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INFLUENCE OF GEOGRAPHICAL LOCATION ON THE OPTIMUM INSULATION THICKNESS

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Abstract: Commercial and residential buildings are responsible for substantial emissions of greenhouse gases, which greatly promote global warming. Sustainable construction practices offer a partial solution to this problem, with effective insulation in the building envelope saving up to 77% of consumed energy, hence reducing GHG emission. However, to make a real difference, sustainable construction has to become more affordable, and thus more attractive to the general public. Therefore, finding an optimum balance between the initial and operational cost of the building can be beneficial not only for the environment, but also to owners' finances. The objective of this paper is to determine the trade-off between insulation cost and life cycle energy cost for a building situated in three different provinces of Canada. This study utilized a 3D BIM model of a single family house constructed by AYO Smart Home Inc. on the University of British Columbia campus in Vancouver. Revit and Green Building Studio were used to run energy simulations for design alternatives that were insulated with expanded polystyrene (EPS) ranging in thickness between 3 5/8" and 11 3/8" and located in selected cities of British Columbia, Alberta and the Yukon. The obtained life cycle energy cost and the insulation cost determined the optimum insulation thickness for each building location. The overall aim of this study was to aid AYO Smart Home Inc. with decision making regarding the design of their housing units in different regions of Canada.

1 INTRODUCTION

The growing awareness of global warming and its dreadful effects on our planet has led to the creation of worldwide and local policies. The recent Paris Agreement bound the signing parties to undertake efforts of "keeping the increase in global average temperature to well below 2°C above pre-industrial levels" (United Nations 2015). The municipal government of the City of Vancouver introduced an action plan of becoming the greenest city in the world by 2020. Working on all levels of the government and through cooperation between residents, businesses and organisations, the main goal is to reduce the city's ecological footprint by consistently achieving measurable targets – i.e. reducing solid waste going to landfills by 50% comparing to 2008 level. In order to meet the requirements of such programs, the building sector needs to become more sustainable, being the major contributor in energy consumption and emission of greenhouse gasses (GHG) in Vancouver. In the United States, commercial and residential buildings consume up to 40% of energy and account for 40% of greenhouse gases production (Berardi 2013). Similar trends can be observed in Vancouver where GHG emission from buildings reached 56% in 2014 (City of Vancouver 2015). One way to reduce GHG emission is to lower the amount of energy we use for heating. Well-insulated building envelopes can save up to 77% of the consumed energy (Mohsen and Akash 2001), hence minimizing the operational cost of the building. The challenge of the today's builders and designers is to build homes that are more energy efficient but also to make their initial and total lifecycle costs affordable. Therefore, finding the optimum between the initial and operational cost of the building can be beneficial not only for the environment, but also to owners' finances.

AYO Smart Home Inc. addressed this challenge in 2015 when they proposed an idea for an affordable, efficient and durable housing. In the fall of the same year, the company build a prototype home on the University of British Columbia campus. The target price per square foot of prototype building was between $100 and $150. The company address its product to remote First Nation communities in Canada, where winter conditions are often particularly unfavorable. The climate of Vancouver, in contrast, is considered to be moderate; it is oceanic with one of the highest annual average temperature in Canada. Moreover, the energy cost is relatively low. It is clear that thickness of the insulation of external walls in future AYO's Smart Homes will have to be altered in order to maintain the high energy efficiency of the buildings in different climates.

The goal of this paper is to determine the economic optimum for thermal insulation thickness for AYO buildings located in selected cities of British Columbia, Alberta and Yukon Territory.

This paper is structured in 5 sections. Section 2 describes the methodology of the research and presents the incorporated research framework, section 3 discuses studies on optimum insulation thickness while section 4 presents the results of the study. Finally, section 5 summarises and concludes the research.

2 METHODOLOGY

The first step of this research was to run energy analysis on the existing 3D model of the AYO building located on the University of British Columbia campus using Revit and Green Building Studio by Autodesk. Energy assessment was done for the AYO smart home constructed with structural insulated panels (SIPs) insulated with expanded polystyrene (EPS), with the thickness adjusted from 3 5/8" to 11 3/8". The output of the energy analysis for each studied insulation thickness is the life-cycle energy use and cost. The increase of the thermal insulation layer is the driving cost of the SIP panels. Therefore, the total cost of the external wall was adjusted accordingly (see Table 1). Obtained life cycle energy and panel costs were used to create the trade-off graph in order to determine the economic optimum insulation thickness. This procedure was repeated for the selected city locations listed in Table 2. The roadmap diagram for the research methodology is presented in the Figure 1.

Table 1: SIP Properties

Insulation thickness (in)	SIP Thickness (in)	R-Value (R)	Cost (Can$)
3 5/8	4 1/2	R-20	10,831.13
5 5/8	6 1/2	R-28	11,194.13
7 3/8	8 1/4	R-32	11,511.76
9 3/8	10 1/4	R-40	11,874.76
11 3/8	12 1/4	R-44	12,237.76

Table 2: Location Parameters

City	Province	HDD (F^o)	Electricity Cost ($/kWh)	Fuel Cost ($/Therm)
Vancouver	BC	3590	0.06	1.21
Tsawwassen	BC	3406	0.06	1.21
Halalt	BC	3639	0.06	1.21
McLeod Lake	BC	7768	0.06	1.21
Heart Lake	AB	9874	0.11	1.21
Ross River	YT	12153	0.14	0.14

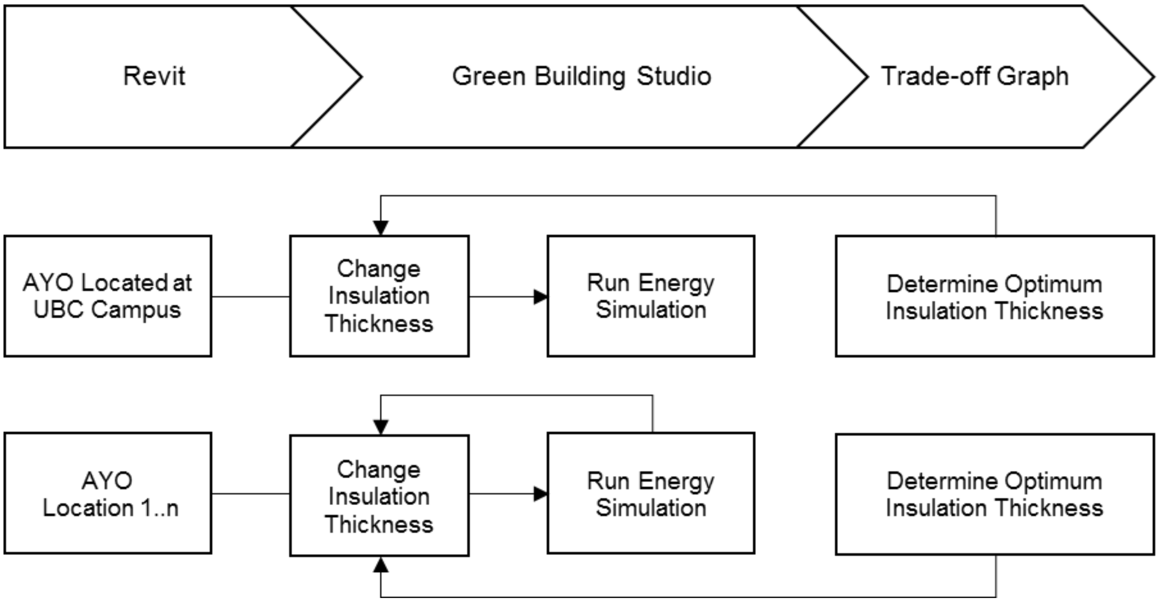


Figure 1: Roadmap diagram

3 POINTS OF DEPARTURE

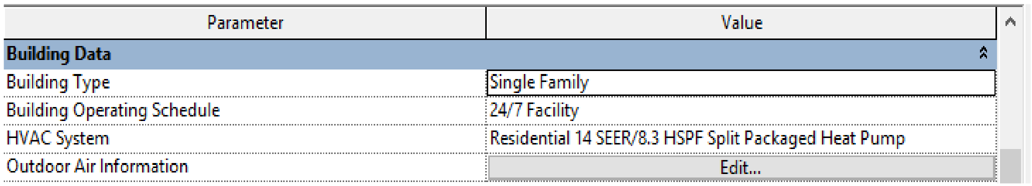
Many studies in recent years have focused on means of delivering energy efficient buildings. Several authors identified the building envelope and its components as one of the most crucial elements for energy saving buildings (Mohsen et al. 2001; Wang et al. 2007; Pacheco et al. 2012). National building codes, as well as municipal governments, define the minimum requirements for the R-value of the building envelope assemblies. For example, the City of Vancouver requires the minimum effective thermal resistance of above-grade walls to be not less than R-15.8 (Homeowner Protection Office 2015). Construction that meets but does not exceed this code will satisfying the minimum requirements for the building envelope and result in a low initial cost of the construction, but it may not produce the lowest energy consumption nor the lowest total cost over time. Therefore, determination and application of the optimum insulation thickness and selection of proper thermal insulation material may reduce the energy consumption, and hence, total life-cycle cost of the building. The optimum insulation thickness “is a function of building type, function, shape, orientation, construction materials, climatic conditions, insulation material and cost, energy type and cost, and the type and efficiency of air-conditioning system” (Kaynakli 2012). However, it is insensitive to the location within the wall assembly or to the number of layers distributed along the wall, as long as their sum is equal to the optimum value. (Al-Sanea et al. 2011). Çomaklı et. al 2003, investigated the optimum insulation thickness in three coldest cities of Turkey. However, they assumed that heat was lost only from the externa walls. Most studies focused on a combination of building location, fuel type, or thermal insulation material (Kaynakli 2012); however, no study was found that considered the whole building characteristics in order to determine the optimum insulation thickness. The use of BIM integrated with energy analysis software has been shown to predict the building performance during life cycle (Jayaram et al. 2015).

4 RESEARCH ACTIVITIES

4.1 BIM Model and SIP Properties

In order to run the energy simulation, a BIM model of the AYO smart home was used (Figure 2). It is a two-storey, single family house with one bathroom on each floor, a living room and a kitchen (which have clear height that spans two levels), and two rooms located on the second level. This makes 1620 sq.ft. total gross floor area. The roof area and external walls area are equal to 1680 sq.ft. and 1815 sq.ft, respectively. The external walls uses Magnesium Oxide (MgO) clad Structural Insulated Panels (SIP) which are insulated with expanded polystyrene (EPS), with the thickness varied in this study to 3 5/8, 5 5/8, 7 3/8, 9 3/8, or 11 3/8 inch thick. Table 1 presents the properties of SIP panels insulated with different thickness of EPS. Revit software combined with Green Building Studio generates the energy analytical model (Figure 2) of the building based on the building type, operating schedule and HVAC system information (**Error! Reference source not found.**). In this case study, a heat pump powered by the electricity and domestic hot water unit powered by the fuel oil were selected. The operating schedule was set as 24/7 because of the residential function of the building.

Figure 3: BIM and energy analytical model of AYO House



Parameter	Value
Building Data	
Building Type	Single Family
Building Operating Schedule	24/7 Facility
HVAC System	Residential 14 SEER/8.3 HSPF Split Packaged Heat Pump
Outdoor Air Information	Edit...

Figure 2: Energy settings

4.2 Finding the Optimum Insulation Thickness

In order to determine the optimal insulation design, the thickness was changed to several values from 3 5/8 to 11 3/8 inch. For each thickness, the energy assessment was performed using Revit and Green Building Studio. The output of the energy assessment is the life cycle energy consumption corresponding to the insulation thickness. Energy consumption multiplied by energy rates in particular location (see Table 2) and Present Value Interest Factor (PVIF), determined for a discount rate of 6.1% and a life span of 30 years yielded the life cycle energy cost. This energy cost and the insulation cost, both expressed as present values, were then graphed. As an example, the chart that represents the relationship between insulation cost and energy cost for the AYO smart house located on Vancouver campus of University of British Columbia is presented in Figure 4. The detailed results are presented in the Table 3. An increasing insulation thickness results in decreasing energy consumption. Hence, the total life cycle cost (life cycle energy cost plus cladding cost) decreases. This trend is true until it reaches a point where the total cost reaches its minimum value. This point is considered to be the economic optimum insulation thickness (Kaynakli 2012). Beyond this point the total cost exceeds the benefit of lesser energy consumption. The optimal insulation for the AYO smart house located in Vancouver UBC campus is a minimum value of the sum of life cycle energy cost and cladding cost (Figure 5). The optimal thickness for studied locations are presented in the Table 4.

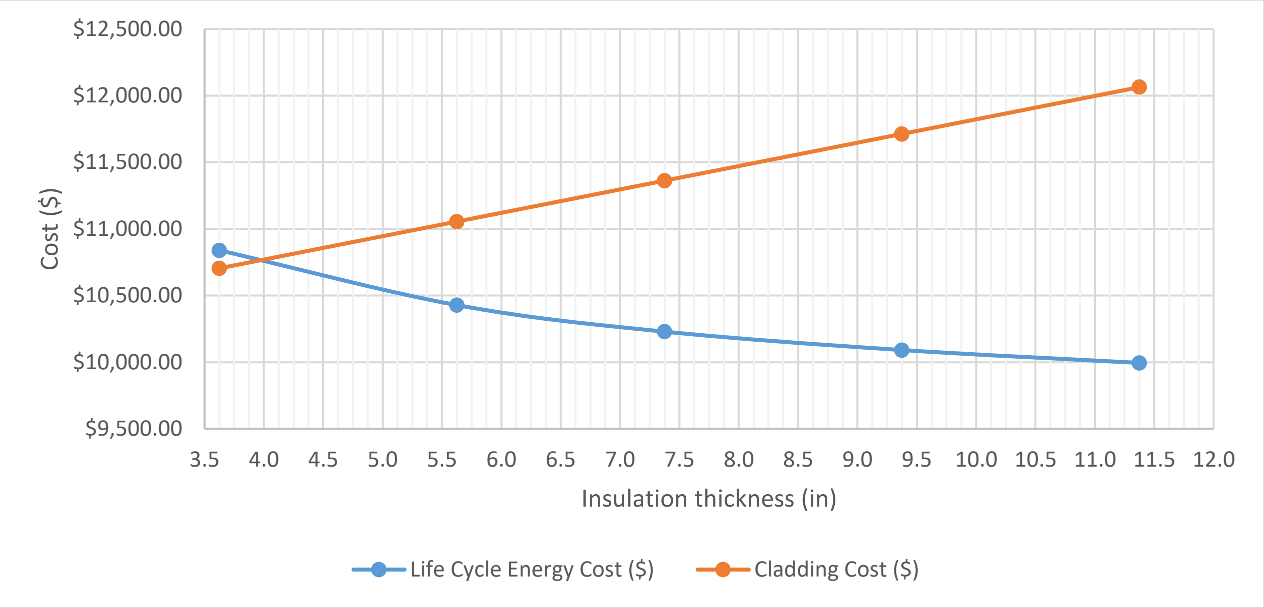


Figure 4: Cladding Cost and Life Cycle Energy Cost, Location UBC Campus

Table 3: Energy Assessment Results, Location UBC campus

Insulation Thickness (in)	3 5/8	5 5/8	7 3/8	9 3/8	11 3/8
Life Cycle Energy Cost ($)	10,839.45	10,428.35	10,229.14	10,091.18	9,994.68
Cladding Cost ($)	10,704.25	11,055.05	11,362.00	11,712.80	12,063.60
Total Cost ($)	21,543.70	21,483.40	21,591.14	21,803.98	22,058.28

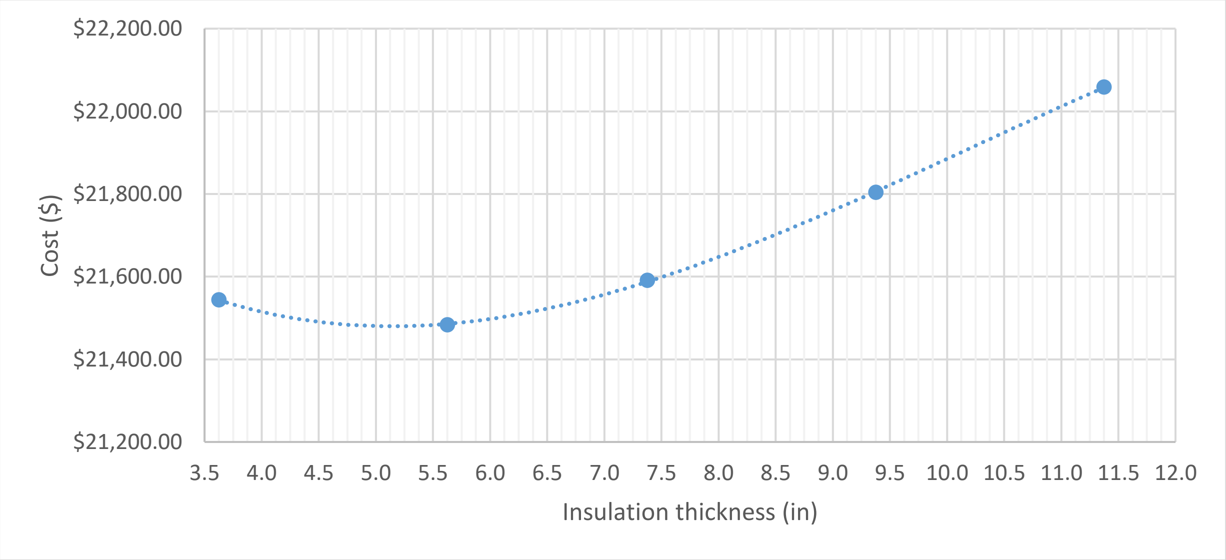


Figure 5: Total Life-Cycle Cost, Location UBC campus

Table 4: Optimum Insulation Thickness

City	Insulation Thickness (in)	Cladding Cost ($)	Electricity Use (kWh)	Fuel Use (Therm)	Energy Cost ($)	Total Cost ($)
Vancouver	5 5/8	11,054.63	348,845.00	1,687.00	10,430.97	21,485.60
Tsawwassen	4 6/7	10,918.69	344,252.62	1,676.00	10,297.22	21,215.91
Halalt	4 2/3	10,878.00	335,074.82	1,672.00	10,045.04	20,923.04
McLeod Lake	9 3/8	11,874.56	540,313.03	2,087.00	15,863.19	27,575.99
Heart Lake	11 3/8	12,063.18	662,594.00	2,274.00	34,336.10	46,399.70
Ross River	11 3/8	12,063.18	767,661.00	2,409.00	48,941.74	61,004.91

The results show that in three cities located in the fourth climatic zone of British Columbia (Homeowner Protection Office 2015), the cost of cladding constitutes nearly half the total cost. However, as the climate gets colder, the disproportion between the cladding cost and life cycle energy cost increases up to the point where optimum insulation thickness is the thickest tested insulation layer (i.e. 11 3/8 inch). The lowest life cycle energy cost of $10,045.04 was achieved by the AYO house located in the Halalt, BC, with optimum insulation thickness equal to 4 2/3 in. Buildings insulated with 11 3/8 in. thick EPS—located in the two coldest cities considered in this study, Ross River and Heart Lake—consumed energy values of $48,941.74 and $34.336.10, respectively, during their life cycle.

5 CONCLUSIONS

In order to determine the economic optimum insulation thickness for AYO Smart Home located in selected cities in the province of British Columbia, Alberta and the Yukon Territory, energy analyses were run using Revit software combined with Green Building Studio for buildings insulated with extruded polystyrene ranging in thickness from 3 5/8 to 11 3/8 inch. Life-cycle energy consumption decreases with the increase of the insulation thickness. This is true for both sources of energy used in this study—electricity, which powers the installed heat pump and lighting, and fuel oil, which powers the water heater. Life cycle energy cost plus the cost of the SIP panels plotted on charts were used to determine the economic optimum insulation thickness for each city, which is the minimum total life cycle cost of the building (Figure 8 and 9). The optimum insulation thickness increases while the climates are getting colder, however in very cold cities like Ross River and Heart Lake, there is a high disproportion between the cost of cladding and the cost of energy (see Figure 10). Therefore, the optimum insulation thickness is the highest possible insulation thickness i.e. 11 3/8 inch.

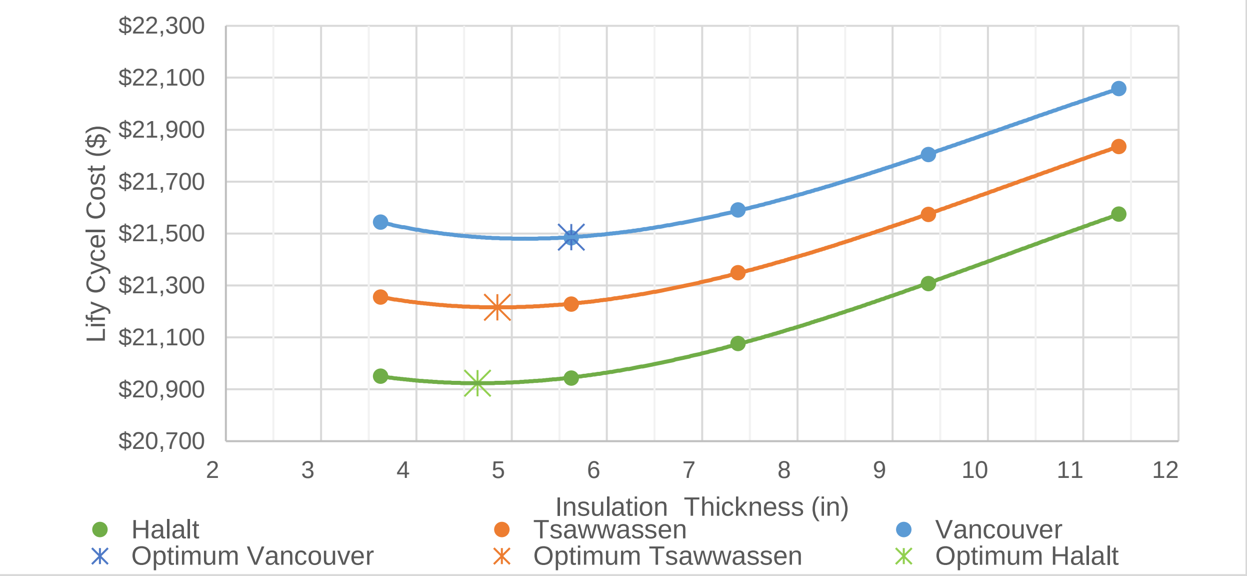


Figure 8: Life cycle cost, Location Halalt, Tsawwassen, and Vancouver

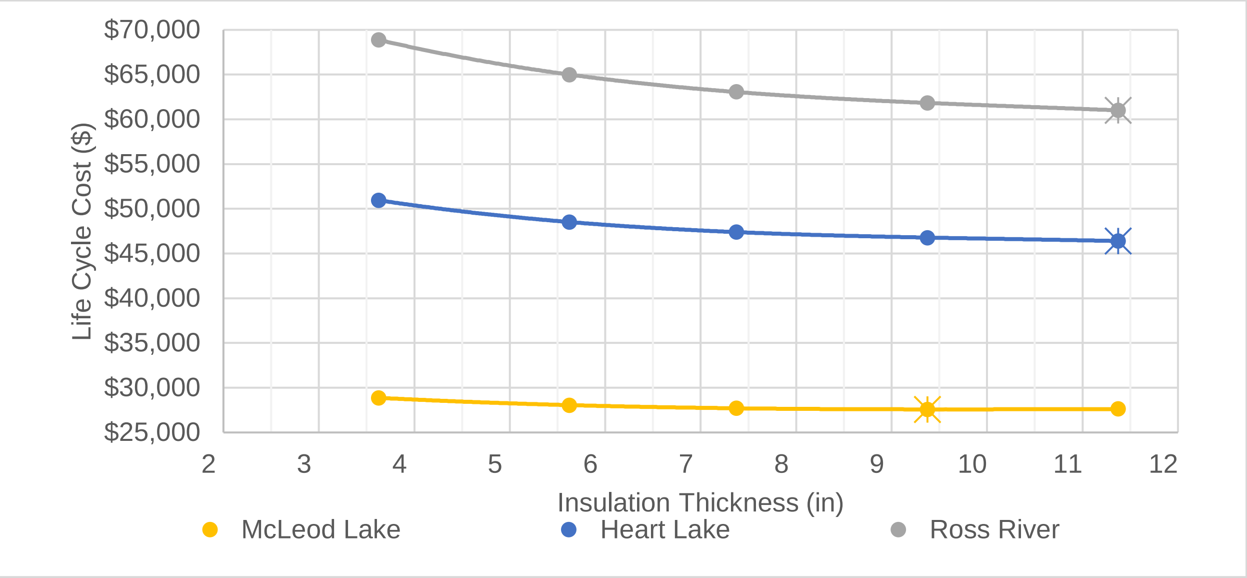
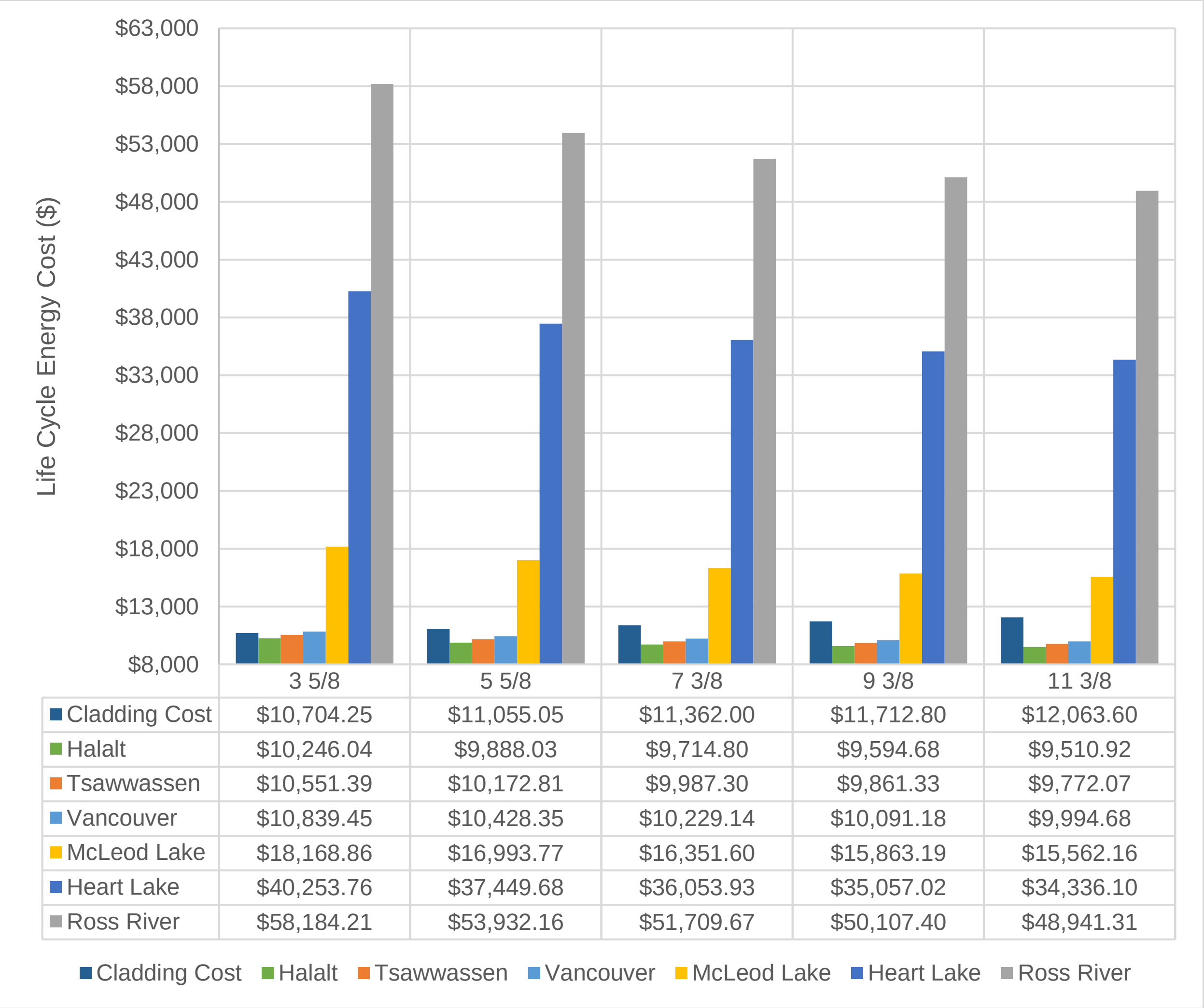


Figure 9: Life cycle cost, Location McLeod Lake, Heart Lake, Ross River



	3 5/8	5 5/8	7 3/8	9 3/8	11 3/8
Cladding Cost	$10,704.25	$11,055.05	$11,362.00	$11,712.80	$12,063.60
Halalt	$10,246.04	$9,888.03	$9,714.80	$9,594.68	$9,510.92
Tsawwassen	$10,551.39	$10,172.81	$9,987.30	$9,861.33	$9,772.07
Vancouver	$10,839.45	$10,428.35	$10,229.14	$10,091.18	$9,994.68
McLeod Lake	$18,168.86	$16,993.77	$16,351.60	$15,863.19	$15,562.16
Heart Lake	$40,253.76	$37,449.68	$36,053.93	$35,057.02	$34,336.10
Ross River	$58,184.21	$53,932.16	$51,709.67	$50,107.40	$48,941.31

Figure 10: Life Cycle Energy Cost

References

Al-Sanea, Sami A. and M. F. Zedan. 2011. "Improving Thermal Performance of Building Walls by Optimizing Insulation Layer Distribution and Thickness for Same Thermal Mass." *Applied Energy* 88 (9): 3113-3124. doi:10.1016/j.apenergy.2011.02.036. http://www.sciencedirect.com/science/article/pii/S0306261911001486.

Berardi, Umberto. 2013. "Clarifying the New Interpretations of the Concept of Sustainable Building." *Sustainable Cities and Society* 8: 72-78. doi:10.1016/j.scs.2013.01.008.

City of Vancouver. 2015. *Greenest City 2020 Action Plan Part Two* City of Vancouver.

Çomaklı, Kemal and Bedri Yüksel. 2003. "Optimum Insulation Thickness of External Walls for Energy Saving." *Applied Thermal Engineering* 23 (4): 473-479. doi:10.1016/S1359-4311(02)00209-0. http://www.sciencedirect.com/science/article/pii/S1359431102002090.

Homeowner Protection Office. 2015. *Illustrated Guide – Energy Efficiency Requirements for Houses in British Columbia*. 4th ed. ed. Homeowner Protection Office.

Jayaram, Raguram, Sreedhar Kalavagunta, and Sivakumar Naganathan. 2015. "Energy Performance Analysis of Buildings in BIM Workflow."Engineers Australia, . http://search.informit.com.au/documentSummary;dn=188271672008584;res=IELENG.

Kaynakli, Omer. 2012. "A Review of the Economical and Optimum Thermal Insulation Thickness for Building Applications." *Renewable and Sustainable Energy Reviews* 16 (1): 415-425. doi:10.1016/j.rser.2011.08.006. http://www.sciencedirect.com/science/article/pii/S1364032111004163.

Mohsen, Mousa S. and Bilal A. Akash. 2001. "Some Prospects of Energy Savings in Buildings." *Energy Conversion and Management* 42 (11): 1307-1315. doi:10.1016/S0196-8904(00)00140-0. http://www.sciencedirect.com/science/article/pii/S0196890400001400.

Pacheco, R., J. Ordonez, and G. Martinez. 2012. "Energy Efficient Design of Building: A Review." *Renewable and Sustainable Energy Reviews* 16 (6): 3559-3573. doi:10.1016/j.rser.2012.03.045.

United Nations. 2015. *Paris Agreement*.

Wang, Yaowu, Zhiye Huang, and Li Heng. 2007. "Cost-Effectiveness Assessment of Insulated Exterior Walls of Residential Buildings in Cold Climate." *International Journal of Project Management* 25 (2): 143-149. doi:10.1016/j.ijproman.2006.09.007. http://www.sciencedirect.com/science/article/pii/S0263786306001372.