Glazing in Residential High Rise Buildings Energy Saving vs. the Optimum Day Lighting

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APSC 598G

April 30, 2014

UNIVERSITY OF BRITISH COLUMBIA

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Sustainable Building Science Program

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Spring 2014

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1. Introduction

A high percentage of glazing versus solid exterior walls is commonly seen in new residential high rises in the lower mainland. In general, glazed surfaces are less insulating than standard walls, resulting in higher energy loss; however, high percentage of glazing is found to be an important selling factor. A careful window design with wise selection of glazing can result in energy savings by providing natural lighting; however, there is a compromise in window design between benefitting from natural light and the waste of energy through windows. In this study, an extensive review is made over different thermal and visual properties of windows and glazing and recommendations are made for selection of energy efficient windows based on Vancouver's climate. Design criteria for windows regarding view and daylighting are reviewed. Internal and external shading are introduced to avoid glare and solar heat gain respectively. The findings from our background study are then used to perform case studies on some of University of British Columbia's related projects. Finally, design modifications are provided for the case studies to improve performance of these buildings regarding their window design.

2. Glazing properties

There are physical and functional properties associated with glazing which determine their optical and energy performances. The main glazing properties are listed below [1]

- *Visible transmittance*, which is the ratio of visible light striking the glazing that passes through
- *Solar heat gain coefficient* determines the percentage of transmitted solar energy to the total incident solar heat.
- *U-value* is the amount of heat transfer through the window due to temperature difference between indoor and outdoor environment per unit area of the window.
- *UV transmittance* determines the percentage of ultra-violate radiation that passes through the glazing. UV radiation causes sunburn to inhabitants and the plants inside building and also results in fading and damage to the furniture.
- *Glazing color* affects the appearance of the building from outside and also influences interior design and lighting. In addition, glazing color affects

visual and thermal properties, as unwanted solar radiation can be filtered by specific glazing colors.

- *Visible reflectance* is the ratio of reflecting light to the light striking the glazing. Higher reflectance means lower visual transmittance of the glazing. This characteristic of the glazing also determines how mirror-like the glazing is.

I. Thermal performance of the windows

The three major energy flows through windows can be characterised as [2]:

- Non-solar heat losses/gains

This type of heat loss occurs between the indoor and outdoor environments by means of different heat transfer mechanisms and mostly by conduction, due to temperature difference.

- Solar heat gain

Solar heat gain is due to radiation from the sun and mostly in the form of infrared wavelengths and visible light.

- Heat loss due to airflow

Airflow through the windows created either intentionally for natural ventilation or by unintentional infiltration results in energy loss in form of convection heat transfer.

a. U-value

Windows acquire heat from the outside in summer and lose heat to the outside in the winter because of temperature difference. U value is a measure of heat which will be transferred between indoor and outdoor for one degree temperature difference per unit area. The glazing itself does not offer much thermal resistance. Additional panes will improve thermal performance by adding still air between the panes which increase thermal resistance of the window. Better insulating gases such as argon and krypton can be used instead of air to achieve higher thermal performances. The insulating value of the window depends not only on the glazing but also on the window frame. In general, non-conductive window frames such as wood, fiber-glass and vinyl frames are preferred to the metallic frames. Thermal breaks should be used with metallic frames in order to increase the thermal insulation values of the window. The U-values of different windows based on their glazing and frame type are compared in Fig. 1.

GLAZING TYPE	Wood or Vinyl Frame (with insulated spacer) U-FACTOR (Btu/hr-ft^2-°F)	Alum. Frame with thermal break (with conventional spacer)	Aluminum Frame without thermal break (with conventional spacer)
Single glass	-----	1.07	1.30
Double glass, 1/2-inch air space	0.48	0.62	0.81
Double glass, e = 0.20*, 1/2-inch air space	0.39	0.52	0.70
Double glass, e = 0.10*, 1/2-inch air space	0.37	0.49	0.67
Double glass, e = 0.10*, 1/2-inch argon space	0.34	0.46	0.64
Triple glass, e = 0.10 on two panes*, 1/2-inch argon spaces	0.23	0.36	0.53
Quadruple glass, e = 0.10 on two panes*, 1/4-inch krypton spaces	0.22	-----	-----

Fig. 1 Different U values for different windows and glazing types [3]

For northern zone of North America which includes Vancouver, the recommended value of $U < 0.30\ \mathrm{Btu/hrft^2F}$ is considered as good performance and $U < 0.25\ \mathrm{Btu/hrft^2F}$ is considered to be exceptional [4].

b. Solar heat gain

The infrared wavelength of the solar radiation is mostly responsible for carrying solar heat. Using specific glazing color or additional reflective thin coating on the glazing surface can respectively filter or reflect back incoming heat from the sun. Light blue and light blue-green glazing color can block solar heat. In fact, colored glazing will act as a low-pass filter which does not let larger wavelengths such as infrared pass through.

Low-e (low emissivity) glazing has a very thin and microscopic coating of metal or metallic oxide which reflects the heat wave back into homes during winter and back to the outdoors during the summer. For Vancouver, there is no specific SHGC recommended, as it is in a mostly heating region; however, for climates which require high cooling loads $SHGC < 0.4$ is suggested [4].

Well-designed exterior shading systems also help in blocking solar heat. Different forms of shading work for different orientations. For example, horizontal shades are used for south windows, vertical shades on the east, west and north for blocking early morning and late afternoon low sun. The priority should go to west and south shading according to the consideration that morning sun is not a serious heat gain issue. But generally speaking windows facing north and south have fewer problems than west and east.

II. Visible transmittance

The visible transmittance is a function of visual task, window size and glare sensitivity. As the window size increases, glare control becomes more critical and the visible transmittance value should be decreased. In general, it is said that 50%-70% is a good initial value for visible transmittance which should be modified based on the window size. The effective aperture which is defined as

$$EA = \text{Visible Transmittance} \times WWR \tag{1}$$

is a useful parameter to determine the visible transmittance value based on the window size. A good target value for EA is between 0.2-0.3.

Glare issue can also be controlled adequately with use of interior shading (Fig. 2). Moreover operable interior shading devices help occupants take control over their comfort needs. To optimize benefits interior devices such as light shelf and weave shades, which filters the light, should be in light color to provide better energy saving.

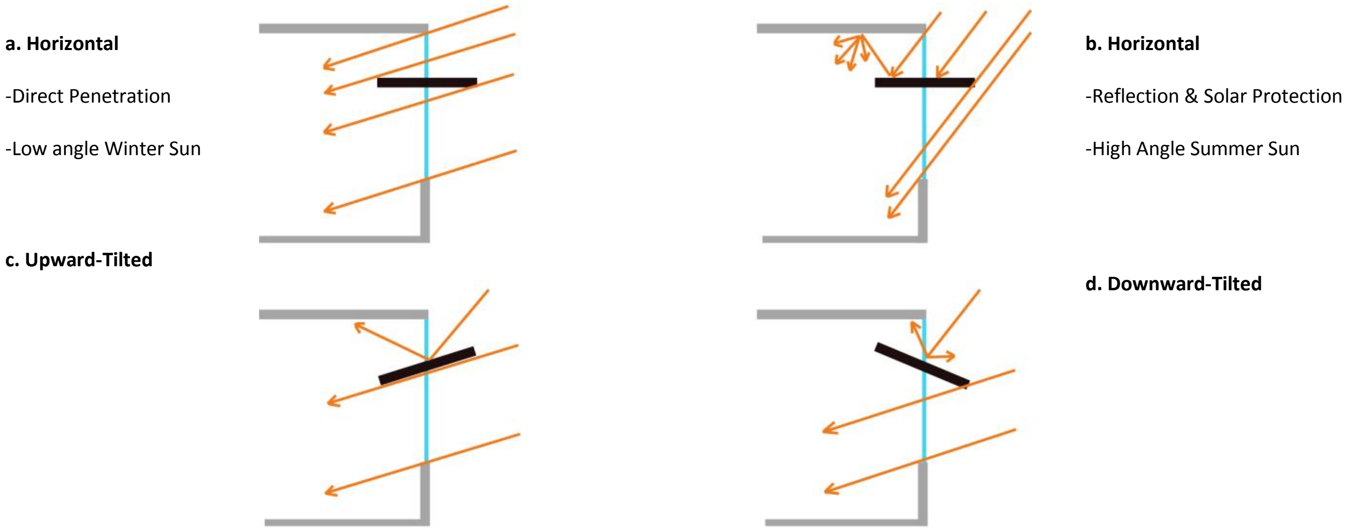

Fig.2 . This figure illustrates the functioning principles of a horizontal (a. and b.), upward- (c.) or downward-tilted (d.) light shelf

3. Window design for daylighting

Desirable day lighting can be provided for every orientation by appropriate window design. Sunlight`s characteristics should be considered before designing the size and shape of the window for each orientation.

- North orientation has high quality consistent day light, with minimum heat gain.
- South orientation contains strong but not consistent illumination during the day.
- Windows facing east and west are more difficult to treat because of sun angle.

Other design considerations include providing deeper day lighting zone by having higher windows, using strip windows to have adequate day lighting rather than punched windows. Strip windows provide more uniform daylight, while punched windows create visual contrast [1].

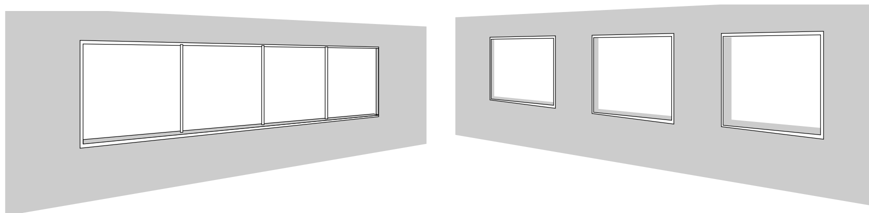

Fig 3. Strip windows and punched windows

Window in residential buildings may influence health and wellbeing of occupants by providing an appropriate view of the external world, exposure to the cycle of day lighting and adequate light dose. Day lighting is vital for regulating physiological and psychological functions of the body such as heart rate, blood pressure, body temperature and emotion, and marking the rhythm of life. Other than these benefits, appropriate day lighting can control a large number of biochemical processes in the body that are important to health. For instance, sufficient amount of light through the day helps with production of vitamin D, absorption of calcium, orienting protein metabolism, and regulating the level of hormones such as serotonin, dopamine, cortisol and melatonin. From the psychological point of view, another consideration is the timing and duration of exposure to light, which should follow natural biological body rhythms. Some studies illustrate that night of higher quality sleep is a result of days with higher total light exposure.

The required day lighting level for correct functioning of biological 'mechanisms' is yet to be systematically defined [5].

I. Feasibility factor

Larger windows can provide more natural lighting if only their view is not obstructed and if their visible transmittance is high enough without causing any glare problems. In order to find out the feasibility of using natural lighting for saving energy, the feasibility factor is defined as

$$Feasibility\ Factor = WWR \times V_T \times OF \tag{2}$$

Where WWR is window to wall ratio, V_T is the visible transmittance and OF is the obstruction factor. OF depends on how much of the view is obstructed when looking from inside through a window, 10 feet away at desk height. The schematic shown in Fig. 4 defines the OF based on the level of view obstruction.

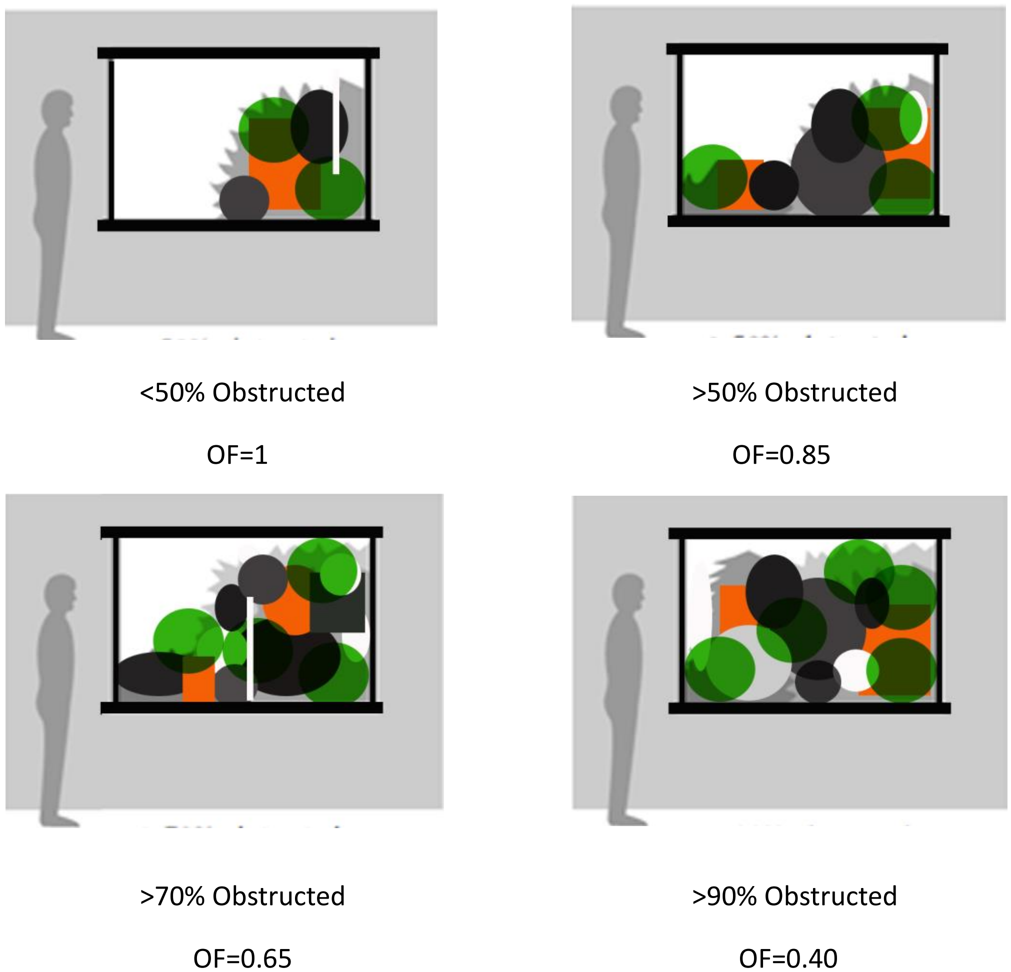

Fig 4. OF determined based on the level of view obstruction

If the feasibility factor ≥ 0.25 then it means natural lighting can potentially be used to achieve significant energy saving; otherwise, lower values of feasibility factor means that the window is so obstructed that it cannot provide sufficient daylighting or the V_T should be increased while avoiding the glare problem. After checking the feasibility of daylighting, it will be time to actually determine the required net glazing area.

II. Required net glazing area

Eq. (3) can be used to find an initial estimate of the required net glazing area for sufficient daylighting [1]

$$Required\ net\ glazing\ area = \frac{2 \times Avg.Daylight\ Factor \times Total\ interior\ surfaces\ area \times (1 - average\ reflactance\ of\ interior\ surfaces)}{V_T \times vertical\ angle\ of\ sky\ from\ center\ of\ the\ window} \quad (3)$$

Average daylight factor can be found based on the level of brightness required inside a room as in Table 1.

Total area of interior surfaces is the sum of all the interior surfaces including walls, ceiling and floors. Average reflectance of interior surfaces can be calculated based on the finish properties of each surface or considered to be 0.5 as default.

The vertical angle of sky from the glazing centre can be calculated based on the schematic shown in Fig. 5 and if there is no obstruction in front of the building, the sky angle is 90°.

Table 1. Average daylight factor based on level of brightness

Level of Light	Average daylight factor
Low-light space	1
Average light	2
Bright space	4

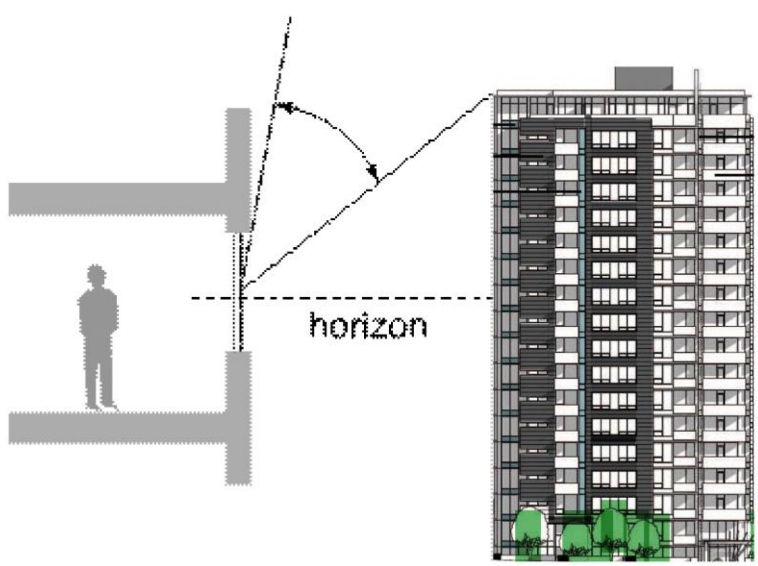

Fig 5. Schematic for vertical angle of sky

In addition to Eq. (3), there are regulations suggested by different resources regarding to the maximum value for WWR (window to wall ratio). BC Building Code 2012 [5] prohibits WWR>0.4 and in general, WWR<0.5 is the rule of thumb for the glazing ratio.

4- View

Window placement, sizing and shape affect the quality of view.

The character of the view is important to human well-being. A good view should provide lots of information and should consist of three layers as listed below: [6]

- Upper layer includes distant landscapes, the sky and the natural to human-made skyline.
- Middle layer contains natural or human made objects, such as fields, trees, hills or buildings.
- Lower layer has the foreground, including plants and paving.

It is not always possible to have a complete view through three mentioned layers. Therefore it would be more preferable to have a part of each layer rather than completely eliminating any of them.

I. Health effects of viewing landscapes:

Vision is by far the most important sense in terms of taking information from environments.

Satisfaction from nature can be achieved by having a view of it, and does not require being in nature. Eexposure to natural landscapes improves individual and social well-being and provides psychological relief. Generally speaking it leads to reduced stress, improved attention capacity, recovery from illness, physical well-being in elderly people and behavioural changes that improve mood and general well-being of occupant.

More specifically, the main health effects of having landscape views can be identified as short-term recovery from stress or mental fatigue, faster physical recovery from illness and long-term overall improvement on people’s health and well-being [6-9].

5. Marketing

The following questions were asked of the Linda Chu (Director of the Marketing-Rennie Marketing Systems) regarding marketing aspects of window/glazing design and their answers are provided below:

- *Do high-rises with higher glass to wall ratio sell better?*

I couldn`t say we have actual data to support this statement. However, floor-to-ceiling window is normally a huge selling factor especially if the suite offers view. The only issue would be if the suite has air conditioning as potentially a floor-to-ceiling glass wall lead to a hotter suite in the summer. Generally speaking though it is considered as a more luxurious finish.

- *Is energy efficiency a concern for homebuyers?*

YES – as it equates to dollars saved on their hydro bills.

- *Popular view type in Vancouver (ocean view, city view, nature view…)?*

Ocean/Water

Parks

Mountains

- *Does the view type affect the window size?*

I would imagine, where there is a great view offering, so as long as the revenue generated from the premium view can justify the more expensive larger window or large glass facade and architecture.

- *Popular high-rise residential elevation/facade design in Vancouver (example projects and their typical design?*

Vancouver is known for its glass towers in Concord Pacific, a master-planned community largely influenced by the architectural style of James KM Cheng. Trends today seem to be leaning towards more curved lines-less rigid and more fluid and organic.

6- Case studies

I- Evaluation of UBC's green building rating system

The UBC Residential Environmental Assessment Program (REAP) is designed to promote sustainable practice for residential developments at UBC. REAP is similar to other green building rating systems, but is specifically designed to ensure that the residential projects built on campus are at a higher quality and with lower negative environmental effects. In this section, the REAP scoring policy with respect to window/glazing design is evaluated.

In general, it is found that REAP 2.1 has guidelines for the maximum overall U value that is allowed to be used for the windows. These limitations are summarized in table.2.

The following comments may be on REAP 2.1 based on the research performed in this project

- A higher overall U value is allowed for aluminium frame which the reason for this exception is not very clear. Aluminium frames are not efficient as they result in more waste of energy. Thermal breaks should be used with aluminium frames to reduce the U value.
- The guideline only provides maximum U factor values, no limits are provided for visible transmittance to avoid the glare problem.
- There are no instructions on the allowed window size, optimum value of window to wall ratio and SHGC.

Table 2. REAP 2.1 requirements for windows

Description	Importance	Maximum U value Btu/hrft2 F	Score
Minimum energy efficiency for windows	Mandatory	0.35 Vinyl Frame 0.5 Aluminum Frame	4 points
Energy Star windows	Optional	0.31 Vinyl Frame 0.46 Aluminum Frame	2 points
High performance energy star windows	Optional	0.26 Vinyl Frame 0.42 Aluminum Frame	2 points

II- Binning Tower project

The Binning Tower is going to be constructed at UBC Westbrook village. Information about the window type that is going to be used in this building was obtained from the developer and its performance is evaluated with respect to its thermal and visual properties. Typically the window manufacturer is chosen through the tender process. A number of window manufacturers will bid on the job and the owner / general contractor decides which product they want to use. The decision is based on price, product quality and other factors.

For the Binning Tower project, the Allan Windows product, Superneutral 68 is selected. In general, it appears that the selected window type has satisfactory thermal and visual properties. U-value is less than 0.31 which results in 2 bonus points based on REAP 2.1. In addition, the SHGC is under 0.4, which is consistent with LEED requirements. A summary of the window properties is provided in Table 3.

Table 3. Window properties of the Binning Tower Project

Properties	Description
Color	Crystaline Gray
Glazing type	1” double glazing with a ½” air gap
Visible transmittance	49%
Reflectance out	8%
Reflectance in	11%
U-value	0.29
Shading coefficient	0.34
SHGC	0.3
Light to solar heat gain	1.65

III. Academy building

Academy is an 18 storey residential building located at UBC Westbrook village which was developed by Polygon in 2013. The building includes one bedroom, one bedroom plus den and two bedroom units. A case study is performed on this project based on its glazing and window design and design modifications are suggested which could have improved the existing design.

a. Window to wall ratio:

The window to wall ratio for all the four building exposures are summarized in Table 4.

- ✓ WWR is properly maximized for the south face
- - Allows sufficient daylighting with maximum heat gain in winter
- - There is less heat gain from south windows in the summer compared to east and west windows [2]
- ✓ WWR is properly minimized for the north side
- - There is high winter heat loss through windows on north side.
- ➢ WWR is above the suggested value of 0.5 for three of all four elevations.

b. Feasibility factor:

The feasibility factor is defined as [1] $Feasibility\ Factor = WWR \times V_T \times OF$

Where WWR is window to wall ratio, V_T is the visual transmittance and OF is the obstruction factor.

For double pane tint-green glazing the typical visual transmittance value is equal to $V_T = 0.65$ [1]. There is only one building beside the Academy in front of the west elevation which means $OF = 1$ for all elevation except for west elevation. Considering the neighbouring building would cause between 50% to 70% view obstruction, $OF = 0.85$ is selected for this elevation.

Table 4. Window to wall ratio in the Academy building

Elevation	**WWR**
North	0.49
South	0.61
East	0.54
West	0.51

Table 5. Daylighting feasibility factor for all four elevations of the Academy building

Elevation	WWR	OF	Feasibility Factor
North	0.49	1	0.3185
South	0.61	1	0.3965
East	0.54	1	0.351
West	0.51	0.85	0.2817

As the feasibility factor is ≥ 0.25, it means daylighting has the potential for significant energy saving in this building.

c. Spandrel glass

Although the Academy is not a curtain wall building, spandrel glazing is used widely in all the four elevations to cover the construction materials. The ratio of spandrel glazing on all the four building exposures is provided in Table 6. As the main glazing of the building is light-transmitting and low-reflective, a good match is not achieved between the vision and the spandrel glazing. The site visit was performed on a typical rainy Vancouver day and a clear contrast between the vision and the spandrel glass was observed (Fig. 6) which is in contrast with the purpose of spandrel glazing to make a uniform appearance. In addition, the vast use of spandrel glass can potentially result in additional heat loss through thermal-bridging effect.

Table 6. Ratio of spandrel glazing in each elevation

Elevation	Spandrel glazing to wall ratio
North	5%
South	10%
East	6%
West	6%

Fig 6. Spandrel glazing used in Academy building to cover the construction material

d. View

The Academy is surrounded by the Pacific Sprit Park and Khorana Park which provide plenty of natural landscape views for occupants. In addition, above a certain floor, the occupants on the north, south and west elevations will have an ocean view. Consequently, it is expected that occupants will benefit from positive effects of view on their mental alertness, productivity and psychological wellbeing. However there are strip windows on the north and the west elevation which do not provide good-quality views, as they do not include three layers of information (upper, middle, lower). These strip windows on the elevation view of the building and the view from these windows are shown in Fig. 8.

Fig 7. A typical view from a unit in the Academy

Fig 8. Strip windows on the north and west elevations

e. Design modifications

Minor changes are made to the elevation design of the Academy based on the remarks mentioned in our case study. These minor changes are expected to improve the window/glazing design by providing a better view while providing sufficient daylighting and increasing energy efficiency.

<u>Design modification I</u>

The strip window used in the north and west elevations are widened and flipped vertically as shown in Fig. 9.

Fig 9. Modified window design in the north and west elevations

It is seen that, the applied modification does not necessary increase WWR, but provides a better view as it will not be blocked anymore by the neighbouring building. In addition, the taller window provides three layers of view and contains more information.

Design modification II

An investigation into the floor plan of the building reveals that for two units at the west and the east elevations, the living room wall is fully glazed. As these two units, are located at elevations with a maximum solar heat gain, the amount of glazing in the modified design is reduced by simply replacing a part of the living room glazing with a solid wall. The outcomes are shown in Figs. 10.

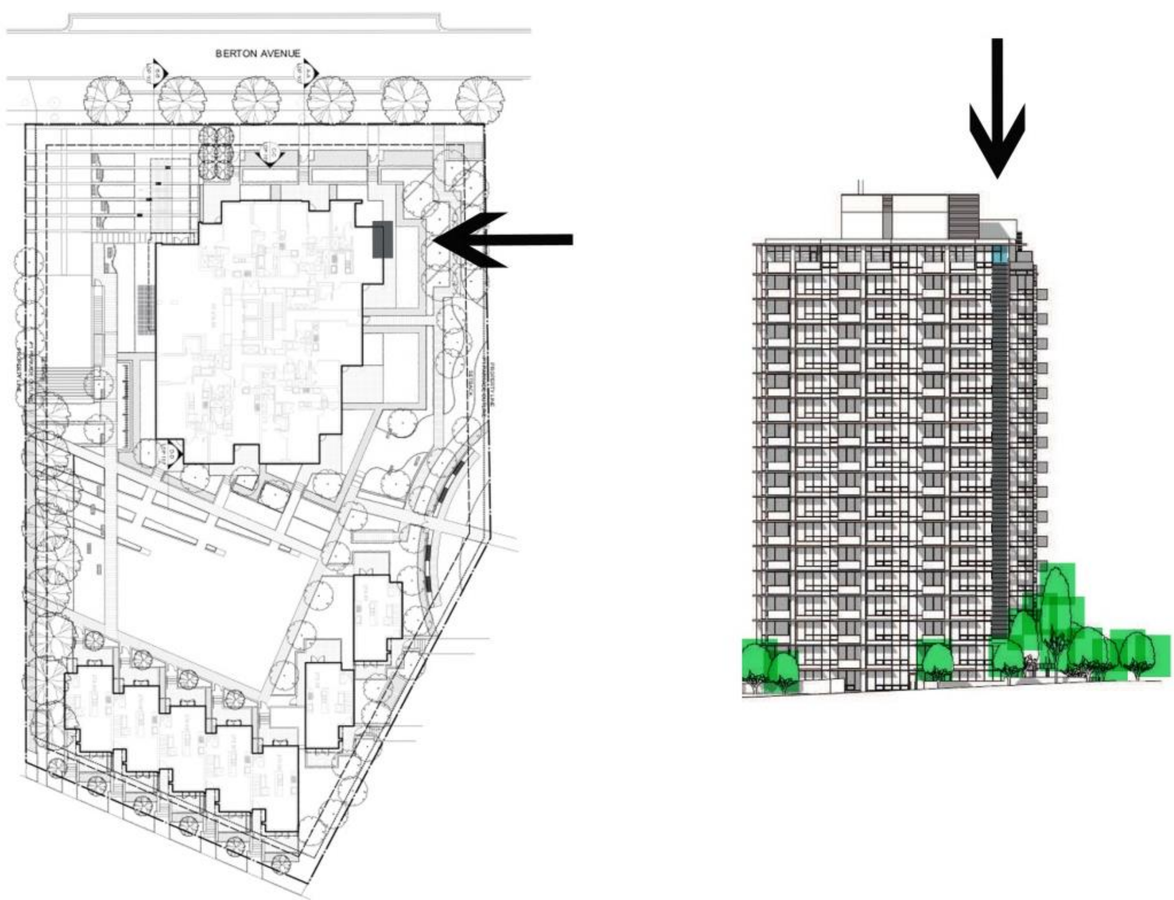

Fig 10. Decreased window to wall ratio on the east elevation

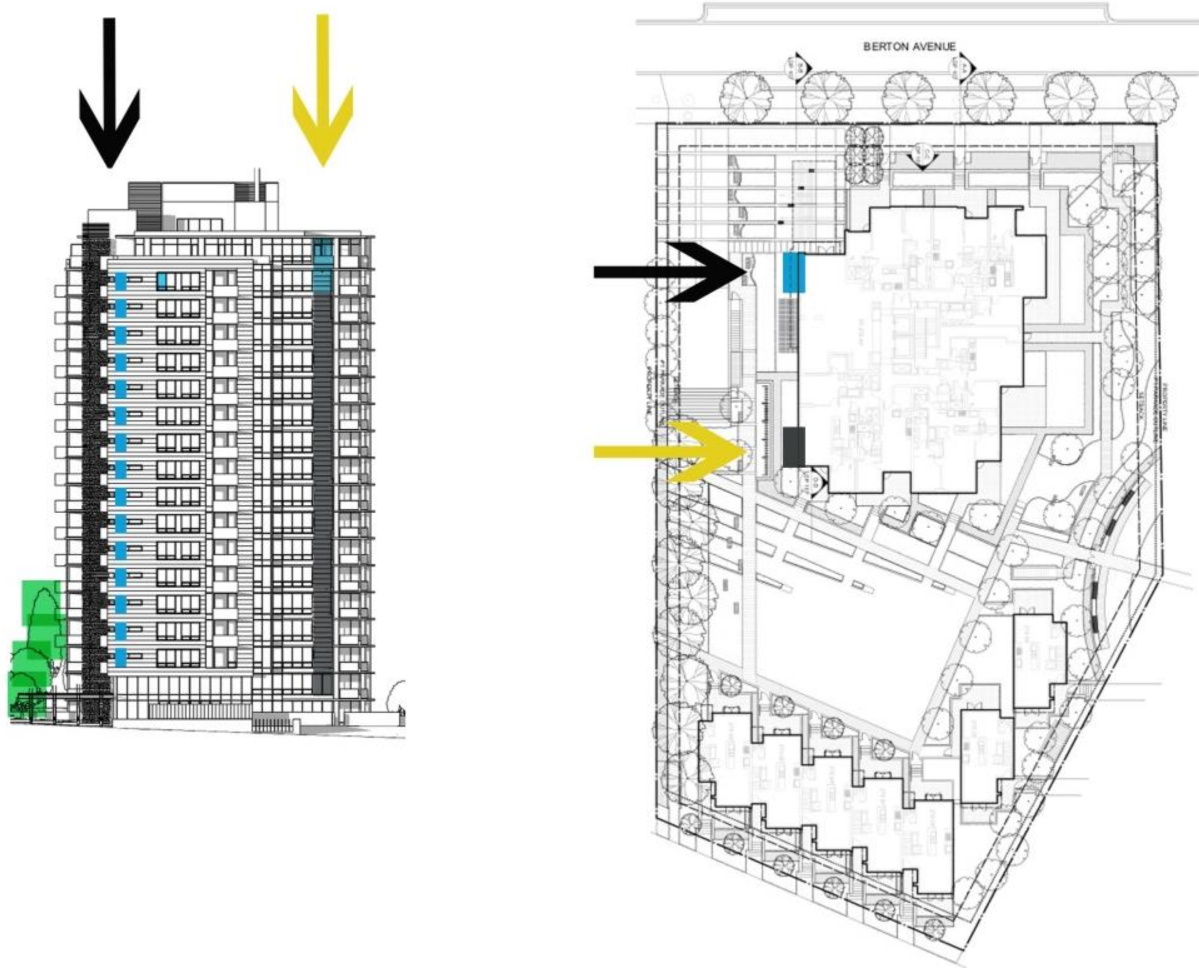

Fig 11. Decreased window to wall ratio in the west elevation

It is found that by performing such minor changes the WWR could be reduced below the general suggested value of 0.5.

Table 7. Reduced WWR after design modification

Elevation	Current WWR	Modified WWR
East	0.54	48.5
West	0.51	45%

7. Conclusions

- The total heat transfer through the window is a function of the size and heat transfer coefficients of the window (U value, SHGC). A larger window size requires use of windows with lower heat transfer coefficients which increases the cost, since a higher window technology should be used.
- In Vancouver, major heat loss through the windows will occur in the winter which necessitates use of windows with U<0.3 $\mathrm{Btu/hrft^2F}$.
- In the summer, solar heat gain on the east/west and south elevation can impose excessive cooling loads on the building and increases the energy costs.
- As Vancouver is in a northern zone and mostly requires heating during the year, solar heat gain in summer is not as critical as in the southern zones such as in California or Arizona; however, in order to prevent extra cooling loads in the summer, windows with SHGC<0.4 should be considered in the design.
- Sufficient daylighting with no glare problem can be achieved by wise selection of window size, visible transmittance or by use of interior shading.
- WWR>0.4 [5] may be justified in Vancouver, only by use of windows with low U-values, low SHGC and preventive actions against the glare problem.
- As total heat transfer through the windows is a linear function of the window size and heat transfer coefficients, any increase in the window size and WWR requires a proportional decrease of the U-value and SHGC. Based on current window technology, WWR=0.6 could be considered as the top limit.
- The UBC green building rating system (REAP) has guidelines only for the U-value, but no regulations for window to wall ratio, SHGC and visible transmittance.

- High WWR (>0.5) are observed in recently constructed residential high-rises on UBC campus. Design modifications were suggested in this report which could have reduced the glazing ratio without sacrificing view or daylighting.
- Suggested design modifications for the Academy building are as listed below:

- Replacing fully glazed wall with partially glazed wall in the living room of units located on or exposed to the west or east side.
- Changing the orientation of strip windows on west and north elevation to provide a better view without increasing the size.
- Using less spandrel glazing.

- Large floor-to-ceiling windows are a big selling factor in Vancouver especially when they provide a natural landscape view. Buildings with lower WWR could also be marketable by optimum design of windows to provide a good quality view which includes three layers of information.
- Daylighting and view of natural landscapes affect human performance, mood, feelings, physiological and psychological well-being, all of which could be achieved through well-designed windows.
- Eexposure to natural landscapes improves individual and social well-being and provides psychological relief.

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