

Analysis of Basement Insulation Alternatives

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**Ian Beausoleil-Morrison
Briana Paige Kemery**

**Mechanical & Aerospace Engineering
Carleton University
1125 Colonel By Drive
Ottawa, ON
Canada K12 5B6**



Carleton
UNIVERSITY

ABSTRACT

The effect of alternate basement insulation configurations on annual house heating load was evaluated. A typical house and basement geometry was defined. Heating loads were estimated using two building energy performance simulation tools: the ESP-r and BASECALC computer programs, and weather data for Whitehorse, Yukon.

The analysis considered convectively-heated and in-floor radiant heating configurations, as well as concrete and preserved wood foundations, and soil conductivity.

A number of insulation configurations were found to result in significant heating cost savings. For the best case, savings exceeded 86% compared to an uninsulated concrete basement. The payback was under two and a half years, based on prices and labour costs current at the time of the study.

The results were presented graphically to help house builders and others more easily compare alternative insulation configurations.

1. INTRODUCTION

An analysis was conducted to quantify the impact of alternate basement insulation placements upon heating loads in Yukon housing. A typical house and basement geometry was defined and then heating loads resulting with alternate basement insulation configurations were estimated using two building energy performance simulation tools. The analysis considered both convectively heated and radiantly heated configurations for Tasks A through D. Additional cases for concrete and preserved wood foundations (PWF) were examined in Tasks G through J. In addition, an assessment was conducted on the impact of soil conductivity in Task F.

The next section summarizes the modelling methods and assumptions employed in the analysis. Following this, results are presented in graphical and tabular form. These results are also contained in an accompanying spreadsheet to facilitate further analysis. A cost analysis including fuel, insulation, labour, and payback period is presented following the results. Finally, general conclusions were drawn from the analysis.

2. METHODOLOGY AND ASSUMPTIONS

2.1 Assumptions

The house model for the ESP-r building simulations conducted for this study has a footprint of 80 m² and an interior volume of 432 m³, including the basement. The house has 4.8 m² of windows facing each cardinal direction. The basement is assumed to have no windows. The analysis considers a full-depth basement where the floor slab is located 1.6 m below grade and the wall of the basement extends 1.1 m above grade for all cases.

The individual ESP-r simulations consider solar gains, infiltration, and thermal losses through the main floor envelope as well as heat losses through the foundation. The sensible heating load represents the energy required to maintain the house at an ambient temperature of 20°C throughout the year. In this analysis the total house heat loss from pairs of simulations are contrasted. Each simulation considers an alternate basement insulation configuration but in all cases the above-grade components of the house and other simulation parameters remain fixed. Consequently, the results shown from this analysis isolate the impact of basement configuration changes: the composition of the above-grade components in the ESP-r house model is inconsequential.

The floors of the PWF foundations are taken to be 100 mm thick. The PWF has a conductivity of 0.12 W/mK. The concrete walls are 200 mm thick, and the concrete basement floors are 100 mm thick. The concrete has a conductivity of 1.73 W/mK.

The energy simulations employed the Canadian Weather for Energy Calculations (CWEC) for Whitehorse. This hourly weather data, available from Environment Canada, is used for investigating building energy consumption compliance in accordance with the National Energy Code of Canada. (DOE)

The soil conductivities used in tasks A, B, C, D, G, H, I, and J are 0.8 and 0.9 W/mK for the above and below floor slab respectively: these are the values used in BASECALC for “normal” soil. The lower soil conductivity above the floor slab is attributed to effect of the lower compaction of the backfilled soil above the floor slab after construction. Task F investigates the impact of changing both the above and below floor slab soil conductivities first to 1.2 and 1.35 W/mK (“high conductivity” soil in BASECALC) respectively in cases F43 and F44 and finally to 1.8 and 2.0 W/mK (“perma-frost” soil in BASECALC) in cases F45 and F46 respectively. The soil conductivity values used are based on typical figures for various soil types that are used in both BASECALC and the HOT2000 computer program for residential energy analysis. For all tasks, the distance from the grade level to the water-table for Whitehorse is taken to be 8.0 m.

2.2 Methodology

Models for the Task base cases were configured in Natural Resources Canada's BASECALC software tool and a simulation was conducted to determine its heat loss factors. The BASECALC software (Natural Resources Canada, 2008) calculates basement heat-loss factors for the user-specified insulation configuration, basement geometry and site conditions using a finite-element approach derived from the Mitalas method that was developed at the National Research Council (Mitalas 1982; Beausoleil-Morrison et al. 1997). BASECALC allows the geographic location, building construction, water table depth and soil conductivity to be entered by the user. It then calculates the heat-loss factors which characterize the heat transfer over time from the basement to the surrounding soil and outdoor air.

The heat-loss factors calculated by BASECALC were then input to a model of the whole house in the ESP-r simulation program (ESRU, 2008). ESP-r is a comprehensive building simulation program and is being used by Natural Resources Canada as the calculation "engine" for HOT3000, the next generation of the HOT2000 energy analysis program. An annual energy simulation of the whole house with the base case basement (G47 for concrete basements and G48 for PWF basements) was then performed using 30-minute time-steps (a sensitivity study indicated this was an appropriate time resolution for this analysis). This simulation resulted in a prediction of the annual space heating demand for the house with the base case basements.

A number of basement wall and sub-slab insulation configurations with varying insulation thicknesses or other parameters, such as soil conductivity, were then analyzed. Each of these insulation configurations was defined as shown in Appendix A. A graphic representation of each insulation configuration is shown in Appendix A as well. Each similar insulation configuration was assigned a task (or group) letter and a case number as an identifier. The base case is typically the one with the lowest level of sub-slab, wall or skirt insulation in each task. Tasks A, B, C, D, F, G, H, I and J used a convective heating system to predict the annual space heating demand required to maintain the indoor air temperature at 20°C. Task E analyses the same insulation configurations of Tasks A, B, C and D but assumes that the house is conditioned with an in-floor heating system located within the basement slab. With this, ESP-r forms an energy balance each 30 minutes of the annual simulation in order to calculate the floor temperature required to maintain the indoor air temperature at 20°C. A modification to the ESP-r source code was made in order to account for the impact of elevated slab temperatures upon heat losses from the basement.

3. RESULTS

The annual heating results for Tasks A through J are presented in bar graphs in the following subsections. Appendix A contains the exhaustive list of cases and their respective insulation configurations. Appendix B provides the net reduction in annual sensible heating load for each case relative to its base case.

Tasks A through D, and F through J were evaluated using convective heat transfer. All the cases in the aforementioned tasks are referenced to the base case G47 and are therefore presented together. Task E re-evaluates the cases of all preceding tasks assuming in-floor heating. Thus, all Task E cases are compared to the base case E22 (annual heat load: 26,848 kWh) and are presented together. Task F examines the impact of different soil conductivity values. The soil conductivity values for each task are in Table 3.1. Cases F43 and F45 are compared to case A1 while cases F44 and F46 are contrasted with case A8. Case A1 (annual heat load: 24,979 kWh) has interior insulation of R20 over the full height of the interior walls. There is no thermal bridge between the floor slab and the walls and there is no insulation under the floor slab. Case A8 (annual heat load: 22,360 kWh) has R30 insulation over the full height of the interior walls, R20 sub-slab insulation and no thermal bridge.

The base case for the concrete cases of Tasks A-D, G, H and J is Case G47 (annual heat load: 51,647 kWh; heat loss through foundation: 35,457 kW), an uninsulated concrete foundation basement. The base case for the PWF cases of Tasks G, H and I is Case G48 (annual heat load: 38,486 kWh), an uninsulated PWF basement. As previously mentioned, the minimum wood sheeting thickness allowable in Basecalc is 50mm. The result is a lower heat loss through the PWF basement.

Table 3.1 Tasks A-J Soil Conductivity Values

Task	Case	Soil Conductivity W/mK	
		Above floor slab	Below floor slab
A	All	0.8	0.9
B	All	0.8	0.9
C	All	0.8	0.9
D	All	0.8	0.9
E	All	0.8	0.9
F	43	1.2	1.35
	44	1.2	1.35
	45	1.8	2.0
	46	1.8	2.0
G	All	0.8	0.9
H	All	0.8	0.9
I	All	0.8	0.9
J	All	0.8	0.9

3.1 Tasks A-D

The base case for Tasks A-D, case G47 has the insulation configuration of Figure 3.1. Of the Task A cases, case A15 shows the greatest reduction in the annual sensible heating load relative to case G47. The insulation configuration of A15 consists of wall insulation of R50 and sub-slab insulation of R40 and no thermal bridge or skirt as shown in Figure 3.2.



Figure 3.1 Base Case (G47) Insulation Configuration



Figure 3.2 Insulation Configuration of Case A15

Case B17 demonstrates the greatest reduction in annual heating load of all the insulation configurations for the convective heating cases of Tasks B, C and D (See Figure 3.3). Case B17 has R30 insulation on the wall, R20 sub-slab insulation, an R10 horizontal skirt (See Figure 3.4) and no thermal bridge. Task C differs from Task B in that it has a 10 cm thermal bridge and no horizontal skirt insulation. However, Task D has a horizontal skirt in addition to the 10 cm thermal bridge. The lower sensible heating load required in case B17 indicates that the heat loss incurred by the thermal bridge is greater than the energy savings effect of horizontal skirt insulation.



Figure 3.3 Tasks A-D Savings in Heat Load versus Base Case G47



Figure 3.4 Insulation Configuration of Case B17

3.2 Task E

Task E re-evaluates the first 21 cases assuming in-floor heating with E22 referenced as the base case. The trends of the results (See Figure 3.5) are consistent with those of the cases discussed in Section 3.1. However, due to the greater heat losses from elevated slab temperatures, the reduction in the annual heating load due to the addition of insulation tends to be greater. For example, for the convection heating case with R20 wall insulation (A1), the heat loss is 24,979 kWh. The reduction in the heat loss from adding R30 sub-slab insulation (A10; 22,989 kWh) is 1,990 kWh. For the in-floor heating case with R20 wall insulation (E22), the heat loss is higher at 26,848 kWh. The reduction in the heat loss from adding R30 sub-slab insulation (E31; 24,381 kWh) is also higher at 2,467 kWh.

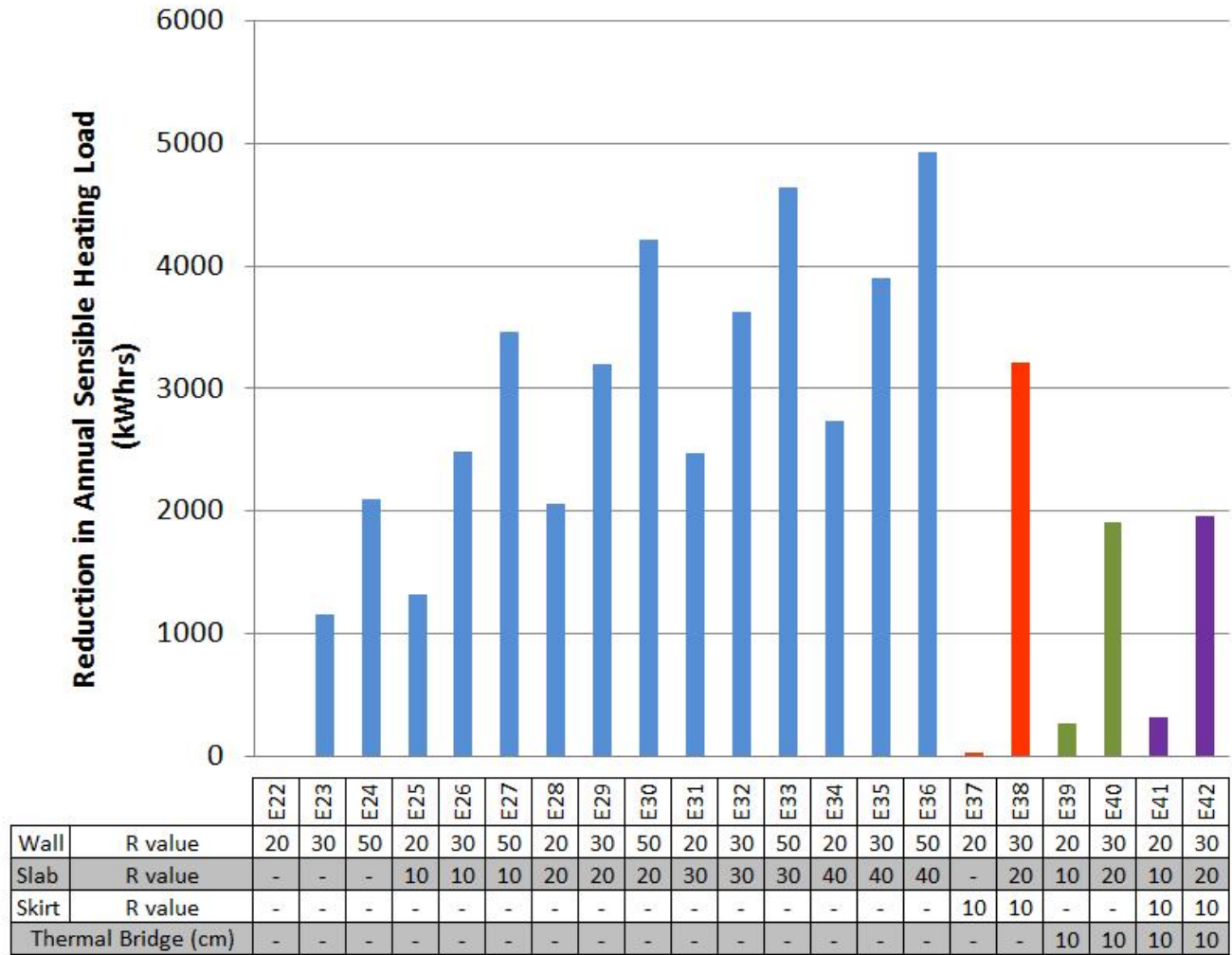


Figure 3.5 Task E (In-floor Heating) Savings in Heat Load Versus Case E22

3.3 Task F

Task F examines the effect of soil conductivity on the sensible heating load results. Figures 3.6 present the results for Task F cases where F43 and F45 are compared to case A1, while cases F44 and F46 are compared to case A8. In all cases, a higher soil conductivity results in a higher annual sensible heating load with reference to the respective base case. As expected, the greater insulation of cases F44 and F46 minimises the influence of soil conductivity.

Wall	R value	20	20	20	30	30	30
Slab	R value	-	-	-	20	20	20
Skirt	R value	-	-	-	-	-	-
Thermal Bridge (cm)		-	-	-	-	-	-
Soil Conductivity	above	0.80	1.20	1.80	0.80	1.20	1.80
	below	0.90	1.35	2.00	0.90	1.35	2.00
		A1	F43	F45	A8	F44	F46

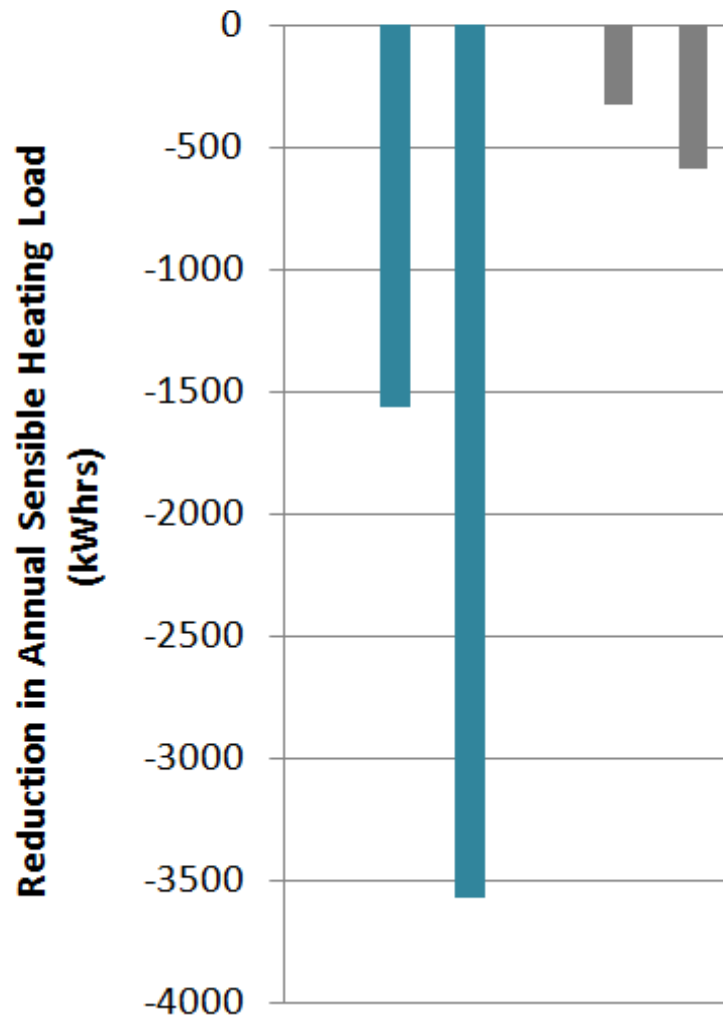


Figure 3.6 Task F Savings in Heat Load versus Base Cases A1 & A8

3.3 Task G

Task G contains two cases which are used as the base cases for the following Tasks H through J.

Case G47 is an uninsulated concrete foundation basement. This is the base case to which all concrete foundation cases are referenced in Tasks H and J. Similarly, Case G48 is an uninsulated preserved wood foundation (PWF) basement. All the PWF cases in Task H and I are referenced to G48 as the base case. Figure 3.7 shows the uninsulated basement Basecalc file.



Figure 3.7 Non-Insulated Base Cases for Tasks H, I & J

3.4 Task H

Task H contains three concrete foundation and three PWF insulation configurations. Cases H49 through H51 are concrete foundation cases with and without R10 insulation on the exterior wall and with and without an R10 horizontal skirt. The diagram of concrete case H51 with G47 as the base case is in Figure 3.8. Cases H52 through H54 are PWF foundations with the same insulation configurations as the concrete Task H cases with additional R20 fibre glass batting insulation on the interior wall for all three cases. The diagram of PWF case H54 with G48 as the base case is in Figure 3.9.



Figure 3.8 Concrete Foundation Case H51



Figure 3.9 PWF Case H54

3.5 Task I

The cases of Task I investigate a PWF basement with R50 insulation on the whole of the interior walls. The results include the basement with and without an R10 horizontal skirt as pictured in Figure 3.10.



Figure 3.10 PWF Case I55

3.5 Task J

Case J57 is a concrete foundation basement with R10 insulation on the interior and exterior walls as shown in Figure 3.11.



Figure 3.11 Concrete Case J57

3.5 Results for Concrete Tasks G-J

The results for the concrete foundation cases indicate the greatest reduction in annual sensible heating load is achieved with R10 exterior and interior wall insulation. Having an R10 horizontal skirt has a negligible impact on the heat loss of the basement.

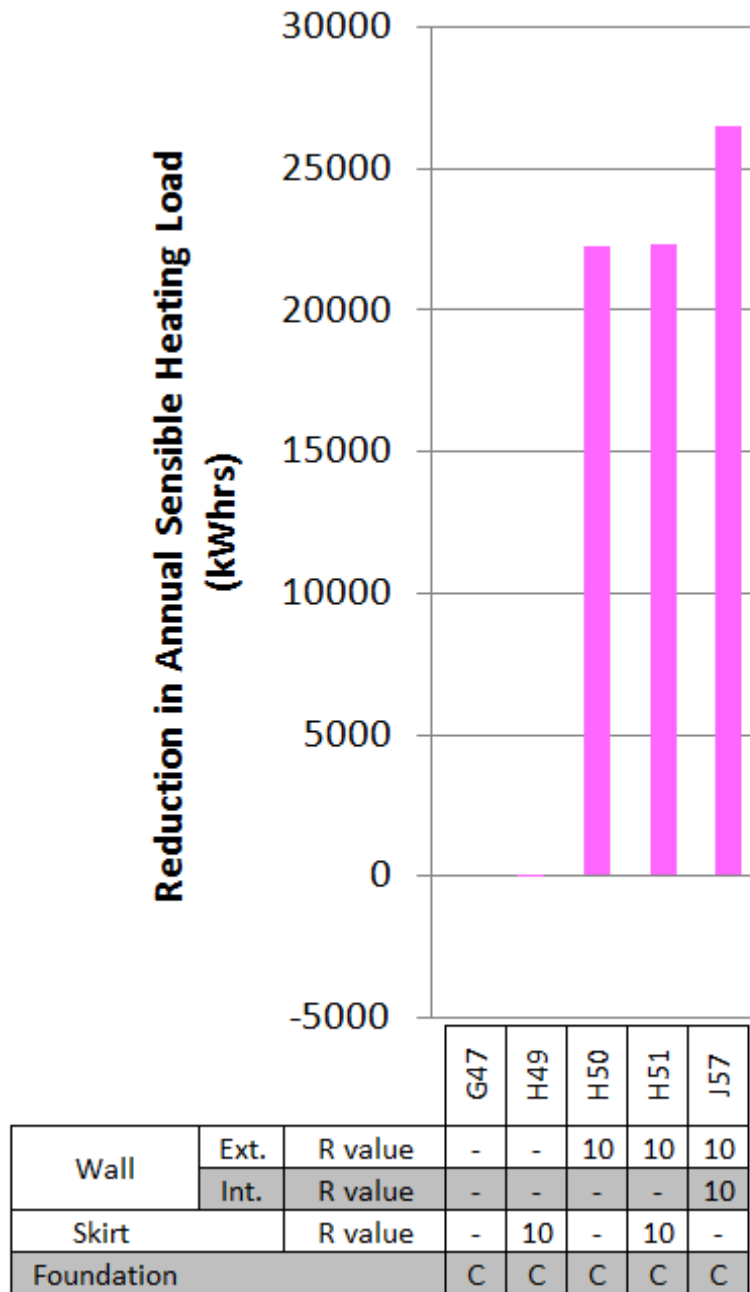


Figure 3.12 Tasks G-J Concrete Foundation Cases

3.5 Results for PWF Tasks G-J

The results for the PWF cases show the same trend as the concrete cases. The greatest reduction in annual sensible heating load is achieved with full interior wall insulation of R50 and an R10 skirt. Once again, the horizontal skirt has minimal impact on the heat loss behaviour of the basement.

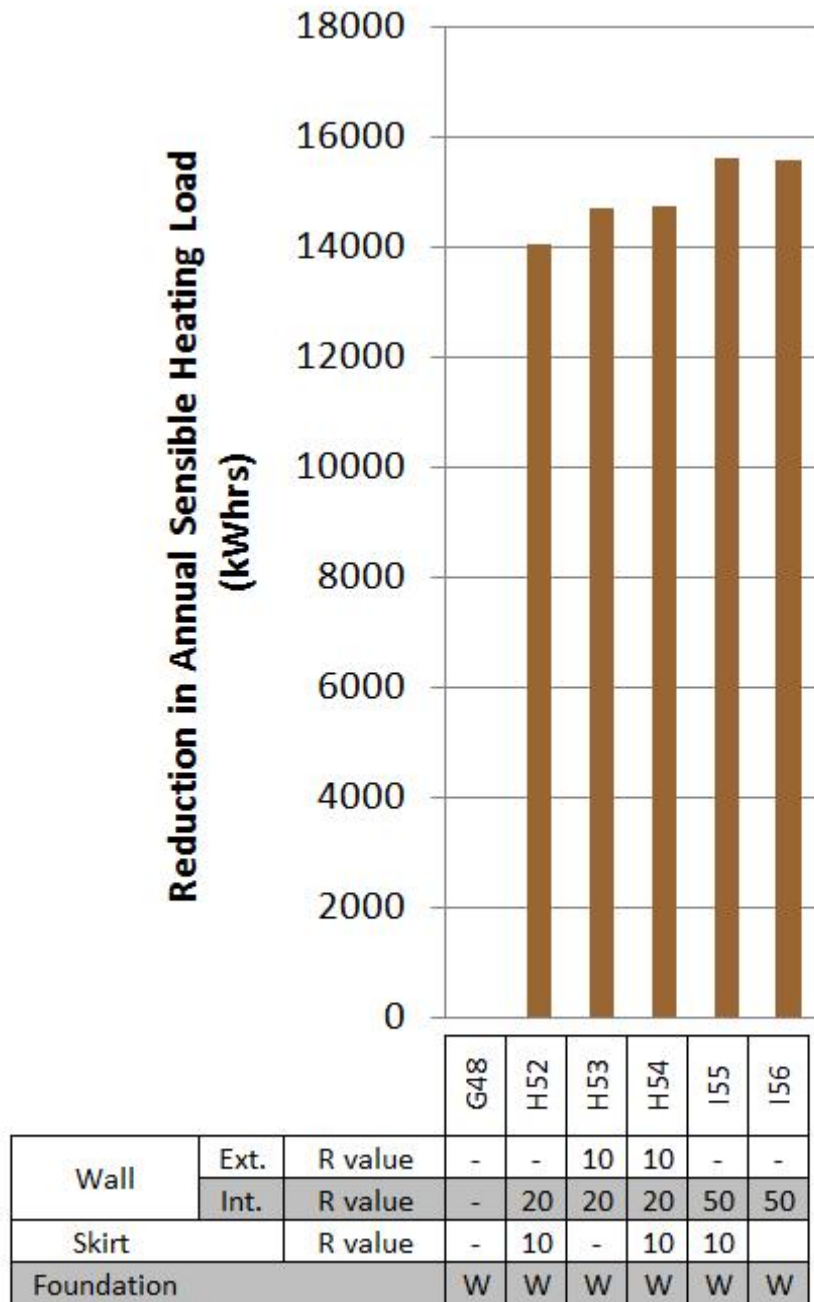


Figure 3.13 Tasks G-J PWF Foundation Cases

4. CAPITAL AND INSULATION COST ANALYSIS

To determine the most cost effective insulation configuration, a number of aspects were considered in a cost analysis.

The capital cost for the insulation and installation and the fuel cost savings associated with increased insulation were estimated. Lastly, the payback time in years for the fuel cost savings to equal the increased capital cost for a basement with more insulation was determined.

4.1 Assumptions

The fuel use efficiency and cost is assumed to be 84% (HHV basis) and \$1.00/L respectively, for the purposes of this analysis.

Insulation prices are quoted by Home Hardware in Whitehorse, Yukon. Exterior wall, skirt and sub-slab insulation material is rigid extruded polystyrene sheets. In all cases R5/inch 2" extruded polystyrene sheets are used. Interior wall insulation is fibreglass batting insulation. Appendix D contains the price for each insulating product as well as labour cost estimate assumptions.

The labour wage (\$30/hr) was selected based on discussion with an Ottawa-based homebuilder. To ascertain the payback period's sensitivity to the labour time estimates, these estimates were doubled and the analysis repeated. The convectively heated case that saw the greatest increase in payback period was A1. It increased from 0.31 to 0.37 years, a difference of 16%. Therefore, it was concluded that the predicted payback period is only weakly sensitive to labour time estimates.

For installation cost estimates, it is assumed there is no additional excavation required and there is no protection required above or below the extruded polystyrene. The exterior wall installation assumes backfill is applied against the extruded polystyrene and that flashing and parging are required. The cost estimate for flashing and parging is included in the labour estimate only, not the materials cost (See Appendix D). The basement is assumed to have 2x6 framed walls for installation of the fibreglass. The framing is pulled back from the walls to accommodate the higher R-value insulation. The interior wall insulation is finished with an air barrier and drywall.

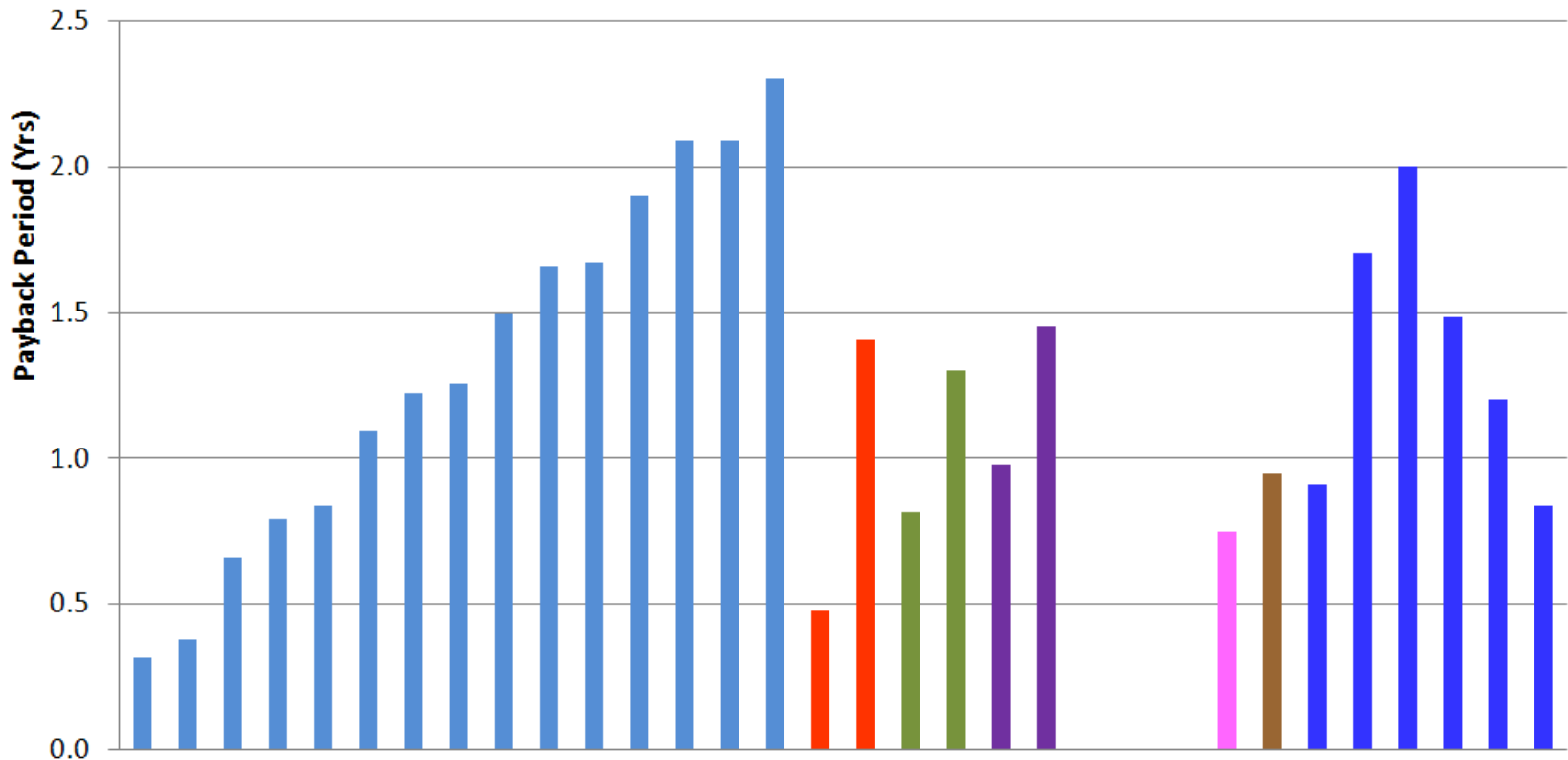
38.2 MJ/L is the energy content (HHV) of the heating fuel oil used in the analysis. (NRCan, 2004)

Appendix C contains the calculation method for insulation quantities and other relevant values. Appendix D gives the cost for insulation and the assumptions in the labour estimates.

4.2 Cost Analysis Results

Table 4.1 Summary of Cost Analysis

Case	XTPS (sheets)		Fibreglass Batting (bundles)			Insulation (\$)	Labour (\$)	Payback (years)
	8x2 ft	8x4 ft	R12	R20	R30			
A1	0	0	0	14	0	755.58	180	0.31
A2	0	0	0	0	17	982.09	180	0.37
A3	0	0	0	14	17	1737.67	360	0.66
A4	27	0	0	14	0	2159.58	300	0.79
A5	27	0	0	0	17	2386.09	300	0.83
A6	27	0	0	14	17	3141.67	480	1.09
A7	54	0	0	14	0	3563.58	330	1.23
A8	54	0	0	0	17	3790.09	330	1.25
A9	54	0	0	14	17	4545.67	510	1.50
A10	81	0	0	14	0	4967.58	360	1.66
A11	81	0	0	0	17	5194.09	360	1.67
A12	81	0	0	14	17	5949.67	540	1.90
A13	108	0	0	14	0	6371.58	390	2.09
A14	108	0	0	0	17	6598.09	390	2.09
A15	108	0	0	14	17	7353.67	570	2.30
B16	0	15	0	14	0	1205.43	225	0.48
B17	54	15	0	0	17	4239.94	375	1.40
C18	27	0	0	14	0	2159.58	300	0.82
C19	54	0	0	0	17	3790.09	330	1.30
D20	27	15	0	14	0	2609.43	345	0.98
D21	54	15	0	0	17	4239.94	375	1.45
G47	0	0	0	0	0	0	0	0.00
G48	0	0	0	0	0	0	0	0.00
H49	0	15	0	0	0	449.85	45	-
H50	33	0	0	0	0	1716	150	0.75
H51	33	15	0	0	0	2165.85	195	0.94
H52	0	15	0	14	0	1205.43	225	0.91
H53	33	0	0	14	0	2471.58	330	1.70
H54	33	15	0	14	0	2921.43	375	2.00
I55	0	15	0	14	17	2187.52	405	1.48
I56	0	0	0	14	17	1737.67	360	1.20
J57	33	0	8	0	0	2155.76	330	0.84



		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	B16	B17	C18	C19	D20	D21	G47	G48	H49	H50	H51	H52	H53	H54	I55	I56	J57
Wall	Int R value	20	30	50	20	30	50	20	30	50	20	30	50	20	30	50	20	30	20	30	20	30	-	-	-	-	-	20	20	20	50	50	10
	Ext R value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	10	-	10	10	-	-	-	10
Slab	R value	-	-	-	10	10	10	20	20	20	30	30	30	40	40	40	-	20	10	20	10	20	-	-	-	-	-	-	-	-	-	-	-
Skirt	R value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	10	-	-	10	10	-	-	10	-	10	10	-	10	10	-	-
Thermal Bridge (cm)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	10	10	10	-	-	-	-	-	-	-	-	-	-	-
Reduction in Annual Sensible Heating Load (kWhrs)		26667.89	27635.85	28420.84	27729.62	28700.50	29519.65	28322.77	29287.43	30112.30	28657.72	29619.62	30453.86	28870.10	29839.81	30677.87	26683.20	29288.16	26878.96	28230.13	26916.92	28271.84	0.00	0.00	-4.82	22244.19	22276.32	14049.09	14684.46	14714.64	22881.14	22919.77	26467.09

Figure 4.1 Tasks A-D, G-J Payback Period

CONCLUSIONS

Compared to an uninsulated concrete basement (case G47; 35,457 kWh), the largest reduction in the annual sensible heating load (30,667.87 kWh or 86.5%) was achieved using R40 sub-slab insulation, and R50 interior wall insulation (case A15; 4,789.13 kWh). As expected, A15 also has the longest payback period. Although this alternative has the longest payback period (2.3 years), it does show that at heating and construction costs current at the time of the study, even installing a high level of insulation has a short payback when compared to uninsulated basement walls.

Some of the wall and sub-slab insulation options have very similar energy savings. For example, R50 wall insulation and R20 sub-slab insulation (A9) result in an annual heat loss that is only 566 kWh (or 2.7%) higher than the best case A15 with R50 wall insulation and R40 sub-slab insulation (payback period: 2.3 years). This amounts to a difference in annual energy cost of approximately \$63 using a heating fuel oil cost of \$1 per litre. The calculated payback for this case is 1.5 years. Similarly, R50 wall insulation and R10 sub-slab insulation (A6) results in an annual heat loss that is only 1,158 kWh (or 5.5% higher) than the best case (A15). This amounts to a difference in annual energy cost of approximately \$130. The calculated payback for this case is 1.09 years. As a final example, R30 wall insulation and R20 sub-slab insulation (A8) results in an annual heat loss which is 1,390 kWh (or 6.6%) greater than the best case (A15). This amounts to a \$156 increase in fuel costs per year. The calculated payback for this case is 1.25 years. Thus there are a number of insulation cases which have similar energy savings and offer a choice in at least one of payback period, construction methods and labour costs.

For the cases examined, horizontal skirt insulation has a negligible impact on the annual sensible heating load. For instance, case H50 (R10 wall, without sub-slab insulation or a skirt) and H51 (R10 wall, no sub-slab insulation with an R10 skirt) have reductions in annual sensible heating loads of 22,244 and 22,276 kWh respectively. So while the skirt results in a less than 1% increase in heating load savings, the payback period increases from 0.75 to 0.94 years (~25% increase). This trend is seen with all the cases where horizontal skirt insulation is implemented. These results suggest that adding an insulation skirt is not very cost effective.

The results for case A4 and C18 indicate that a 10 cm thermal bridge has a detrimental impact on the effectiveness of the basement insulation. Both cases have an R20 interior wall and R10 sub-slab insulation configuration; however, C18 also has a 10cm thermal bridge. A4 and C18 have annual sensible heat load reductions of 27,730 and 26,879 kWh respectively, a difference of roughly 3%. It should be noted that the payback analysis does not account for the material or labour savings that may be associated with the thermal bridge as this information was not available. The thermal bridge does result in an increase in annual energy use of 851 kWh, or approximately 3% of the total for the basement insulation, for an additional heating cost of approximately \$95.

In-floor heating resulted in an increase in heating load relative to convective heating, ranging from 4.5 to 7.5%. The case with the highest amount of insulation (E36) had the smallest increase of 4.5% whereas the case with the least insulation (E22) saw the greatest increase of 7.5%. In Task F where higher soil conductivity (1.8 W/mK below grade and 2.0 W/mK above floor slab) is modelled, the annual sensible heating load was less for case A8 (R30 wall, R20 sub-slab insulation) versus A1 (R20 wall, no sub-slab insulation).

Installing R20 insulation on the interior walls results in a 201 kWh (0.8%) reduction in annual sensible heating load compared to R10 insulation on exterior and interior walls.

Although fewer preserved wood cases were analysed, the PWF results showed similar trends to the concrete cases analysed.

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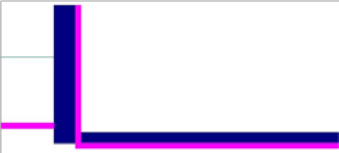


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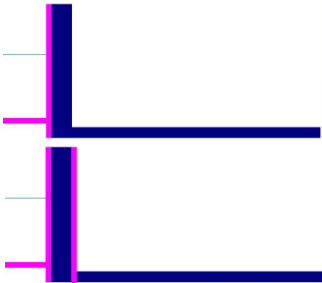
Price Estimates: Home Hardware, Whitehorse, Yukon.


APPENDIX A – INSULATION CONFIGURATIONS


Task A	Case	Wall ft ² ·°F·h/Btu	Sub-slab ft ² ·°F·h/Btu	Skirt ft ² ·°F·h/Btu	Thermal Bridge (cm)
	1	R20	N/A	N/A	N/A
	2	R30	N/A	N/A	N/A
	3	R50	N/A	N/A	N/A
	4	R20	R10	N/A	N/A
	5	R30	R10	N/A	N/A
	6	R50	R10	N/A	N/A
	7	R20	R20	N/A	N/A
	8	R30	R20	N/A	N/A
	9	R50	R20	N/A	N/A
	10	R20	R30	N/A	N/A
	11	R30	R30	N/A	N/A
	12	R50	R30	N/A	N/A
	13	R20	R40	N/A	N/A
	14	R30	R40	N/A	N/A
	15	R50	R40	N/A	N/A
Task B	Case	Wall ft ² ·°F·h/Btu	Sub-slab ft ² ·°F·h/Btu	Skirt ft ² ·°F·h/Btu	Thermal Bridge (cm)
	16	R20	N/A	R10	N/A
	17	R30	R20	R10	N/A
Task C	Case	Wall ft ² ·°F·h/Btu	Sub-slab ft ² ·°F·h/Btu	Skirt ft ² ·°F·h/Btu	Thermal Bridge (cm)
	18	R20	R10	N/A	10
	19	R30	R20	N/A	10
Task D	Case	Wall ft ² ·°F·h/Btu	Sub-slab ft ² ·°F·h/Btu	Skirt ft ² ·°F·h/Btu	Thermal Bridge (cm)
	20	R20	R10	R10	10
	21	R30	R20	R10	10

<i>Task E</i>	<i>Case</i>	<i>Wall</i> ft ² ·°F·h/Btu	<i>Sub-slab</i> ft ² ·°F·h/Btu	<i>Skirt</i> ft ² ·°F·h/Btu	<i>Thermal Bridge</i> (cm)
	22	R20	N/A	N/A	N/A
	23	R30	N/A	N/A	N/A
	24	R50	N/A	N/A	N/A
	25	R20	R10	N/A	N/A
	26	R30	R10	N/A	N/A
	27	R50	R10	N/A	N/A
	28	R20	R20	N/A	N/A
	29	R30	R20	N/A	N/A
	30	R50	R20	N/A	N/A
	31	R20	R30	N/A	N/A
	32	R30	R30	N/A	N/A
	33	R50	R30	N/A	N/A
	34	R20	R40	N/A	N/A
	35	R30	R40	N/A	N/A
	36	R50	R40	N/A	N/A
		37	R20	N/A	R10
38		R30	R20	R10	N/A
	39	R20	R10	N/A	10
	40	R30	R20	N/A	10
	41	R20	R10	R10	10
	42	R30	R20	R10	10
<i>Task F</i>	<i>Case</i>	<i>Wall</i> ft ² ·°F·h/Btu	<i>Sub-slab</i> ft ² ·°F·h/Btu	<i>Skirt</i> ft ² ·°F·h/Btu	<i>Thermal Bridge</i> (cm)
	43	R20	N/A	N/A	N/A
	44	R30	R20	N/A	N/A
	45	R20	N/A	N/A	N/A
	46	R30	R20	N/A	N/A


Task G	Case	Exterior Wall ft ² ·°F·h/Btu	Interior Wall ft ² ·°F·h/Btu	Skirt ft ² ·°F·h/Btu	Thermal Bridge (cm)
	47	N/A	N/A	N/A	N/A
	48	N/A	N/A	N/A	N/A


Task H	Case	Exterior Wall ft ² ·°F·h/Btu	Interior Wall ft ² ·°F·h/Btu	Skirt ft ² ·°F·h/Btu	Thermal Bridge (cm)
	49	N/A	N/A	R10	N/A
	50	R10	N/A	N/A	N/A
	51	R10	N/A	R10	N/A
	52	N/A	R20	R10	N/A
	53	R10	R20	N/A	N/A
	54	R10	R20	R10	N/A


Task I	Case	Exterior Wall ft ² ·°F·h/Btu	Interior Wall ft ² ·°F·h/Btu	Skirt ft ² ·°F·h/Btu	Thermal Bridge (cm)
	55	N/A	R50	R10	N/A
	56	N/A	R50	N/A	N/A


Task J	Case	Exterior Wall ft ² ·°F·h/Btu	Interior Wall ft ² ·°F·h/Btu	Skirt ft ² ·°F·h/Btu	Thermal Bridge (cm)
	57	R10	R10	N/A	N/A





APPENDIX B – ANNUAL SENSIBLE HEATING LOADS


<i>Task A</i>	<i>Case</i>	<i>Reduction in Annual Sensible Heating Load Relative to G47 (kWh)</i>
	1	26667.89
	2	27635.85
	3	28420.84
	4	27729.62
	5	28700.50
	6	29519.65
	7	28322.77
	8	29287.43
	9	30112.30
	10	28657.72
	11	29619.62
	12	30453.86
	13	28870.10
	14	29839.81
	15	30677.87

<i>Task B</i>	<i>Case</i>	<i>Reduction in Annual Sensible Heating Load Relative to G47 (kWh)</i>
	16	26683.20
	17	29288.16


<i>Task C</i>	<i>Case</i>	<i>Reduction in Annual Sensible Heating Load Relative to G47 (kWh)</i>
	18	26878.96
	19	28230.13


<i>Task D</i>	<i>Case</i>	<i>Reduction in Annual Sensible Heating Load Relative to G47 (kWh)</i>
	20	26916.92
	21	28271.84


<i>Task E</i>	<i>Case</i>	<i>Reduction in Annual Sensible Heating Load Relative to E22 (kWh)</i>
	22	0.00
	23	1151.04
	24	2096.00
	25	1314.84
	26	2482.55
	27	3455.96
	28	2058.24
	29	3202.38
	30	4209.09
	31	2467.27
	32	3625.39
	33	4635.25
	34	2738.52
	35	3903.93
36	4925.98	
	37	24.63
	38	3215.59
	39	265.89
	40	1908.35
	41	312.78
	42	1958.19
<i>Task F</i>	<i>Case</i>	<i>Reduction in Annual Sensible Heating Load Relative to A1 (kWh)</i>
	43	-1566.35
	45	-3571.00
<i>Task F</i>	<i>Case</i>	<i>Reduction in Annual Sensible Heating Load Relative to A8 (kWh)</i>
	44	-322.58
	46	-584.64

Task G	Case	Reduction in Annual Sensible Heating Load (kWh)
	47	0.00
	48	0.00

Task H	Case	Reduction in Annual Sensible Heating Load Relative to G47 (kWh)
	49	-4.82
	50	22244.19
	51	22276.32

	Case	Reduction in Annual Sensible Heating Load Relative to G48 (kWh)
	52	14049.09
	53	14684.46
	54	14714.64

Task I	Case	Reduction in Annual Sensible Heating Load Relative to G48 (kWh)
	55	15604.66
	56	15566.03

Task J	Case	Reduction in Annual Sensible Heating Load Relative to G47 (kWh)
	57	26467.09

APPENDIX C - INSULATION COST CALCULATIONS

Surface Area and Perimeter Calculations

$$y \equiv 26.25\text{ft}$$

$$x \equiv 32.83\text{ft}$$

$$z \equiv 8.86\text{ft}$$

$$\text{wall_P} \equiv (2 \cdot y + 2 \cdot x)$$

$$\text{wall_P} = 118.16\text{ft}$$

$$\text{wall_SA} \equiv \text{wall_P} \cdot z$$

$$\text{wall_SA} = 1046.90\text{ft}^2$$

Extruded Polystyrene and Fibreglass Batting Insulation Dimensions and Coverage

$$\text{XTPS_width1} \equiv 4\text{ft}$$

$$\text{XTPS_width2} \equiv 2\text{ft}$$

$$\text{XTPS_height} \equiv 8\text{ft}$$

$$\text{XTPS_2inch} \equiv 5 \cdot \frac{1}{\text{in}}$$

$$\text{Fibreglass_R12} \equiv 135\text{ft}^2$$

$$\text{Fibreglass_R20} \equiv 75\text{ft}^2$$

$$\text{Fibreglass_R28} \equiv 64\text{ft}^2$$

Fibreglass Batting Bundles Required for each R-value

$$\text{Bundles_R12} \equiv \frac{\text{wall_SA}}{\text{Fibreglass_R12}}$$

$$\text{Bundles_R12} = 7.755$$

$$\text{Bundles_R20} \equiv \frac{\text{wall_SA}}{\text{Fibreglass_R20}}$$

$$\text{Bundles_R20} = 13.959$$

$$\text{Bundles_R28} \equiv \frac{\text{wall_SA}}{\text{Fibreglass_R28}}$$

$$\text{Bundles_R28} = 16.358$$

No. Of Extruded Polystyrene Sheets Required for Exterior Wall and Skirt

$$\text{Sheets_ext} \equiv \frac{\text{wall_SA}}{\text{XTPS_width1} \cdot \text{XTPS_height}}$$

$$\text{Sheets_ext} = 32.716$$

$$\text{Sheets_skirt} \equiv \frac{\text{wall_P}}{\text{XTPS_height}}$$

$$\text{Sheets_skirt} = 14.77$$

APPENDIX D - INSULATION PRICES AND LABOUR ASSUMPTIONS

R5/inch 2" Sheets of Extruded Polystyrene (\$)		R12 Fibreglass 2x6 Batting (\$)	R20 Fibreglass 2x6 Batting (\$)	R28 Fibreglass 2x6 Batting (\$)
8 ft x 4 ft	8 ft x 2 ft	135 ft ²	75 ft ²	64 ft ²
52.00	29.99	54.97	53.97	57.77

2' Wide R10 Horizontal Skirt Extending Around Exterior Perimeter Of Basement

Material: 2" Extruded Polystyrene In 96" X 24" Sheets (R5/Inch)
 Quantity: 15 Sheets (~5min/Sheet)
 Insulators Time: 1.5 Hrs
 Insulators Labour: \$45.00 (30 \$/Hr)

Assumptions:

- The R10 Horizontal Skirt Is Located 4.59' Below Grade
- No Additional Excavation Required
- No Protection Required Below Or Above XTPS

R10 External Wall Insulation

Material: 2" Extruded Polystyrene In 96" X 48" Sheets (R5/Inch)
 Quantity: 33 Sheets (~5min/Sheet)
 Insulators Time: 5 Hrs
 Insulators Labour: \$150.00 (30 \$/Hr)

Assumptions:

- Backfill Applied Against XTPS
- Includes 2 Hrs In The Insulators Time Estimate To Account For Flashing And Parging

R12 Internal Wall Insulation

Material: Fibre Glass Batting Bundles
 Quantity: 8 Bundles (135 Sq Ft Coverage/Bundle)
 Insulators Time: 5 Hrs
 Insulators Labour: \$150.00 (30 \$/Hr)

Assumptions:

- Framing Already Complete
- Wall Will Be Finished With An Air Barrier And Drywall

R20 Internal Wall Insulation

Material: Fibre Glass Batting Bundles
Quantity: 14 Bundles (75 Sq Ft Coverage/Bundle)
Insulators Time: 6 Hrs
Insulators Labour: \$180.00 (30 \$/Hr)

Assumptions:

- Framing Already Complete
- Wall Will Be Finished With An Air Barrier And Drywall

R28 Internal Wall Insulation

Material: Fibre Glass Batting Bundles
Quantity: 17 Bundles (64 Sq Ft Coverage/Bundle)
Insulators Time: 6 Hrs
Insulators Labour: \$180.00 (30 \$/Hr)

Assumptions:

- Framing Already Complete
- Wall Will Be Finished With An Air Barrier And Drywall

R10 Sub-slab Insulation (One Layer)

Material: 2" Extruded Polystyrene In 96" X 48" Sheets (R5/Inch)
Quantity: 27 Sheets
Insulators Time: 4 Hrs
Insulators Labour: \$120.00 (30 \$/Hr)

R20 Sub-slab Insulation (Two Layers)

Material: 2" Extruded Polystyrene In 96" X 48" Sheets (R5/Inch)
Quantity: 54 Sheets
Insulators Time: 5 Hrs
Insulators Labour: \$150.00 (30 \$/Hr)

R30 Sub-slab Insulation (Three Layers)

Material: 2" Extruded Polystyrene In 96" X 48" Sheets (R5/Inch)
Quantity: 81 Sheets
Insulators Time: 6 Hrs
Insulators Labour: \$180.00 (30 \$/Hr)

R40 Sub-slab Insulation (Four Layers)

Material: 2" Extruded Polystyrene In 96" X 48" Sheets (R5/Inch)
Quantity: 108 Sheets
Insulators Time: 7 Hrs
Insulators Labour: \$210.00 (30 \$/Hr)