detailing is continue required to integrate water, air, vapor barriers with the window frames and maintain their y at the window perimeters. [www.wbdg.org, Accessed July 2016]

Adding exterior or interior blinds is another solution technology offers to assist windows in reducing heat transfer and controlling light. Exterior blinds are more effective in this regard while interiors are easier to install and maintain. The issue with both of them is, they block the view and natural light as well. Using blinds to improve building thermal insulation is more common in Europe but there are some companies in BC improving blinds to higher energy efficient products.

[Figure 4. Post Production Render by Author, Ordered by www.*mithrasolarsolutions.co*]

" Smart micro-grid, a sun tracking solar farm or a green building photovoltaic blinds" [www.mithrasolarsolutions.com, Accessed: August 2016]

• Windows in Passive House:

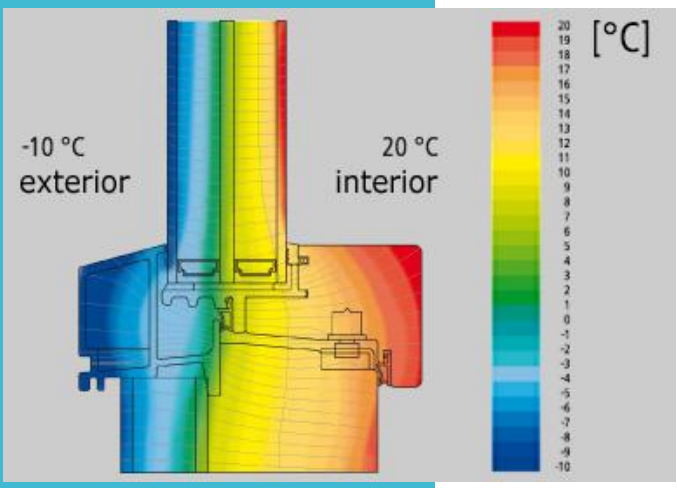


Figure 5. Passive House Windows, Thermal Performance , Extremely energy efficient, [*passivehousepa.blogspot.ca* July 2016]

Passive House, the world's most energy efficient construction pioneered by Passive House Institute in Germany, ranks windows not just as energy savers but as a prime energy source.[passivehousepa.blogspot.ca, accessed June 2016]
Passive buildings reduce energy consumption by up to 80% without the use of renewables or conventional heating systems. Achieving these efficiency levels requires advanced building technology that includes super insulation, super windows and super HVAC systems.

- Windows could be the defining characteristic of Passive Houses

Windows in Passive Houses must have a U-value no greater than **0.80** W/m2-K, which is more stringent than the tough new Vancouver Building Bylaw requirement of 1.4 W/m2-K and well below the Canadian average of 2.1 W/m2-K. Passive House windows also usually have a solar heat gain coefficient (SHGC) higher than 0.50 for south facing windows and 0.40 for north facing windows. Windows with such a high rating – allowing more solar heat into a building – are desirable in cold climates, like Canada and northern Europe. In part, that's the meaning of the term "passive" in Passive House.
Most BC window manufacturers could reach the Passive House requirements with the use of thicker frames, triple-pane glazing, argon gas and low-E coatings. [FenWest, Spring 2014]

- Passive House Niche market in Canada

The challenge is that the domestic Passive House market is so tiny – only **42** Passive Houses have been built in Canada! 20 are either built, under construction or proposed in British Columbia. That each window would be an expensive, custom creation. Only building permits submitted after June 30 2014 will be required to comply with the new Building Bylaw which includes updates to windows, insulation, heating systems, and accessibility. [FnWeest, Spring 2014]

Window Frame Materials in Comparison

Commonly used window frame materials include **aluminum, vinyl, fiberglass, steel wood, and PVC**. Aluminum frames are the most widely used window frame materials, and provide design flexibility because of the wide range of available stock systems and the relative economy of creating custom extrusions. In the **residential market,** wood and vinyl are the most widely used window frames. They provide better energy performance than aluminum and offer welded components that seal the joinery. Steel frames are less common than aluminum; there are relatively few manufacturers who produce high quality steel windows. [www.wbdg.org]

Replacing windows: how many years can they last?

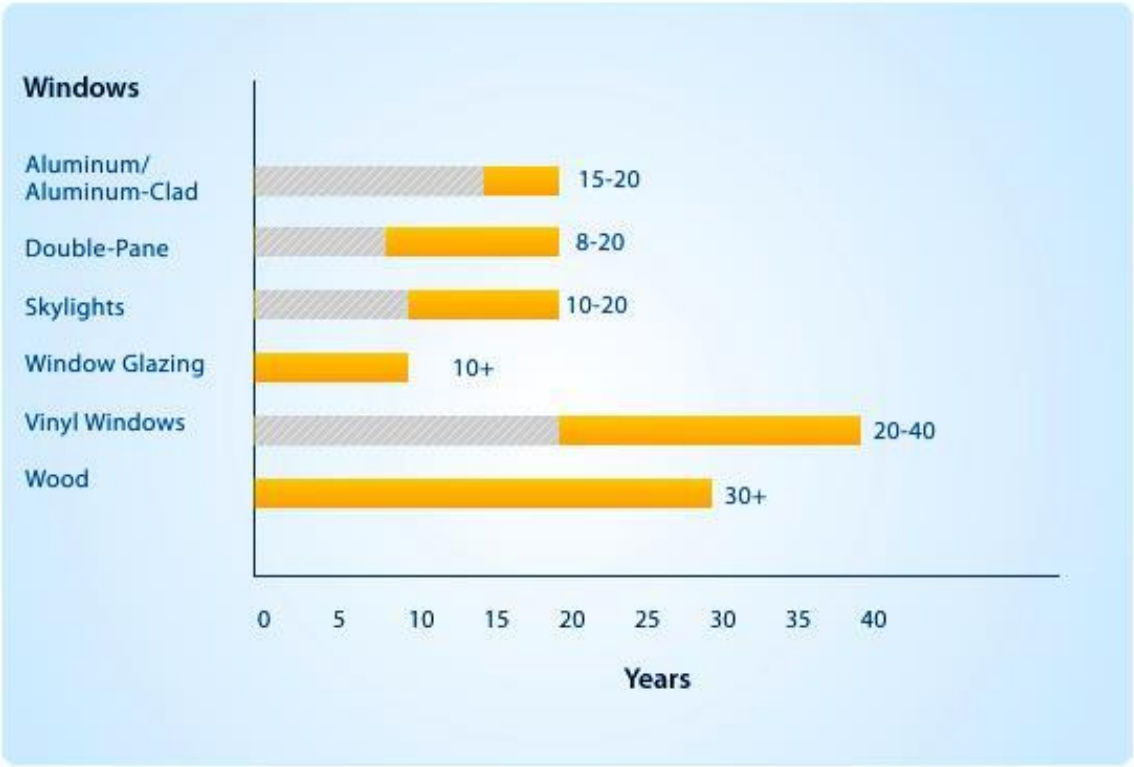


Figure 6: Window Frame Materials Life Span
[www.improvementcenter.com, Accessed: June 2016]

There is no standard procedure to compare the capital cost of frames of different materials due to a number of factors including the quality and functionality of windows, brand names and marketing strategies such as, discounts and incentives. A comparison of common window frame materials, assessed on the basis of their production, energy consumption and environmental impacts, shows that:

- **Life span:**

Aluminum and timber windows can easily last more than 40 years. Al-clad timber being new on the market, is expected to have a service life well over 40 years. PVC windows, in most cases, are reported to have an optimum service life of 25 years.

- **U-value:**

Aluminum windows have very low thermal resistance (high U-value) unless provided with thermal breaks. Timber and PVC windows have good thermal resistance while AL-clad windows exhibit the same thermal properties as timber.

- **Long-term costs:**

Timber frames are the most expensive in terms of initial and maintenance cost, as they require regular maintenance of the frame i.e. painting or staining after every 5 years.

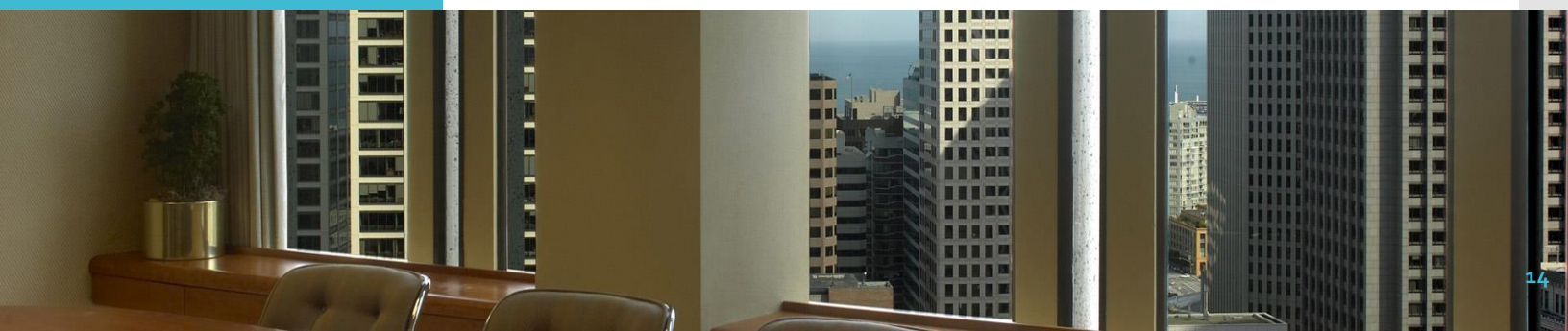
- **Environmental Considerations:**

Aluminum frames cause the highest burden to the environment because of the dangerous pollutants release and high energy consumption during aluminum production. PVC contributes large amounts of poisonous pollutants throughout its life cycle, while timber window frames have the least environmental burdens.

- **Embodied energy**

That has been carried out in a study in UK; for a standard 1.2m × 1.2m window. **Aluminum windows** have the highest embodied energy, amounting to 6GJ. PVC, Al-clad timber and timber windows have embodied energy of 2980MJ, 1460MJ and 995MJ respectively.

Sources: [www.renovation-headquarters.com, Accessed June 2016]
[www.improvementcenter.com, Accessed June 2016]
[Parks Canada, www.ohp.parks.ca.gov, Accessed June 2016]



Aluminum

Aluminum frames have been around for decades.

- **Cost:** Expect to pay between **$100** and **$250** each for strictly aluminum windows -- and add **$100** per window for aluminum-clad.
- **Maintenance:** Only needs to be cleaned to maintain their bright appearance
- **U-value:** have very low thermal resistance (high U-value) unless provided with thermal breaks. They transfer heat and cold extremely well and hence they are known to sweat in cold, climates which can damage drywall and wood window sills and trim.
- **Life Span:** These windows last 15 to 20 years without maintenance
- **Environmental considerations:** Aluminum frames cause the **highest burden to the environment** because of the dangerous pollutants release and high energy consumption during aluminum production
- **Deterioration:** If not protected well by coatings, gets damaged under corrosive conditions especially in coastal and industrial areas as salt is a corrosive to aluminum.

Clad

A clad window is manufactured from wood. The inside of the frame, the part that is visible in the room is either stained or painted. The outside of the frame is clad in either a vinyl, or an aluminum skin.

- **Cost:** These windows are generally the most expensive one of the replacement window group
- **Maintenance:** require no external maintenance since the coating keeps the cladding protected against environmental impacts. Underneath the cladding a well treated timber should not require any maintenance since it is not exposed to environmental degradation
- **U-value:** The thermal properties of vinyl are excellent as it does not transmit heat or cold well, giving you an added insulation factor. Aluminum also makes an excellent cladding, but it's thermal properties are not as good as vinyl as aluminum will transfer heat and cold. AL-clad windows exhibit the same thermal properties that of timber ones.
- **Life Span:** The cladding protects the wood from the elements and provides a durable very long-life window frame. Vinyl is best for colder climates and because the color pigment is throughout the material, scratches and other light surface damage is generally not noticeable.
- **Deterioration:** Al-clad frames are unlikely to deteriorate due to their protective coatings and appear to be the best choice from this point of view. Aluminum can be painted if the frame is marred in the future.

Vinyl or PVC

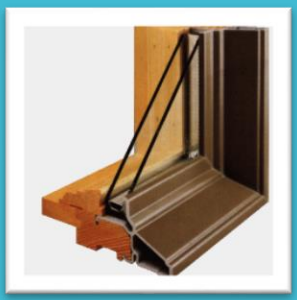
One of the most popular options on the market today, vinyl . The vinyl window frame, is generally hollow although some manufacturers place a foam insert to provide some added insulation. For tall buildings Vinyl is the best but not combustible.

- **Cost:** The least expensive of all the possible choices. You can get basic vinyl windows for around $100 a piece and larger, more complex models for as much as $400 each
- **Maintenance:** The color is blended into the material so that scratches, and other marring will not show. But, Vinyl expands and contracts more than other materials, though, which makes them more prone to failure than other types of windows -- especially in high-heat situations
- **U-value:** Are thermally efficient and can be made to match almost any home.
- **Life Span:** Expected to last 20 to 40 years
- **Environmental impacts:** PVC contributes large amounts of poisonous pollutants throughout its life cycle
- **Deterioration:** is sensitive towards heat and UV radiation.

Wood

Easy to work with, which makes it easier to find custom shapes, give the warmth and class look to buildings.

- **Cost:** Wood windows can run anywhere from $200 to $600 each
- **Maintenance:** The most expensive in terms of maintenance cost, as they require regular maintenance of the frame i.e. painting or staining after every 5 years.
  If not cared for properly wood will rot, split and warp.
- **U-value:** Wood is naturally very thermally efficient
- **Life Span:** can last about 30 years
- **Environmental considerations:** timber window frames have the least environmental burdens compared to other materials
- **Deterioration:** if not frequently treated, can easily be affected by environment



Fiberglass

Fiberglass is not overly common because it is a relatively new material to be used on window frames. Fiberglass is usually used as the outside material of the window frame and combined with wood or vinyl tor the inside of the frame.

- **Maintenance:** It requires little if any maintenance and accepts paint and does not bow, crack or split.
- **U-value:** Fiberglass has excellent thermal qualities for windows as it does not transmit heat or cold well.
- **Life Span:** It has a long life
- **Deterioration:** As more and more manufacturer's start making window frames from fiberglass they will become very popular

• Windows in the BC Building Code Regulations

The Vancouver Building By-Law is already recognized by the World Green Council as a world leading green building policy.

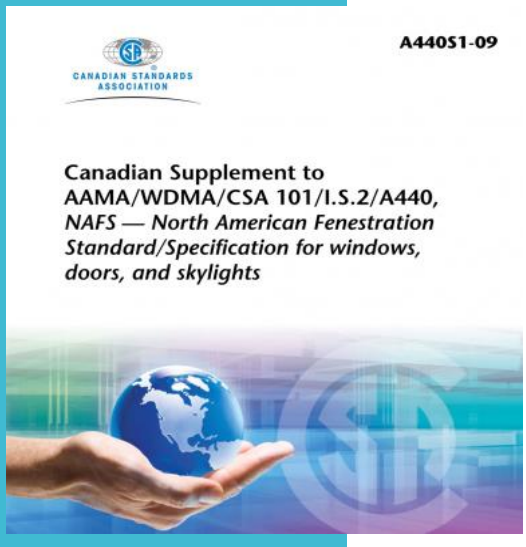
10.2.2.2. Windows, Glass Doors and Skylights in *Vancouver Building By-law 2014*

1) Windows and glass doors shall have **a maximum thermal conductance (U value) of 1.4 W/(K•m²)** and shall be **labeled** accordingly.

2) Skylights shall have a maximum thermal conductance (U value) of 2.4 W/(K.m²).

[Vancouver Building By-law 2014, Part 10 — Energy and Water Efficiency]

• Windows in Rating and Labeling systems



The North American Fenestration Standard (NAFS) came into effect in December 2013 and the new energy and ventilation requirements for low-rise housing in December 2014. These code requirements introduced major changes and some complex implementation challenges. In most jurisdictions across the United States, building energy codes require that windows bear the NFRC label so that the code compliance of their energy ratings can be verified. [http://housing.gov.bc.ca]

Energy-efficient window technologies and design for maximum service life of the installation play an essential role in ensuring the sustainability of windows. The best strategy for durability of windows is to employ good design practices to ensure the maximum service life of the installation.

ENERGY STAR:

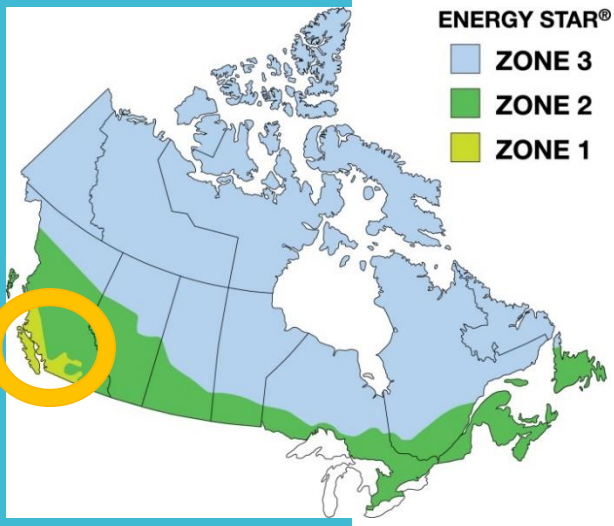
A government-backed program aimed to protect the environment by promoting energy efficiency. Windows built by window manufacturers (as opposed to site-built windows) can be designated as ENERGY STAR®

ENERGY STAR® Windows Offer:

- Lower household energy bills by 7-15 percent, shrinks a house's carbon footprint.
- Reduce condensation and outside noise, reduce heating costs, protect from sun damage and fading, and increase comfort by regulating temperature in hot and cold seasons.
- Energy-efficient windows have a thermal break in the frame to prevent heat flow,
- Using technologically advanced materials such as vinyl (PVC) for the frame maximizes window insulation properties
- Double glazing with a sealed insulating glass unit, not only reducing energy costs, but also increasing comfort.
- Low-emissivity (Low-E) coatings, which are like insulation and sunscreen on windows. This thin layer of transparent protection, applied in the gap between window glass panes, improves your family's comfort by reducing the quantity of heat passing through the windows.
- Inert gas, such as argon or krypton, sealed between windowpanes results in reduced heat transfer and minimized condensation, increasing the windows' insulation U-value and energy efficiency.
- Low conductivity spacer bars that prevent heat loss and minimize drafts.
- Lower overall heat loss ratings (U-values), meaning greater comfort with less energy used.
- Heat transfer between the inside and outside of a home is slowed.
- Heat reflection that keeps the sun out during summertime and keeps rooms from feeling drafty
  during the winter.
- Reduced fading of fabrics and wall coverings.
- Low-E coated glass, reduces the amount of radiant heat and ultraviolet rays that pass through the window, Low-E improves the value from
- R-2 to R-3 to R-4 depending on the coating type"

[www.nrcan.gc.ca/, Accessed: June 2016]

The climate zones are defined based on an average annual temperature indicator called a heating-degree day (HDD)The higher the HDD value, the colder the location. This map shows that Vancouver is located in the warmest zone which is less than 3500 HDDs.

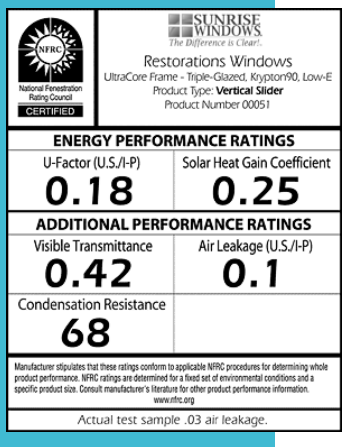


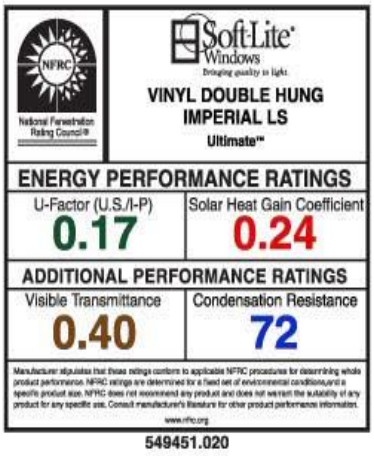
EnergyStar Zone	Example of Cities in Canada for this Zone	Minimum R-Value equivalent to meet Energy Star Requirements
Zone 1	Vancouver	3.2
Zone 2	Toronto, Ottawa, Montreal, Quebec, Halifax, Saint John's	3.6
Zone 3	Edmonton, Saskatoon, Winnipeg, Thunder Bay	4.0

[Figure 7. Energystar Zoning, www.nrcan.gc.ca, Accessed July 2016]

National Fenestration Rating Council NFRC:

A new, comprehensive standard addressing performance and quality requirements of windows, doors and skylights.
Window manufacturers certify products through NFRC so they are eligible for the Energy Star program for residential windows.





[NFRC Labels, www.ecobuildingstore.ca, Accessed: July 2016]

• Windows Pricing

Pricing windows depends on a number of variables such as:

- Dimensions
- Design
- Glass type , U-Value and R-Value
- Frame type and material

The window cost is confidential and everything is custom-made to meet project needs. Even the installation can vary, depending on the complexity of the installation, access, and location etc.
Typical windows in MURBs pricing policy as shown in Table 1, price range rises due to decrease of U-Value:

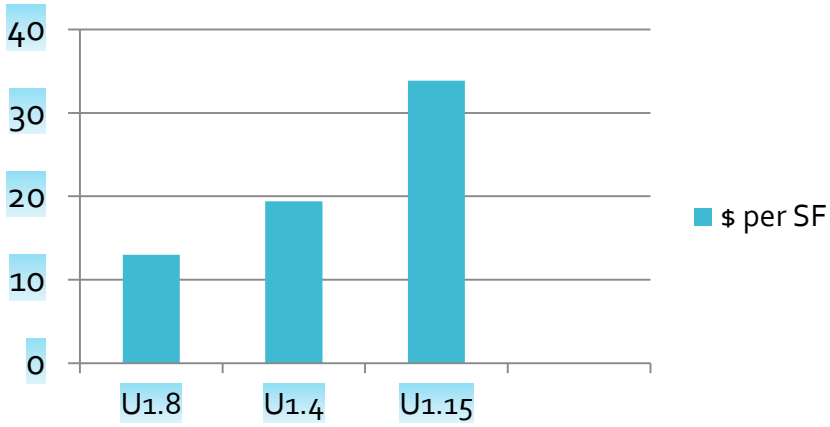


Figure 8: Average Window Pricing Vs. U-Value

As an example, a wood frame window replacement costs around $270,000 on 146 windows in a 100 years old rental building, located at Davie and Thurlow, so an average of about **$1,850** per window. *[Source: Property Owner interview, June 2016]*

The issue in pricing is the manufactures who struggle to meet the NAFS standard are putting them in retrofit jobs as there are no inspections. This is an *undocumented market*, plus a non-rated product is about 20% less in cost and a 20% difference is too big a number for customers to overcome. This is not an issue for strata's as there is more concern about quality, but rentals are more concerned about cost efficiency. One other barrier is, some landlords do not want to take the time to really understand the long term benefit of such replacements. *[Source: Vice President of Sales and Business Development interview, Fenestration company, May 2016]*

- What happens when windows fail?

[Figure 9. windows-flats-urban-apartment, Retrieved from, www. pixabay.com, August 2016]

Windows and skylights are an integral part of our homes. Poorly-performing products can be a significant source of heat loss and uncomfortable drafts. These products will often have condensation or even frost on them during cold weather, possibly causing mold. Also, they play a significant role in how buildings look.

Repair, improve or replace?

Upgrading windows does not always mean replacing them with new ones, some upgrades may be easier and less costly:

- Repairing Leakage is difficult, but sealants, foam, drainage vents or water diversion caps may help;
- Repairs following failed air and water tests are on a trial and error basis, and retesting is required, with additional factory or lab testing sometimes necessary;
- Poor window operation may be corrected by adjusting weather stripping and hardware;
- Condensation problems can be improved by applying additional sealants to interior components
- Window drainage can be repaired by clearing drainage holes, adding drainage to the exterior, adding drainage slots to inside tracks or sealing window corner joints;
- Staining at window corners can be reduced by using end deflectors on window sills. [2001 Building Failures Study]

Using these adjustments, the relative frequency and cost of deficiencies for 10 common building components were determined in the Building Failure Study, as shown in Figure 2, windows & doors are of the top six most frequent and costly problem areas. *[2001 Building Failures Study]*

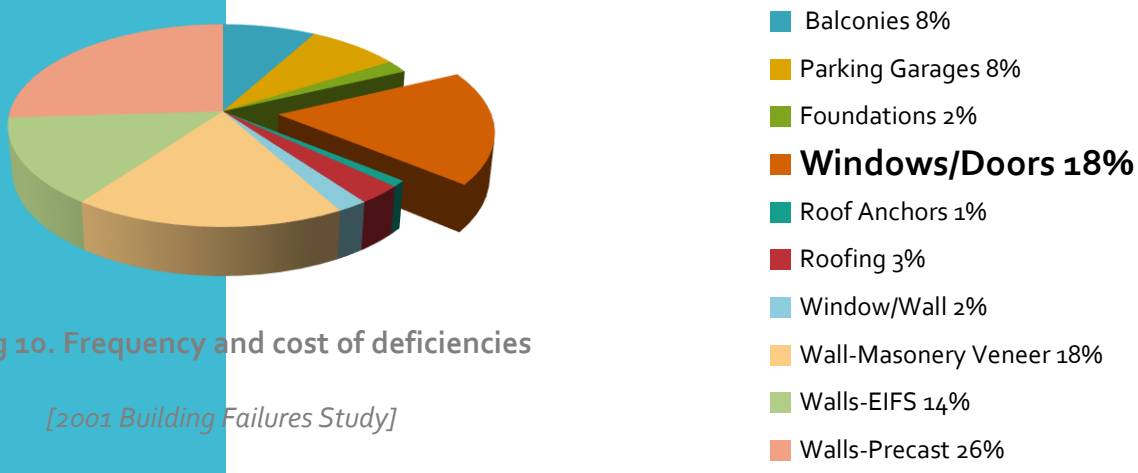


Fig 10. Frequency and cost of deficiencies

[2001 Building Failures Study]

When you need to replace windows?

Sometimes windows just break, but most of the time this isn't the motivating factor in replacement -- particularly for an entire house. Here are three common issues that often get the window-replacement conversation started:

1. Noise

According to interview feedback, reducing noise is one of the main reasons that encourages residents, owners or managers to pursue window replacement. Specially, old MURBs in noisy zones like downtown Vancouver need to replace windows with higher noise reduction rated products to bring comfort to homes.

2. Fogginess or condensation

The space between the panes in double-pane windows is filled with air or inert gas. As temperature varies, the fill and the seal around it both expand and contract, which causes the seal to break down, letting in outside air and, with it, moisture. Double-pane windows can last eight to 20 years, but if moisture gets between the panes, you might notice condensation and fogginess.

3. Lack of function

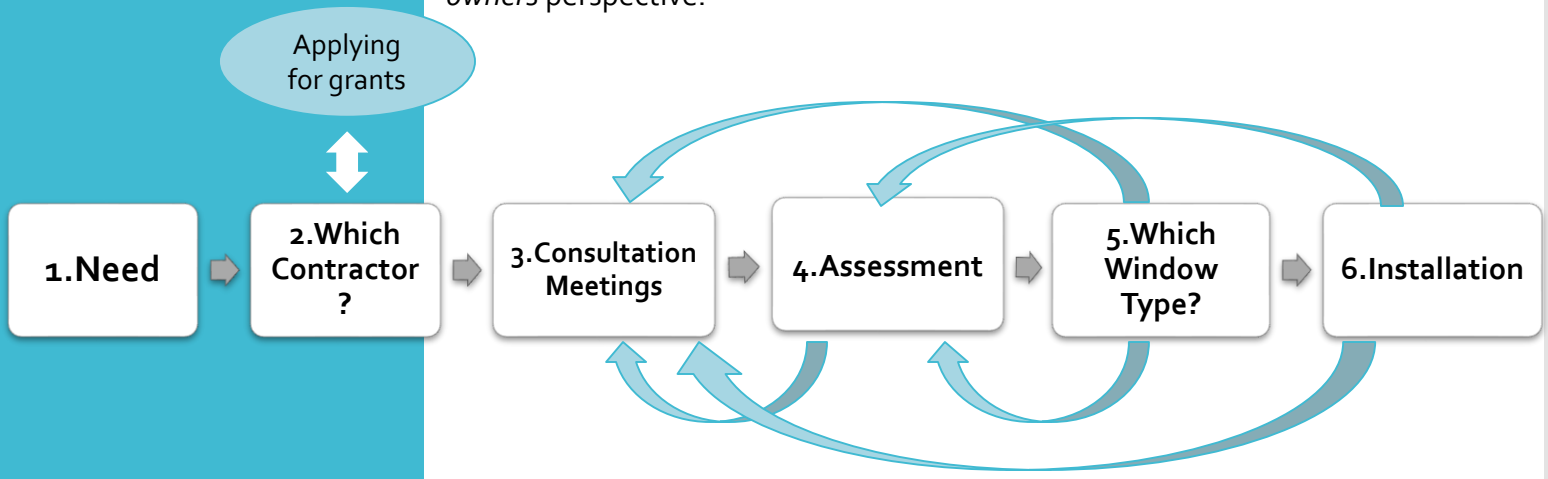
Eventually windows just stop working, whether because of broken hardware, abuse or any number of other issues. Sometimes the problems can be fixed as they occur, but unfortunately, this isn't the case with all window types. The expansion/contraction cycle that happens everyday as windows are exposed to sun rays and temperature variations.

3. Window Replacement Process

Steps and Considerations

Process Breakdown

Changing windows is not simply a matter of calling a window company, there are a few steps that need to be carefully taken to make the right decision. The wide variety of window companies and products make this process challenging and in some cases hazardous. A more careful study of the process breakdown is required to know the steps, define considerations for each step and finally, map out the barriers in current practice. This breakdown is structured based on previous studies, existing guides and some property owners opinions. As defined step by step below, several key objectives must be met for a successful window replacement from the *owners* perspective:



Step1: The need to replace windows: Make informed decisions!

What are the main reasons that make building owners/managers replace the windows? The homeowner's motivation may dictate particular solutions. The reasons for replacing the windows and doors may include a combination of factors:

- Reducing noise
- Improving appearance
- Improving thermal comfort
- Alleviating condensation problems
- Solving water penetration problems
- Improving operational characteristics
- Taking advantage of new functionality that was not available when the existing windows were selected
- Upgrading energy performance
- Improving security

Step2: Choosing the right contractor

This step is the most important one in this process, owners need to decide which company can provide them with a proper window type due to the scope of their project.

To make a safe decision, after doing a bit of online research and visiting their websites, ask the contractor for:

- References from both customers, and window and door manufacturers.
- Their WorkSafeBC clearance letter and evidence of their general liability insurance.
- Visit some previous projects
- Find how long they have been in this business.
- Contact the Fenestration Association of BC (Fen-BC) if you have questions about that company

Landlord BC offers some reliable companies due to its criteria system; [https://landlordbc.ca/]

Step3: Consultation Meetings

- Why is the consultation meeting important?

People generally obtain information in consultation meetings with the selected contractor. During meetings, there are several aspects and points need to clearly discussed between owners and companies.

- What are the owners/managers priorities in this project?
- How much is the cost/budget for this project?
- How long does it take? Start date? Consider weather conditions and some pre-approval they might need to get in advance.
- Are they living in the units while the project is on?
- Do they need some sort of education about this process?
- Can they benefit from any available window financing? Some companies have financing program offers flexible rates, terms and amortization and FREE in-home consultation as well to make window replacement smoother for their customers. ttp://www.westeckwindows.com
- How can they take advantage of energy efficiency incentive programs?

Step 4: Assessment

A visual assessment of the existing building is required to define:

- Which windows need to be replaced? And why?
- What is the interior and exterior condition of the windows?
- Does this replacement involve more envelope retrofitting like adjacent exterior walls or cladding?
- Does the project need any surveying?
- What is the solar orientation of windows?
- Are they facing rain load or wind load? Or both?
- Can existing walls hold the new window load?
- Are there any water penetration or moisture intrusion problems?
- Whether the building contains led paint or asbestos. How are the contractors going to deal with this issue? (Owners are responsible to help contractor identify hazardous materials)
- How disruptive will the construction be?

Step 5: Choosing the Right Window Type

In this step the owner(s) and contractor normally meet again to select the right window type(s). This is based on the owner(s) priorities, the assessment report, the budget and a large number of variables;

- What should a building owner focus on?
- How can a window supplier help the owner make a good decision?

- Is there any regulations or building codes to comply with?
- What is the building type? How old is the building? Is it classified as Heritage building?
- Is there any special aesthetic they want the building to retain?

The level of attention to detail needed in this step depends on the project and customer demands. Some product attributes worth considering are listed in this table:

Product Attributes:

- Thermal performance
- Air infiltration
- Water penetration resistance
- Condensation resistance
- Acoustical performance
- Shading
- Daylighting
- Natural Ventilation
- Anodized coating
- Durability
- Safety
- Economics
- Installation
- Maintenance
- Material
- Operation
- Look
- Price
- label

Step 6: Installation

Replacement of windows is a complicated process that involves:
• Cutting into a wall and disturbing the existing measures for controlling air and water penetration.
• Removing all or part of the existing window framing.
• minimizing the disruption to the existing finishes.
• Installing the new window or door so that primary functions such as air and water tightness are achieved.

Ask for *PROFESSIONAL INSTALLATION*
What sort of installation is suggested according to the building type?
And Why?
Who is allowed or recommended to install?
What are the considerations for the installation process?
How much does it cost on average?
And How long does it take?
Is any maintenance required after installation?

Step Zero! : Applying for Grants

Currently, there is only one program for homeowners to apply for home renovation incentives. Applying for grants or incentives is a timely process so it is advised to start at least one year prior to project start date.

• Home Renovation Rebate:

Provided in partnership by BC Hydro Power Smart and FortisBC, this Program offers homeowners a wide variety of incentives to help reduce ongoing energy costs. Rebates are provided for both natural gas and electric energy-efficient upgrades, including insulation, draft proofing, ventilation, ENERGY STAR® certified hot water and heating systems.

Where to apply?

BC Hydro - Residential Customers
(800) 224-9376
Web address: http://www.bchydro.com/powersmart/residential

• Existing Guides Comparison

For a customer guide, it is important to address considerations mentioned in this process. In order to find gaps, three different notable existing window guides are compared :

1. **Consumer Guide to window and Door Replacement,** Home Owner Protection Office, Branch of BC Housing: A **12** pages guide, targeting public, available online for free. It is produced by the Homeowner protection office (HPO) prepared by RDH in collaboration with Canada mortgage and Housing Corporation,

Fenestration Association of BC,BC Hydro, and the City of Vancouver . This guide addresses the key issues homeowners should consider when replacing windows and doors.

2. **Best Practices for Window and Door Replacement in Wood-Frame Buildings** : A **315** pages guide, Published by HPO, prepared by RDH Building engineering in collaboration with Canada mortgage and Housing Corporation, Fenestration Association of BC, BC Hydro, and the City of Vancouver . This comprehensive guide provides quality installations and achieve high performance for all types of window and door replacement projects to help industry meet standard expectations. Targeting at engineers, builders architects, contractors and installers, not the general public, purchasable online for about **$290**.

3. **Widows Exteriors Restorations, Centra Windows:** A **36** pages guide by Centra company to help customers in selecting windows, doors & sidings as well as Technical Specifications.

	Why they need to replace Windows	How practical is the information	Window types Considerations	Choosing Contractor Considerations	Installation Considerations	Cost Estimation	Availability to the public	Affordability
HPO	◐	○	◐	○	◐	●	○	○
RDH	○	◐	○	●	○	●	●	●
Centra	◐	◐	◐	●	●	●	○	○

[Figure 11. Guides Comparison Table]

○ Well addressed
◐ Addressed but insufficient
● Not addressed

This table shows that, existing guides address required considerations to some extent but not completely, which is why they are not all well appreciated by the customers.

Based on the content as well as interviews, *HPO* window guide is the most referred one by both fenestration companies and customers. *RDH* guide is the most comprehensive one in terms of installation detailing samples and building code requirements for replacement. But, it is less user friendly due to high price and level of details. *Centra* guide, works as a window shop to give an overall view or introduction to *Centra* products and services. Normally, more information is discussed in consultation meetings based on each project specifications.

4. MURBs Window Replacement Case Studies

The Crystallis

[Figure 11. The Crystallis, www.rdh.com]

The Challenge

The Crystallis is a unique-looking high-rise residential building with 25 levels, 102 units, and circular balconies located in Downtown Vancouver. RDH's involvement with the building began in 2000 with a condition assessment of the building enclosure. This investigation discovered that water ingress had caused significant deterioration of the fasteners that secured the windows into the building. Water ingress was also affecting the walls, which had an exterior insulation finish system (

Further investigation in 2010 found numerous other problems associated with the windows, such as multiple failed sealed units, damaged hardware, and poor thermal performance. RDH developed a comprehensive repair program to address all of these performance issues.

The Replacement

Retrofitting included repairing deficient and moisture-damaged steel stud framing and rebuilding the wall assemblies to prevent future problems and enhance performance. the exterior cladding replaced with a metal panel system attached with thermally efficient cladding clips and new rock wool exterior insulation. New windows were installed with improved thermal performance and water resistance along with new sloped glazing at the upper levels of the building.

The Result

The Crystallis now has an almost completely new building enclosure that will not require any significant renewal work for many years to come.

[Source: www.rdh.com/case-studies, Accessed May 2016]

1243 Thurlow Street, SAH properties, Vancouver

[Figure 12, East View, looking from Thurlow]

[Figure 13. East View, looking from Thurlow]

A successful whole building window replacement from the owner of a family owned property perspective:

About the Project :

- The 6 story wood-frame rental building, located at Davie and Thurlow.
- The main reason they replaced windows of this building was generally comfort of the tenants by cutting down the noise of traffic and also look.
- It is a 100 years old building, considered as heritage classification B or C which are not very restrictive in terms of window replacement.
- Owners preferred to retain the heritage character of this building so they chose wood-frame windows even though they are the most expensive and highly maintenance frames.
- spent around $270,000 on 146 windows, so an average of about $1,850 per window.
- Old windows were single pane and doing ok but they need to replace it for aesthetic and acoustic reasons.

About the Replacement:

- The process took about 6 months with no noticeable challenge.
- Single owners decided about the whole process.
- They did not use any window guilds in the process, information was obtained from quotes and since the **Vintage woodworks**, is the only company for wood-frame windows in the Island, the contractor choosing process was easy
- They had the building tested a few years ago and there was not noticeable amount of Asbestos.
- No particular issue after installation has occurred.
- No grants was taken for this project.
- No need for special permit from city or Vancouver Heritage Foundation.
- No complain from tenants after the installation

Results:

- The final result was satisfying for both property owners and tenants.
- Upgrading windows from single pane to double was effective in terms of noise control and comfort when you sit next to them but doesn't really affect on the core temperature of the building or huge change in energy saving.

Barriers to window replacement project from her perspective:

Even though decision making in this project was based on personal interest in maintaining the building look rather than a business decision, the cost was mentioned as the main barrier.

5. MURBs Window Replacement

Barriers and Opportunities in Current Practice

• Interview Process:

Gathering first hand information from key industry experts was one of the main resources in this study. In order to identify real barriers in the current practice, we started talking to people onsite and offsite using the questions list as a framework of interviews. Each meeting took between 30 to 90 minutes. The interviewee list includes:

- **Fenestration Specialist**
- **Fenestration sales and business development managers**
- **Property managers**
- **Property owners**
- **Building Inspection department manager at City of Vancouver**
- **City Staff, Green Building Team**
- **BCIT Faculty, building envelope consultant**
- **HVAC Mechanical Engineering**

Looking at window replacement projects through different lenses, demonstrates a variety of barriers to this practice. The issues are different for each party involved in this process, some outcomes are:

Building Inspection department manager at City of Vancouver:

*'We deal with owners, strata's, they have to have **licensed contractor** but it is not hard to get this license for anyone, doesn't mean they are qualified to do it. You just need to be the owner... Also no requirement for us to collect certification from installers not like plumbing inspectors or electricians, some sort of qualification or certification for installers is helpful"*

Property managers:

*"Most critical barrier is **poor financial pay back** on window upgrades, does not financially make sense due to the **low price of gas** as a source of space heating. Some property managers have a policy of implementing a regular repair and inspection program, rather than replacing components.*
Changing windows is not a single process to be done just by calling a window company"

Property owners:

*"**Ownership matters**; In strata's, there is a desire for higher end windows versus the rental buildings. Strata councils show more interest to aesthetics and higher U-values than rental building managers..."...they believe that, lack of connections is the main issue, not lack of information."*

Fenestration Specialist:

" Comfort is the main reason for 80% of customers to change windows....In this industry, the fact that manufacturers has no control on installation job brings a lot of premature failure of windows in particular which falls under the name of the manufacturer company."

Findings of these interviews are significant. One basic outcome drives from comparing information received during interviews to research background is; what motivates the public to spend on window replacement projects is different from what building science studies, city managers and planners are focused on. we realized that priorities for these two groups are different in window replacement projects:

Different priority set

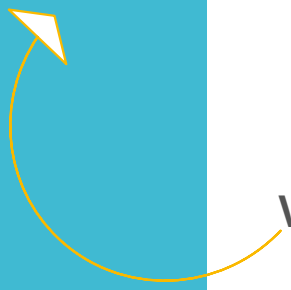
City managers, policy researchers, and academic studies objectives:

1. **Energy & Cost Saving**
2. **Lower HVAC Costs**
3. **Improve Comfort**
4. **Reduce Condensation**
5. **Increase Light & View**
6. Reduce Noise

Versus

What property owners, managers and/or customers look for:

1. **Improve Comfort**
2. **Reduce Noise**
3. **Improve Operation**
4. **Improve Reduce Condensation**
5. **Increase Light & View**
6. **Lower HVAC Costs**
7. Energy & Cost Saving



What people find when they search for links?

Comfort, Noise, Condensation and appearance are main reason for the public to spend on the window replacement. Surprisingly, energy and cost savings are at the bottom of this list of motivating factors, but what users find while searching online is mostly not tailored to their preferences. Considering the different priority sets shown above, there is a need to shift our perspective to what motivates people undergoing window replacement projects rather than any presumptions.

• Barriers to Window Replacement Practice

When you know that a properly installed new, energy-efficient window will reduce your energy consumption, save you money, increase your comfort, reduce condensation, often reduce noise, and minimize dust penetration, then what prevents people from replacing old inefficient windows with new ones? Based on previous research on building retrofits as well as first hand information from talking to key people in this market there are a number of barriers to this job listed as below:

- **Costly process with poor financial payback, lack of incentives**

Due to the financial matters, the design rehabilitation projects typically focus solely on cost effective remediation, and do not intentionally include upgrades to the buildings, such as upgrades to reduce energy consumption. Therefore, these rehabilitation programs do not take full advantage of the opportunities that exist.

- **Lack of useful connections for owners and property managers**

Owners often have aspirations to upgrade their buildings, but lacking connections and experience, especially for smaller scale and family owned operations, may cause wading into the mire of an undertaking that can prove overwhelming resulting in indecisiveness and ultimately, inaction.

- **Competing demands and lack of owner awareness**

Low owner awareness of long-term cost savings of window upgrades as well as which contractor to trust when they are deciding to upgrade

- **Limited policy as well as code for existing buildings window replacement**
- **Lack of available/practical guides**

There are few window guides available to help public make the right decisions, but some are too long, too detailed or too expensive to use. In some cases the marketing tone of these guides is not well received appreciated by customers.

- **Un-documented market**

Since window replacement is a non-permit job, there are not many documents to track whether these projects are meeting customers expectations or not.

- **Non-Permit process**

Although getting a permit is a costly and timely process, it ensures meeting codes and standards as well as documents to track and inspect window replacement projects

- **Low natural gas prices versus high expenses to upgrade windows to save energy**
- **Unsafe jobs and hazardous materials such as Asbestos**

Down grading the unhealthy aspect of ongoing retrofitting in this city might bring serious risk to citizens health

- **Cheaper non-efficient products are available**

A non-rated product is about 20% less in cost and 20% difference is too big a number to overcome on the value side.

- **The disconnect between decision makers, consumers and who pays the bills!**

These barriers cause many old MURBs in Vancouver to avoid replacing old and inefficient windows. Removing some barriers may need further research, but based on findings in this study, some recommendations in order to make this process easier and more efficient are presented as follows.

[Figure 14. Retrieved from www.by.undp.org, August 2016]

• Recommendations

This project seeks to identify barriers to MURBs window upgrades in current state of practice, and then puts together some practical recommendations in order to make this process easier while improving it. The recommendations include:

• Support window replacement to be cost-effective

When apartment owners decide to upgrade their buildings, they want to make sure that the upgrades are cost-effective. Therefore, leverage and enhance existing incentives through partnerships with BC Hydro, Fortis BC, and strong industry associations is the most effective step to take.

• How City can help:

- **This study shows having more concise ways of navigation is required in window upgrade practice.** One idea would be developing a ***website*** or a online link to support public decision making in building upgrade projects. Also, this link can help monitor and document this huge market of retrofitting which is another barrier in such projects. One way to improve monitoring is an online permit application within the proposed website.

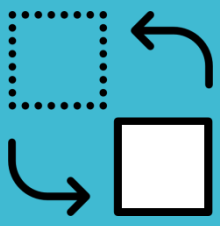
Possible hosts to operate the site are: City Social Media page, Vancouver.ca, Municipality, FenBC, HOP office or Landlord BC.

- **Make MURBs window replacement a permit required job,** which isn't mean to add more bureaucracy to the process but help document the market as well as assuring that a required basic checklist is considered early in this job. By making it a low cost or a free online submission permit, the City can provide support so this job can be done safely, correctly

The recommended checklist may includes:

- ✓ Required building code for windows
- ✓ Having the building tested for hazardous materials like Asbestos and if there is any, owners, project managers or contractors should show they have trained people to deal with it safely.
- ✓ Have factory trained people to install windows properly
- ✓ Having a professional (building envelope consultant, architect, etc) be involved to oversee the process.

- **Strata Energy Adviser program** Metro Vancouver, in partnership with local governments in the region, is planning to launch an energy advisor support program for strata buildings in 2017. This program could provide guidance to owners on window replacement options and process.



- **Window guides improvement:**

➢ Improve Guidelines, transform them to a more clear map of what steps to take and what to consider for each step

➢ Engage and Educate Building Developers, Designers and Users: Educate people to have a better vision of long term savings of energy efficient windows through similar projects and dollar figure examples in visual format.

- **Window design Enhancement:**

➢ Windows and doors have traditionally been installed as permanent elements within walls with no provision for future replacement. Architects or industrial designers can think of designing replaceable windows. Since the life span of windows is significantly shorter than the life span of buildings, replacing windows is an inevitable job that often needs to be considered . Therefore, maybe the next generation of windows can be designed with the provision of easier replicability.

- **Installation Improvement:**

There is a need to explore potential partnerships with industry associations and window companies to offer more widespread and standardized training for window installers. This could include the creation of a certificate program through a local academic institution.

After framing the recommendations, in order to make sure they are addressing real problems, we tested them all by sending the barriers as well as recommendations list to the same interviewees. Different feedback from each party, showing us the practicality of each recommendation through different lenses of the key people involved in this job. These opinions led us to refine the recommendations and to draw up ideas for the next step of this study.

Testing The Recommendations

First, there is mention of determining a value in terms of energy/cost savings for window replacement. There are a number of good reasons to replace windows but in my experience, **cost savings is not among them**. Perhaps better educating owners about the more tangible benefits is key.

Financial incentives are always appealing to building owners, so development in that area would likely attract interest.

I am unsure about making window replacement a permit required job, because we have found permits to be slow, expensive and laborious. I do understand the potential benefits in terms of offering more regulation, standardization and potentially support to owners seeking to replace windows, but I am unconvinced that the reality would reach the potential. That said, if it can be an easy process, or if there is a better way **to reach building owners** and provide support for window replacement and other 'green' building upgrades, it would likely be a greatly appreciated tool. I think that owners often have aspirations to do things, but **lacking connections** and experience results in overwhelming and ultimately, inaction. (property owner, June 2016)

One item to potentially add would be to perhaps determine a **grant** if an owner wants to take an old multi-family building that has been poorly renovated over the years and bring it back to the original character? Those kind of buildings add a ton of character to certain areas of Vancouver so it would be neat seeing people invest in that. (Principal at one of the fenestration companies in Vancouver Windows, July 2016)

I recommend having a professional (building envelope consultant, architect, etc.) be involved to **oversea the process such as installation.**
(BCIT faculty in Building Science program+ Building envelop consultant, July 2016)

7. Next Steps

Proposals to Improve MURBs Window Replacement Practice

What Next?

Examining recommendations by considering feedback, I created two proposal to develop as next steps of this study:

1. Creating an Interactive online Guide for Window replacement Best Practice:

Will provide the public with practical information, links, codes as well as connection between customers with companies. There is plenty of information about windows, window replacement and associated companies online, but a ***lack of connection with relevant information*** is still an issue for landlords and managers. So, there is a need for a specific guide, tailored to customers priority set to walk users through the necessary steps, provide them with useful links in the decision-making process. Also, this online guide creates an opportunity to write reviews and share their experience with future owners/managers who want to start the same retrofit project. A graphic of the proposed website is illustrated in the next page.

1. Reach out to Existing Old MURBs:

There are a number of MURBs in Vancouver that require window upgrades but they refuse to undergo upgrading because of some existing barriers. To achieve the Green Building target in GCAP2020, one idea would be reversing the process, contact managers or owners to provide them with useful input, inform them of how window replacement would upgrade their property as well as investigating opportunities to encourage replacement either as a part of envelop retrofit or as an individual project. This idea might come into action through programs such as, *The Landlord BC's Operation Cost Cutter* program or FortisBC's Rental Apartment Efficiency Program, which enables building owners to identify savings opportunities in building upgrade projects.

Each of these ideas requires additional studies and testing as well as more consultation with stakeholders in future research.

How the On-line Guide look like?

www. Windowreplacementguide.ca

An interactive, step-by-step decision-making tool to help determine the most efficient window replacement for your building

Apply for Permit

- **Window Selection Tool**
  - **Select location**
  - **Select Building Type**
  - **Select Window Type**
  - Learn more and Compare how various window or skylight types affect estimated energy cost for a typical house in your location
- **Design guidelines** → Get general feedback on certain design conditions such as orientation, shading and window area.
- **Assessing Options** → Find manufacturers who offer windows and skylights within the categories shown
- **Selecting Contractor** → Learn more about manufacturers' specific product options → **Reviews**
- **Installation tips** → Learn more about the variety of installation methods as well as finding the method works best for your building

Any grants or financial support? → How to apply?

Projects Library → **Reviews**

This webpage/link, provides the public with an opportunity to compare, educate, decide and finally write reviews to automatically create a rating system of contractors based on the products and services they provide. Above all, having more concise way of navigation in this large market is the main role of such a site.

Having a more comprehensive approach, these strategies can be applied to other building components, which results in upgrading existing buildings to perform as newly constructed, to achieve the Green Building goal of Greenest City Action Plan, by 2020.

Where to obtain more information

Natural Resources Canada

More information about ENERGY STAR qualified windows, doors and skylights, including a list of qualified products, is available on the Canadian ENERGY STAR Web site at energystar.nrcan.gc.ca. To order additional free copies existing publication or fact sheets entitled *Improving Window Energy Efficiency, Air Leakage Control and Moisture Problems*, contact

Energy Publications
Office of Energy Efficiency
Natural Resources Canada
Tel.: 1-800-387-2000 (toll-free)
Web site: http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.search-recherche&appliance=WINDOWS

Canada Mortgage and Housing Corporation Canadian Housing Information Centre

Technical information on windows, doors and skylights, and home construction and renovations is also available from
Tel.: in the National Capital Region, call 613-748-2367
Tel.: 1-800-668-2642 (toll-free)
Web site: cmhc-schl.gc.ca

The Canadian Window and Door Manufacturers Association (CWDMA)

More information may also be available from your provincial or territorial energy and environment ministries and electric and gas utilities. CWDMA resources include Sill to Sash, an informative guide to buying energy-efficient windows, doors and skylights. Sill to Sash is available on the CWDMA Web site or can be ordered by mail or telephone at Canadian Window and Door Manufacturers Association
Tel.: 613-235-5511
Web site: cwdma.ca

8. References

1. Energy-Efficient Residential Windows, Doors and Skylights, Natural Resources, Canada, Updated October 2010, *www.nrcan.gc.ca*
2. Energy impact of building retrofitting, efficient MURBs, *www.living-future.org*
3. MURBs Energy Study, RDH Building Engineering Ltd., 2012, *www.rdh.com*
4. Home Owner Protection Office, HPO, *www.hpo.bc.ca*
5. Energy consumption and conservation in mid- and high-rise residential building in British Columbia, 2012, RDH Building Engineering Ltd.
6. 2001 Building Failures Study, Housing Research at Canada Mortgage and Housing Corporation (CMHC), Canadian Housing Information Centre, *www.cmhc-schl.gc.ca*
7. LIFE CYCLE OF WINDOW MATERIALS - A COMPARATIVE ASSESSMENT, M. Asif BSc MSc, A. Davidson BSc and T.Muneer PhD DSc CEng MlmechE FICBSE Millennium Fellow
8. Life Cycle Assessment of Residential Windows: Saving Energy with Window Restoration, Katherine M. Switala-Elmhurst, Ph.D. Candidate, LEED AP and Philip D. Udo-Inyang, Ph.D., PE Temple University Philadelphia, PA
9. BC Building Code, *www.bccodes.ca*
10. North American Fenestration Standard (NAFS).
11. Building Drawings, Photos and Information for MURB Study Buildings, RDH Building Engineering Ltd. 2007-2011.
12. Energy Retrofit Opportunities for Multi-Unit Residential Buildings in the City of Toronto, 2013, *www.towerwise.ca*
13. Energy Retrofit Strategy for Buildings reports by City of Vancouver
14. The EnerGuide™ Rating Service of Natural Resources Canada
15. *www.passivehousepa.blogspot.ca*
16. *www.landlordbc.ca*
17. www.*fen-bc.org*
18. Energy star vinyl windows and doors, w*ww.housesmarthomeimprovements.com*
19. Building Envelope Design Guide, Curtain Walls, *www.wbdg.org*
20. Choosing Replacement Windows, *www.renovation-headquarters.com*
21. Replacement windows; how many years they last, *www.improvementcenter.com*
22. *www.centrawindows.com*
23. *www. homestars.com*
24. *www.efficientwindows.org*
25. *www.ecobuildingstore.ca*
26. *www.busqueengineering.ca*
27. *www.mithrasolarsolutions.com*

[Retrieved from 1000+ ideas about Windows on Pinterest, www.pinterest.com, August 2016]