UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Life Cycle Costing & Analysis of Two UBC Research Buildings

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Life Cycle Costing & Analysis of Two UBC Research Buildings

Earth Sciences Building vs. Pharmaceutical Sciences Building

APSC 598G Final Project Report

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Abstract

UBC aims to provide an exceptional learning environment while exemplifying economic, environmental and social sustainability in its the built environment. One of its main goals is to enhance infrastructures to support leading edge research. In 2010, laboratory buildings accounted for almost ten percent of UBC core buildings but consumed disproportionately higher resources and contributed significantly to UBC's financial investments. This project performed a life cycle cost analysis for two high-performance laboratory buildings on the campus of the University of British Columbia, the Earth Sciences Building (ESB) and the Pharmaceutical Sciences Building (PSB). The propose of this project was to test current assumptions about life cycle costs of new research buildings on campus and also to attempt to verify an observation that one building's energy performance (ESB) was significantly better than the other (PSB), despite many similarities across the two buildings. Additionally, this initial life cycle costing was to provide a basis and platform for further analysis of data, testing of various assumptions and hypotheses, and opportunities to create recommendations for improving UBC's LCC standards, with the larger goal of finding ways the University could increase its confidence in long-term performance from designs for future buildings.

For a base-case LCC actual energy consumption data was used along with estimations for maintenance and repair costs to estimate operation costs for the two buildings. On a net present value basis, it was found that operation and maintenance costs account for approximately 40 percent of the total life cycle cost over 50 years for both buildings. When two industry standard cost estimation systems (Whitestone CostLab, and the Whitestone printed reference volumes) were used to refine this analysis, the operation and maintenance costs increased to between 50 percent and 60 percent of the total life cycle cost. The results of the industry reference tools indicate that a more detailed evaluation of operation costs for research buildings at UBC are required.

Furthermore, it was found that the average annual operation costs for laboratory buildings as indicated by Whitestone Research is significantly higher than UBC's current building operation budget of \$8.60/ft^2 and approximately \$0.66/ft^2 for capital renewal differed maintenance (CRDM) per year. While Whitestone Costlab suggests average operation cost of approximately \$14/ft^2 per year, calculations based on Whitestone Reference Books indicate average annual operation cost of approximately \$21/ft^2 for laboratory buildings.

Additionally, multiple primary data gaps necessitated the use of rough assumptions and heuristics in order to fill these areas lacking in empirical information, leading to opportunities for

improvement in standards for LCC. Based on this, the following improvements are recommended for further LCC's at UBC:

1) Acquire more detailed operation cost information for new buildings on UBC campus using local Whitestone Research data to provide a better foundation for the extended life cycle costing and to obtain a more realistic operational budget than the current standardized value of $\$8.60/ft^2$ and approximately $\$0.66/ft^2$ for capital renewal differed maintenance (CRDM). Information could be acquired either through the use of available operation cost tools such as Whitestone Costlab or through the collection of additional primary empirical data.
2) Investigate further the potential advantages of adopting a preventive-maintenance and scheduled-replacement regime for campus assets, rather than continuing the present practice of implicit cost saving through deferred maintenance.
3) Raise the budget for building operation to ensure scheduled maintenance can be done more frequently according to Whitestone operation costs assumptions.

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List of Abbreviations

ESB – Earth Sciences Building

PSB – Pharmaceutical Science Building

LCC – Life cycle costing

M&R – Maintenance and Repair

MRM – Maintenance, Replacement and Management

NVP – Net Present Value

PSB – Pharmaceutical Sciences Building

UBC – University of British Columbia

VAV system – Variable air volume system

1 The Subject Buildings

In September 2012, two new institutional buildings were opened on University of British Columbia's (UBC) campus in Vancouver. While not exact replicas of each other, and created by different design teams, both were conceived with high standards of energy performance in mind. Each was a mix of offices, classrooms and auditoriums, common areas and cafes, and laboratories. For each building many of the same contractors were used to realize the designs and plans for operation.

1.1 Earth Sciences Building

The Earth Sciences Building (ESB), designed by a team led by Perkins + Will Canada, is the home of the Earth, Ocean and Atmospheric Sciences department, the Statistics program, the Pacific Institute of the Mathematical Sciences, and the dean's office of the Faculty of Science. It houses some seismic recording instruments, as well as some other geological laboratories which contribute to elevated energy and design demands for this building. The ESB, like all new buildings on the UBC campus, was designed to meet LEED Gold requirements, setting high expectations for performance. Its most unique characteristic for this analysis, however, is the inclusion of the Thermenex heat energy management system. This system "redirects" heat from where it is unwanted, or being wasted, to where it is needed via a system of water-filled pipes, connected to a unifying header pipe, which distribute different grades of heat from areas of the building where it would potentially be wasted, to areas where it can be appropriately used.[1]

1.2 Pharmaceutical Sciences Building

The Pharmaceutical Sciences Building (PSB) was created to bring together all of the teaching, learning, research and community outreach activities of the Faculty of Pharmaceutical Sciences into one building, which had previously been hosted in several buildings on campus. The design, led by a partnership of Saucier & Perrotte Architectes of Montreal, and Vancouver's Hughes Condon Marler Architects, won several awards, including the Canadian Architect Award of Excellence, and the Ontario Association of Architects 2013 Design Excellence Award. Also achieving LEED Gold certification, performance expectations were high from the beginning.

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[1] Please see Appendix A for an illustrative diagram of the Thermenex system.

In addition of having a larger floor area (about twice the size) than the ESB, there are two uses that set the PSB apart. First, there are pharmaceutical testing laboratories, which house living animals. Additionally, this building was chosen to be the site of a new, large data centre for the university, a centralized hub for much of its information technology hardware. Both of these uses created unique design and elevated performance needs, setting it apart from the ESB and which will be discussed further below.

Table 1: Characteristics of the two subject buildings

	Unit	ESB	PSB
Gross floor area[2]	[ft^2]	171,254	319,654
Capital budget	[CA$]	$74,700,000	$150,903,000
Levels (above ground)	[1]	6	5

2 Project Objectives & Approach

2.1 Research Questions & Project Schedule

On 19 January 2015, the project team met with Jeff Giffin, Energy Conservation Manager for the UBC's Energy and Water Services, to outline a research protocol for life cycle costing (LCC) of two campus buildings, and analysis of both the techniques used and their results[3]. A two-step investigation was proposed, consisting of a baseline LCC expressed in net present value (NPV) per square foot (ft^2) for both buildings, based on a 50-year expected life cycle. This could then be used as a basis for further investigations into possible outcomes of different design and operations choices, and how these might affect the cost of operating other research and institutional buildings on campus, both existing and future. The outcomes of this meeting were refined into research questions, with the goal of creating an investigation that could be pursued strategically, and result

[2] Gross floor area excluding stairs and elevators as provided by UBC Building Operations.

[3] As part of UBC's building management team, Giffin had been investigating ways to increase energy efficiency and overall performance of campus buildings for some time, in order to meet university sustainability goals as well as operational budgets. He and his colleagues had noticed different energy performance results from the two buildings discussed above, despite both being designed to roughly the same performance standards and usage expectations, and opening for use at roughly the same time. Giffin believed an interesting investigation into the performance differences between the two buildings, founded in a LCC and operation analysis and comparison of the two buildings, could point to potential ways in which the University could increase long-term performance for future construction.

in outcomes with the maximum potential of utility for the client, as well as minimum potential for unexpected problems[4]. This was formulated into a two-step investigation:

> QUESTION 1: What are the contributing factors to the different LCC performances, both perceived and actual, of the two buildings?
>
> QUESTION 2: What are the *actual* differences in cost, both capital and operation cost, between these two buildings?

- How many percent of the total 50-year life cycle costs are covered by upfront capital costs (i.e. construction cost) and how much is the total operation cost (management, maintenance, repair, etc.)?
- What are Whitestone Research results for a 50-year life cycle cost analysis for both laboratory facilities?
- Are there clear outcomes of this research that show how UBC can lower operating costs in other buildings, new and old, across campus?

In consultation with the client, these two overall research questions were then converted into project deliverables, and a strategy for performing this project was designed. This strategy is expressed in the schedule below (Table 2).

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[4] Based on this initial meeting, the team formulated this summation of the client's stated goals for the project, which were later refined into the research questions:
STEP 1: Build a baseline: expressed in LCC per $/square foot for both buildings on a 50 year life cycle.
STEP 2: Investigate how UBC can create buildings with the lowest LCC & highest performance.

- Is Thermenex a system that should be implemented across campus?
- Why do we generally go for the lowest construction/design costs, when it is only 10% of the life cycle costs?
- How can we lower the operating costs, as we are overshooting the UBC building operations budget ($9.00/ft^2)?

Table 2: Project Schedule

Tasks	Week	Start Date	End Date
PREPARATION: Review Literature on LCCA studies/ methods/tools	Week 1-2	January 13	January 27
STAGE 1: Initial LCCs (detailed capital/operation/ maintenance cost analysis)	Week 3-4	January 22	February 12
Building Site Visits	Week 3 (&6)	February 4 (& 25)	
Deliverable 1 Handover: Initial LCCs	Week 4		February 12
Progress Presentation to class	Week 4	February 12	
STAGE 2: Evaluation of LCC findings	Week 5-7	February 12	April 2
Cost breakdown, Whitestone Evaluation, Sensitivity Analysis	Week 5-6		
Sponsor Presentation (to class and sponsor)		Mar. 10 or 12	
Deliverable 2 Handover: LCC Analysis and Findings			April 2
Final Presentation (sponsor, class, guests)		April 7 or 9	

Finally, in order to provide a system for evaluation and evaluation of the calculated life cycle cost, the directions for further analysis were described in these three categories of variables:

A. Variables of *capital cost* for materials, equipment, etc.
B. Variables of *known information from empirical operations data* (that is, not assumed consumption data) to determine the effect of increased or decreased efficiency or demand.
C. Variables of *future environment*—that is, the larger contexts in which operational decisions are made, but are not able to be influenced or manipulated by the building managers or owners. This category of variables includes predictive values such as inflation and discount rate.

2.2 Literature Review and Background Research

In order to gain some context and foundation for performing an industry-standard LCC of an institutional, research-oriented, education-based multi-use facility, a review of best practices and background literature was undertaken. This section will review the primary texts referenced for background, issues, and applications.

As a response to a growing need for certainty and reduced risk in budgeting and financial forecasting for institutional and government buildings starting in the post-World-War-II period in the United States, LCC has been developed in stages over the past 50 years and was first formalized by the International Standards Organization (ISO) in ISO 15686 (Storey 2014; ISO 2006). A typical challenge is a focus on the capital, near-term, and therefore better quantified, expenditures of designing and constructing a building; operation costs, being less predictable and in any further into the future, are a discounted priority typically. "[…] typically most assessment methods only capture up-front impacts. In the case of financial impacts, the focus is on construction cost" (Storey 2014, p.7). LCC attempts to close this gap and account for future costs: "As a measurement tool, life cycle costing attempts to evaluate the costs for each year of life phase and aggregate them into a single score — namely total cost of ownership" (Storey 2014, p.10; (Fuller and Petersen 1997). In a general sense, LCC assessments are most valuable in exposing and quantifying the existence of future operation and maintenance costs of a building in the future, which are often downplayed when considering the valuation of a building, either existing or still in design:

> Buildings are durable and building decisions have long-term consequences [5]. Yet often, building owners or investors focus only on the investment cost when they make decisions about, e.g., building design, equipment, energy systems, and they fully neglect future operation or replacement costs [8]. With this praxis, they lack the holistic view of actual cost of a building, and this can result in not choosing the cost-effective solution. […] The life cycle cost analysis is a commonly deployed method for investigating cost-optimal solution or product design. It has also become one of commonly used tools in the design phase of a building. (Marszal and Heiselberg 2011) p.5601

As a general note, LCC is often used to quantify the financial impact of different design or equipment choices initially, over a given period (not necessarily for the entire life cycle of the building, but perhaps the expected life of a specific piece of equipment or building material choice). "LCC of buildings compares the cost from a 'base case' building design costs from alternative building designs. LCC is generally used to determine if future operational savings justify higher initial investments." (Kneifel 2010) p. 337

More specifically, certain aspects of research facilities can affect their long-term valuation as well, in ways worth noting when performing a LCC:

> High-tech facilities have a number of common characteristics, including around-the-clock operation, high air-change rates, and critical activities and safety requirements that rely on proper indoor environmental control building performance. In some cases all of the air is "once-through" and/or requires dehumidification, with far larger volumes of air needing to be treated than in conventional buildings. Taken together, these requirements translate into particularly high energy intensities, and correspondingly large opportunities for energy savings. (Mills 2011) p.161/62

Because of the sensitive nature of these research facilities, the commissioning stage of the building carries specific cost-associated risks, primarily related to ensuring all the equipment and facilities are properly operating and installed correctly:

> While problems identified in the commissioning of high-tech facilities can manifest in ordinary buildings, the cost—in terms of excessive energy use—when they occur in high-tech facilities is far, far higher. Some technical issues and opportunities are unique to these facilities, as are some of the barriers. Because these facilities are also highly mission critical, the non-energy benefits having to do with factors such as safety, equipment life, and reliability often associated with energy-related commissioning can be very substantial. While we have found that commissioning can be cost-effective in virtually any building type or size, the results are particularly impressive in high-tech facilities. (Mills 2011) (p. 163)

LCC is limited in its ability to estimate long-term costs that are often difficult to predict. Economical changes that appear at the macroscopic level are often unpredictable and thus are difficult to model (Storey 2014). For example, in the volatile and energetic real estate market of British Columbia's Lower Mainland, construction prices can vary widely and with little predictive capability. By way of example, recently "[…] construction price escalation costs have been recently observed to vary between -10% to +14% per annum in British Columbia, in a narrow three year window." (Storey 2014, p.10)

Beyond the volatility of future expenses, it can also be difficult to determine with full confidence an appropriate discount rate that can describe accurately the degradation of the time value of money, as well as the physical assets of the building itself, in the future (Storey 2014; Weikard & Zhu 2005; Dasgupta 2008; Sumaila & Walters 2005; Frederick et al. 2002). As a consequence of the uncertainty of an appropriate discount rate, a constant discounting over long time periods could be inadvisable, introducing more uncertainty rather than reducing variability in forecasting:

> Longer study periods are more effective at capturing all relevant costs of owning and operating a building. However, longer study periods increase uncertainty in the precision of the life cycle cost estimates because of the assumptions made about costs and occupant behavior decades into the future, such as future energy costs and energy consumption. (Kneifel 2010) p.334

The literature as a whole contributed invaluable context for the initial practice of costing the two buildings, as well as illuminating potential direction for refinement in the next phase of the project.

3 Project Information

3.1 Mechanical Systems

As research laboratories, both buildings require large amounts of energy for the mechanical system. The HVAC system is the main contributor to the overall energy consumption of the building.

The ESB uses centrifugal chillers to cool and heat the building. The backup heating system of the building is a gas boiler that is only used during peak heating demands. The cooling system is supported evaporative cooling towers that are run by large fans and water pumps. Heat exchangers are connecting the cooling towers to the chillers. The chillers and gas boilers are connected to the Thermenex system that provides hot water at different temperature to a multiple-zone variable air volume (VAV) system (Figure 1). The air-handling units of the VAV system are connected to Thermenex and provide in-slab radiant heating and displacement ventilation in the building. To reduce the energy consumption of the building, heat is recovered from the building cooling load and from lab exhaust air, using cooling coils connected to the heat pump chillers (Soderlund 2011b).

Similar to ESB, PSB's main mechanical systems include centrifugal chillers, condensing gas boilers, evaporating boilers, evaporating cooling towers and a multiple-zone VAV system. Additionally, non-condensing gas boilers condensing gas boilers are used as a backup system. Steam boilers are required for the life science research research laboratories. The data centre requires additional cooling that is provided by chillers. The heat recovery heat recovery strategy of PSB is fairly complex and includes heat recovery from exhaust air and interior air interior air cooling (including the data centre and information technology rooms) through chillers and cooling and cooling coils (Soderlund 2011a) (

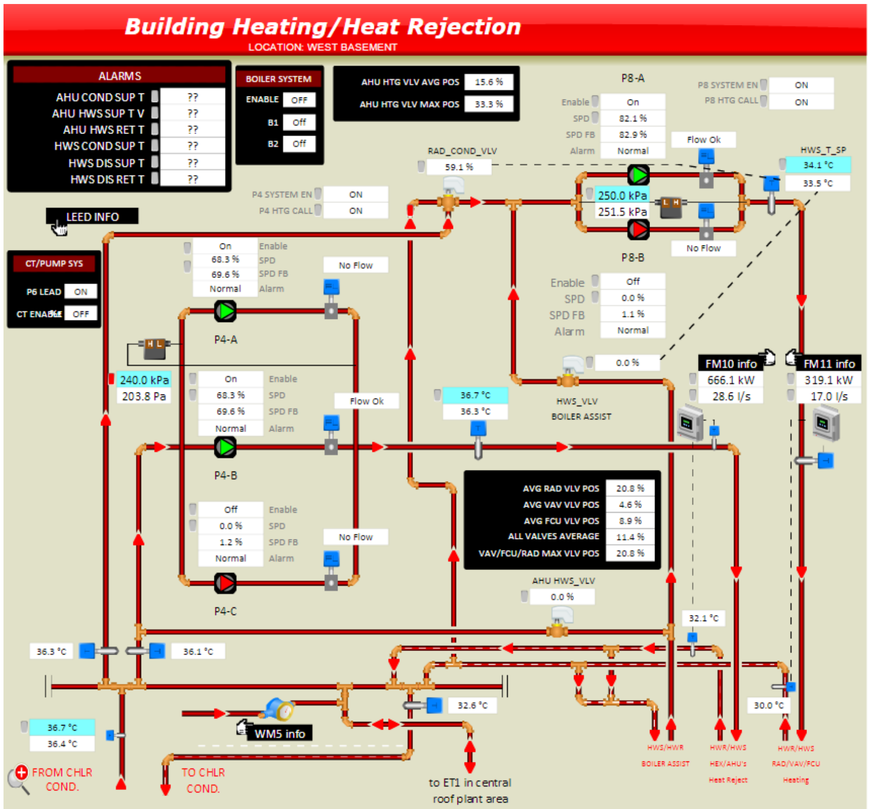

Figure 2). In both buildings, standard-efficiency, natural gas hot water boilers provide domestic hot water. Table 3 gives an overview of the major mechanical systems in both buildings.

Table 3: Comparison of major mechanical systems of ESB and PSB.

	ESB Quantity	PSB Quantity
Centrifugal Chillers	2	4
Evaporating Cooling Towers	1	3
Condensing Gas Boilers	3	2
Non-condensing Gas Boilers	0	2
Steam Boilers (membrane wall water tube boiler)	0	6
Air Handling Units	8	20

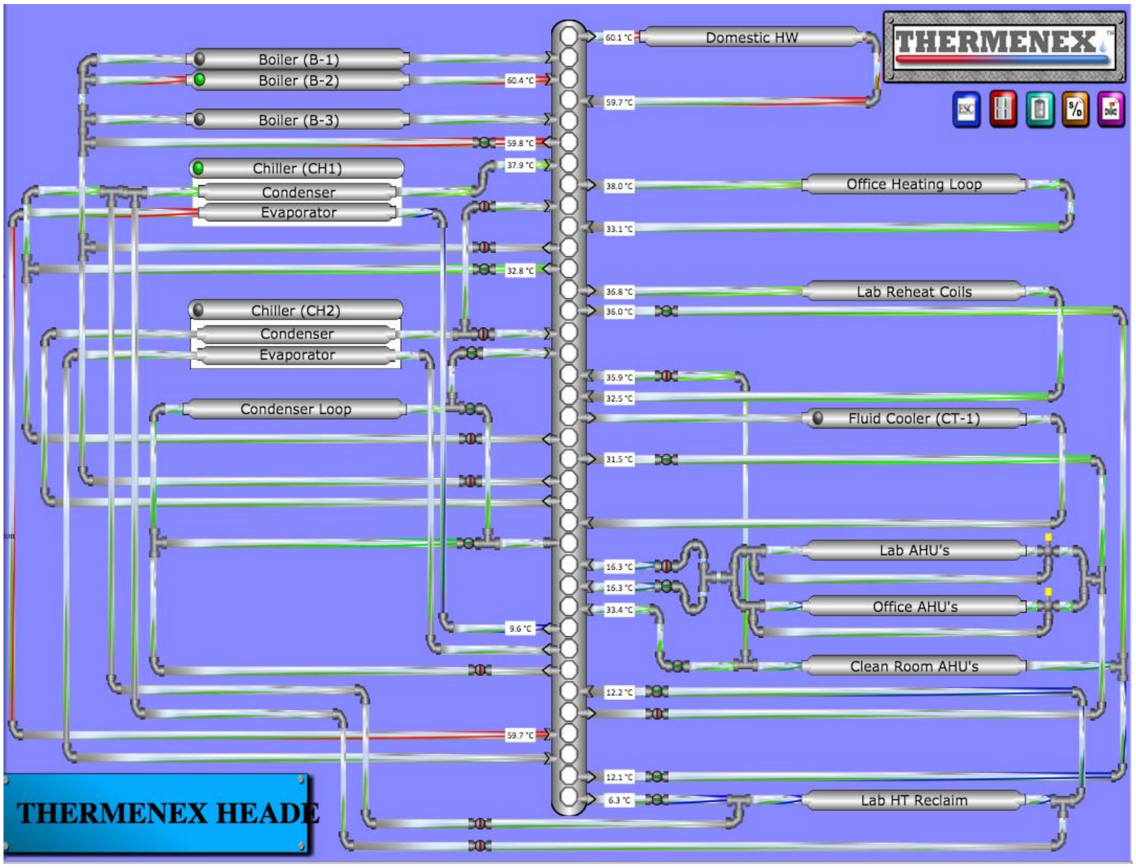

Figure 1: Schematic of the Thermenex header and connections to major mechanical systems, as seen in the ESB's building management system.

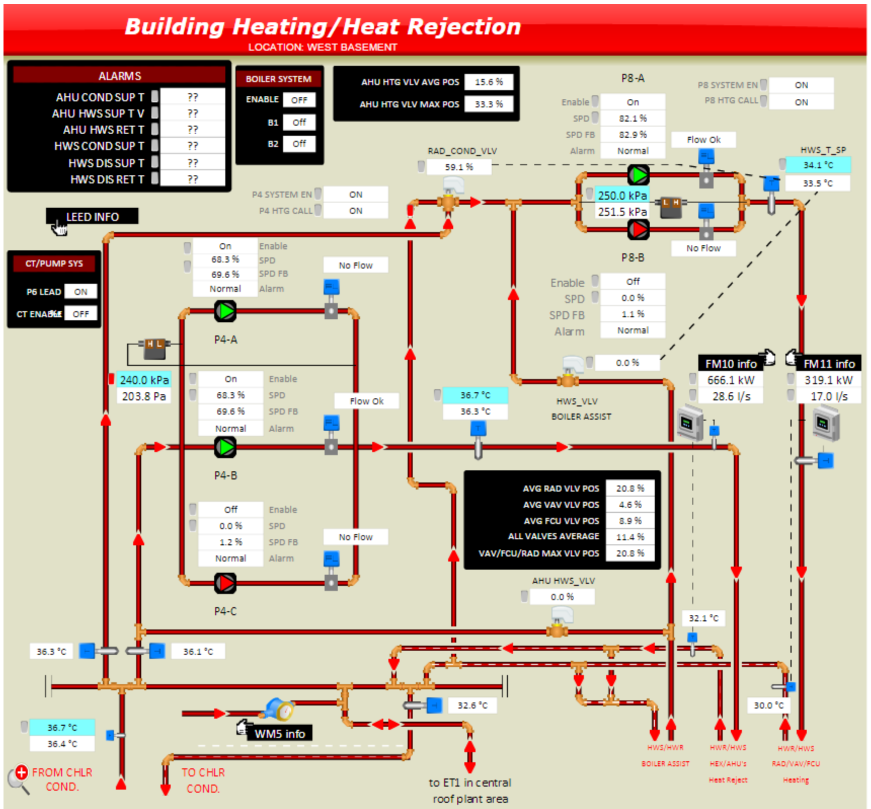

Figure 2: PSB: Schematic representation of building's heating and heat rejection system. (Source: Building Information system of PSB; accessed April 15th, 2015)

3.1.1 ESB site tour

In order to gain a better understanding of these technical systems, it was decided to visit the buildings to inspect the mechanical systems and their characteristics, advantages and issues first-hand. On 4 February 2015, the project team toured the ESB[5]. This tour's objective was to introduce and explain some of the design and performance characteristics and issues of the building as previously discussed, and ideally gain some insights into how to refine the investigation. The tour covered primarily the rooftop areas, noting that the cooling towers were operating constantly, despite the lack of constant demand. In order to further optimize the performance of this building, Giffin noted that this system's operation will be

cooling tower.

[5] Jeff Giffin and Steve Rogak were also present, Giffin guiding the tour.

further optimized to correlate more appropriately with the daily cycle of demand peaks.

The tour continued to the basement, the Thermenex system was explained, and its links to the various other mechanical systems were shown.

Generally, all the major mechanical systems were seen to be oversized, in terms of the current demand existing in the building (it was noted that the building is only 70 to 80 percent occupied at present).

Figure 4: ESB: Thermenex header, with chilled water connection

3.1.2 PSB Site Tour

On February 25, the project team met again with Giffin and Rogak for a tour of the second subject structure, the PSB. Initial impressions were that design standards were higher, in terms of aesthetics, if not performance. For example, interactive video screens were prominently displayed in a common area on the ground floor, designed to provide information on the happenings of the pharmaceutical program as well as up-to-the-minute performance data of the building itself. (The screens were inoperable at the time of the visit.)

Figure 5: PSB: four pumps and headers, connected to four boilers indicating redundancies in hot water supply

Significant redundancies in hot-water boiler provision were noted. It was explained by Giffin that this was likely to provide emergency capacity in case of a failure. In light of the sensitive nature of life animal subjects in the building's laboratories, this superficial excess could be seen as justifiable. Similar to ESB, all the major mechanical systems were oversized for the current demand of the building. For example, only one of four chillers was operating, in light of the existing demand. Here also there is excess capacity provision in case of emergency.

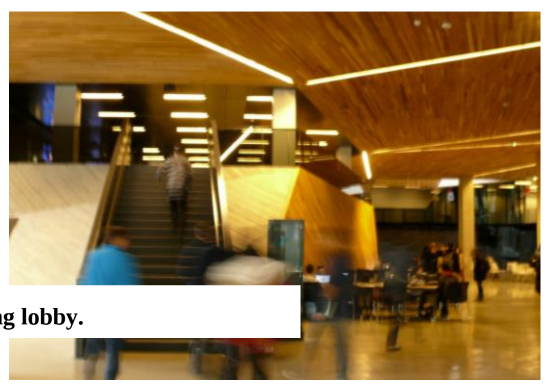

Figure 6: PSB: Building lobby.

3.2 Energy Consumption of the Buildings

To better understand the performance of the buildings, the predicted energy consumptions were compared the actual energy use in both buildings. Predicted energy consumption data were based on energy models made at during the development of the buildings (Soderlund 2011a; Soderlund 2011b). For actual energy consumptions metered energy data were used[6]. Both buildings are equipped with several meters for electricity and natural gas. For the ESB, data have been logged since mid 2013. For the PSB, only the electricity consumption has been logged since December 2013. Although, natural gas meters have been installed they have not been connecting to UBC Ion network. Thus, the gas consumption for PSB was estimated based on the natural gas consumption per square foot for ESB. Figure 7 and Figure 8 show that both buildings consumed significantly more energy (electricity and natural gas) than predicted in the first two years of operation. While ESB consumed 25 percent more energy than predicted, PSB consumed 40 percent more energy than predicted in the design. UBC Building Operations has already taken steps to reduce the current consumption of the buildings. These improvements are not yet reflected in the current data and will require further data collection in order to make accurate long-term predictions.

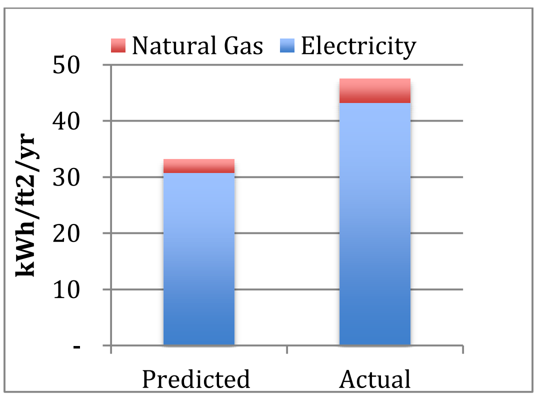

Figure 7: PSB: Predicted and actual energy use intensity.

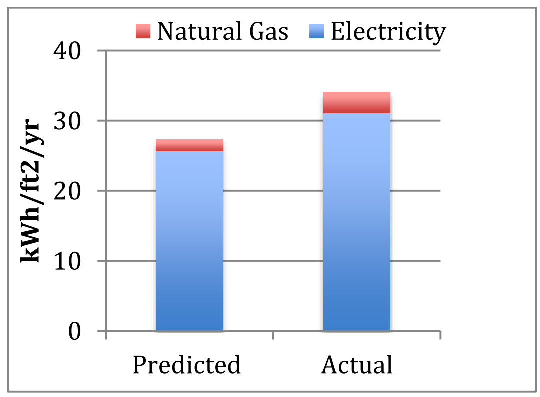

Figure 8: ESB: Predicted and actual energy use intensity

4 Initial LCC – UBC Case

As set out in the initial project strategy, an initial and simplified LCC of the PSB and the ESB was performed, according to standards and assumptions provided by the client, and using an excel template provided by the client as well. The purpose was not to generate the most accurate life

[6] The data were provided by UBC Building Operations.

cycle costs of these two buildings over 50 years, but to be an exercise to provide a first estimate for both projects; and, create a basis for further exploration and testing of various options and possibilities for refinement of the costing calculation method. This section will explain the assumptions and the process of these base-level LCC calculations, outline their results, and give directions for the further refinements and analysis to be done in the second phase of this project.

4.1 Data

For the first part of this project UBC provided the latest Board Reports for both buildings (Farrar, Castle, et al. 2014; Farrar, Coughtrie, et al. 2014). The reports included information about the overall budget for each project. A breakdown of the capital cost in divisions were not available for both building projects.

The energy costs for both buildings are based on metered consumption values and direct cost to UBC for electricity and natural gas (Table 4). Energy bills for individual UBC buildings are generally not available. As mentioned earlier, both buildings are equipped with several meters for electricity and natural gas. The available data that have been logged since 2013 were used to estimate energy cost. Data for water consumption in both buildings were not available. Both buildings were equipped with water meters at construction, but the meters were never connected to the Ion network.

The costs for maintenance and repair (M&R) are not available for the individual subject buildings, as this information is tracked on a larger scale within the greater campus system. Previous research studies estimated operation costs for UBC buildings based on an in-house spreadsheet tool constructed by UBC Infrastructure Development (Storey 2014). Since the tool has not been updated for the last few years, it was not used for this study. Typically, M&R costs can be difficult to calculate on a building level since operation schedules and occupancy vary a lot across buildings (Fuller and Petersen 1997).

UBC Building Operations receives \$9/ft^2 to operate the buildings[7]. This budget includes \$2.55/ft^2 for energy costs, \$0.6/ft^2 for cyclical renewal and deferred maintenance, and \$5.85/ft^2 for management/operation costs including all utility services, janitorial services, ground services, and routine maintenance. Since actual building management/operation costs were not available the

[7] Information were provided by UBC Building Operations and have been confirmed in the UBC 10 Year Finance Plan from September 2011: http://www.vpfinance.ubc.ca/wp-content/uploads/ubc_ten_year_finance_plan.pdf

provided information for the operation budget of \$5.85/ft^2 was used to estimate the total operation cost for both buildings.

Table 4: Cost to UBC for electricity and natural gas (for boilers, not for the district energy system), including carbon tax and carbon offset.

	Unit	Rates
Electricity[8]	[$/kWh]	0.06
Natural Gas for non-interruptible supply[9]	[$/GJ]	7.20
Carbon Tax	[$/GJ]	1.50
Carbon Offsets	[$/GJ]	1.25
Total Natural Gas	[$/GJ]	9.95

Table 5: Price increase forecast plans from BC Hydro, for electricity and natural gas cost (information provided by UBC Building Operations), expressed in annual percent increase, including additional 2% annual inflation assumption.

	2015	2016	2017	2018	2019
Electricity	**9**	**6**	**4**	**3.5**	**3**
Natural Gas	**7**	**4.5**	**2.5**	**2.8**	**3**

The inflation rate for energy costs are based on a five-year price forecast that UBC Building Operations received from BC Hydro (Table 5), with a standard assumed base inflation rate of 2% added, and included within. (For example, the electricity percent increase value for 2015, 9.0%, includes the 7.0% planned tariff increase from BC Hydro, as well as the 2.0% assumed inflation rate from UBC Building Operation.

The nominal discount rate used for this assessment was 5.75%, as requested by the client. This is the discount rate used by UBC Building Operations for LCC for energy related projects. In accordance with standard UBC practice, this rate was applied to all future costs, including operations and maintenance.

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[8] Electricity costs are based on most recent British Columbia Utilities Commission (BCUC) approved fillings from BC Hydro.

[9] Natural gas costs are based on estimates of future contracts with energy providers. All information is provided by UBC Building Operations.

4.2 Methods

This section explains in detail the method used to calculate the initial LCC for the ESB and the PSB. In several instances rough, heuristic rules of thumb are used to estimate certain costs or their component breakdown, and these are explained as well.

A first step is to break down the single value available for capital expenditures to its component categories, each of which have different associated presumptions for operation and maintenance once installed or constructed. According to the method typically used by UBC and advised for use by the client, the total capital cost is divided into "equipment" costs (physical assets), including their installation, and "soft" costs (those not directly related to the physical assets), such as permitting. The soft costs are assumed to be 23% of the total capital cost (or 30% of the equipment costs), and respectively the equipment and installation costs are 77% of the total capital cost. As further advised, the latter can be further divided into mechanical, interior, and structural cost at an equal ratio of 33% according to Equation 1. This method gives us a rough approximation of the breakdown of costs between mechanical, interior and structure.

Equation 1: Division of capital costs used for base-case LCC

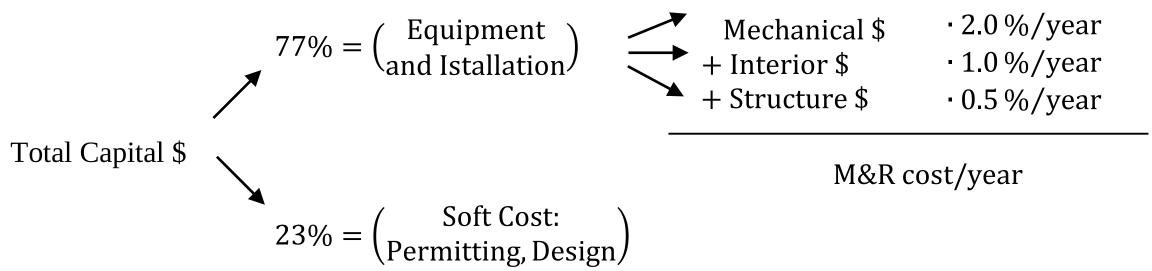
$$77\% * \text{Total Capital Cost} = \text{Equipment \& Installation}$$

$$\text{Equipment \& Installation} = \begin{bmatrix} 33\% \text{ Mechanical Cost} \\ 33\% \text{ Interior Cost} \\ 33\% \text{ Structure Cost} \end{bmatrix}$$

To estimate the M&R costs for these three categories, the project team used a simplistic approach based on industry standards to calculate 2 percent of the mechanical cost, 1 percent of the interior cost, and 0.5 percent of the structure cost on an annual basis. This rule of thumb was applied to the base-case LCC. The cost is in relation to a 50-year life cycle.[10] The percentage for mechanical and interior cost was assumed on similar ways. The total operation cost is summarized over 50 years as shown in **Error! Reference source not found.**.

[10] For instance, one may think that 0.5% of the structure cost seems to be inappropriately low according to the resulting budget per year that may have to cover a roof replacement after several decades. However, after summarizing the yearly 0.5% of the structure cost over the building's entire life cycle of 50 years the resulting budget is more than sufficient to replace the roof and some other parts of the building that are expected to break within the building's life cycle.

Equation 2: Calculation of maintenance cost based on estimates given by UBC Building Operations



Based on the UBC budget of $5.85/ft^2$ that is allocated to building management/operation and the gross floor area, the total building operation cost is calculated. The operation cost is added to the M&R cost for the building, which is then referred to as maintenance, replacement, and management (MRM) cost for the building. Finally, the energy cost is added to the MRM cost. The product equals the building's total operation cost for year 1. The inflation rate of 2% is added to the maintenance cost for each following year and similarly to the energy cost but with changing inflation rates as described in section 4.1 and Equation 3:

$$\sum_{i=0}^{x} \begin{pmatrix} {}^{*}\text{MRM/year} \\ + \\ {}^{*}\text{Energy/year} \end{pmatrix}$$

*Inflation rate added for each following year

The sum of inflated M&R costs and energy costs over 50 years is discounted to get the Net Present Value (NPV) for the operation cost as described in Equation 4:

$$\text{NPV} = \sum_{i=1}^{n} \frac{\text{values}_i}{(1 + \text{discount rate})^i}$$

with n = number of cash flows[11]. The capital costs of the building together with the NPV of M&R cost and of energy cost over 50 years, represents and estimated total cost that will be invested in the building within 50 years.

4.3 Results

The total soft costs for the ESB were calculated to be $13,229,370, while equipment and installation costs account for $57,519,000 (Table 6). As described, the equipment and installation costs were equally split into mechanical, interior, and structure cost, resulting in $18,981,270 for each of these categories. After applying the cost factors for maintenance and repair of the mechanical system, interior and structure, the total M&R cost for the first year (2015) was calculated to be $664,344. By category, this breaks down into $379,625 for mechanical; $189,813 for interior; and $94,906 for structure (Table 6). The total energy costs for the first year was $338,017.

Similarly for the PSB the soft costs were calculated to be $34,707,690, and $116,079,231 for equipment & installation costs. The equipment & installation costs break down to $38,306,146 each, for mechanical, interior, and structure costs. After applying the M&R cost factors for each category the total cost for year one was calculated to be $1,340,715 as shown in Table 6. The total energy cost for the first year of operation was $878,837.

Table 6: M&R cost calculations for both buildings.

		ESB		PSB	
	Factor	Cost	M&R	Cost	M&R
	[%]	[CA$]	[CA$]	[CA$]	[CA$]
Total Capital Cost		$74,700,000		$150,903,000	
Soft costs		$13,229,370		$34,707,690	

[11] Based on the formula for net NVP that allows variable values of cash flow (e.g. annual electricity costs) (different to PV for which cash flows have to be constant throughout the investment) (https://support.office.com/en-sg/article/NPV-function-5c52df05-07cb-48e0-a006-97225eb960bc)

Equipment + Installation		$57,519,000		$116,079,231	
Mechanical	2%	$18,981,270	**$379,625**	$38,306,146	**$766,123**
Interior	1%	$18,981,270	**$189,813**	$38,306,146	**$383,061**
Structure	0.5%	$18,981,270	**$94,906**	$38,306,146	**$191,531**
Maintenance/Operation		$1,001,866	**$1,001,866**	$1,783,669	**$1,783,669**
Total M&R Cost Year 1			**$1,666,180**		**$3,124,384**

After applying the constant inflation rate of 2% as well as the UBC standard discount rate of 5.75% to first year MRM and energy cost the 50-year total NPV for the ESB was calculated to be $121,793,000 (Table 7). Dividing this number by the building's gross floor area yielded a NPV per square foot of $707.22.

The same method was applied to the PSB, resulting in a 50-year total NPV of $204,922,000. This value divided by the building's gross floor area equals a cost of $765.43/ft^2.

Table 7: LLC Summary for both buildings.

	Unit	ESB	PSB
Discount Rate	[%]	5.75%	5.75%
NPV Energy Costs	[CA$]	$9,290,000	$24,145,000
NPV MRM Costs	[CA$]	$37,125,000	$29,874,000
NPV Operation Cost	[CA$]	$46,415,000	$54,019,000
Total Capital Cost	[CA$]	$74,700,000	$150,903,000
50-Year LCC NPV	[CA$]	**$121,115,000**	**$244,665,000**
LCC NPV per sft	[CA$/sft]	**$707.22**	**$765.43**

Figure 9 illustrates the total cost per square foot distribution according to UBC data for ESB and PSB. For ESB the total capital cost compounds for $436.19/ft^2, the NPV for the energy cost is $54.25/ft^2 and the NPV for M&R is $86.44/ft^2. The total cost per square foot of PSB is divided into $472.08/ft^2 for total capital cost, $75.53/ft^2 for the NPV of the energy costs, and $93.46/ft^2 for the NPV for M&R costs.

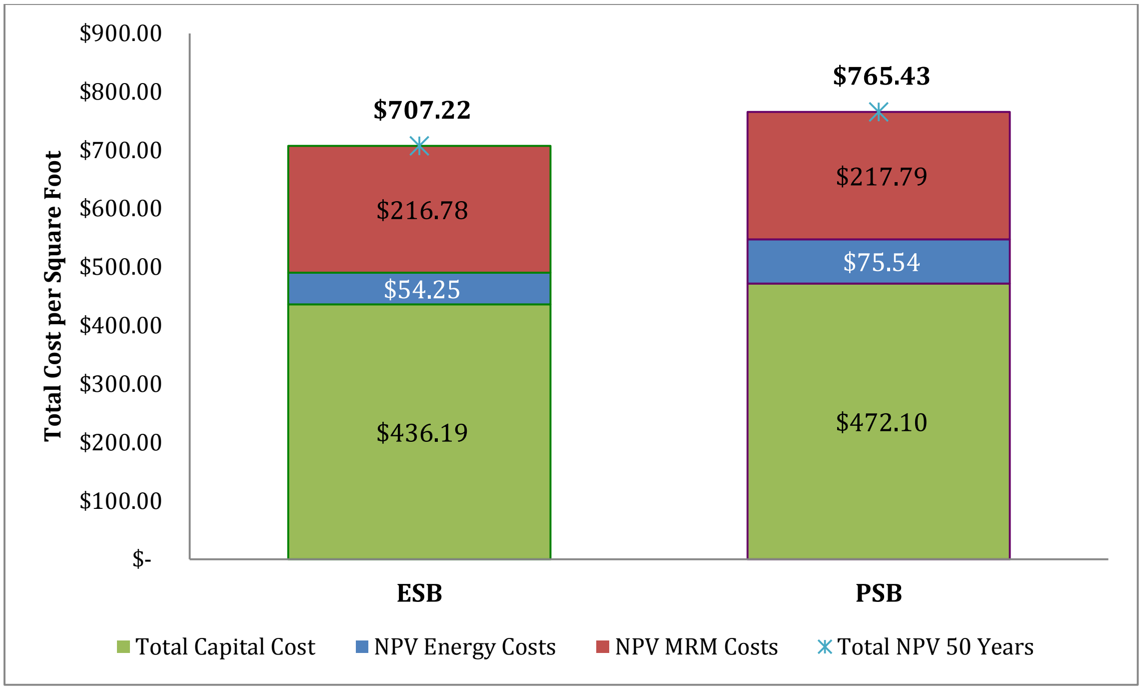


Figure 9: Cost distribution of the total cost per square foot for ESB and PSB.

4.4 Outcomes

This base-level calculation of the life cycle costs for these two buildings resulted in values expressed in dollars per square foot of gross building floor area, for a NPV based on a cycle of 50 years. The ESB LCC value is about 8 percent less than the PSB value ($707.22/ft^2 vs. $765.43/ft^2). The difference was less than that expected based on known information about the two buildings' energy consumption, and the hypothesized positive influence of Thermenex on the efficiency of ESB's energy usage.

Additionally, it was shown that when a LCC is calculated for these two buildings according to standard UBC estimates and practice, the capital expenses contribute 62% to the life cycle cost over 50 years, while MRM cost contribute 28% for ESB and 30% for PSB. Based on the current energy consumption, energy costs contribute 8% to the ESB's and 10% to the PSB's life cycle cost over 50 years.

4.5 Directions for further analysis

A primary area for further refinement and testing that the project team and client identified dealt with assumptions of the maintenance, repair, and management costs a used for unknown building operation data. For instance, the breakdown of capital expenses into equal thirds between mechanical equipment, architectural structure, and interior fit-out, which then cascade into a further set of assumptions determining the operation, maintenance and replacement costs for each of these three categories, was an obvious target for refinement. Additionally, it was hoped that more-detailed building design data could be obtained, in order to perform a comparative analysis of Thermenex's impact on energy usage in ESB vs. PSB.

To accomplish an investigation into these possibilities, a more detailed dissection and application of operation, maintenance, and capital replacement costs was formulated. This required the use of reference tools created by Whitestone Research, as detailed capital and facility costs were not available for the two UBC buildings. Two reference tools provided by Whitestone Research were used to evaluate overall operation cost (including maintenance, M&R cost) of the buildings: Whitestone Reference Books and Whitestone CostLab.

To provide some system of understanding for the next stage of this project, these directions for further analysis were described in two categories of variables to manipulate:

A. Refine variables of *capital choices*; materials, equipment, etc.
B. Refine variables of *known information from empirical operations data* (that is, not assumed consumption data) to determine the effect of increased or decreased efficiency or demand.

5 Second LCC – Whitestone Reference Books

The Whitestone Facility Operations Cost Reference Books for North America, provides operation costs for 74 building and utility types in major North American areas, including Vancouver. The Whitestone Reference Books have been used in previous research studies, evaluating operational cost of buildings (Arpke and Hutzler 2005; Kneifel 2010). In the following analysis Whitestone information are used to improve the LCC calculations by refining operation costs.

5.1 Data

All data that was available from the initial LCC was used in the following analysis, except for M&R costs. The *Whitestone Facility Operations Cost Reference 2011-2012*[12] were used to evaluate

[12] Please see the list of references appended to the end of this report; this volume will heretofore be referenced as "Romani et al 2011".

maintenance, replacement, and management (MRM) costs (i.e. total operation without energy costs) for the two studied buildings. Whitestone operation costs are estimated based on local labor, material, and service costs that are reflected in local cost indexes. Local cost indexes are based on "a comparison of costs across 257 cities for the same asset model – a 2-story office building – using Washington, D.C. as a reference point" (Romani et al 2011). Operations costs are broken down in custodial, energy, grounds, M&R, management, pest control, refuse, road clearance, security, telecommunication, water and sewer (for definition of each category see Appendix B). The energy costs provided by Whitestone were not used in the following analysis, since actual energy consumption values were available for both projects. Whitestone operation cost breakdowns are available for a general laboratory and a life science laboratory in Washington DC.

5.2 Method

The Whitestone books only provide operation cost data for a 2-story office building in Vancouver but not for laboratory facilities in this city. However, data for laboratory facilities is given for Washington DC. The total operation cost and its previously discussed sub-categories are different for the 2-story office building compared to operation cost for laboratory facilities, a general laboratory and a life science laboratory. The general laboratory was chosen to represent the ESB while the life science laboratory matches the purpose of the PSB.

Therefore, the cost difference between the 2-story office building and the general laboratory as well as the cost difference between the 2-story office building and the life science laboratory is adjusted as calculated by Equation 3, which creates a factor that represents the cost difference between a 2-story office building and a general laboratory or a life science laboratory.[13]

Equation 3: Whitestone costing localization method

$$C_{LV} = \frac{C_{LW}}{C_{OW}} * C_{OV}$$

C_{LV} = Cost for a laboratory in Vancouver

C_{LW} = Cost for a laboratory in Washington DC.

[13] Both laboratories in the equation are represented by the same variables C_{LV} and C_{LW}. However, the Cost for the general laboratory in Vancouver was calculated with the matching data for a general laboratory in Washington DC. and the life science laboratory in Vancouver was calculated with the matching data for a life science laboratory in Washington DC.

C_{OW} = Cost for a 2 − story office building in Washington DC

C_{OV} = Cost for a 2 − story office buidling in Vancouver

Energy costs are one of the sub-categories of Whitestone's total operation cost calculations. However, Whitestone energy cost assumptions were not used for the LCC calculation since actual energy data for both buildings was available as discussed in section 5.1 (see Table 15 and Table 16 in Appendix C). Therefore, the energy costs as assumed by Whitestone were subtracted of the total operation cost for both laboratories and actual energy data was used. All data collected in the Whitestone books that were used for this study, were from 2011. After calculating the operation cost for the general laboratory and life science laboratory in Vancouver, a inflation rate of 2 percent was applied to the MRM cost for each consecutive year until 2015.

5.3 Results

All Whitestone cost assumptions are in US$ and based on an exchange rate of 1 US$ = 1.03 CA$ as of May 17, 2011[14]. This exchange rate was applied to all cost assumptions as demonstrated by Equation 4.

Equation 4: Example for converting US$ to CA$ according to the May 17, 2011 currency exchange rate.

$$\text{2011 Operation Cost} = \frac{\text{US\$14.74 sft}^{-1}}{1.03} = \text{CA\$14.31 sft}^{-1}$$

After inflating the 2011 MRM cost (total operation cost *without* energy cost), for both buildings as summarized in Table 8; the ESB MRM cost was calculated to be $2,49,193 and $15.49/ft², and $7,895,060 and $28.20/ft² for the PSB.

Table 8: Inflating the MRM cost for ESB and PSB; using 2011 Whetstone book data.

Inflation for Year	Unit	ESB	PSB
2011	[CA$/ft²]	$14.31	$26.05
2012	[CA$/ft²]	$14.60	$26.57
2013	[CA$/ft²]	$14.89	$27.10
2014	[CA$/ft²]	$15.19	$27.64
2015	[CA$/ft²]	$15.49	$28.20

[14] The *Whitestone Facility Operations Cost Reference 2011-2012* used exchange rates from May 17, 2011 for calculating foreign currencies.

MRM Cost	[CA$]	$2,459,193	$7,895,060

Figure 10 illustrates the cost distribution between all operation cost sub-categories for a general laboratory and a life science laboratory in Vancouver. However, the Whitestone energy cost assumptions were replaced by actual energy data for the ESB (in the graphic corresponding to "Laboratory General") and PSB (in the graphic corresponding to "Laboratory Life Science").

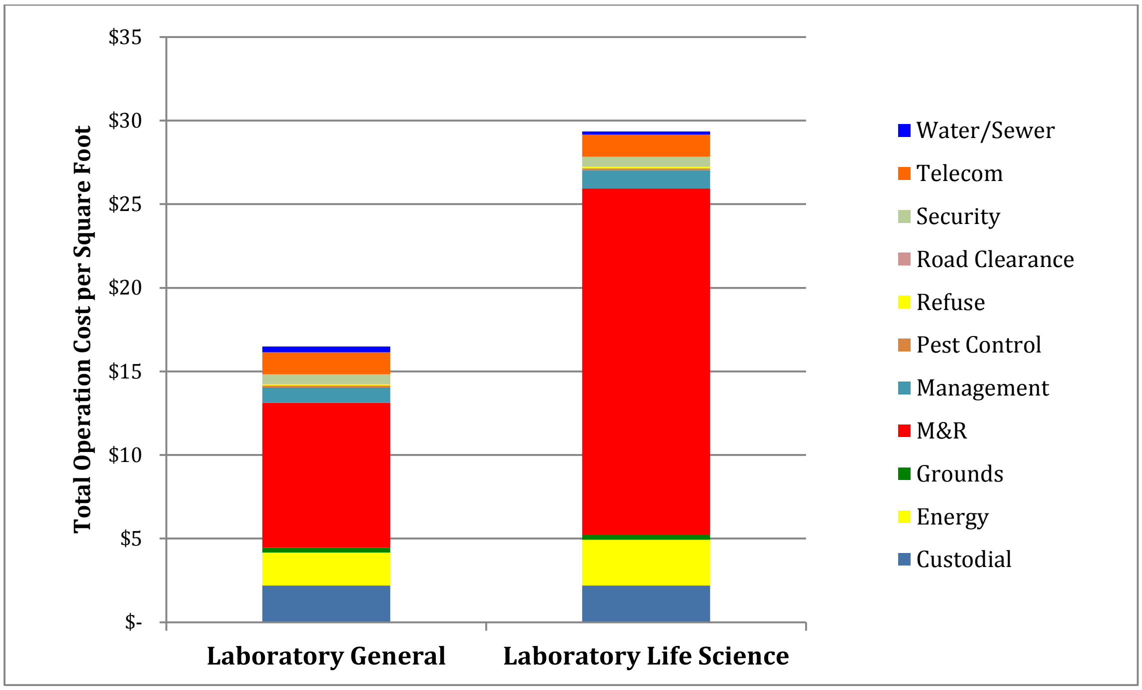


Figure 10: Operation cost distribution according to Whitestone for both, a general laboratory and a life science laboratory.

The total life cycle cost for both buildings was again simulated over a period of 50 years. This resulted in a NPV for the total 50-year life cycle of $138,785,000 for the ESB and $810.40/ft^2 according to the building's gross floor area. The NPV for the total 50-year life cycle of the PSB was calculated to be $350,964,000 resulting in $1,097.98/ft^2 according to its gross floor area.

Table 9: 50-year LCC NPV for the ESB and the PSB and the LCC NPV per square foot.

	Unit	ESB	PSB
Discount Rate	[%]	5.75%	5.75%
NPV Energy Costs	[CA$]	$9,290,000	$24,145,000
NPV MRM	[CA$]	$54,795,000	$175,916,000
NPV Operation Cost	[CA$]	$64,085,000	$200,061,000
Total Capital Cost	[CA$]	$74,700,000	$150,903,000

LCC NPV (50-Years)	[CA$]	**$138,785,000**	**$350,964,000**
LCC NPV per square foot	[CA$/ft^2]	**$810.40**	**$1,097.98**

The 50-year life cycle cost per square foot is summarized in Table 9 and Figure 11. The ESB's total life cycle cost of $810.40/ft^2 is divided into $436.19/ft^2 for total capital cost, $54.25/ft^2 for energy cost, and $319.96/ft^2 for MRM cost. In the PSB case, the total capital cost accounts for $472.10/ft^2 while the energy cost and MRM cost account for $75.54/ft^2 and $550.35/ft^2, respectively.

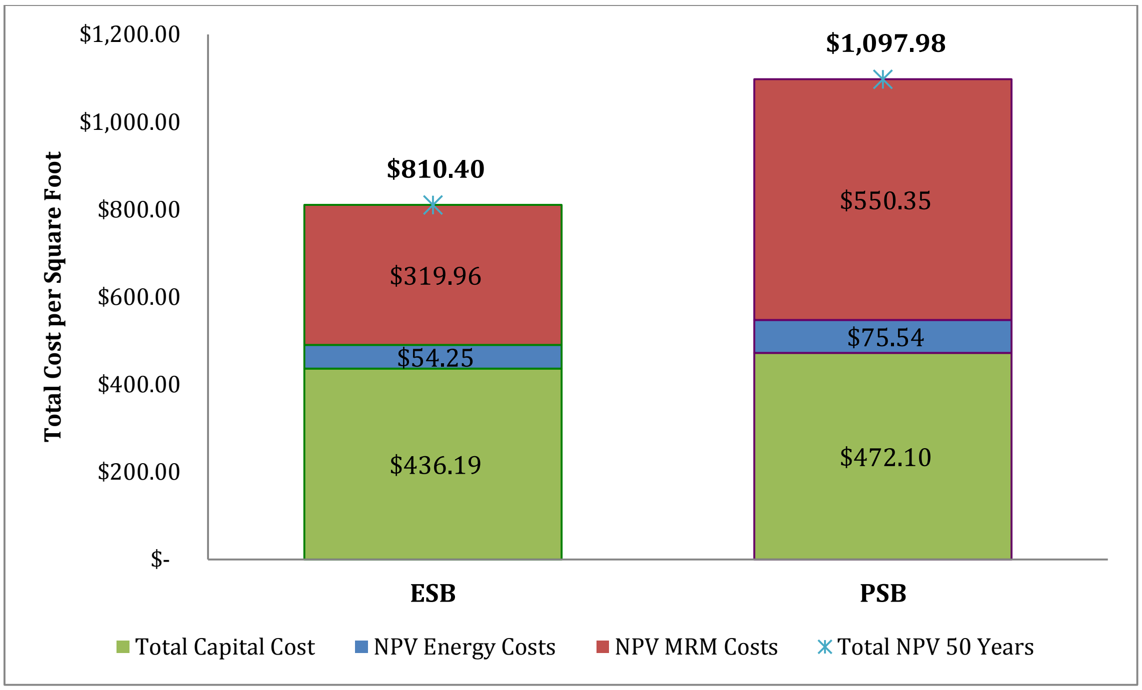


Figure 11: Whitestone's LCC prediction for the ESB and the PSB. Costs are divided by the buildings' gross floor area.

6 Third LCC – Whitestone CostLab

Whitestone CostLab is an online facility cost tool, also designed by Whitestone Research. Unlike the *Whitestone Facility Operations Cost Reference Books*, this online tool generates a more sensitive estimate of costs based on component level analysis for the project and its own location by using frequently updated data of local labor, material, and service costs.

6.1 Data

The input of Whitestone CostLab is a set of values for seven categories of the project, which are Basic Information, Structural Details, Mechanical Details, Utilization, Operations, Recapitalization Assumptions and Asset Description.

The data for Whitestone CostLab was mainly obtained from UBC Building Operations and UBC SEEDS Program Library (Baumann, Ho, and Valedebenito 2012; Amiri and Hashemi 2012). The CostLab category of Utilization and Operations was chosen for further analysis, and client desire for more informative basis for evaluation of performance of these two subject buildings, and by inference potentially other buildings on campus, both present and future. Table 10 shows the major information needed to create the online project profile for CostLab.

Table 10: CostLab: Information required for online Project Profile and chosen categories for ESB and PSB (for each category only one option could be chosen).

1. Building Information		
Name	Earth Sciences Building	Pharmaceutical Sciences Building
Cost Location	BC, Vancouver	BC, Vancouver
Size	Size: 15,910 m2 (171,254 sft)	29,696 m2 (319,645 sft)
Year	Year built: September 2012	September 2012
Type	Type: Lab, general	Laboratory, Life Science
2. Structural Details		
Roof Coverings	Concrete	Concrete
Exterior Walls	Concrete Cast-in-place	Steel
Interior Wall	Sheetrock	Sheetrock
Floor Finishes	Concrete	Concrete

Ceiling Finishes	Wood	Concrete
3. Mechanical Details		
Heat Generating Systems	Boiler, Gas	Boiler, Gas
Cooling Generating Systems	Centrifugal Hermetic	Chiller, Centrifugal Hermetic
Distribution Systems	Air Handler, Multizone	Air Handler, Multizone
4. Utilization		
Hours of operation	Medium	Medium
Security	Low	Medium
Safety & Permitting	Medium	Medium
5. Operations		
Custodial	Medium	Medium
Energy	Low	Low
Grounds	Low	Low
Management	Low	Low
Pest Control	Low	Low
Refuse	Medium	Medium
Road Clearance	Low	Low
Security	Low	Medium
Telecom	Low	Low
Water/Sewer	Medium	Medium
6. Recapitalization		
Replacement Value	0	0
Prior Recap Investment	0	0

6.2 Method

A full set of project information[15] is required for creating a Whitestone CostLab cost summary report as described in Table 10. CostLab creates an asset portfolio for each building. Once the asset is created in CostLab, building information for the main seven categories of the project are entered. For each category (e.g. mechanical details) only one option (or system) can be chosen. Based on the provided information, CostLab models the asset of the entire facility and saves the project portfolio online (Figure 12). The detailed data of the created building can be changed on a component level of materials and systems before exporting the cost reports. However, this requires detailed information of material quantities and systems that were not available to this project.

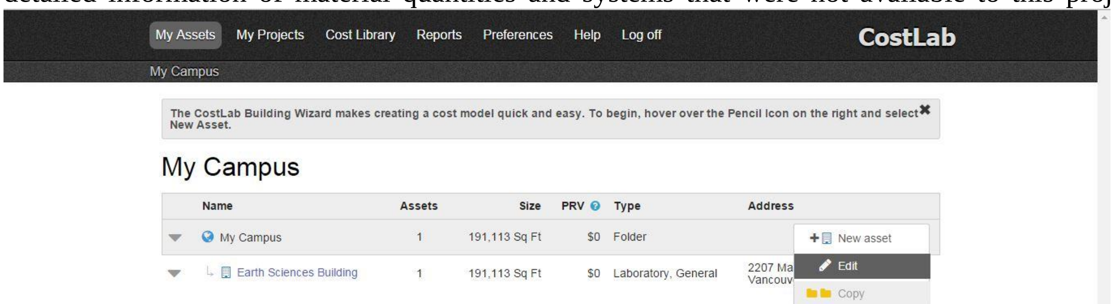


Figure 12: Screenshots of Online Project Database for Earth Sciences Building under "My Assets". https://CostLab.whitestoneresearch.com

The input project information is used by Whitestone CostLab to calculate the different types of cost based on its extensive internal Cost Libraries (for detailed definitions see Appendix B). Base on the created project profile online, CostLab provides detailed reports of average, annual, and deferred costs for a 1 to 50 year range (Figure 13).

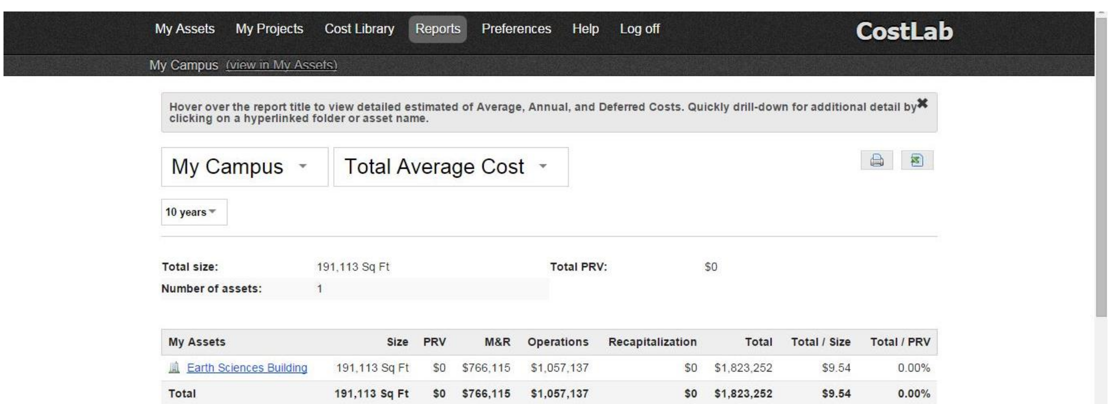


Figure 13: Screenshot of total average cost summary in 10 years under "Report". https://CostLab.whitestonereseach.com

[15] The following project information is required: Basic Information, Structural Details, Mechanical Details, Utilization, Operations, Recapitalization Assumptions and Asset Description

Table 11: Annual, average operation costs breakdown for both buildings.

6.3 Results

Whitestone CostLab assumes the total average cost during the 50 years range equals to the total of M&R, operations and recapitalization average cost. The recapitalization value was set as zero as advised by the client, based on the CostLab definition of this category as the cost of refinancing project debt at some point in the life cycle, rather than the cost for replacing capital assets. The total average operation cost for PSB ($6,773,980) is almost three times of that for ESB ($2,236,620) (Table 13). The main reasons for the discrepancy are the great differences in the categories of preventive maintenance cost, replacement cost, security cost and telecom cost.

Cost Type	ESB	PSB
Average M&R Cost	$1,287,037	$4,468,871
PM	$253,037	$1,316,009
Unscheduled	$203,551	$690,709
Repair	$157,049	$299,289
Replacement	$673,400	$2,162,864
Average Operations Cost	$949,583	$2,305,109
Custodial	$378,560	$844,972
Energy	$278,475	$688,250
Grounds	$28,625	$65,020
Management	$0	$0
Pest Control	$10,068	$22,869
Refuse	$17,561	$39,889
Road Clearance	$7,110	$16,149
Security	$10,412	$189,790
Telecom	$154,556	$351,059
Water / Sewer	$64,216	$87,111
Average Recapitalization Cost	$0	$0
Total Average Cost	$2,236,620	$6,773,980

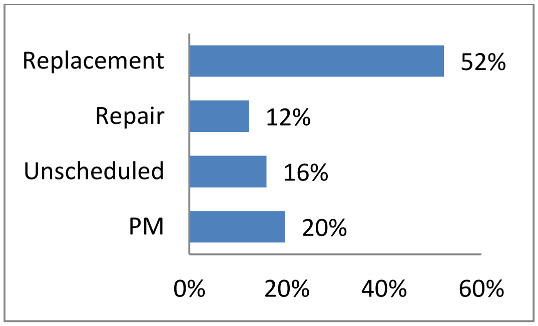


Figure 14: ESB: Average M&R Cost Breakdown (2015-2064)

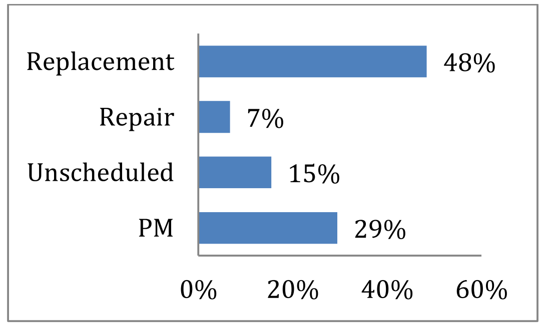


Figure 15: PSB: Average M&R Cost Breakdown of PSB (2015-2064)

Figure 14 and **Figure 15** above show the average M&R cost breakdowns as shares of the total. According to the CostLab framework, it is clear to see that the average M&R cost is composed of four main sectors, Preventive Maintenance (PM), unscheduled maintenance, replacement, and repair. The replacement costs for both the ESB and the PSB account for about half of all average M&R costs.

Figure 16 **shows the cumulative operations cost breakdowns for ESB and PSB over 50 years (2015-2064). In** Table 12 the operations costs are expressed as shares of the total. For both buildings operations costs are predominantly made up of custodial and energy, 40% custodial and 29% energy for the ESB and 36% custodial and 30% energy for PSB. The biggest proportion among the remainder is telecom, which is 16% for the ESB and 15% for the PSB.

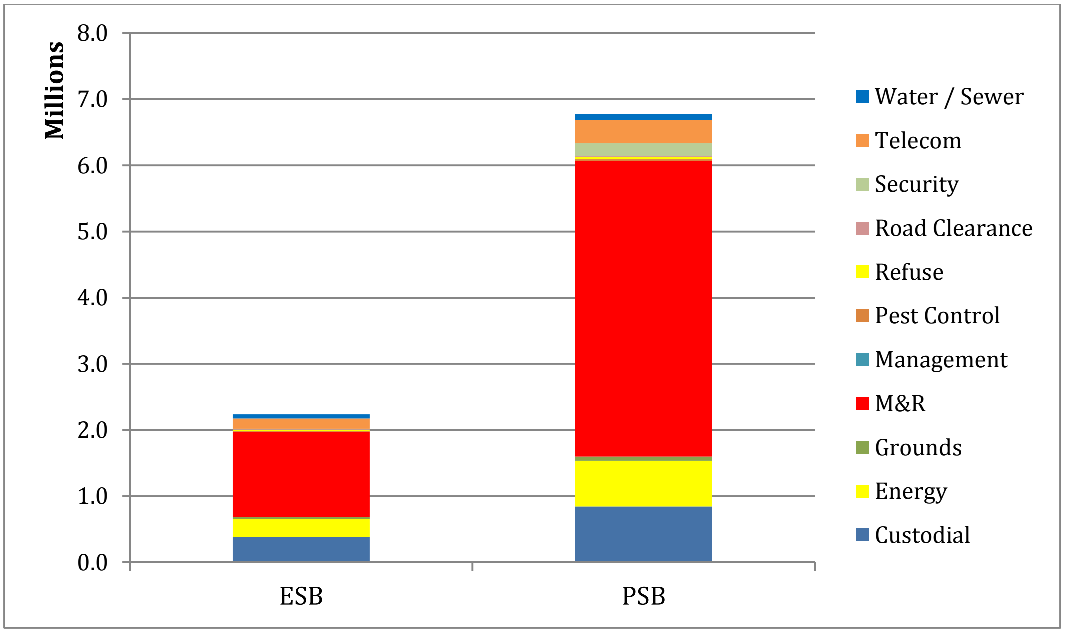


Figure 16: Average annual operation cost distribution according to CostLab, including M&R, for both buildings calculated over 50 year life cycle.

Table 12: Operation cost breakdowns (excluding M&R) for both buildings

Breakdown	ESB (%)	PSB (%)
Custodial	39.9%	36.7%
Energy	29.3%	29.9%
Grounds	3.0%	2.8%
Management	0.0%	0.0%
Pest Control	1.1%	1.0%
Refuse	1.8%	1.7%
Road Clearance	0.7%	0.7%
Security	1.1%	8.2%
Telecom	16.3%	15.2%
Water / Sewer	6.8%	3.8%
Total	100.0%	100.0%

Figure 15 represents the trends of total annual costs for the ESB and the PSB per square foot from 2015 to 2064. It is clear to see that costs for the ESB and the PSB hovered around $\$8.5/ft^2$ and $\$13/ft^2$ respectively during this 50-year range. However, both of these two costs begin to increase dramatically every five years starting from the year 2022. The total annual cost per square foot for the ESB reaches its peak (approximately \$45.45/ft^2) in 2042 while the highest cost (about \$85.43/ ft^2) for the PSB appears in the year 2062. The cyclical peaks show the scheduled capital replacement costs for various high-value assets, such as hot-water boilers.

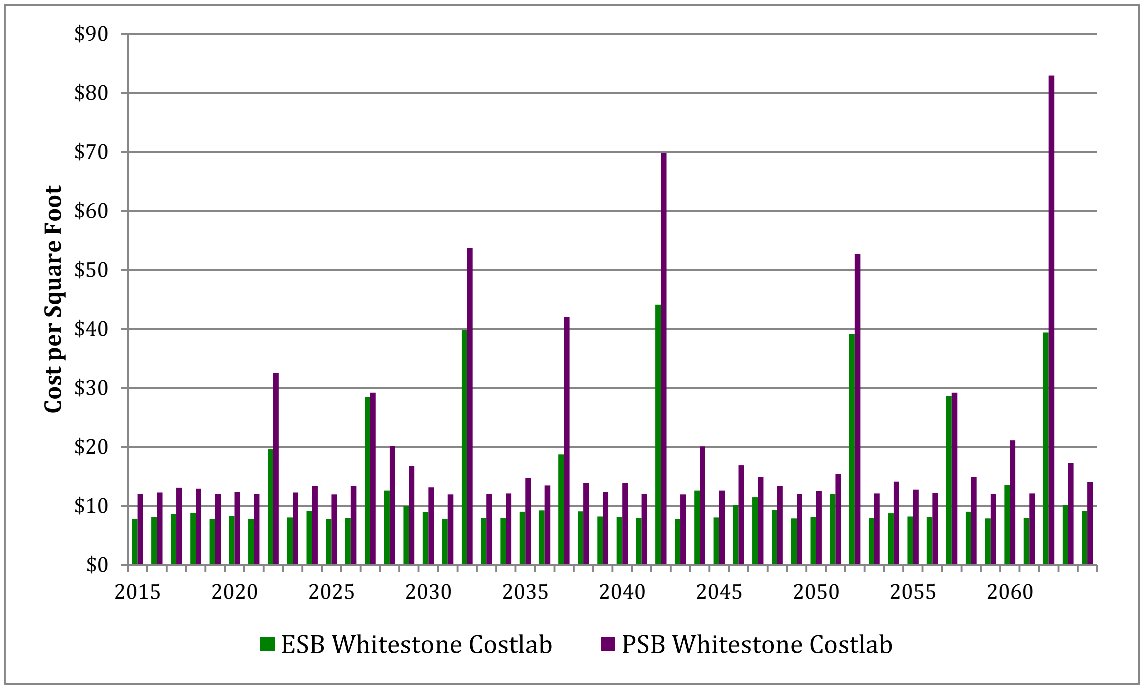


Figure 17: Trends of total annual costs for the ESB and the PSB per square foot (2015-2064)

6.4 Discussion

Based on this method of costing the operations for these two buildings over a 50-year life cycle, it seems that the average operations cost breakdowns of ESB and PSB are quite similar. For instance, both operations costs are mainly made up of custodial and energy (40% custodial and 29% energy for the ESB, and 36% custodial and 30% energy for the PSB). Telecommunications, the largest proportion among the remainder, takes up 16% for the ESB and 15% for the PSB. In light of this, an evaluative comparison of the two buildings' performances based on any unexposed differences in qualitative performance is not available; instead, it is interesting to note that despite the variances in plant equipment, especially the ESB's use of Thermenex, performance is qualitatively similar.

There is also a limitation in the resolution of detail with which CostLab allows information input to be able to reference its extensive internal cost libraries. Taking the operations category as an example, as shown in Table 10; ten choices need to be made among "Low/Medium/High" for all the ten elements of operations. The explanations from the Whitestone Facility Operations Cost Reference Books can help with making these choices, but often there is no definite difference among the options and their explanations. Therefore, the corresponding results of some indefinitely categorized, ambiguous options may not be able to reflect the actual building operations in practice, and further lead to less academic and practical value of the CostLab cost report. For major building systems only one option can be chosen for each system[16]. In that case, the life cycle cost results based on these answers may deviate from the true values. Furthermore, the model that is use for the online CostLab tool is not accessible to the user, which makes a direct comparison of the results of the initial LCC and the second LCC (using Whitestone Reference Books) more difficult.

In summary, although CostLab contributed useful data for analyzing LCC practices, this exercise shows that it still needs to be developed further to correspond to reality.

[16] For instance, only the "concrete cast-in-place" was chosen for the exterior wall material for the ESB, even though its exterior wall is a combination of concrete, curtain wall, and metal sheathing.

7 Evaluation and Discussion of Results

The following chapter includes a comparison of all three LCC analyses (UBC data vs. Whitestone Reference Books vs. Whitestone CostLab); a sensitivity analysis of the input variables for the initial LCC and of possible discount rates; and a comparison of operation costs (UBC data vs. Whitestone Reference Books; and UBC vs. Whitestone CostLab).

7.1 Comparison of LCCs: Base-case, Whitestone Reference Books, & CostLab

To bring some order and synthesis to the overall results, the following observations were made. **Figure 18** shows a comparison of the results for the three LCC that has been conducted. The proportion of capital cost and operation cost in the total life cycle costs for these two buildings changes significantly for the three LCCs. In the initial LCC (i.e. UBC Data), the capital cost covered approx. 60% of the total life cycle cost while MRM cost were only approx. 30% and energy cost approx. 10% of the total cost. In the second LCC (Whitestone Reference Books), the capital cost covered 50%, energy cost 7% and MRM cost between 43% and 54% of the total life cycle cost. In the third LCC (CostLab), the capital cost covered only 40% of the total life cycle cost for ESB, and 31% for PSB. MRM cost covered 53% for ESB and 62% for PSB of the total cost over 50 years. Energy cost remained at 7% of the total life cycle cost for both buildings.

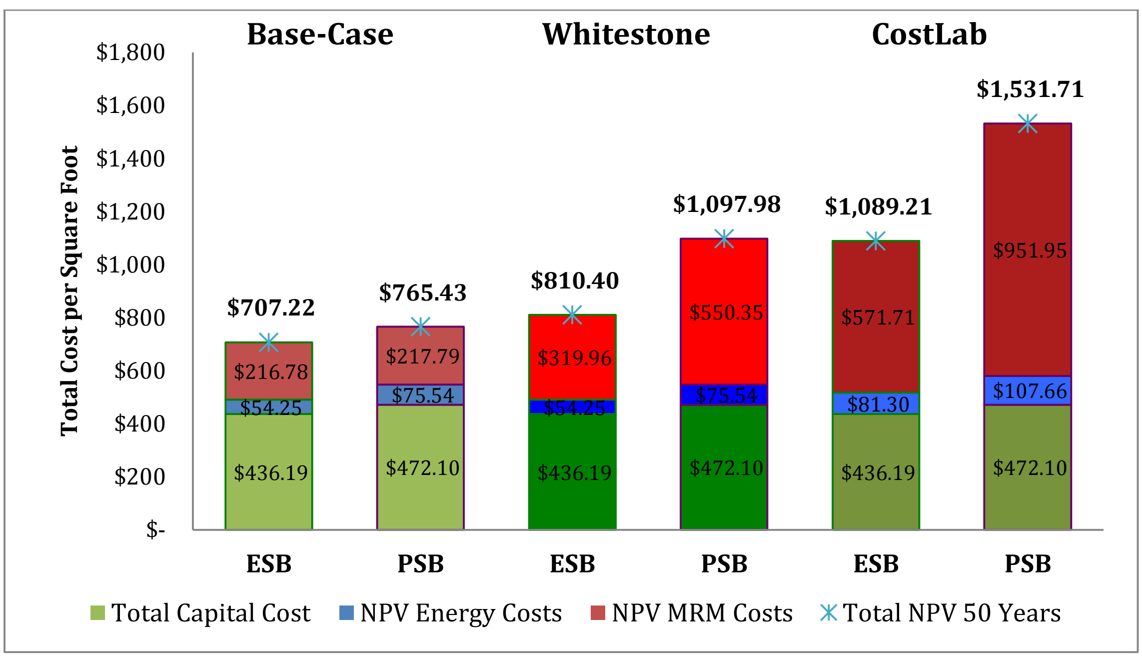


Figure 18: Comparison of three LCC analyses: base-case (UBC Data), Whitestone (Reference Books), and CostLab results (For UBC Data, instead of MRM cost M&R cost have been used).

The UBC base-case assumptions for division of capital expenses are split evenly between structural costs, interior fit-out costs, and mechanical equipment costs (compare Equation 1). While useful for an individual-building analysis, this costing practice does only account for other operational costs such as grounds maintenance and janitorial expenses by using the current allocated UBC budget instead of real costs (see Section 4.2). On a university campus these costs are difficult to quantify on a single-building basis; within the Whitestone operation estimation system, they are fundamentally included within the estimation of operation costs.

According to the results using the Whitestone Reference Books from 2011, the life cycle costs are almost evenly split between capital costs and operation costs (**Figure 18**). This is primarily because the M&R cost for the Whitestone Reference Books include regular repair and replacement costs that were only estimated for the UBC base-case. Whitestone management/operation costs include service costs such as telecommunication and security that are not included in the management/operation budget provided by UBC. However, those cost were only 7-8% of the total MRM cost and thus had a small impact on the final results.

Furthermore, the mid-range assumptions for operation used by Whitestone Reference Books, assume a cycle of *scheduled* capital replacement for all asset stock, while UBC practices generally do not follow this regime (compare Appendix B). It is significant to note that this was not the maximum possible set of assumptions available within the simulation. The dramatic difference between the expenses in the first LCC (UBC Data) and second LCC (Whitestone Reference Books) could be even greater if a different set of operational expense assumptions were used, or if future expenses prove themselves to be more than that assumed under this mid-range series of choices.

The CostLab results are significantly different for the two buildings (**Figure 18**). The difference is mainly due to higher MRM cost for mechanical systems that are significantly higher for a life science laboratory (used for PSB) than for a general laboratory (used for ESB) (compare Section 6.3). For both buildings the MRM costs are significantly higher than the MRM cost estimated by Whitestone reference books. This is mainly due to the different method (i.e. model) used to calculate the LCC. Similar to the initial LCC for the second LCC (Whitestone Reference Books) an initial annual MRM rate was used to calculate the NPV of MRM cost over 50 years. The CostLab calculations for MRM cost include regularly scheduled replacement costs (further discussion in Section **Error! Reference source not found.**) that are significantly higher than what the replacement costs estimated by Whitestone Reference Books.

Despite the increase of operation costs in the second and third LCC, none of the scenarios confirms the original hypothetical heuristic that approximately 90% of the life cycle expenses of a building are associated with its operations costs. However, this hypothesis cannot be verified within the bounds of this project. Both of the subject buildings are designed and operated with high levels of efficiency, consumption and overall sustainability in mind. This generally means elevated capital costs, in order to gain lowered operation costs in the future, as compared to a 'typical' building.

7.2 Uncertainty in LCC: Sensitivity Analyses

As mentioned earlier in the report LCC includes inherent uncertainties in estimating long-term cost with regards to building function and regulation, as well as macroeconomic changes such as technological development (Storey 2014; Arja, Sauce, and Souyri 2010).

One way to address uncertainty in LCC is to conduct a sensitivity analysis. This is "a technique for determining which input values, if different would make a crucial difference to the outcome of the analysis" (Fuller and Petersen 1997) Section 8.1). That is, by isolating one variable for evaluation, other values' influence on it can be simulated. The advantage of a sensitivity analysis, compared to other uncertainty assessment tools for a LCC, is that it can be performed with little resources available. The disadvantage is that it does not provide information on the likelihood of different outcomes (Fuller and Petersen 1997). For this, probabilistic methods such as building simulations would be required.

7.2.1 Sensitivity Analysis 1: Capital, Energy and M&R Costs

To evaluate the influence of three significant variables—capital costs, energy costs, and M&R costs--a sensitivity analysis was used to model the degree of uncertainty by adopting an increment of 10 percent as recommended by the National Institute of Standards and Technology (NIST). Each cost variable, capital cost, energy cost and M&R cost, is analyzed to evaluated the influence on the total cost of ownership for each building, for both life cycle cost scenarios (Table 13 & Table 14).

Table 13: ESB: Evaluation of the cost difference for an incremental increase of 10% for each variable in the NVP (in 2014 dollars) and % of total cost of ownership.

Cost Assumption	Input value increased by 10%	Change in LCC 1 (UBC)		Change in LCC 2 (Whitestone)	
		in NPV (2012 $)	in %	in NPV (2012 $)	in %
Capital Cost	$82,170,000	621	7.6%	854	5.4%

Energy Costs	$0.07/kWh (elect.) $13.68/GJ (gas)	582	0.9%	816	0.6%
M&R Costs	$731,000/yr $2,705,000/yr	586	1.5%	842	3.9%

Table 14: PSB: Evaluation the cost difference for an incremental increase of 10% for each variable in the NVP (in 2014 dollars) and % of total cost of ownership.

Cost Assumption	Input value increased by 10%	Change in LCC 1 (UBC)		Change in LCC 2 (Whitestone)	
		in NPV (2012 $)	in %	in NPV (2012 $)	in %
Capital Cost	$165,993,000	688	7.4%	1,145	4.3%
Energy Costs	$0.07/kWh (elect.) $13.68/GJ (gas)	648	1.1%	1,105	0.6%
M&R Costs	1,475,000/yr 8,685,000/yr	650	1.5%	1,153	5.0%

For both buildings the impact for a 10% increase in the capital cost is significant in both scenarios (i.e. values from UBC and Whitestone), with between 4.3% and 7.6% increase (Table 13 & Table 14). This shows that in this analysis capital, up-front costs had the major impact on the total life cycle cost over 50 years for both scenarios.

The budget impact of a 10% increase in the energy cost is significantly smaller for both buildings compared to the capital cost, with 0.6% to 1.1% increase. Although both buildings are consuming more energy than predicted, the costs for energy are the smallest contributing factor in both life cycle cost scenarios.

A 10% M&R cost increase, has cost impacts of 1.5% (for ESB and PSB) in the first scenario, and 3.9% (5.0% respectively) in the second scenario (Table 13 & Table 14). The estimated annual M&R costs were significantly higher in the Whitestone scenarios than in the UBC scenario. And thus, the impacts on the overall life cycle cost are proportionally bigger in the Whitestone LCC analysis.

7.2.2 Sensitivity Analysis 2: Discount Rate

Discount rates have a large impact on LCC results and the rates vary within the literature and across different jurisdictions and contexts. The BC Government nominal discount rate is 7.1% (including inflation) while the real discount rate is 5.0% setting the escalation rates at the Canada consumer price index of 2.1% (Storey 2014). While market rates including opportunity cost of private capital are typically high, a social discount rate, ranging from 3-4%, is lower considering public work and environmental costs and benefits (Storey 2014).

The nominal discount rate used by UBC Building Operations is 5.75%, and thus lies between official numbers for the nominal discount rate and the social discount rate.

To evaluate the impact of different discount rates on the overall project cost over 50 years, the operation cost of the buildings (i.e. energy cost and M&R cost) is calculated for discount rates of 4%, 5.75%, and 7.1% and compared to the capital cost (Figure 19 & Figure 20).

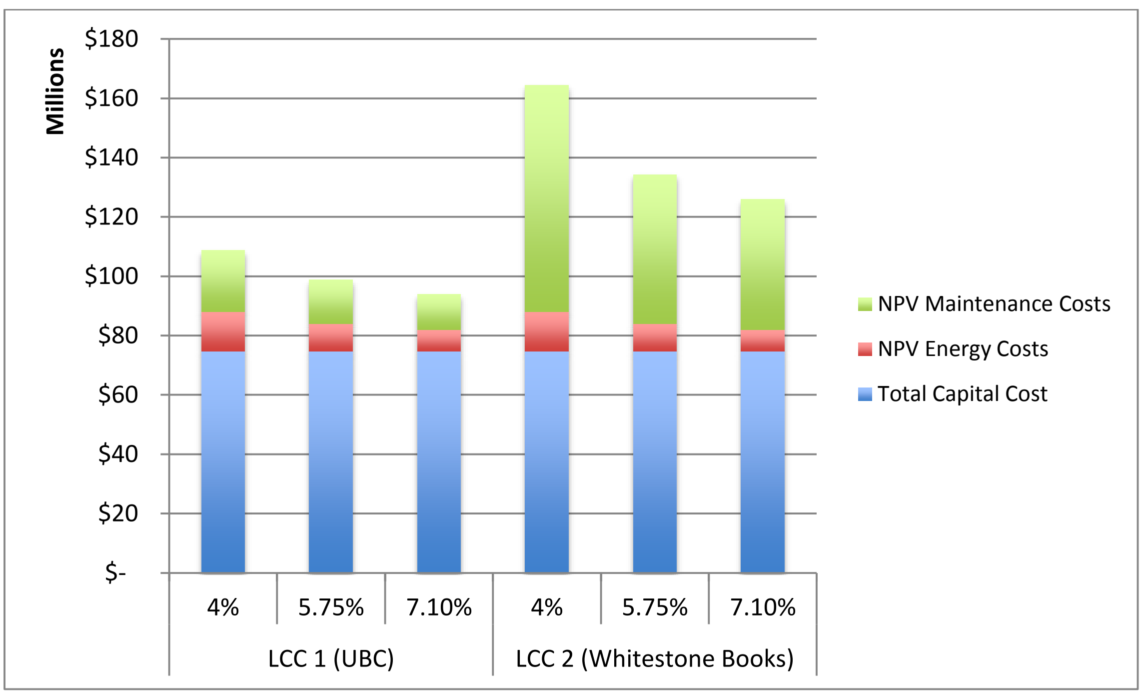


Figure 19: ESB building: Comparison of capital cost with NPV of energy cost, and M&R costs over 50 years for discount rates of 4 percent, 5.75 percent, and 7.1 percent.

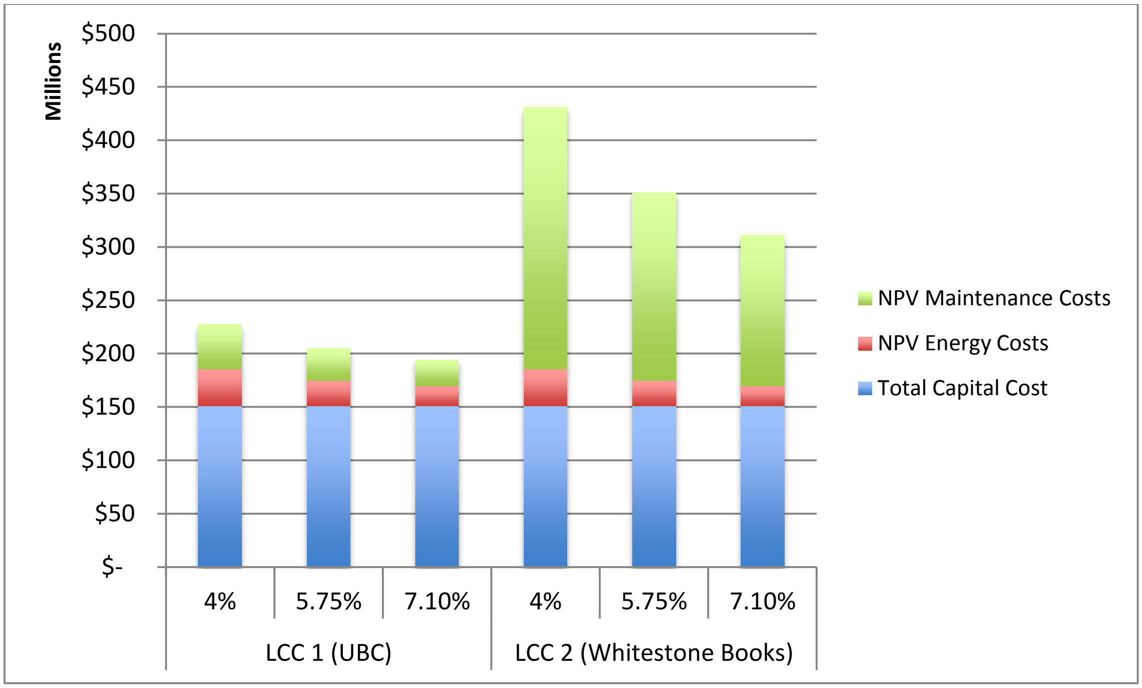


Figure 20: PSB building: Comparison of capital cost with NPV of energy cost, and M&R costs over 50 years for discount rates of 4 percent, 5.75 percent, and 7.1 percent.

For both buildings the results follow the same trend: lower discount rates increases the NPV of operation costs. For both cases, the UBC scenario and the Whitestone scenario, the same estimations for energy costs were applied based on actual consumption values. Thus, the only difference between both cases is estimates for M&R costs.

In the UBC scenario (i.e. LCC 1) changes in the discount rate have a minor effect on the NPV of operation costs, since annual energy cost and M&R cost were fairly low. Consequently, energy cost and M&R cost together are less than one third of the total project cost over 50 years.

In the Whitestone scenario (i.e. LCC 2) annual operation cost were estimated to be more than 3 times as high as in the UBC scenario. Consequently, changes in the discount rate have a significant impact on the overall project cost over 50 years. For a discount rate of 4%, energy cost and M&R cost cover 56% of the total project cost (over 50 years). For a discount rate of 7.1% operation cost (NPV) are still responsible for 42% of the overall cost.

In order to evaluate the affect of discounting M&R cost, discount rates between 1% and 10% are applied to both, the UBC scenario and the Whitestone scenario (Figure 21).

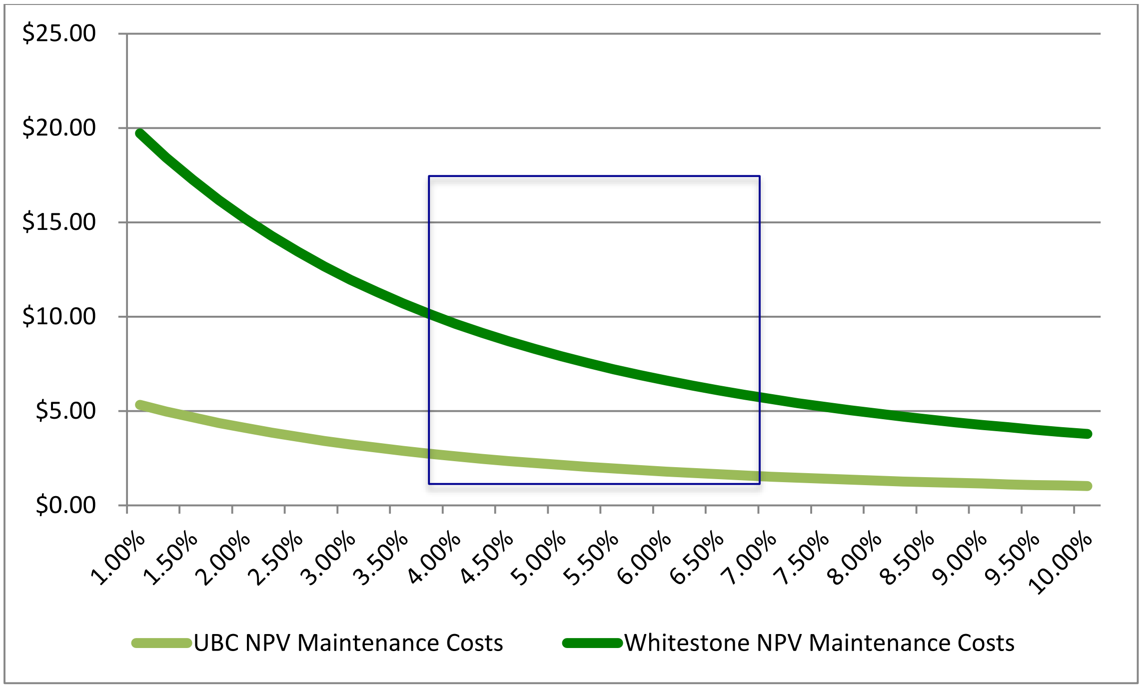


Figure 21: ESB building: M&R costs over 50 years for discount rates between 1% and 10%.

The evaluation shows that for lower discount rates, the difference in annual operation cost are more significant than for higher discount rates.

In summary, the sensitivity analysis for discounting clearly shows that for high discount rates the capital cost and early operation cost remain dominant over a life cycle of 50 years.

7.3 Operation Costs: UBC Base-case vs. Whitestone Reference Books vs. CostLab

The Whitestone Reference Books are only designed to create predictions and estimates of operation costs. In order to evaluate UBC's current budget for building operation, first year operations costs from the base-case LCC and the second LCC based on Whitestone Books were compared. The current operation budget for UBC buildings is $\$8.60/ft^2$ with approximately $\$0.66/ft^2$ for capital renewal differed maintenance (CRDM) per year. For the base-case average annual operation cost were estimated to be $\$9.8/ft^2$, while calculations based on Whitestone reference books suggested a average operation cost of $\$15.49/ft^2$ for a general laboratory building (i.e. ESB) and $\$28.20/ft^2$ for a life science laboratory building (i.e. PSB) in Vancouver (compare Section 5.3).

The building operations budget allocation factor at UBC has not changed in nearly a decade,[17] remaining static at a total of $9/ft^2 despite increases in operation costs due to inflation pressures, fuel price increases, and multiple other factors. It is unknown whether or when this budget might increase in the future. Therefore, to compare simulated future operation costs, this current budget value was extended forward to the end of the fifty-year test life cycle for both buildings, and graphed against the predicted future building operation expenses per square foot (Figure 20 and Figure 21). The figures below show the expected increase of operation costs generated by these two techniques, as the UBC current building operations budget (per square foot of floor area). The UBC base-case values are significantly less than the Whitestone reference book predictions, and they increase less over time as well. This is because the simplified analysis includes estimates for M&R costs and the current operation budget, while the Reference Books include MRM costs based on industry standards. In any case, even these fractional values will surpass the current budget long before the end of the life cycle.

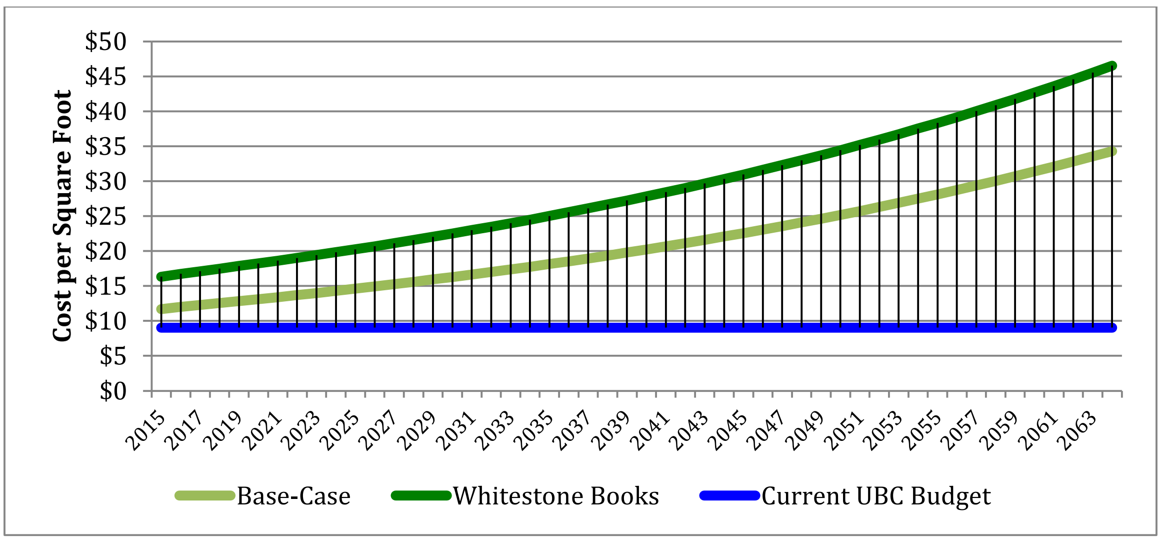


Figure 22: ESB: Estimated total operation costs over 50 years (inflation included, but no discount rate)[18].

This analysis highlights one way in which a more comprehensive and responsive building operations budget could be determined at UBC, in association with other operation policy decisions, such as choice of scheduled maintenance regime.

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[17] This information was provided by UBC Building Operations Department.

[18] "ESB Our Assumptions" include only operational expenses for the building only and do not include some expenses such as grounds maintenance and janitorial costs, as the "Option 2" and "UBC expenses" options do. To compare like expense characterizations, the differences would likely be greater.

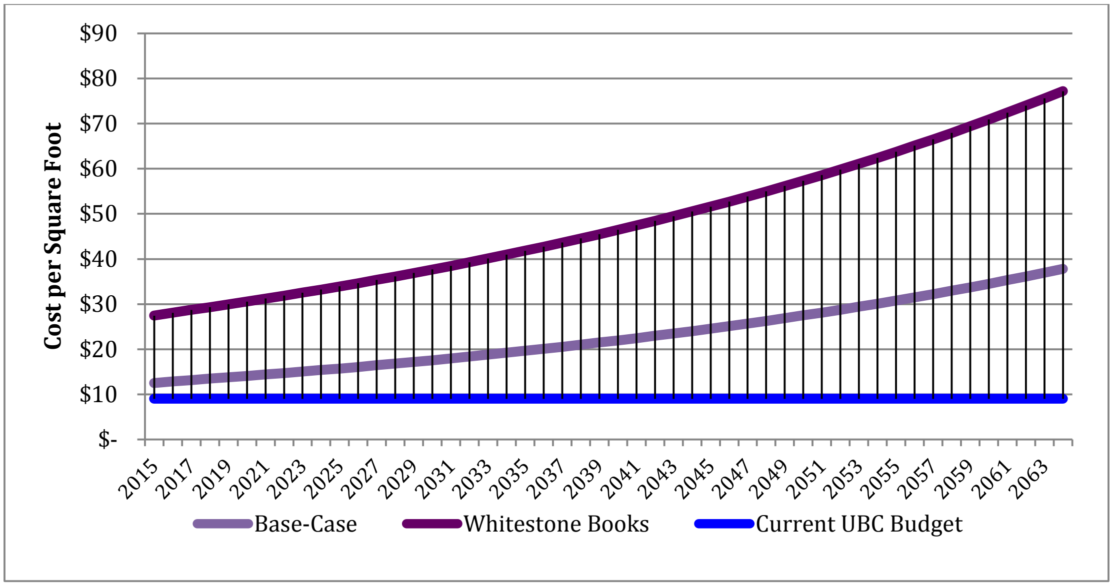

Figure 23: PSB: Estimated total operation costs over 50 years (inflation included, but no discount rate).

CostLab, as mentioned above, includes a more granular simulation of future costs, estimating capital replacement on a predictive cyclical schedule. As seen in Figure 24 and Figure 25, if the CostLab-generated costs for comprehensive, all-inclusive building operations are averaged on a yearly basis, the average operation cost is $12.70/ft^2 for a ESB (a general laboratory building) and $19.40/ft^2 for PSB (a life science laboratory building). Similar to the Whitestone reference book results, these results are higher than the $9/ft^2 per year that UBC has budgeted for the last 13 years, for building operation.

In 2010, laboratories accounted for almost 10 percent of UBC's building stock, the second largest category after offices (covering 87%)[19]. Whitestone reference books estimate $10.8/ft^2 per year of operation costs for a two-story office building which is still higher than the current budget provided by UBC. Based in the here applied industry standards (Whitestone Reference Books and Whitestone CostLab), UBC's building stock requires a higher building operation budget for its buildings.

It is assumed that savings (unquantified through this study) could be realized by avoidance of unscheduled capital replacement costs, and associated 'emergency' repair and replacement of

[19] The information is based on accumulated service areas including the following categories: class, laboratory, library, and office. Data were originally provided by UBC Records (2012) and retrieved from Storey (2014).

ancillary damages and other expenses associated with unanticipated equipment failure and capital replacement.

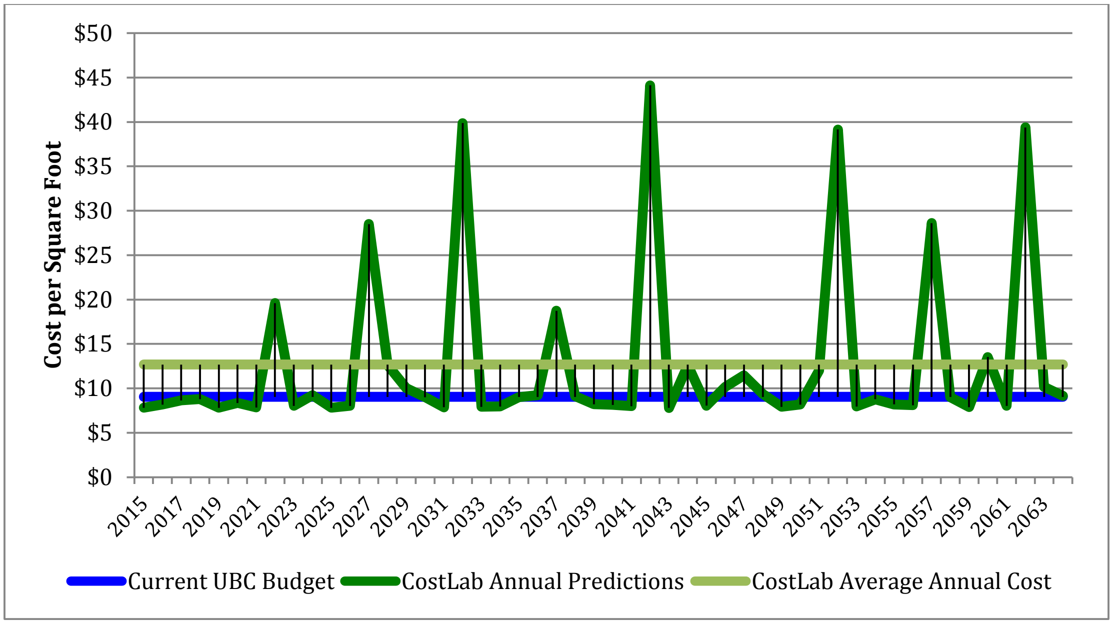

Figure 24: ESB CostLab capital replacement estimations vs. current UBC expenses,.

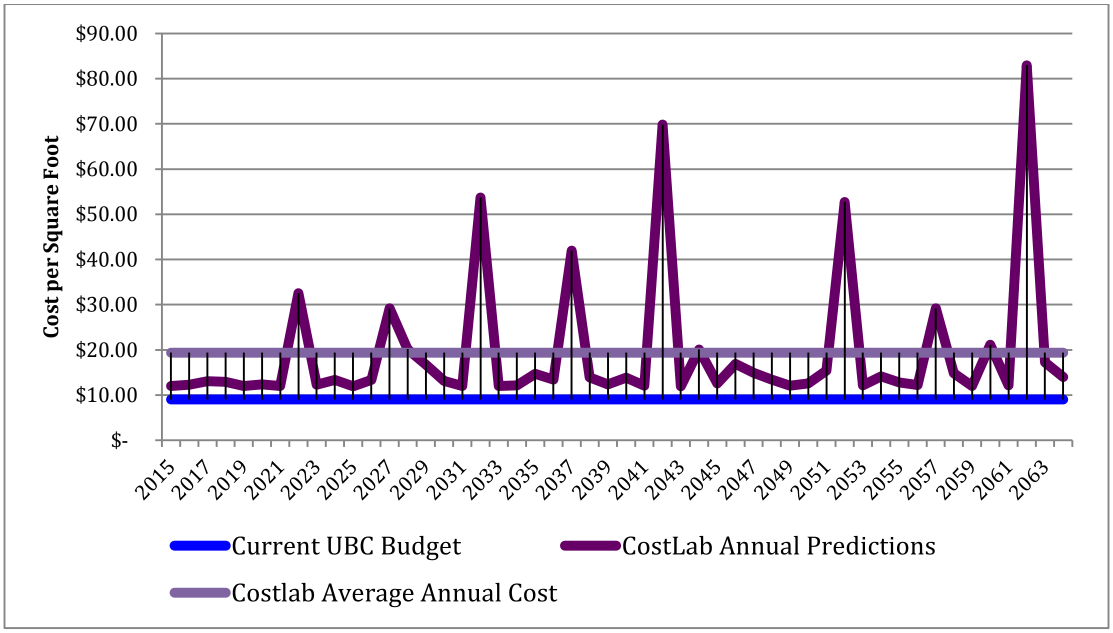

Figure 25: PSB CostLab capital replacement estimations vs. current UBC expenses.

8 Recommendations

In summary, after performing LCC for the ESB and the PSB at UBC, according to a variety of methods (including the present standard as well as several other widely-accepted methods of estimating life cycle costs), the results lead to a set of recommendations for the UBC administration and operations staff.

8.1 Data

In order to better manage its existing facilities, and create better plans for future buildings, it is apparent that more extensive and reliable data must first be made available. While estimation methods like the Whitestone references and the proprietary CostLab system can help replace missing data and make assumptions that can help forecast future needs, there are limitations to these methods that constrain their utility.

8.2 Deferred Maintenance

The UBC practices generally are seen to assume the lowest possible costs for maintenance and operation of a building, with limited preventative maintenance, or regular scheduled maintenance of equipment. This is assumed to be, at least primarily, how UBC has been able to achieve these lower operational costs compared to Whitestone mid-range and best-practice assumptions.

According to UBC Building Operations, UBC has accumulated a significant estimated account of deferred maintenance. If UBC were to change their building operation practices away from minimal 'as-needed' emergency replacement costs for capital assets, and toward a more accepted best-practice of scheduled replacement (as described in Whitestone CostLab), a significant amount of fundamentally unpredictable expenses could likely be avoided (that it is assumed UBC has been accruing as expenses associated with emergency equipment or structural failures or weaknesses), and a potentially large amount savings could be realized. Further research is needed to reliably quantify these expected savings and unplanned collateral expenses associated with deferred maintenance.

8.3 Discount Rates

Additionally, the use of a broadly-applied discount rate of 5.75 percent across all capital and operations values may not appropriate for the specifics of UBC's typical mode of financing building operations, or indeed the general characteristics of building operations. The rate above is based on the standard interest rate available for financing capital construction on campus, and as such its application within a LCC would only be useful if the entire building were financed at this rate. Instead, new construction on campus is usually financed through a mix of provincial or other government grants, private grants, previously budgeted or allocated funds, and (occasionally) debt, making a discounting of the cost of the building in the future based on the price of debt inappropriate. Further, this standard UBC practice discounts expenses which should only be increasing in the future, such as labor or energy costs, in accordance with expected or known inflation rates and price increases.

In light of all of these observations, it is recommended that in the future, no discounting may be used when estimating operation budgets for new buildings that are not paid initially by UBC as a one time payment, but on an annual base. In the case of a significant portion of the financing of a new building is through debt, then a discount rate reflecting the cost of that debt (the interest rate on the loan) should be used.

9 Conclusion

UBC aims to provide an exceptional learning environment while exemplifying economic, environmental and social sustainability in its the built environment. One of its main goals is to enhance infrastructures to support leading edge research. In 2010, laboratory buildings were the second largest category in UBC's building stock, accounting for almost ten percent of all buildings and contributing significantly to UBC's financial investments. This project performed a life cycle cost analysis for two high-performance laboratory buildings on the campus of the University of British Columbia, the Earth Sciences Building (ESB) and the Pharmaceutical Sciences Building (PSB). The propose of this project was to test current assumptions about life cycle costs of new research buildings on campus and also to attempt to verify an observation that one building's energy performance (ESB) was significantly better than the other (PSB), despite many similarities across the two buildings. Additionally, this initial life cycle costing was to provide a basis and platform for further analysis of data, testing of various assumptions and hypotheses, and opportunities to create recommendations for improving UBC's LCC standards, with the larger goal of finding ways the University could increase its confidence in long-term performance from designs for future buildings.

For a base-case LCC actual energy consumption data were used along with estimations for maintenance and repair costs to estimate operation costs for the two buildings. On a net present value basis, it was found that operation and maintenance costs account for 38 percent for ESB and 40 percent for PSB of the total life cycle cost over 50 years. When industry standard cost estimation systems (Whitestone CostLab, and the Whitestone printed reference volumes) were applied to refine this analysis, the total operation costs increased significantly. When estimates for maintenance and repair costs in the base-case are replaced with data as provided by Whitestone reference books, operation cost account for 50 percent and 61 percent, respectively, of the total life cycle cost. When the online Whitestone Costlab tool is applied using a building component level analysis, operation costs cover more than half of the total life cycle cost over 50 years (accounting for between 50 and 60 percent).

Furthermore, it was found that the average annual operation costs for laboratory buildings as indicated by Whitestone Research is significantly higher than UBC's current building operation budget of \$8.60/ft^2 and approximately \$0.66/ft^2 for capital renewal differed maintenance (CRDM) per year. While Whitestone Costlab suggests average operation cost of approximately \$14/ft^2 per year, calculations based on Whitestone Reference Books indicate average annual operation cost of approximately \$21/ft^2 for laboratory buildings.

Theses results indicate that a more detailed evaluation of operation costs for research buildings at UBC are required. Multiple data gaps assumed to exist for many or most buildings campus-wide could either be filled with primary data collected by UBC, or through the use of simulated data (in this project supplied through the two Whitestone methods). Based on the outcomes of this project, the following improvements are recommended for further LCC's at UBC:

1) Acquire more detailed operation cost information for new buildings on UBC campus using local Whitestone Research data to provide a better foundation for the extended life cycle costing and to obtain a more realistic operational budget than the current standardized value of \$8.60/ft^2 and approximately \$0.66/ft^2 for capital renewal differed maintenance (CRDM). Information could be acquired either through the use of available operation cost tools such as Whitestone Costlab or through the collection of additional primary empirical data.
2) Investigate further the potential advantages of adopting a preventive-maintenance and scheduled-replacement regime for campus assets, rather than continuing the present practice of implicit cost saving through deferred maintenance.
3) Raise the budget for building operation to ensure scheduled maintenance can be done more frequently according to Whitestone operation costs assumptions.

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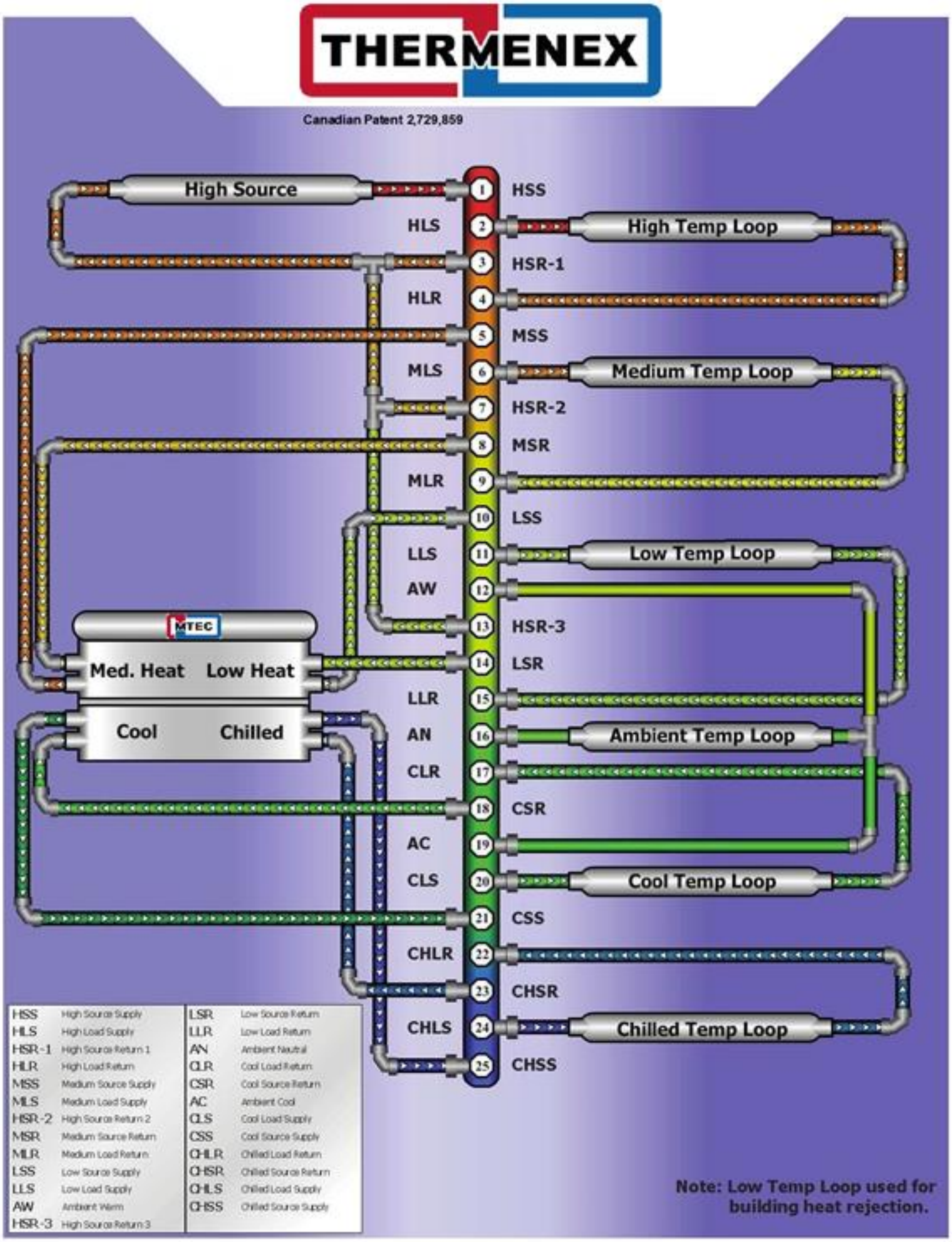
Appendices

Appendix A: Thermenex heat-distribution header network system diagram



source: http://thermenex.com/about-us/

Appendix B: Whitestone Information

Whitestone Definitions

The following information were retrieved from the Whitestone Research website, in the help section of the CostLab Tool.

Operations costs are broken down in custodial, energy, grounds, maintenance and repair (M&R), management, pest control, refuse, road clearance, security, telecommunication, water and sewer.

Key Definitions [20]

Maintenance and repair (M&R): The collection of activities necessary for keeping a facility in good working order. Other tasks associated with facility operation such as custodial services, landscaping, waste disposal, and the provision of central utilities are not included in our definition of M&R, nor are costs associated with recapitalization. M&R activities are divided into four types:

Preventative maintenance (PM) and minor repair consists of scheduled tasks that sustain a component's level of service during a prescribed lifetime.

Unscheduled maintenance consists of service calls, emergency response, and other tasks that cannot be individually anticipated.

Renewal and replacement consists of component overhaul or major replacement tasks. These tasks extend a component lifetime, and reset the schedule of PM and minor repair tasks.

Deferred Maintenance is all major renewal and replacement tasks not performed on schedule.

Operations: The services necessary to realize the productive value of an asset. Excluded is the cost of M&R activities and recapitalization. Facility operations are divided into ten types:

Custodial services include the cleaning of offices, work areas, restrooms and common areas. Trash removal is not included.

[20] Information from CostLab tool from Whitestone Research website: https://CostLab.whitestoneresearch.com/Help/Help.htm

Energy includes all expenses related to the purchase, generation, distribution, and conservation of energy and source fuels necessary to operate an asset and its typical programmatic equipment. Not included is utilities maintenance or supervision.

Grounds include the maintenance of exterior landscaped areas. It does not include street sweeping or snow removal, the maintenance of parking lots or roadways, or the maintenance of signage. Also not included is the maintenance of semi-improved and unimproved areas.

Management includes management services common to a large commercial facility or campus: project management, material procurement, facility IT support, business services, planning and engineering. It does not include leasing commissions or direct supervision of M&R, grounds, or utilities.

Pest Control includes rodent control and insect abatement procedures and inspections, both indoors and outdoors. Use of herbicides is not included.

Refuse service includes trash collection and disposal, pick-up services, fees, recycling operations and administration. Not included are the handling and disposal of hazardous materials and investment in recycling programs or facilities.

Road Clearance includes sweeping sand and debris and removing snow and ice from paved areas including roads, sidewalks, walkways, and parking lots.

Security services insure the physical security of assets and occupants, and include monitoring equipment, personnel, and patrol services.

Telecommunications (Telecom) includes voice and data equipment and service.

Water and Sewer includes potable water, irrigation water, and sewage service.

Recapitalization: The investment required to restore and modernize real property assets. Distinct from sustainment and operations, recapitalization costs are largely a function of obsolescence, change in use, and changes to codes & policy. Recapitalization costs (targets) for each asset type are derived from a depreciation–based model used by the U.S Department of Defense, NASA, the US Bureau of Economic Analysis, and others.

Deferred Recapitalization is all restoration and modernization requirements not performed on schedule.

Operation cost calculations

The following information were retrieved from *The Whitestone Facility Operations Cost Reference 2011-2012, North America Version*, chapter 6 'Definitions and Methods':

- Whitestone provides profiles for 75 common asset types and assess operation costs for each asset over a 50-year period.
- **The estimation of each profile** is done with the MARS Facility Cost Forecast System, a software developed by Whitestone Research. The software uses information from a relational database that includes asset templates, component-related maintenance tasks, in-house shop rates, and contract trade rates, and material and equipment costs.
- **Variation in cost estimates** was evaluated through a Monte Carlo simulation; the input values of 18 variables for a 2 Story Office Building model was varied. The results showed that estimates varied between plus or minus 37%, thus within a 68% confidence interval.
- **Asset characteristics** are expressed as a percentage of replacement costs, that are derived from Whitestone survey data of actual federal projects normalized to Washington D.C. (replacement costs are: supervision, inspection, overhead, design and planning, contingencies).
- **Occupancy** is based on maximum design.

Appendix C: Detailed Whitestone Operation Cost Data

Table 15: ESB: Breakdown of Whitestone Operation Cost Data for Washington D.C. and calculated data for Vancouver.

ESB	Washington D.C.		Factor	Vancouver	
	Office Building	Laboratory General		Office Building	Laboratory General
Area	[US$ ft^{-2}]	[US$ft^{-2}]	[%]	[US$ ft^{-2}]	[US$ ft^{-2}]
Custodial	$2.52	$2.50	99.2%	$2.22	$2.20
Energy	$2.85	$11.64	408.4%	$1.04	$4.26
Grounds	$0.25	$0.25	100.0%	$0.29	$0.29
M&R	$3.02	$8.87	293.7%	$2.95	$8.67
Management	$2.45	$0.88	35.9%	$2.55	$0.92
Pest Control	$0.12	$0.12	100.0%	$0.11	$0.11
Refuse	$0.08	$0.08	100.0%	$0.08	$0.08
Road Clearance	$0.01	$0.01	100.0%	$0.01	$0.01
Security	$0.55	$0.68	123.6%	$0.47	$0.59
Telecom	$1.24	$1.05	84.7%	$1.55	$1.32
Water/Sewer	$0.44	$0.54	122.7%	$0.27	$0.33
Total	$13.530	$26.62	196.7%	$11.55	$22.73
Total - Energy	**$10.68**	**$14.98**	**140.3%**	**$10.51**	**$14.74**

Table 16: PSB: Breakdown of Whitestone Operation Cost Data for Washington D.C. and calculated data for Vancouver.

PSB	Washington D.C.		Factor	Vancouver	
	Office Building	Laboratory Life Sci.		Office Building	Laboratory Life Sci.
Area	[US$ per ft^{-2}]	[US$ per ft^{-2}]	[%]	[US$ per ft^{-2}]	[US$ per ft^{-2}]
Custodial	$2.52	$2.49	98.8%	$2.22	$2.19
Energy	$2.85	$12.67	444.6%	$1.04	$4.64
Grounds	$0.25	$0.25	100.0%	$0.29	$0.29
M&R	$3.02	$21.21	702.3%	$2.95	$20.73

Management	$2.45	$1.05	42.9%	$2.55	$1.09
Pest Control	$0.12	$0.12	100.0%	$0.11	$0.11
Refuse	$0.08	$0.08	100.0%	$0.08	$0.08
Road Clearance	$0.01	$0.01	100.0%	$0.01	$0.01
Security	$0.55	$0.69	125.5%	$0.47	$0.59
Telecom	$1.24	$1.05	84.7%	$1.55	$1.32
Water/Sewer	$0.44	$0.32	72.7%	$0.27	$0.20
Total	$13.530	$39.940	295.2%	$11.55	$34.10
Total - Energy	**$10.680**	**$27.270**	**255.3%**	**$10.51**	**$26.83**

Appendix D: Detailed Project Information used for CostLab

The following table shows the breakdown of the seven aspects information needed to create the online project profile for ESB and PSB:

Table 17: Detailed online Project Profile Breakdown

1. Building Information		
Name	Earth Sciences Building	Pharmaceutical Sciences Building
Cost	BC, Vancouver	BC, Vancouver
Size	Size: 15,910 m2 (171,254 sft)	29,696 m2 (319,645 sft)
Year	Year built: September 2012	September 2012
Type	Type: Lab, general	Laboratory, Life Science
2. Structural Details		
Roof Coverings	Concrete	Concrete
Exterior Walls	Concrete Cast-in-place	Steel
Interior Wall	Sheetrock	Sheetrock
Floor Finishes	Concrete	Concrete
Ceiling Finishes	Wood	Concrete
Elevator Quantity	2	2
Bathroom Quantity	10	10
Stories Quantity	6	5
3. Mechanical Details		
Heat Generating	Boiler, Gas	Boiler, Gas
Cooling Generating	Centrifugal Hermetic	Chiller, Centrifugal Hermetic
Distribution Systems	Air Handler, Multizone	Air Handler, Multizone
Terminal & Package Units	None	None
4. Utilization		
Hours of operation	Medium	Medium
Security	Low	Medium

Safety & Permitting	Medium	Medium
5. Operations		
Custodial	Medium	Medium
Energy	Low	Low
Grounds	Low	Low
Management	Low	Low
Pest Control	Low	Low
Refuse	Medium	Medium
Road Clearance	Low	Low
Security	Low	Medium
Telecom	Low	Low
Water/Sewer	Medium	Medium
6. Recapitalization		
Replacement Value	0	0
Prior Recap Investment	0	0
7. Asset Description		
Address	2207 Main Mall	2405 Wesbrook Mall
ID	not available	not available
Postal Code	V6T 1Z4	V6T 1Z3
City Name	Vancouver	
State Abbreviation	BC	BC
Country	Canada	Canada
Last Inspected Date	not available	not available