PART 2
ENERGY SAVINGS AND COST BENEFIT ANALYSIS

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2.1 OVERVIEW

Part 1 of this guide addresses the impact of thermal bridging on the thermal performance of building envelope assemblies. Part 2 assesses the impact and significance of thermal bridging from the broader perspective of whole building energy use and the cost effectiveness of different approaches to mitigating thermal bridging.

An energy analysis of several archetypal buildings was performed in conjunction with evaluating incremental construction costs for several different scenarios of interface details. The methodology for whole building energy analysis is described below, followed by construction cost estimates. Finally, the energy use and construction costs are combined in a cost-benefit analysis associated with addressing (or not addressing) thermal bridges.

Throughout Part 2, several fundamental questions are addressed:

1. What is the difference between energy consumption for whole building energy models that do and do not account for the extra heat flow through thermal bridging at interface details?

2. What are the incremental costs associated with mitigating thermal bridges?

3. What is the payback for improving the thermal performance of the building envelope and mitigating thermal bridges?

Part 2 gives an overview of the cost-benefit analysis methodology with the intent of showcasing how the methodology can be used to determine order of magnitude estimation of the cost effectiveness of mitigating thermal bridging to reduce energy consumption in buildings. To demonstrate the methodology, the cost-benefit analysis was performed on several archetypal buildings in British Columbia for a variety of design scenarios. Key findings and discussion from the cost-benefit analysis performed for this guide can be found in Part 3 – Significance and Insights.

Part 2 is intended to demonstrate to all stakeholders how the impact of thermal bridging can be related to building energy use and how incremental construction costs can be evaluated for mitigating thermal bridging in construction.

2.2 WHOLE BUILDING ENERGY USE

2.2.1 ASSESSING WHOLE BUILDING ENERGY USE

Demonstrating the effects of thermal bridging on whole building energy use is an integral part of this study, as it provides greater context to the building envelope thermal performance analysis. While U-values are important for determining compliance with prescriptive codes and comparing alternate envelope solutions, the values are often a means to answering the larger question of building energy consumption.

A building's energy use, and the influence of building envelope U-values on that energy use, depends on a number of parameters, for example:

- Regional Climate
- Building Type, which determines occupancy uses and densities, internal gains and various schedules
- Building Envelope Performance, including envelope U-values and air tightness
- Mechanical Systems, including those for space and ventilation heating and cooling, service hot water heating, and auxiliary equipment such as pumps and fans
- Electrical Systems, including lighting and plug loads

The impact of envelope thermal transmittance on whole building energy use was quantified for a set of archetypal buildings, discussed in the following section, that cover the majority of the BC market. Each archetypal building represents a different set of parameters that result in varying impacts of the envelope U-value on building energy use. This energy use analysis sets the basic framework for the cost-benefit analysis in section 2.4.

2.2.2 Building Archetypes and Modeling Variables

Whole building energy analysis was performed on eight archetype buildings, each representing a different building sector. The characteristics of the archetype buildings were selected based on current BC design and construction practice. The eight archetype buildings that were analyzed are detailed in Appendix C and listed below:

- High-Rise Multi-unit Residential
- Low-Rise Multi-unit Residential
- Hotel / Motel
- Institutional
- Secondary School
- Commercial Office
- Community/Recreation Centre
- Non-Food Retail

Each archetype building was analyzed for two glazing ratios, which varied by sector and three climates representing the major climate zones in the province. The climates modeled were:

Vancouver	**Summerland**	**Prince George**
Lower Mainland BC, Cool-Marine Climate Zone	*Interior BC, Cool-Dry Climate Zone*	*Northern BC, Very Cold Climate Zone*

The thermal resistance of the wall was varied for each archetype building, glazing ratio and climate zone while all other parameters of the building were kept constant. In general, the R-values input into the model for the walls ranged from R2.5 to R20. The thermal mass of building materials was also considered and that analysis, along with more detailed modeling parameters, is provided in Appendix C.

2.2.3 Impacts of Thermal Performance on Whole Building Energy Use

The energy use versus envelope R-value was plotted on a curve to show the impact of building envelope thermal transmittance on whole building energy use. An example is shown in Figure 2.1. The energy curve for each building type, climate zone and glazing ratios are given in Appendix C. The curves in Appendix C are also separated by electrical or natural gas use per building. The curves provide an easy reference which can be used to show:

- The energy use overlooked by ignoring the impact of thermal bridges associated with interface details. This comparison is done by comparing the energy use at an R-value that considers only the clear field thermal resistance to the effective R-value that accounts for interface details. This comparison is intended to highlight the optimistic view of current energy modeling practice to more realistic building energy consumption.
- The energy use associated with improving building envelope thermal performance by more thermally efficient interface details when they have been considered in a whole building energy analysis.

These curves can be created for any specific project design. Figure 2.1 shows the electrical energy use curve for a high-rise MURB with a 40% glazing ratio in Vancouver, BC that is heated with electric baseboards.

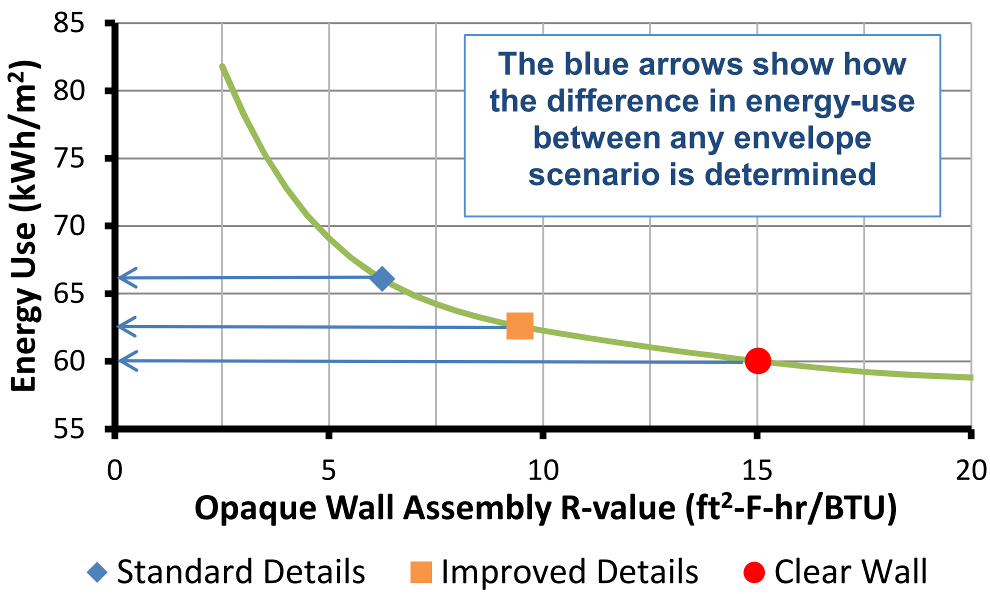


Figure 2.1: Annual Electrical Energy for a 40% Glazed High-Rise MURB in Vancouver, Heated with Electric Baseboards

From Figure 2.1, there are several things to note. First, the curve (in green) shows that there are diminishing returns on energy savings with increasing opaque wall R-value. In this example building, after an overall opaque wall R-value of 15, there is very minimal benefit for further improving the building envelope thermal performance because the reduction in energy use is marginal. The shape of this curve and the severity of the diminishing returns depend on the climate, glazing percentage and other parameters mentioned in section 2.2.1.

The next thing to note is where an opaque wall design falls on the curve when thermal bridges have or have not been considered. As part of this example, Figure 2.1 shows three wall R-value scenarios, each a separate point on the curve:

- Only the clear wall is considered (red circle)
- The clear wall is considered along with thermal bridging through standard details (blue diamond)
- The clear wall is considered along with improved details that minimize thermal bridging (orange square)

The location of each of these R-value points depends on the building design, however, they can be found for any design scenario by following the methodology in Part 1 of this guide. When only the clear wall values are considered, the energy use typically sits at the flat end of the curve. For an energy modeler or architect, this gives the false impression that the building envelope, as designed, is providing its maximum potential in reducing space heating energy and no other improvements are needed. In reality, when thermal bridging is fully taken into account, the actual opaque wall R-value can be much lower and the energy use can sit at the steeper end of the curve. Recognizing this higher energy use provides an incentive to improve the building envelope thermal performance by mitigating thermal bridging that is otherwise overlooked. In using improved details that minimize thermal bridging, it can be seen that the energy use can drop significantly and approach the flat end of the curve, closer to the clear wall or “idealized” value.

The opaque envelope has varying potential for energy savings depending on the building type and climate. These relationships are summarized in Appendix C. The reduction in energy use related to the building envelope is also related to the utility (electricity or gas) that provides space heating. This is typically natural gas except for the low-rise and high-rise MURB archetypes. Several building types also show modest changes in energy use in the non-heating utility, which is a result of changes in ancillary energy use, such as fans, pumps, etc. For example, reductions in heating may lead to slight reductions in fan and pump energy. Some anomalies in energy use are evident for certain archetypes, notably institutional, where building loads are dominated by internal gains and ventilation, rather than envelope losses.

The energy use curves for each of the building archetypes are used in the cost-benefit analysis to compare the reduction in energy use (and thus, energy cost) between different building envelope scenarios. This in turn is used to determine the payback for each scenario, for example mitigating thermal bridging at interface details, higher performance assemblies, or the more conventional method of adding more insulation. The methodology of the cost-benefit analysis is presented in section 2.4.

2.3 CONSTRUCTION COSTS

Construction cost estimates for the building envelope assemblies that are covered by the guide were provided by a general contractor in preparation of this guide. Assembly costs were provided for low- and high-rise construction for three insulation levels. The cost estimates are for installed assemblies that include assumptions for installation access (for example exterior access by swing stage) and material and labour for all components related to the assembly from the exterior façade to the interior drywall. Labour and materials and incremental costs of non-standard details were also provided. Examples of incremental costs include manufactured thermal breaks, extra parapet insulation, and exterior insulation at footings.

Figure 2.2: Mid-Rise Construction in Vancouver

The general contractor arrived at these estimates through consultation with sub-trades, review of costs on past projects, and consultation with manufacturers. A detailed summary of the construction cost estimates are found in Appendix D.

The construction assembly costs are subjective and are order of magnitude estimates. There are many variables and constraints on real projects that will overshadow some of the estimated cost differences between the assemblies. The main point to remember is that construction costs vary quite widely in practice. This variability is part of the reason that construction projects typically have a bid process, where there can be a big difference between the highest and lowest bid. Consideration of the nature of this analysis and the fluidity of construction costs is required to reach meaningful conclusions. The construction cost estimates utilized by this guide are broad cost estimates with more uncertainty than a Class D estimate, because the estimates were not arrived for a specific building nor is there a comprehensive list of requirements to base assumptions. Accordingly, order of magnitude means that the construction costs estimates are +/- 50%.

Comparisons of energy use and construction costs are made for different types of assemblies in the cost-benefit analysis in section 2.4. For example, poured-in-place concrete is compared to precast concrete panels, because precast panels inherently have less thermal bridging at floor slabs than interior insulated poured-in-place concrete walls. However, the construction estimates are too general to make broad conclusions between competing assemblies. Moreover, the construction costs do not consider all synergies that go into a design, such as shear walls that are part of the building envelope. Sweeping conclusions should not be made, such as precast concrete panels should always be used over poured-in-place concrete because the construction costs are less and you get better performance. Project teams can choose any method of construction for any number of reasons.

The incremental costs were arrived at by comparing a detail that was deemed standard practice to a non-standard detail.

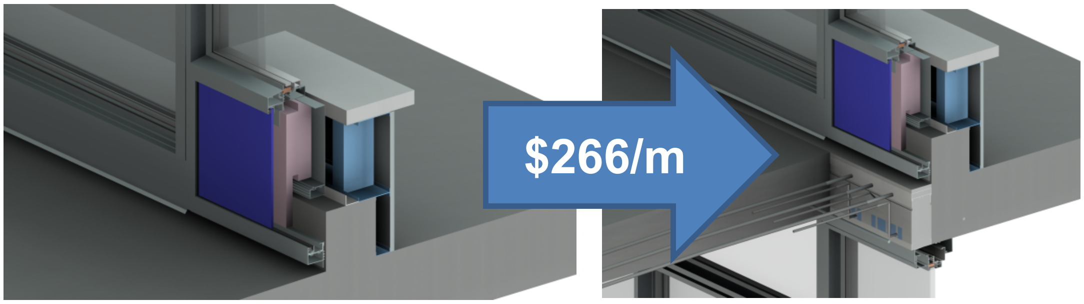
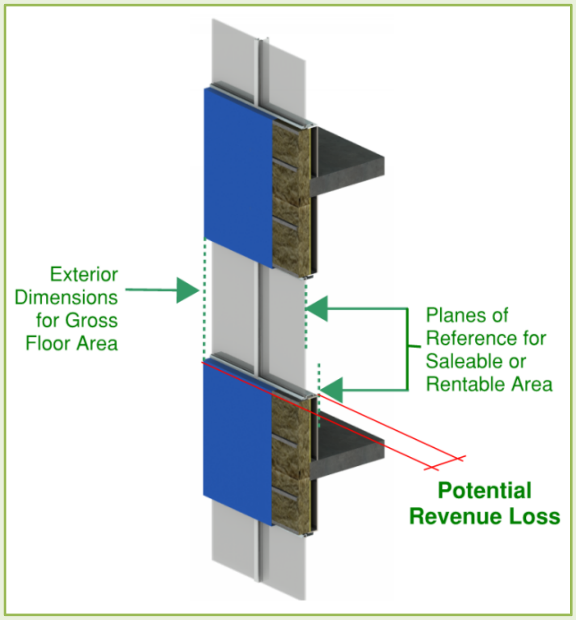


Figure 2.3: Approximate costs to move from a continuous concrete balcony to a thermally broken concrete balcony

The estimates for new technologies, such as manufactured thermal break solutions, vary but appear to be priced at a premium. However, opportunities for this kind of product to be more cost effective in the future are likely as industry in BC becomes more familiar with the new technology.

What ultimately matters to developers is a level playing field and opportunities to choose the most effective method to comply with code while balancing factors that can affect the success of a project by a greater measure, (for example, suitable granite countertops or great views of the mountains). It is a hard decision to invest in improving the building envelope performance when any difference between your building and a neighouring site in energy efficiency may not be easily recognized by consumers, especially when code does not require a design team to seriously consider thermal bridging. Code requirements that force major thermal bridges to be accounted for during design will be more effective in transforming the market than relying on the “fluid” analysis of cost benefits of new technologies. The market will naturally gravitate to cost-effective solutions within the margins of accepted practice.

Floor Space Ratios and Costs for Thicker Walls to Accommodate Extra Insulation



Some municipalities have a metric in zoning bylaws to control development density by limiting the ratio of a building's total floor area (gross floor area including exterior walls based on exterior dimensions) to the area of the land parcel upon which it is built. This metric is referred to as the **Floor Space Ratio** (**FSR**) in British Columbia. In densely populated jurisdictions with FSR zoning requirements, developers typically strive to maximize the saleable or rentable floor area for a fixed overall gross floor area. There are differences in what areas are included or excluded in the calculation, but in principle, developers will try to maximize the building's saleable or rentable floor area. With the external building dimensions fixed by the FSR, an increase in thickness of walls to accommodate extra insulation can in theory affect the saleable floor or rentable area. However, saleable or rentable floor area can be measured at either the glass, interior of wall, or some other defined plane, depending on the methodology followed by the quantity surveyor. The reference point can be dependent on factors like whether there is more or less glass compared to the opaque wall area in the vertical floor-to-ceiling dimension.

For interior insulated assemblies, such as architectural poured-in-place concrete walls with "continuous insulation," the saleable or rentable floor area may or may not be impacted by extra insulation thickness depending on the plane of reference for establishing the saleable or rentable space. The saleable or rental floor area could be impacted by extra insulation for exterior insulated assemblies but municipalities like the City of Vancouver have recognized this possibility and have enacted FSR exclusions to make sure there is less of a disincentive for extra insulation. In the Lower Mainland of BC, where allowable FSR's come into play, the floor area is likely largely dominated by the glass, since glazing ratios are high.

In conclusion, there could be a cost associated with thicker walls to accommodate extra insulation, in some jurisdictions, for some types of construction. Conceivably this could become more of an issue if energy performance became more of a driving factor, glazing ratios come down, and insulation levels could be reduced for the reward of high overall building envelope thermal performance through efficient detailing. However, the cost impact of increased wall thickness to accommodate higher insulation levels does not appear to be a significant driving factor in BC. Moreover, there is no tangible rule of thumb to the incremental cost per area and the cases that extra costs might apply. In section 3.4, this concept is illustrated by using a cost of $150/ft^2 for extra wall thickness but this extra cost was not used for all the extra insulation scenarios in the cost benefit analysis in section 2.4.

2.4 COST BENEFIT

2.4.1 METHODOLOGY

This guide presents the cost benefit to improving the opaque building envelope through broad strategies that include improving interface details, increasing insulation levels, and selecting assemblies that characteristically have less thermal bridging than other types of construction. The analysis was performed on the chosen archetypal buildings using the energy use curves developed in section 2.2, with the construction costs from section 2.3 for a variety of construction scenarios. These scenarios include:

1. **The Impact of Interface Details**: the energy-use of buildings without thermal bridging at interface details, per U-values required by codes and standards, is compared to more realistic expectations for how buildings are commonly constructed in BC.

2. **Thermal Bridging Avoidance**: some thermal bridging can be simply avoided by better design. The impact of better design is evaluated by looking at the impact of details that are often unnecessary, such as concrete shear walls that intersect with the exterior walls, and selecting assemblies that inherently have less thermal bridging.

3. **The Effectiveness of Adding More Insulation**: current trends of energy codes and standards are to simply require more insulation be added to wall assemblies. The effectiveness of the “more insulation is better” strategy provides a benchmark for the cost effectiveness of solutions that are happening in practice to meet current codes. The “more insulation is better” strategy is compared to the cost benefit of what solutions will likely be explored more often by industry if thermal bridging was thoroughly addressed by codes and standards.

4. **Ranking of Opaque Thermal Performance:** current trends in BC are to increase glazing performance, which is resulting in triple glazing being considered more often than in the past. The cost benefit of triple glazing provides another benchmark, with the addition of more insulation, to the cost effectiveness of solutions already accepted by industry.

These broad scenarios were evaluated for all the building types, glazing ratios, and climates identified in section 1.2. By determining the overall thermal performance of the opaque envelope (U- and R-values) for each scenario following the steps in Part 1, the total building energy use was found using the curves determined in section 2.2 (and Appendix C). The energy costs and construction costs for each scenario were then determined. Incremental energy and construction costs were then compared to determine a payback period for various building envelope scenarios. A summary of the complete cost-benefit analysis can be found in Appendix E. The key findings from this cost-benefit analysis are presented in Part 3. A general example of the cost benefit process is given in the next section.

2.4.2 Example Cost Benefit Procedure

The following is an example on how to review and assess other detail permutations of interest in a cost-benefit analysis using the procedures and data contained in this guide.

Example: *Cost Benefit of Improving Practice for Multi-unit Residential Building with 70% Glazing in Vancouver for Concrete Construction, shown in Figure 2.4. This is similar to the example building in section 1.4, however, with different dimensions and interface details.*

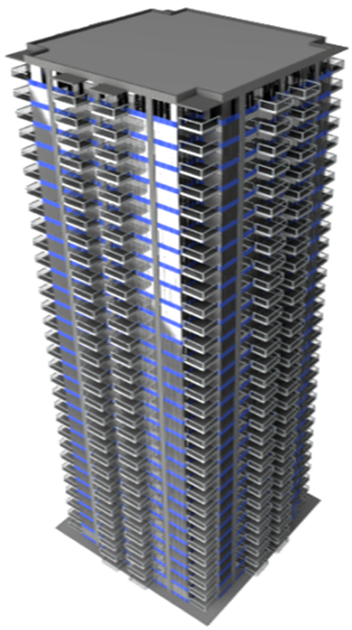
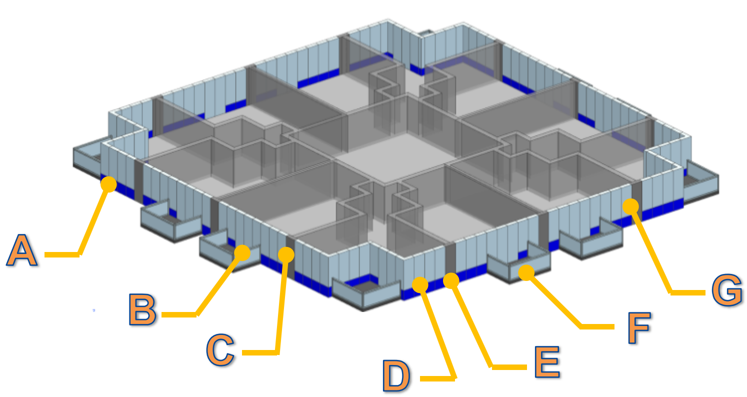


Figure 2.4: High-Rise MURB Example Building

The steps of the cost benefit are:

1	Determine the wall areas and lengths of the interface details
2	Determine overall U-value
3	Determine construction costs
4	Relate U-value to energy savings
5	Determine incremental energy savings and incremental costs
6	Determine Simple Payback

Step 1. The geometry analyzed for the cost-benefit analysis is based on the building archetypes utilized for the energy modeling. However, for some cases more complicated geometry was used to better reflect common practice in terms of U-value and costs. In this example, the multi-unit residential building incorporated some articulating architecture to illustrate the impact of corners and to reflect a real high-rise residential architecture in BC. A typical floor illustrating the clear wall and interface detail quantities are shown in Figure 2.5.



Opaque wall area
A. Window-wall spandrel
B. Curb at sliding door
C. Concrete wall

Floor slab interface detail
D. At window-wall spandrel bypass
E. At concrete wall
F. At balcony

Glazing interface detail
G. Vertical

Figure 2.5: High-Rise MURB Layout with detail listing

Steps 2 and 3. The overall U-value and construction costs are determined using the quantify takeoffs from step 1. The cost calculation is simply an extension to the procedure outlined in Part 1 to determine the overall U-value. An example table showing the determination of the overall U-value and construction costs follows.

		Step 1		Step 2			Step 3	
Transmittance Type		Quantity (m^2 or m)	Detail Ref.	Trans-mittance (W/m^2K or W/mK)	Heat Flow (W/K)	% Total	Unit Rate ($/quantity)	Total Cost ($)
Clear Wall	Spandrel	2090 m^2	1.2.1	1.21	2529	33%	580	$1,212,200
Clear Wall	Door Curb + Balcony Slab	209 m^2	8.13	2.86	598	8%	580	$121,373
Clear Wall	Concrete	886 m^2	6.2.2	0.42	372	5%	674	$597,164
Parapet	At Concrete	11 m	6.5.3	0.78	9	0%	-	-
Parapet	At Window-wall	117 m	1.3.1	0.81	94	1%	-	-
Floor	Window-wall By-pass	1768 m	1.2.1	0.51	900	12%	-	-
Floor	Window-wall At Balcony	679 m	8.1.9	1.13	767	10%	-	-
Floor	At Concrete Wall	312 m	6.2.5	1.00	310	4%	-	-
Glazing Interface	Vertical Interface	1975 m	6.3.2	0.56	1106	17%	-	-
Interior Wall	Concrete Shear Wall	988 m	6.2.2	0.67	658	9%	-	-
At Grade	At Window-wall	95 m	2.5.1	0.86	81	1%	-	-
At Grade	At Concrete Wall	11 m	ISO-14863	0.75	8	0%	-	-
At Grade	At Sliding Door	22 m	2.5.1	0.86	19	0%	-	-
Total					**7452**	**100%**	**$ 1,930,737**	
Overall Opaque U-value, BTU / hr ft^2 °F (W/m^2K)					0.41 (2.34)			
Effective R-value, hr ft^2 °F/ BTU (m^2K/W)					2.4 (0.43)			

Steps 4 to 6. The overall U-value is related to the energy savings using the curves that are discussed in section 2.2.3. Then the incremental energy savings and costs are determined and are utilized to calculate the simple payback. An example showing the determination of the simple payback for the high-rise MURB example is shown below.

	Step 4				Step 5			Step 6
Case	U-value		Total Energy		Annual Energy Savings		Incr. Cost	Pay Back (yrs)
	$\frac{W}{m^2K}$	% Red.	$\frac{kWh}{m^2}$	Cost	$\frac{kWh}{m^2}$	Cost	$	
ASHRAE 90.1-2010 Zone 5 (Assembly Only)	0.45	-	193.3	$255,729	-	-	-	-
NECB 2011 Zone 5 (Assembly Only)	0.28	-	192.1	$252,888	-	-	-	-
Base Case: Standard Assemblies + Details	2.07	-	203.6	$278,536	-	-	-	-
More Insulation for Concrete Wall; R-10 i.e. + R-12	2.03	2%	203.4	$278,130	0.16	$406	$15,062	37
Avoid Shear Wall Intersection	1.86	10%	202.7	$276,114	0.97	$2,421	-	0
Avoid Shear Wall Intersection and more Insulation	1.83	12%	202.5	$275,664	1.15	$2,871	$15,062	5
Improve Window-wall spandrel, more insulation, and thermally broken balconies and parapet	1.25	40%	199.5	$267,443	4.45	$11,092	$424,175	38

Detailed Economic Analysis

Currently natural gas prices are relatively low in BC compared with electricity rates. Although the rates vary somewhat by building size and geographic area, they are relatively similar. The economic analysis considers a common utility price across the board of $0.09 / kWh of electricity and $7.00 / GJ of natural gas (equal to $0.025 / ekWh). As a result, the multi-unit residential buildings with electrical baseboards have lower payback periods than similar buildings heated by natural gas. The payback years are almost irrelevant for market buildings that are only intended to meet the code minimums. When looking at solutions to meet code minimums, the only number that matters is the minimum cost for code compliance. For projects where compliance is demonstrated by energy modeling, the building envelope performance can be traded off against other energy efficiency measures that are typically more cost effective from a capital cost perspective. Nevertheless, the simple payback analysis provides a tool to rank different envelope scenarios.

Appendix E provides absolute energy savings for electricity and gas for each scenario in the cost-benefit analysis. These values can be used directly for any external economic analysis that considers different utility rates, either to account for geographic area or future utility rate forecasting.

The cost-benefit analysis presented in this guide provides a methodology to effectively quantify the energy savings and incremental costs associated with improving the thermal performance of the building envelope, including the impact of interface details. However, ASHRAE 90.1 and BC utility incentive programs also have their own detailed economic analysis. The raw data presented in this guide can be used in a more detailed economic analysis based on specific criteria, assumptions, and procedures required by these organizations.

For life cycle cost analysis, it should be noted that the expected service, maintenance requirements, and operation requirements can differ for building envelope components. However, as a general guideline, any component introduced into an assembly that is structural or not easily accessible should be designed to last the life of the building.