Energy Conservation Considerations During Building Enclosure Rehabilitation of Large Multi-Unit Residential Buildings

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ABSTRACT

In the Pacific Northwest and especially the lower mainland of British Columbia, many large residential buildings have experienced premature failure of the building enclosure largely due to moisture. Often extensive and costly remediation is needed and consequently there is considerable pressure to minimize the short term capital costs. One potential benefit of the situation, is that there is an opportunity to improve the energy efficiency of building enclosures during major rehabilitation. Typically the thermal resistance of the enclosure is improved as a result of replacing cladding, increasing insulation levels and reducing the amount of air leakage across the enclosure. Collectively this will provide higher levels of occupant comfort and reduce the operating energy requirements of a building, especially the space conditioning energy requirements. However these are the consequences of rehabilitating the enclosure. The issue for us and the tenants, alike is how to use the occasion to directly and effectively reduce energy consumption given that the overall cost of rehabilitation will increase and the benefits will only be gained over a number of years. More precisely how does one, as the Consultant, make the case for an increase in present costs, that are already an unwelcome and expensive necessity, against future savings. To examine this issue is largely the objective of this paper.

This paper presents the effect that major enclosure rehabilitation has on overall building energy use using, as a case study, the rehabilitation of a large high-rise residential complex located in Burnaby, BC. Heating is primarily provided by electricity and actual energy use data has been provided by the local utilities; there is no mechanical air conditioning (cooling). Various methods of estimating building energy consumption performance before and after rehabilitation are considered.

The actual building's energy billing data is compared with modeled figures to validate the analysis model for predicting building energy consumption. The modeling is also used to compare the relative impact of enclosure characteristics such as air leakage and thermal resistance on energy consumption. Field measurements of air leakage are used to further refine estimation techniques. Air leakage and natural ventilation are probably the most difficult variables to quantify. The case is then made for seriously considering the option of providing additional conservation of space heating energy over and above that needed for enclosure rehabilitation.

INTRODUCTION

In places like the lower mainland region of British Columbia, the "leaky condo" problem has resulted in the replacement of many building enclosure assemblies that have deteriorated prematurely. As this region continues to have one of the highest concentrations of new construction in Canada, the addition of a large number of rehabilitation projects has left the region in a huge deficit, both in terms of rehabilitation costs and in terms of the material and labour resources needed to complete the work. However, it has been found that rehabilitation of the building enclosures not only improves the moisture management characteristics, it also likely improves the energy efficiency of the buildings by reducing heat losses through air leakage and increased levels of thermal resistance.

Although multi-unit residential buildings (MURBs) represent some of the largest areas of past and current construction development, there is relatively little information available regarding actual energy performance characteristics for these types of buildings. However, the rehabilitation of moisture damaged buildings offers a growing body of data that could be made available to show the energy consumption patterns of these buildings before and after a major rehabilitation. Based on some of our preliminary work, there is a significant opportunity to realize reductions in the energy consumption for space conditioning of residential units by improving the air tightness and heat transfer characteristics of the building enclosures during the rehabilitation process. The review of the actual energy reductions realized during this process will in turn provide information needed to refine our economic analyses of different rehabilitation options. Information gathered during this review may also be applied to new buildings in order to improve energy consumption, moisture management and other performance characteristics.

The intent of this paper is to promote higher levels of energy efficiency in large multi-unit residential homes during the rehabilitation process, and to promote the gathering of more information that can be used to encourage Owners to consider the long-term benefits of reducing energy consumption in buildings.

CASE STUDY ENCLOSURE ASSEMBLIES

This paper presents a case study of a "leaky condo" rehabilitation of a single condominium complex in Burnaby, BC, constructed between 1986 and 1987. The complex includes 2 residential high-rise towers constructed above a shared 2-storey underground parking structure. One tower is 20 storeys high, the other 23 storeys high. Figure 1 provides an aerial view of the 2 towers, and the extensively landscaped deck of the underground parking structure that links the 2 towers below grade. Figure 2 is a typical elevation of one of the towers showing the relative proportion of glazed to solid wall area, and the proportion of exposed, thermally connected cast in place concrete elements including structural shear walls and concrete balcony slabs and integral concrete upstand/guards. RDH was not involved in the original design or construction of the buildings.

The overall design and detailing of the two towers is similar. The original design incorporated 3 basic wall assemblies; face sealed (painted) cast in place concrete with nominal interior glass batt insulation, face sealed cast in place concrete with bonded 'thermo' stucco (i.e. with polystyrene beads in the basecoat) on the exterior, and nominal glass batt insulation on the interior, and face sealed 'thermo' stucco over building paper on gypsum sheathing and light gauge metal stud framing with nominal glass batt insulation in the stud cavity. All wall assemblies included interior gypsum wallboard over medium weight vapour resistive polyethylene sheeting. Some of the unique features of the original building design included the use of a continuous concrete upstand around the floor slab perimeters, and 2 independent light gauge metal stud assemblies where the exterior assembly spans from the top of the concrete upstands to the underside of the slab above, and the interior metal stud assembly spans from the top of the floor slab to the underside of the floor slab above. These concrete upstands extend beyond the wall assemblies to form part of the typical suite balcony guards on the exterior. Non-thermally broken aluminum window and door assemblies were also incorporated in the typical exterior wall assemblies.

REQUIRED REPAIRS

The original building enclosure assemblies performed poorly at a number of locations, primarily as a result of moisture ingress and/or moisture retention within the wall assemblies.

Figure 1. Aerial view, case study complex.

Figure 2. Elevation view of Tower 2, case study complex.

Windows

The original non-thermally broken aluminum windows were exterior glazed and were relatively poor in terms of water penetration resistance and thermal performance compared to the current industry standards. There was evidence of extensive water ingress at windows and reports of condensation accumulating on windows from a majority of suite owners. Water penetration testing of the aged window assemblies identified major water penetration under neutral pressure differentials, and systemic leakage as differential testing pressures were applied. Excessive air leakage was also identified during testing through the window assemblies. The window assemblies spanned from the top of the concrete upstands to the underside of the floor slab above. The window to wall assembly interfaces were also face sealed, without window head or sub-sill flashings.

Walls

As discussed, there were 3 basic wall assemblies; 1) face sealed (painted) cast in place concrete, 2) face sealed cast in place concrete with bonded thermo stucco on the exterior, and 3) face sealed 'thermo' stucco supported by gypsum sheathing and metal stud framing. The concrete upstands are approximately 2' feet high and directly supported the mulled window assemblies (window bands). The wall areas adjacent to the window bands were clad with stucco (the 3rd assembly). To make the exterior stucco face uniform, the metal stud framing was set back towards the building interior to allow the exterior face of the gypsum sheathing/building paper face to be flush with the face of the concrete upstands. The thermo stucco was then applied, in a relatively uniform thickness, over these two different substrates. The metal stud framing directly supporting the thermo stucco was moderately to severely corroded. In addition, the gauge of the metal stud framing was undersized, increasing the rate and significance of the corrosion. The amount of corrosion had a significant impact on the capacity of the screw fasteners used to laterally attach the metal mesh reinforced stucco to the metal stud assemblies. In addition, the gypsum board deterioration and the loss of cross-sectional area of the sheathing was sufficient enough (due to repeated and sustained wetting) to further reduce the lateral load resistance of the stucco to metal stud connections.

The interior faces of the concrete upstands and shearwalls, have 2 ½" deep metal stud framing, with glass batt insulation in the stud cavities, a 4 mil polyethylene vapour retarder sheet membrane, and painted gypsum wallboard finish. This interior stud framing was independent of the exterior (corroded) metal stud framing that supported the thermo stucco. Although likely a function of building geometry (i.e. the continuous concrete upstands at the slab edges), this offset double stud wall configuration provided a thermal break between the interior and exterior stud assemblies (which typically doesn't exist in other similar buildings). There was a gap between the inside face of the exterior sheathing supporting the thermo stucco and the glass batt insulation. This gap permitted interstitial air flows (air flow within the double metal stud framing). During demolition, the exterior stud flange corrosion of the metal studs supporting the thermo stucco was consistent with corrosion that would have been observed on non-thermally broken, single stud wall assemblies.

Figures 3 and 4 show the overall building form and a close up showing the typical relationship of the main wall assemblies. Figures 5 and 6 show the typical locations of the stucco clad metal stud wall assemblies, and a conceptual relationship of the interior components. Figures 7 and 8 show the typical locations of the painted concrete shearwall faces and shearwall ends. Figures 9 and 10 show the typical locations for the stucco covered concrete upstands.

Figure 3. Northeast corner, Tower 2.

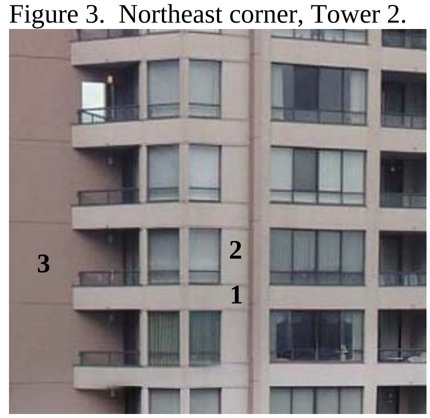
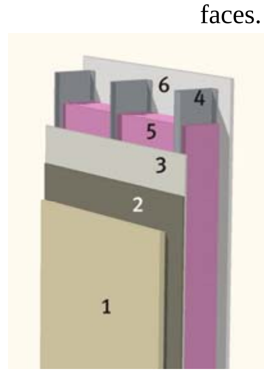


Figure 4. Typical wall assemblies:
1. Stucco over concrete upstands above/below windows,
2. Stucco over metal stud framed walls adjacent to windows,
3. Painted concrete shearwall ends / faces.

Figure 5. Stucco infill walls (denoted by purple highlight).



1. Stucco cladding
2. Sheathing paper
3. Gypsum sheathing
   Steel studs
4. Fibreglass insulation
5. Interior gypsum board and poly

Figure 6. Isometric view of face-sealed stucco infill wall assembly.

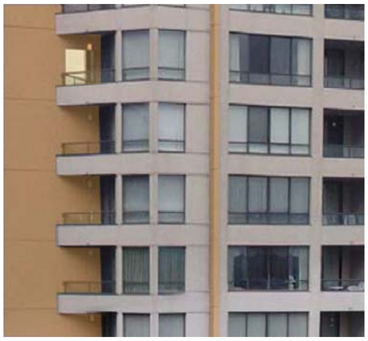
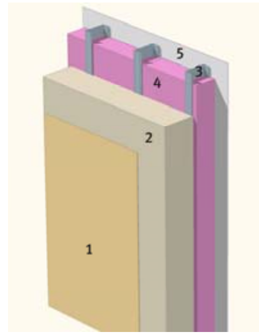


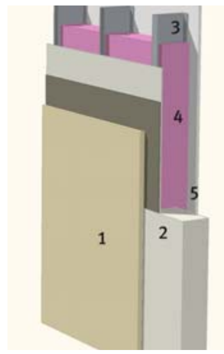
Figure 7. Painted concrete shearwalls and shearwall ends (denoted by orange highlight).



1. Painted exterior finish
2. Concrete wall
3. Metal studs
4. Fibreglass insulation
5. Interior gypsum board and poly

Figure 8. Original coated concrete wall assembly

Figure 9. Stucco covered concrete upstands (denoted by light-green highlight).



1. Stucco Cladding
2. Concrete wall
3. Metal studs
4. Fibreglass insulation
5. Interior gypsum board and poly

Figure 10. Isometric view of Stucco clad concrete and steel stud assemblies

REHABILITATION STRATEGY

One of the primary objectives of the rehabilitation was to correct water ingress that had lead to significant metal support framing corrosion, deterioration of the paper faced gypsum sheathing including the loss of flexural strength and fungal growth on the face and backsides of boards, and the corrosion of the stucco lath and metal fasteners. To achieve this, the selected rehabilitated stucco wall assemblies are pressure moderated, drained and ventilated assemblies (rainscreen assemblies).

The existing stucco clad metal stud wall assemblies and concrete upstands below the metal stud wall areas are being rehabilitated using the following (simplified) sequence:

- Remove exterior stucco cladding and gypsum sheathing,
- Remove glass batt stud cavity insulation, above and behind the concrete upstand,
- Score and remove interior polyethylene vapour retarder, above and below the concrete upstand,
- Repair / reinforce / replace corroded exterior metal stud framing,
- Install exterior sheathing and continuous polyethylene coated self adhesive membrane over sheathing and face of concrete upstand below,
- Install new heavier gauge, galvalume coated, custom z-shaped girt assembly, fastening the bottom of each girt to the face of the concrete upstand, and the top to a custom shaped, horizontally aligned z-girt,
- Install semi-rigid rock wool insulation in girt cavity spaces recessed from the face of the girts to create a capillary break/vented air space in completed assembly, and

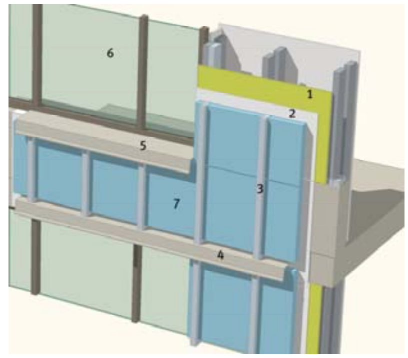
- Install conventional stucco cladding, drained and ventilated at each floor level, with finish coating and perimeter sealant joints.

The new girt assembly is attached to the existing structure, using angle shaped clips and shimmed, bolted connections, minimizing the thermal connectivity of the girts with the now exterior insulated concrete building frame. These supports are designed so that the attachment points have been made at the top and bottom of the girts, leaving the stucco support thermally broken along the majority of its length, eliminating the typical z-girt to metal stud framing connections.

Figures 11 & 12 conceptually show the multiple layers of the rehabilitated stucco wall, and the continuity of the new thermal insulation over the concrete building frame. These figures also show the girt assembly passing below the window bands, which was later revised (see below).

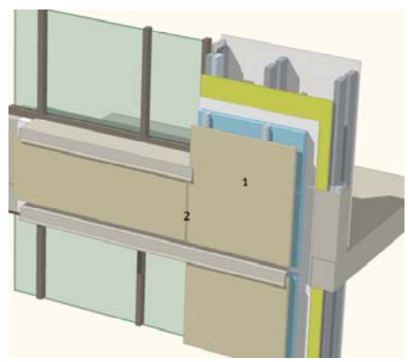
As discussed in the next section of this paper, a more cost effective cladding assembly was chosen below the windows, to be applied over the concrete upstands supporting the new window assemblies, in lieu of the normal, direct connected Z-girt assembly. Similarly, the painted exposed concrete walls posed moisture management challenges that required additional design considerations. To achieve acceptable levels of moisture management, to reduce the thermal losses due to exposed wall to supported concrete floor slabs, and to achieve some thermal storage/moderating benefits, the originally exposed concrete wall areas were overclad with a drained and vented EIFS assembly, as described in the next section.

In addition to the wall improvements, the original windows were replaced with residential quality, thermally broken aluminum windows with a low emissivity coating applied to the No. 2 glass surface on all elevations. The perimeter interfaces of the new windows were also designed and installed as drained and vented interface assemblies.



1. New fibreglass faced exterior gypsum sheathing
2. New self-adhesive membrane air and moisture barrier
3. Steel z-girts
4. Cross-cavity flashing
5. Window sill flashing
6. New window assembly
7. Rigid or semi-rigid exterior insulation

Figure 11. Isometric view of partially rehabilitated wall



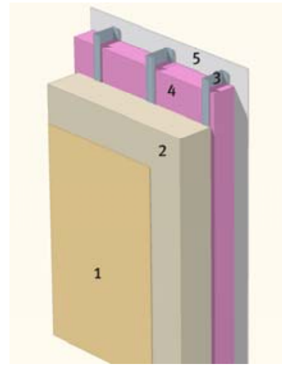
1. New stucco cladding
2. Control joint / sealant

Figure 12. Isometric view of rehabilitated wall, all layers.

DESIGN CONSIDERATIONS TO IMPROVE THERMAL PERFORMANCE

There is a direct correlation between thermal performance (heat loss) and energy consumption in the heating or cooling seasons. To improve the effective overall thermal performance of the rehabilitated enclosures, the following thermal performance improvements were introduced in 2 general ways:

1) Reduced Thermal Conduction:
   - Thermally broken aluminum window frames, with Low-E coated IGUs to improve heat retention during the heating season (and heat reflection during the summer),
   - Thermally continuous layer of insulation over the original metal stud assemblies and thermo stucco clad concrete upstands in a stucco rainscreen assembly (using non-standard girt attachment),
   - Thermally continuous layer of insulation over original painted concrete shear walls and exposed floor slab edges, in a drained and vented EIFS assembly.



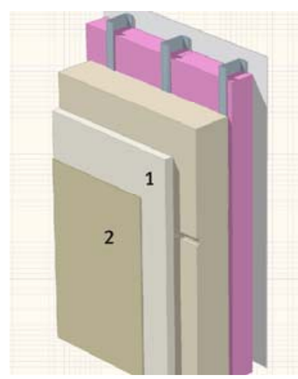
1. Painted exterior finish
2. Concrete wall
3. Metal studs
4. Fibreglass insulation
5. Interior gypsum board and poly

Figure 13. Isometric view of original assembly.

2) Reduced Uncontrolled Air Exchange (Air Leakage):
   - Fixed and operable window assemblies with improved air leakage resistance,
   - Air sealed window-to-wall and door-to-wall interfaces,
   - Relocated air barrier (i.e. moved to the plane of the concealed, continuous air and moisture barrier membrane). (This applies to the stucco assemblies only – the poured in place concrete effectively provides air barrier on shear walls and concrete upstands.)

REDUCED THERMAL CONDUCTION

The original painted concrete shearwall assemblies and thermo stucco clad concrete upstands thermally bridged the existing interior insulation where they supported each floor slab, and where they extended beyond through the cladding assembly to form balcony and deck upstands. The shearwalls also thermally bridged the wall insulation where they projected beyond the building faces. A least cost option to manage the risk of moisture ingress in these wall assemblies, would have been to surface treat all visible cracks by injection or by routing the existing cracks and sealing with a flexible sealant, and subsequently re-
coating the wall areas with a flexible and vapour permeable coating. This approach would not have improved the effective thermal performance of the building, and referring to Table 2, without consideration to the effects of heat loss due to air leakage (bulk convective heat transfer) the effective thermal performance of the rehabilitated enclosure would have been roughly equal to the pre-rehabilitation condition.



1. Polystyrene insulation on vapour permeable, water resistive cementitious barrier
2. Reinforced cemetitious base with acrylic finish coat

Figure 14. Isometric view EIFS cladding

To improve the thermal performance of these buildings and to provide a higher level of moisture management performance, a continuous insulated cladding was adopted over the exterior wall elements (i.e. excluding the projecting balcony slabs and upstands that do not provide environmental separation). However, providing a layer of insulation on the exterior to reduce the amount of thermal bridging requires consideration of the vapour permeability of the entire wall assembly. Specifically, unlike metal stud framed exterior wall assemblies, where removal of the exterior sheathing provides access to remove an existing polyethylene vapour retarder (from the outside), the concrete wall areas can only be cost effectively rehabilitated from the building exterior. Therefore, a thermally improved, rehabilitated wall assembly was designed to manage wetting and drying effects (direct wetting/drying and vapour diffusion), with the existing polyethylene vapour retarder remaining in place. To achieve this, a vapour permeable cementitious membrane and an adhesively attached, drained Exterior Insulation and Finish System were selected (see Figures 13 and 14).

Improvements were made to all roof and deck level membrane assemblies, primarily to improve moisture management. The supporting roof structures are cast in place concrete and pre-cast concrete. Thermal performance improvements were generally focused on their interfaces with wall and window assemblies. However significant thermal improvements were made at the large sloped metal roofs (supported by precast concrete panels).

PREDICTING THERMAL IMPROVEMENT

Improving the energy efficiency of building enclosures requires improving the overall effective thermal resistance of an assembly, reducing the amount of air leakage through each assembly, and reducing the air leakage at the interfaces between assemblies. In this case study all of these measures were undertaken. The differences in thermal performance before and after rehabilitation are summarized in Tables 1 and 2, respectively.

Table 1 – Estimated Original Effective Thermal Resistance Values – One Tower

Assembly Type	Description	Effective Resistance		Percentage Wall Area [%]	Approximate Representative Wall Areas [m^2]
		RSI [m^2*K/W]	R [hr*ft^2*°F/Btu]		
W1	Thermo Stucco over Steel Stud Framing	2.24	12.7	6.5%	437
W2	Thermo Stucco over Concrete (with original batt insulation on interior)	2.55	14.5	4%	270
W3	Thermo Stucco over Double Steel Stud Framing (with original batt insulation on interior)	2.78	15.8	10%	673
W4	Exposed Concrete (with original batt insulation on interior)	1.83	10.4	26.5%	1783
Windows and Doors	Combined window and door glass area and frame area properties (from historical, non-site specific data)	0.09	0.5	53%	3567
Totals				**100%**	**6730**

Table 2 – Estimated Rehabilitated Effective Thermal Resistance Values – One Tower

Assembly Type	Description	Effective Resistance		Percentage Wall Area [%]	Approximate Representative Wall Areas [m^2]
		RSI [m^2*K/W]	R [hr*ft^2*°F/Btu]		
W1	EIFS over Single Steel Stud Framing (original batt insulation removed)	1.92	10.9	6.5%	437
W2	Rainscreen Stucco over Concrete (original batt insulation removed)	2.62	14.9	4%	270
W3	Rainscreen Stucco over Double Steel Stud Framing (original batt insulation removed)	2.62	14.9	10%	673
W4	EIFS over Concrete (original batt insulation inaccessible and not removed)	3.29	18.7	26.5%	1783
Windows and Doors	Combined window and door glass area and frame area properties (provided by Window Manufacturer)	0.41	2.3	53%	3567
Totals				**100%**	**6730**

The effects of minimizing thermal bridging in the wall assemblies is illustrated in Figure 15. The rainscreen stucco was designed and installed so that the girts that are supporting the stucco lath are connected only at the top and bottom of each girt to the building frame. Therefore the model in Figure 15 shows the predominant conditions between points of attachment to the building structure. The results of 2-D thermal modeling using the software model THERM, shown in Figure 16 indicates the interior temperature is cooler at the stud location for a typical wall as compared to the thermally isolated rainscreen wall. Providing the thermal break for the framing supports lowers the potential for stud shadowing to occur and contributes to increasing the effective thermal resistance of the wall assembly.

Knowledge of thermal resistance properties is useful to assist in designing and specifying improved levels of insulation. This information is also useful to help predict building energy requirements for space conditioning.

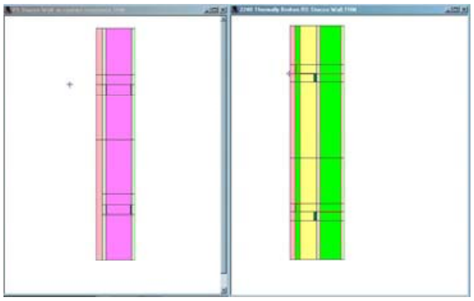


Figure 15 LHS: Cross section of typical face-sealed stucco wall assembly. RHS: Cross section of rainscreen stucco wall assembly

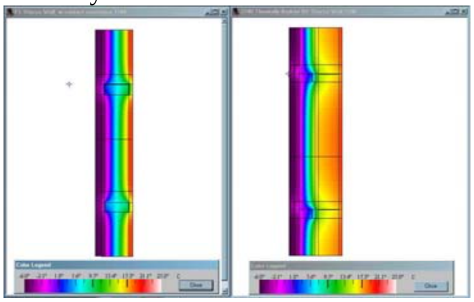


Figure 16. Colour isotherms of assemblies in Figure 14. Temp ext. = –6 °C, and Temp. int. = 21°C.

PREDICTING AIR LEAKAGE

However, the overall heat loss, and hence a measure of the energy efficiency of the enclosure before and after rehabilitation, is greatly affected by air leakage, not just the heat flow rate due to conduction (thermal radiation). In conjunction with another study, one rehabilitated suite in one of the Towers was air leakage tested using a six stage, precisely controlled multi blower door procedure in order to confirm the design assumptions, and in anticipation of the need to make adjustments to the supply air to suites following the rehabilitation work. The tests were designed to assess air leakage rates to the exterior, by isolating (neutralizing) interior corridor, and suite interfaces with adjacent suites (above, below, and each side). The testing was performed using a 50 Pa pressure differential. This pressure differential was selected, although it represents a significantly higher pressure than would be expected in service, as it is generally sufficient to overcome minor wind and stack effects that can introduce testing errors. (Standardizing the testing procedure, also allows the results to be compared to published unit leakage rates for single family dwellings – see ASHRAE 2005, 29.6, Table 3.)

The results of the air leakage testing indicated the following, post rehabilitation for a suite on the 8th floor are summarized in Table 3. The suite floor area is approximately 100.5 m^2, with a clear ceiling height of 2.44 m, giving a total suite air volume of approximately 245 m^3.

Table 3: Incremental Air Leakage Test Results – One Suite (Ref. 1)

Leakage Surface	Average Equivalent Leakage Area	ACH50	Normalized Equivalent. Leakage Area
All 6 sides *314 m^2*	319 cm^2	2.6	1.0 cm^2/m^2
9th floor + suite above *101 m^2*	58 cm^2	0.5	0.6 cm^2/m^2
7th floor + suite below *101 m^2*	16 cm^2	0.1	0.2 cm^2/m^2
Hallway 8th floor *11 m^2*	117 cm^2	1.0	11.0 cm^2/m^2
Adjacent Suite 1 *33 m^2*	13 cm^2	0.1	0.4 cm^2/m^2
Adjacent Suite 2 *27 m^2*	5 cm^2	<0.1	0.2 cm^2/m^2
Exterior walls *42 m^2*	112 cm^2	0.9	2.7 cm^2/m^2

The testing indicates that roughly 35% of the post-rehabilitation air leakage, or 0.9 ACH at 50 Pa pressure differential, is through the exterior enclosure, 37% is through unplanned hallway/corridor openings, 23% floor-to-floor leakage, with the remaining 5% suite-to-suite leakage. (The suite-to-suite leakage is representative of the type of construction – cast in place concrete walls.)

PREDICTING HEAT FLOW

Heat flow can be expressed as a function of air flow, expressed as Air Changes per Hour (ACH). If we assume the air in the room has a density of 1.2 kg/m^3, and a heat capacity of 1000 J/kg (Ref. 3), heat flow can be expressed as:

$$q = 0.3 * [(ACH) * \text{Volume of Air}] * \Delta T \qquad \text{(Ref. 3)}$$

However, a more easily used expression, one that can be used in combination with heat loss from conduction, can be found by rearranging the above equation, to express an equivalent heat loss coefficient for air leakage, per degree of temperature differential:

$$U_{air} = 0.3 * ACH * \text{Volume of Air}$$

Assuming only the air exchanged through the exterior walls would require re-heating, and that all other sources are heated by adjacent suites (above, below, left and right), or the common area roof top ventilation unit (serving the corridors) the ACH 50 would be 0.9. However, it is more reasonable to assume a much lower leakage rate, under normal pressure differentials. Even for a tall building, with a large pressure differential of 20 Pa across the exterior walls, the ACH would be in the order of 0.5 (Ref. 1). Therefore, the heat loss due to air leakage in one typical suite, under high but less than the tested pressure differential, can be expressed as:

$$U_{air} = 0.3 * (0.5) * 245 \ \text{W/ °C}$$

$$U_{air} = 36.75 \ \text{W/ °C (for one typical suite)}$$

If we compare the amount of heat loss through air leakage (attributable to the suite owners) with the heat loss due to radiation, per degree of external temperature differential, we can assess the relative effectiveness of the thermal and air leakage improvements that have resulted from the enclosure rehabilitation. Table 4 summarizes the results of this comparison.

Table 4 – Estimated Rehabilitated Cladding Building Heat Loss Coefficient – One Tower

Assembly Type	Description	Effective U [W/m² /°C]	Approximate Representative Wall Areas [m²]	Q Heat Loss [W/°C]	Total Heat Loss [%]
Walls	Combined wall assemblies (see Table 2)	0.34	3163	1,075	6.8
Windows and Doors	Combined fenestration assemblies (see Table 2)	2.44	3567	8,703	55.6
Air Leakage	Based on results of one typical suite, multiplied up to represent 160 typical suites	-	-	5,880	37.6
Overall Building Heat Loss Coefficient [W/°C]				15,658	100

Not surprisingly, there remains significant opportunity to improve the energy efficiency of the fenestration (i.e. mostly the sliding doors). However, even under the apparently small amount of remaining air leakage, post rehabilitation, the exterior wall assemblies contribute roughly 20 to 40% of the total heat loss per degree of differential temperature, depending on the exterior pressure differential.

Unfortunately, at these low air leakage levels, some suite owners encounter problems with maintaining acceptable indoor relative humidity levels. Elevated indoor relative humidities, due to effective rehabilitation that reduces uncontrolled air changes (air leakage), must then be offset by passive, and mechanical ventilation. In some cases, the building mechanical systems and method of delivering supply air to the suites (i.e. through door under cuts etc.) are insufficient. In addition, there is often unwillingness on the part of suite owners to leave the door under cuts free of obstruction, which can worsen the problem. One primary ventilation strategy is to have the unit owners, in a controlled fashion, open their windows a few hours a day, depending on the occupant/use loads. Obviously, tempering this fresh air results in additional energy consumption, unless heat recovering or other alternative methods are used.

MODELING AND PREDICTING BUILDING ENERGY PERFORMANCE

In order to promote improved energy efficiency in building rehabilitation designs it is necessary to accurately model and predict the effect that building rehabilitation has on the building's energy requirements for space conditioning needs. This requires accurately modeling the energy consumption characteristics of a building before rehabilitation and using the model to predict the energy consumption characteristics of the building after rehabilitation at the design stage.

Using approximations of thermal resistance properties for the building enclosure components modeling of one of the high-rise buildings' annual space heat energy requirements was performed using two models. The first, Model 1, is based on a simple heat loss calculation that takes into effect the heating degree days for the Burnaby region of British Columbia, the overall thermal resistance of the building and area of exposed building envelope. The other model, Model 2, was approximated using a computer building energy performance modeling tool called eQUEST. The results of the predicted annual energy requirements for space heat from these two models are shown in Figure 17 and compared to approximated space heat electricity purchased by a sample of suites calculated from the previous year's billing data.

There is a large amount of variation between the modeling predictions and the estimate taken from billing data shown in Figure 19. There are too many unknown variables to obtain an accurate picture of the effect that this retrofit may have on space conditioning energy requirements at this time. By examining actual billing data from other rehabilitated buildings, these unknown variables can be better determined and incorporated into the modelling.

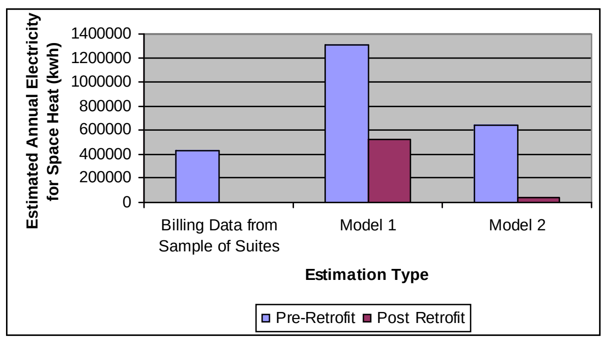


Figure 17. Comparing before and after retrofit electricity requirements for space heat estimated using two models to an estimate of electricity purchased for space heat from billing data. Model 1 is by calculation and Model 2 is using eQUEST.

In both of the models, the values of the air leakage used in the models affects the variability in the predicted energy requirements the most. The proportion of heat loss attributed to air leakage as compared to heat loss through the enclosure is shown in Figure 18 for Model 1. The values of air leakage in this model are taken from literature values for the pre-retrofit case and from field measurements for the rehabilitation case (Ref. 2).

BUILDING ENERGY CONSUMPTION DATA

The most direct approach to determine what extent building rehabilitation has on space conditioning energy requirements is to analyze utility billing data before and after rehabilitation is complete. This task is challenged by the fact that MURBs often have more than one energy source contributing to space conditioning. Individual suites are typically heated using electrical resistance baseboard heating at the exterior walls. Suite ventilation is provided by pressurized corridor air that is heated using natural gas. Billing data from previous natural gas consumption is required to augment this analysis.

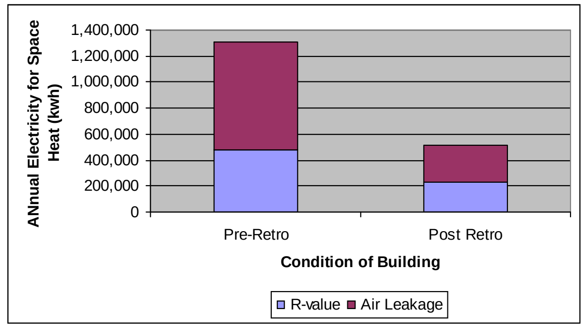


Figure 18. Breakdown of Model 1 components for space heat requirements into heat loss through enclosure (R-value) and heat loss through air leakage

Electricity billing data was provided by the utility provider for 5 years prior to the rehabilitation construction, with construction taking place into early 2007. Based on the monthly electricity billing data in Figure 19, there appears to be season peaks that correlate with the heating season. The baseline, or electricity purchased shown as Rate 1, can be assumed to be plug load or electrical load that is not contributing to space heating requirements. The electricity purchased at Rate 2 appears to be for space heating requirements. From Figure 19, the amount of electricity purchased annually is closer to the estimate provided by Model 2. Additional years of post rehabilitation utility billing is required to further assess the effect that leaky condo rehabilitation has on electricity for space conditioning.

CONCLUSIONS / RECOMMENDATIONS

There is little quantitative evidence available to support that enclosure rehabilitation typical of high-rise leaky condo repairs that are predominant in the lower mainland region of BC, reduces the space conditioning energy requirements of a building. And until recently, assessing and measuring the pre and post rehabilitation energy consumption of enclosure rehabilitated buildings has not received the same level of attention as other post rehabilitation monitoring programs (which have mostly focused on assessing monitoring moisture management, and moisture load reduction within enclosure assemblies). There is, however, a desire to believe that increasing the effective thermal performance of a building enclosure during rehabilitation improves energy consumption. There has also been an increase in awareness of high-rise residents about the escalation of heating costs in the lower mainland of BC, and an accompanying expectation that enclosure rehabilitation should also provide future energy savings, not just correct moisture management problems. At present, little incentive is offered to these types of

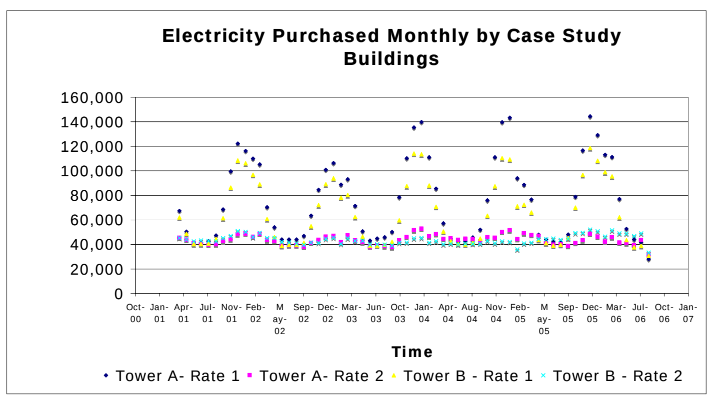


Figure 19. Monthly electricity consumption for each of the high-rise buildings of the case study complex. Rate 1 is residential rate, Rate 2 is commercial rate.

homeowners by government agencies. The reasons to date are considered to be somewhat obvious - there has been the perception that MURBs are inherently more energy efficient because the ratio of enclosure surface area to usable floor area is much lower than in comparison to a typical single family dwelling. This, of course, is not the same as stating there are no opportunities to reduce energy consumption in both types of dwellings. In fact, significant opportunities exist for reduction in residential space heating energy consumption in multi unit residential buildings.

The methods used to evaluate and subsequently rehabilitate typical enclosure assemblies are now well established. However, there is a need to better assess, implement and measure energy reduction opportunities in large rehabilitation projects. Further research is required to better determine the range of overall savings as a result of improved building enclosure assemblies, and to determine how various building enclosure improvements affect a building's energy consumption. This will require a more integrated approach to enclosure rehabilitation, one that goes beyond improving thermal performance, air leakage control, and moisture management, to include passive (or natural) ventilation, mechanical ventilation, heating and in some cases, mechanical cooling. Achieving this will lead to a better understanding of the life-cycle costs of more energy efficient design options.

Specific areas of further research and industry work that could help to improve the selection of energy efficient rehabilitation options, includes:

- Collecting integrated billing data for natural gas and electricity consumption in both common areas and in representative suites within each building in order to account for all fuel sources used in space conditioning.
- Expanded research into and in-situ testing of the air leakage characteristics of multi unit residential buildings.
- Quantifying the actual air leakage and thermal conductivity characteristics of in-service buildings. Actual data could be used to better calibrate design models and determine where the greatest opportunities exist to improve the energy consumption of buildings.

Many buildings in the Lower Mainland of British Columbia have tragically been required (or currently require) to undergo comprehensive rehabilitation to remedy moisture-related problems. However, such rehabilitation presents a unique opportunity to examine and assess the energy-related performance of traditional building enclosures, examine the impact of building enclosure improvements, and to identify opportunities to improve energy conservation in buildings. Further research of the effects of major rehabilitation on in-service buildings would provide a basis for more effective design, building code improvements, and possibly incentive programs for both new and existing buildings.

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