Energy Efficiency Calculations for the Lincoln Block® System

In Accordance With 2012 Washington State Energy Code, Residential Provisions.

1 Scope of Work

In this short report we provide consumers and design professionals with the information required to assess the thermal performance of the Lincoln Block System as part of conventional construction in the Puget Sound basin. After demonstrating the R-value of the walls alone we then calculate the interior thermal mass and analyze projected heating/cooling costs of a specific blueprint offered by Lincoln Block, Inc.

2 R-value Calculation

2.1 Open Walls

To calculate the R-value of Lincoln Block wood-block walls we sum over the layers of the system and employ an area weighted average to calculate the R-value of the core. The thermal resistance of our wood-block walls is due to two components: softwood (sides, members, and splines) and DAP 2-component 1.75 PCF FR ICC closed cell spray polyurethane foam (SPF). Specific R-values for each are listed below.

Material	R-value per inch
Softwood (fir/pine)	1.41[4]
SPF (1.75 ICC)	6.2[3]

Table 1: R-values in $ft^2 \cdot \Delta F^o/BTU/hr$ per inch for Lincoln Block System components.

The members and spline pieces interrupt the spray foam insulation core increasing the conductivity of the wall. In light of this we overestimate the spline density based on the 25×33 cabin blueprint. This plan calls for 16 full-height spline pieces to reinforce window and door frames along the 116 feet of perimeter wall which works out to 7.3 ft of wood-block per spline on average. We overestimate the density as 6 ft per spline to compensate for discretionary splines added by the contractor and for ease of calculation.

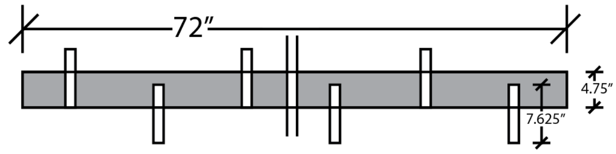

Figure 1: Schematic of the core of a typical 6 foot course of wood-block. White is softwood while the gray is spray polyurethane foam.

A typical $6'$ course of wood-block contains three $1.5'' \times 7.625''$ members and at most one spline comprising an area of $1.5'' \times 4.75''$ (see figure 1 above). This means that 41.4 in^2 of the $72'' \times 4.75'' = 342\ in^2$ area of the core of a $6'$ course is softwood, while the remaining 300.6 in^2 contains SPF. Given the core thickness of $3.125''$ we take the area-weighted average of the corresponding R-values per inch to deduce,

$$R_{core} = 3.125 \cdot \frac{1.41(41.4) + 6.2(300.6)}{342} = 17.6.$$

This core is sandwiched between a pair of $R-1.41$ per inch, $1.375''$ thick softwood sides yielding,

$$R_{block} = R_{core} + 2.75(1.41) = 21.4.$$

Hence unperforated reinforced Lincoln Block forms an $R-21.4$ wall system that **meets the Washington State Energy Efficiency Code minimum** of $R-21$ for Wood Frame and Mass Walls in the 4 & 5 temperate climate zones[7]. Note: Snohomish, Skagit, Whatcom, King, Pierce, Lewis, Thurston, Mason, Kitsap, Jefferson, Island, San Juan, Clallam, Grays Harbor, Pacific, Wahkiakum, Cowlitz, and Clark counties are all zone $4C$ temperate marine climate zones.

3 U-factor for Specific Designs

3.1 The 25×33 Cabin - Gable End

We turn now to assessing the thermal conductivity of the 25×33 cabin, as designed. As the conventional parts of the cabin, the roof, floor, windows and doors (fenestration), in the blueprint meet the prescriptive codes, we calculate the area of each component based on the material takeoff to deduce the cabin's U-factor (or thermal flux per degree temperature difference in $BTU/hr/ft^2\Delta F^o$). The results are summarized below.

Component	R-value	Area $[ft^2]$
Block Walls	21.4	951.6
Fenestration	$3.\overline{33}$	159.5
Roof	49	873.5
Floor	30	825.0
Areal Average	31.5	2810

Table 2: Summary of components of the envelope 25×33 (gable) and their R-values.

Taking the reciprocal of the areal averaged R-value we deduce that the envelope of 25×33 gable end roofed cabin has an **effective U-factor of 0.032**.

4 Thermal Mass

Thermal Mass (or specific heat capacity) of building materials allow structures to absorb excess heat during the day (esp. from solar radiation) and re-radiate this energy throughout the night. Thermal mass is an advantage in all seasons. During the winter, fenestration positioned such that sunlight falls upon dense interior walls and floors passively charges up these thermal energy stores; come summer, that same mass requires additional heating from without before rising in temperature. Thermal mass is essentially a buffer that protects a structure's inhabitants from the drastic temperature swings of the environment.

Log cabins and concrete/masonry structures are well known for having large thermal mass and relatively low R-values, thus exceptions exist for them in some prescriptive codes. According to Saldanha and Piñon, ASHRAE 90.1-2010, the 2009 IECC, and "various state codes" allow for up to a 30% increase in prescriptive U-values (decrease in R-values) when the exterior walls incorporate thermal mass[1]. The California Energy Commission's 2016 codes also exempt roofs weighing in excess of 25 lb/ft^2 from meeting their Prescriptive Requirements for Building Envelopes in section 140.3(a)[2].

While the Washington State Energy codes include no such exceptions (perhaps due to an unreliable distribution of sunny days) we include this section to better inform consumers and designers in all jurisdictions. Saldanha and Piñon conclude that thermal mass inside the building envelope (here established by closed cell foam and sealant between courses) is of greatest benefit. Hence we quantify the weight and heat capacity of this interior facing wood in the Lincoln Block System. The data in the table below was determined directly by measuring and weighing wood-block sections and members separately.

	Len. (in)	Weight (lb)	Mem. (#)
Wood-block	$335\frac{5}{16}$	$103\frac{1}{2}$	16
Members	0	20	24
Per Mem.		$0.8\overline{33}$	
		(lb/block ft)	
Sides		3.23	
Side		1.61	

Table 3: Data collected from a small sample of wood-block 10 Dec 2019.

The specific heat of wood increases with moisture content and temperature. Thus to underestimate the specific heat capacity of the interior wood we use the Forest Products Laboratory's equation for dry wood,

$$c_{p_0}(t) = 0.2605 + 0.0005132t \; [BTU/lb/^oF]$$

at the lowest supported temperature of 45^oF[5]. This yields $c_{p_o}(45) = 0.2836$ BTU/lb/°F. With the above length densities and heat capacity we proceed to calculate the total interior thermal mass of the walls in the 25×33 cabin blueprint.

Plan	Block-ft (ft)	Interior Wood (lb)	Heat Cap. (BTU/°F)
25×33	2404.0	3878.7	1100.0

Table 4: Total interior facing wood heat capacity for the 25×33 cabin.

Given a similar interior wall surface area of 950 ft^2, 1/2 inch gypsum wall boards weigh

$$(950 \; ft^2)(2.08 \; lb/ft^2) = 1,976 \; lb$$

and have a heat capacity of

$$(1,976 \; lb)(0.259 \; BTU/lb/^oF) = 511.8 \; BTU/^oF,$$

or less than half of the heat capacity of the interior facing wood of Lincoln Block walls (included at no additional cost). For reference, at standard temperature and pressure, the nearly 9000 ft^3 of air inside the 25×33 cabin has a much lower heat capacity of

$$(9000 \; ft^3)(0.0797 \; lb/ft^3)(0.24028 \; BTU/lb/^oF) \\ = 172.4 \; BTU/^oF.$$

5 Cost Estimates

We conclude this report with rough calculations of *design* heating and cooling costs for Lincoln Block structures built in Marysville/Tulalip, Snohomish County. As the Washington State Energy Efficiency codes neglect thermal mass so shall we in this section. These codes denote outdoor design temperatures for Marysville, WA as 23^oF and 79^oF for winter and summer respectively[7]. Given the heating and cooling design indoor temperatures of 72^o and 75^o F, along with the Snohomish County PUD rate of $\$0.10414/kWh$ (effective Oct. 1, 2017 and declining[6]) we calculate the projected monthly costs for heating and cooling. We assume 100% efficiency for electrical heating (as electrical energy is losslessly transformed into heat) and a modest EER rating of 8 BTU/hr/Watt for cooling.

5.1 The 25×33 Cabin - Gable End

Given the U-factor of 0.032 calculated above, and assuming uniform temperature outside the structure we expect heat transfer 89.2 BTU/hr per degree ^oF of temperature difference though the 2810 ft^2 building envelope. Monthly *design costs* are listed below. Note, for heating, this corresponds to having a constant temperature of 23^o F outside and 72^o F inside for an entire 720 hr month, while for cooling 79^o F outside and 75^o F inside over the same time period. Thus heating costs are likely an overestimated while the cooling costs are likely underestimated.

To better model reality we identify two extreme Marysville days, 11 January 1998 and 08 August 2018, where lows and highs were recorded to be 23 to 29^o F and 63 to 93^o F respectively. Then using a *periodic* (sinusoidal) model with a 24-hour period for the outdoor temperature we integrate to calculate the average temperature difference over when the heating/cooling system is *active*. In this model heating must be run continuously (as outdoor temperatures do not rise above the 72^o indoor design temperature) while the air conditioning need only be run when the outdoor temperatures are in excess of 75^o F or about 11.5* hours per day. The results of each approximation are summarized below with details of the *periodic* model in figure 2. These *periodic* costs too are likely over and underestimates as we assume each day of a 30 day month is equally extreme as our chosen outlier date.

Mode	Temp. Diff.	Heat Loss [BTU/hr]	Energy Use [kWh/hr]	Cost $/mo
Design				
-Heat	49^o F	4371	1.281	95.93
-Cool	-4^o F	-357	0.045	3.34
Periodic				
-Heat	46^o F	4103	1.203	90.17
-Cool*	-13^o F	-1155	0.144	5.18

Table 5: Projected monthly heating and cooling costs for the 25×33 cabin in Marysville/Tulalip under current Snohomish County PUD rates.

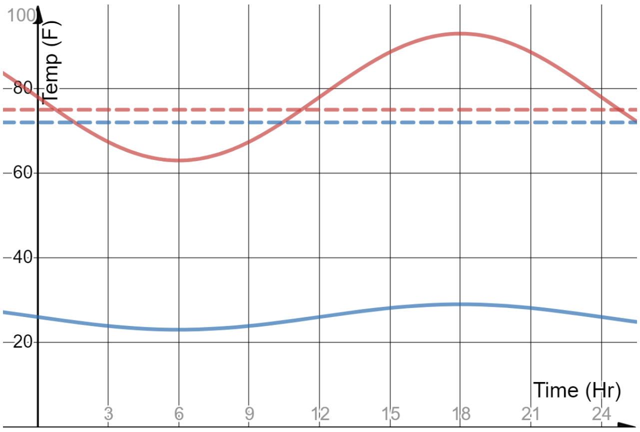

Figure 2: Graph of outdoor (solid) and indoor (dashed) temperature curves used for periodic heating (red) and cooling (blue) cost approximations.

6 Summary

While the results of individual projects may vary, we hope this report has enhanced your understanding of the projected thermal performance of the Lincoln Block® System. Based on these calculations, it appears 1) that Lincoln Block walls meet Washington State Energy Efficiency Code minimums for R-21 wood frame and mass walls, 2) Lincoln Block walls have up to double the internal facing thermal mass (or heat capacity) of conventional 1/2 inch gypsum wall boards, and 3) our 25×33-foot gable-end cabin boasts a system U-factor of 0.032 which should keep winter electric heating bills below $90 per month even through the harshest winter months.

References

[1] Saldanha and Piñon. (2013). *Influence of Building Design on Energy Benefit of Thermal Mass Compared to Prescriptive U-Factors.* American Society of Heating and Air-Conditioning Engineers. web.ornl.gov/sci/buildings/conf-archive/2013%20B12%20papers/165_Saldanha.pdf

[2] California Energy Commission. (2015). *2016 Building Energy Efficiency Standards for Residential and Non-Residential Buildings.* ww2.energy.ca.gov/2015publications/CEC-400-2015-037/CEC-400-2015-037-CMF.pdf

[3] ICC Evaluation Service, LLC. (2017). *Touch n' Seal Class I FR Spray Foam System: ICC-ES Evaluation Report* www.touch-n-seal.com/cmss_files/attachmentlibrary/ESR-3052.pdf

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[6] Snohomish County PUD. (2019). *Electric Utility Rates.* www.snopud.com/Site/Content/Documents/rates/electricrates_110119.pdf

[7] Washington State Energy Code. (2012). *Washington State Energy Code, Residential Provisions.*