The Energy Performance of Log Homes

Documented Energy-efficiency and Thermal Mass Benefits

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FORWARD

This white paper, produced by an independent consultant for the NAHB Log Homes Council, is a builder and consumer-oriented summary of documented studies and analysis on energy efficiency and the role of thermal mass in homes using log wall construction. Included is discussion of the documented competitive energy efficiency performance of log homes, as well as a summary of measures used by log home builders that continue to improve the performance of this popular and fast-growing home type.

The results of a comprehensive review of the literature indicates that in most U.S. climates there are proven benefits of thermal mass – using a wall's heat capacity – to control and reduce annual heating and cooling energy demand. These benefits vary by climate, wall thickness, levels and placement of insulation, even the type of windows installed. These properties of log homes significantly benefit homeowners, and also help our environment by reducing energy waste hence lowering the power plant and fuel-combustion emissions including CO2 implicated in changing our climate.

Background

For 20 years, there have been concerns about the proper representation of thermal performance of buildings having greater "heat capacity" or thermal mass in their walls, compared to typical lightweight wood framing construction practices. There are also legitimate concerns about the ability of simple "steady state" calculations used to size heating and air-conditioning equipment in homes, being able to properly consider the effects of thermal mass on annual utility bills for heating and air-conditioning under real-world weather conditions

With the accelerating growth of log home construction across the U.S. the National Association of Home Builders (NAHB) Log Homes Council conducted a comprehensively review the available studies that document log homes' energy-efficiency and thermal mass benefits to help improve understanding in the construction codes and HVAC engineering community.

To complete this study, the Log Homes Council utilized thermal mass documentation from U.S. Department of Energy (DOE) programs, and other energy efficiency information compiled by an independent "green building" consultant over a two-year study period. Supporting data, reports and analysis remains on file at NAHB, and is summarized in the reference section of this white paper.

LOG HOME ENERGY-EFFICIENCY PERFORMANCE

How Log Homes Are Different

Log walled production homes are (as differentiated from historic structures erected from raw logs often felled on site) assembled using modern techniques including computer aided design (CAD) and factory milling. The solid wood components are professionally graded to modern standards. The result is a quality-controlled product shipped as a “kit” for erection on a home site by a skilled crew to the specifications of the log home supplier.

Design Differences and “Green Building”

A home constructed of solid wood walls need not appear fundamentally different from conventional wood frame housing types, but in reality designers and prospective buyers of log homes often include more contemporary appearance, larger south-facing windows, and traditional “western” features such as porches and verandas in their design preferences. While many log homes are constructed as vacation and second homes in scenic settings, they have seen a growing market penetration into conventional housing markets.

Today’s log homes still tend to be erected from regionally available materials (tree species). However, the consumer is not “locked into” a specific type of wood, due to modern transportation modes. So while not necessarily reliant on local material availability, local materials are often used particularly in geographic areas where the forest products industry is a significant part of the local economy.

Log homes fit the latest housing trend; towards greater environmental awareness in how we construct homes and develop our communities with an eye to sustainability. Sustainability is the effort to reduce the impacts on future needs of those development activities we undertake today to meet our own needs; in essence saying, ‘don’t rob our environmental future to meet today’s wants and needs.’

Since log homes can save energy and reduce environmental impacts through the use of renewable resources, they will play a role in green building. In most cases log homes can be “greener” (less impact on the environment) compared to conventional residential framing methods. There are several reasons supporting this claim for log homes – including:

- ☑ *Use of fundamentally renewable resources (timber);*
- ☑ *The potential to use fire-killed or wind-downed timber that could be more difficult for a conventional saw-mill to process;*
- ☑ *Less energy and labor are consumed processing the timber for log components between harvest and emplacement on site;*
- ☑ *Logs are often shipped to construction sites within smaller distances of harvest locations, resulting in lower transportation energy-use than conventional framing lumber;*
- ☑ *Log walls provide “surface as finish” saving material and labor costs since added layers of other building materials are not required;*
- ☑ *Fewer (albeit proportionally stronger) fasteners are needed to erect a log-walled building, resulting in lower quantities of metals employed to complete the job (manufactured metals have high embodied energy);*
- ☑ *Modern log homes save energy compared to similarly well-insulated stick-framed homes; and*
- ☑ *In the future, when log buildings are demolished there is a high potential for recycling logs (log homes would more likely be “deconstructed” for their valuable timbers).*

The Energy Performance of Log Homes

Energy Efficiency Matters

Introductory Comparison – Log Homes versus Frame Homes Energy Efficiency

Technical data from both instrumented field studies and computer modeling supports the efficiency of properly constructed log homes. The following is a real-world example of the performance potential of log homes, according to studies conducted over more than 20 years.

A log home constructed of 7-inch solid wood walls might have an indicated steady-state R-value of R-9, but in most U.S. climates – especially those where log homes are most popular – a stick-framed home would have to be insulated to about R-13 (or even R-15 in some areas) to perform as well for heating and air-conditioning energy use on an annual basis. This comparison assumes similar attic insulation, window performance, foundation design and the use of identically efficient mechanical systems for heating and cooling. In practical terms, log homes may be expected to perform from 2.5% to over 15% more energy efficiently compared to an identical wood-frame home, considering annual purchased heating and cooling energy needs.

In real terms, this means an owner of a log home might expend $150 to $400 less per year on their heating and cooling-related utility bills, while maintaining equal or superior comfort under real-world weather conditions. Over the long term, these savings add up – for example an owner could have over $12,000 in today's dollars in the bank due to energy efficiency. Since inflation eats into the value of money over time, such savings could be worth on the order of $30,000 in future dollars, according to example calculations from the EPA/DOE ***EnergyStar*** Homes program.

The summary above is based on information from a variety of US Department of Energy sponsored studies concerning thermal mass as it relates to energy efficiency in buildings, conducted during 1978 through the late 1980's. (1)

HOW ENERGY-EFFICIENCY PERFORMANCE IS DETERMINED

Steady-state calculations: R-value and U-factors

Engineers use design conditions where steady state values must be estimated to predict maximum loads for sizing HVAC equipment. The term "steady-state" means pretty much what is says. The indoor comfort temperature is compared to outdoor design temperatures and then used with estimated heat-loss factors over the surface areas of the building. These data are used to calculate "worst-case" heating and cooling loads that may be placed on a buildings' mechanical equipment during its useful life. For a specific location, long-term weather data is used with simplified calculations to estimate how large a mechanical system may be needed. These calculations are done for a specific building depending on its surface areas, insulation levels, windows and doors, foundation type, and assumptions about how much air leaks into and out of the exterior "shell."

A building materials' "R-value" is a measure of its resistance to heat flow over the thickness of the material, or over a fixed thickness (R- per inch for example). In reality, building assemblies – such as walls, the roof, or other sections – are put together from a variety of materials, each layer or section having its own R-value. The engineer calculates the overall system thermal effectiveness (U overall or "U_o") using equations that represent the assembly thermal transmittance, which is then reported as a U-factor (2) The U-factor is the reciprocal of the calculated assembly's R-values over their effective heat flow pathways. These R-value data are reported in design manuals and manufacturer's data sheets, and conform to regulations put forth by the U.S. Federal Trade Commission (FTC) in the mid-1970s.

When materials with markedly different R-values are used in an assembly then problems crop up getting an accurate U-factor. An example is a wall with steel framing. Steel is a highly thermal-conductive material. When attempting to determine an accurate overall U-factor, often the difference between the R-value of the insulation material (high) and the steel stud (almost no R-value) is not properly adjusted for differences between elements of the assembly. This results in erroneously high estimates of overall thermal performance of the wall, resulting from incorrect U-factors.

Real-world "Dynamic Energy" Performance

Design conditions are rarely achieved in real life due to variations in local weather from long-term climate. Typically a building may operate under these severe conditions only 1% or 3% of the time during a "typical year." (2) Knowledgeable energy-engineers realize this limitation of design calculations; that they do not reflect actual energy demand for comfort conditioning in real buildings in use by occupants.

The heat capacity of common building materials is also not reflected in their steady-state heat transfer values reported in design handbooks used by engineers and architects. To obtain or estimate the benefits of thermal mass, engineers and designers are often provided with little data to go by. Limited mass correction factors acting upon thermal transmittance "U-factors" appear in some of the prominent energy efficiency standards and codes.

However, American Society of Heating Refrigerating and Engineers (ASHRAE) Standards 90.1 and 90.2, as well as several versions of the "Model Energy Code" (MEC), recently absorbed into the International Energy Conservation Code (IECC) – managed by the International Code Council (ICC), include thermal mass correction factors and calculation methods that better reflect real-world building performance than steady-state estimates.

HEAT CAPACITY "THERMAL MASS" EFFECTS

Heat Capacity in Building Walls

Why do log walled homes perform better than estimated by steady-state indexes of thermal value – the R-value and U-factor – for building materials and systems? The dynamic interactions of outdoor weather and building design and operating parameters – such as thermostat setting, amount of glazing, air-leakage rates, added insulation and its location, etc. – greatly influence the extent to which thermal mass effects reduce long term energy use for comfort conditioning.

There are several reasons that work together to boost the relative effectiveness of log walls to improve indoor comfort on an annual basis compared to frame walls. The first factor is "thermal mass." The thermal mass of a material is a function of its density – typically measured in pounds per cubic foot (kg/square meter) and the specific heat – typically measured in Btu/pound - deg. Fahrenheit (kJ/kg x Celsius).

The thermal mass of a material is a result of its heat capacity over a sectional area. The important factors determining how much thermal mass is in a building's walls are its thickness, density and specific heat of the material – from which heat capacity is estimated. While a frame wall often has a heat capacity near 1 Btu/square foot – Deg. F, a log wall often has 6 to 8 times more heat capacity over an identical surface area.

Documented Effects of Heat Capacity in Log and Masonry Walls

The summary information included in this section is referenced in detail in the 2001 NAHB Log Homes Council Study "Log Homes Thermal Mass and Energy Efficiency: Assessment of Energy Efficiency Calculations and Ratings of Log Homes Compared to Other Residential Wall Structural Systems." **(1)**

As early as 1967, thermal mass effects were being explored, as documented by J. F. Van Straaten, in the classic book Thermal Performance of Buildings. (3) He identified, but did not yet name, a distinct property of building physics that discussed a function of heat storage capacity and resistance to heat flow of a structures' various assemblies like its walls, roof, and foundation.

Researchers using data from both computer models and instrumented test structures were actively discussing thermal mass effects in the engineering literature after 1973. A result of the early work at National Institutes of Standards and Technology (NIST) was a breakthrough building energy-simulation computer model called "NBSLD - Computer Program for Heating and Cooling Loads in Buildings," published in late 1974. It was capable of dynamic simulations based on weather, rather than just more traditional steady state calculations. Many subsequent computer energy models are based on this early software. NIST was formerly called the National Bureau of Standards.

Using the NBSLD model, engineers at the Illinois-based Portland Cement Association (PCA) compared a frame building with a masonry building using NBSLD. Their analysis compared light frame buildings with a higher insulation R-value (by over 30%) than an equivalently sized and shaped masonry building. They calculated the lightweight walls had peak cooling loads 38% to 65% higher than for a masonry wall with the much lower R-value. The overall building seasonal heating loads for the "heavy" case were 12.3% less and the seasonal cooling loads were 17.4% less than the better-insulated light frame case. (4)

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In 1977, Dougall and Goldthwait coined the term "thermal mass" in a paper also reporting NBSLD results. They reported thermal mass saved energy in homes over a range of 3% to 12% for heating in five climates. (5) Their findings however, also indicated adding thermal mass to walls in some hotter climates such as Phoenix and Sacramento might somewhat increase cooling loads by a few percent. A report at the 1979 International Conference on Energy-use Management concluded that masonry buildings performed as if they were better insulated than steady state calculations indicate, and that heating equipment in such cases could be erroneously be over-sized by about 30%. Their wall analyses had 4% to 8% variations between calculated and measured loads. A model building configuration where thermal insulation was placed outside the mass walls resulted in better heating performance than could be predicted by steady-state calculations. (6)

At the 1979 ASHRAE Winter meeting, Goodwin and Catani presented the Masonry Industry "M-factor." The M-factor was developed from numerous NBSLD computer runs calculating ratios of heating and cooling loads for mass wall buildings compared with light frame buildings of similar design. At that time, ASHRAE standards called for more costly insulation levels to be added to masonry walls compared to the requirements for light frame walls in housing. The purpose of the M-factor was to show that equivalent annual heating and air-conditioning performance could be achieved in high-mass buildings fitted with lower R-values, hence making them more affordable to construct. (6)

The University of New Mexico (UNM) conducted independent work on thermal mass during 1978 through 1982. Dr. Leigh of UNM conducted studies that essentially validated the masonry industry "M-factor" in spite of objections by researchers from the insulation industry. Leigh's work continued to indicate that block walls performed much better in some climates than steady state calculations suggest. (7)

By late 1982, the DOE Thermal Mass Program was underway, and NIST presented initial results of an instrumented field test comparing frame, masonry and log-walled residential-scale test buildings located in Maryland. The NIST test buildings were designed to be similar in every respect but their wall constructions in order to explore the differences between the thermal performance of different wall types. NIST researcher Doug Burch reported mass-wall buildings including concrete masonry and log home construction appeared to save heating energy compared to a well insulated light frame wall building. The log wall test building performed better than both the insulated wood frame house and the interior insulated block wall house, both of which had higher steady state R-values. (8)

The NIST data also showed something else about the log walls, which was not expressly discussed in the reports. Their tested R-values tended to be lower than predicted steady state R-values compared to the other buildings. However the measured heating and cooling performance of the log walled test home *was much better than predicted* in computer models. This was a clear indication that the steady state calculations used by the engineering community was consistently over-predicting log wall heat losses. (9)

Work on measuring heat capacity effects by NIST continued through 1984, when detailed ASHRAE papers were published on both observed heating and cooling thermal mass "behavior." The log wall ("Cell #5") in the two reports showed very good performance. It saved energy compared to the insulated frame building with a much higher wall R-value, during both heating and cooling seasons. For heating (cumulative heating load), the energy savings was 45% according to the NIST data. For cooling, the energy savings was 37%, which was slightly better than the exterior-insulated block building. (10)

NIST also extrapolated the heating results to other climates. Results indicated a range of 3.3% heating savings based on absolute difference in kWh heating demand in cold climates such as Madison, WI. In mild Los Angeles up to about 62% heating savings were indicated based on computer extrapolations of the field test data. This range compared the exterior insulated masonry building with the insulated frame building. Hence one might expect the range for the log wall home (not directly reported by NIST) to be somewhat less, since in winter the highest performing exterior insulated block building saved about 22% heating compared to the log wall building. A reasonable range for log wall expected heating and cooling annual energy savings would be about 2.5% savings in Madison, Wisconsin a very cold climate; up to 48% savings in milder Southern California. (11)

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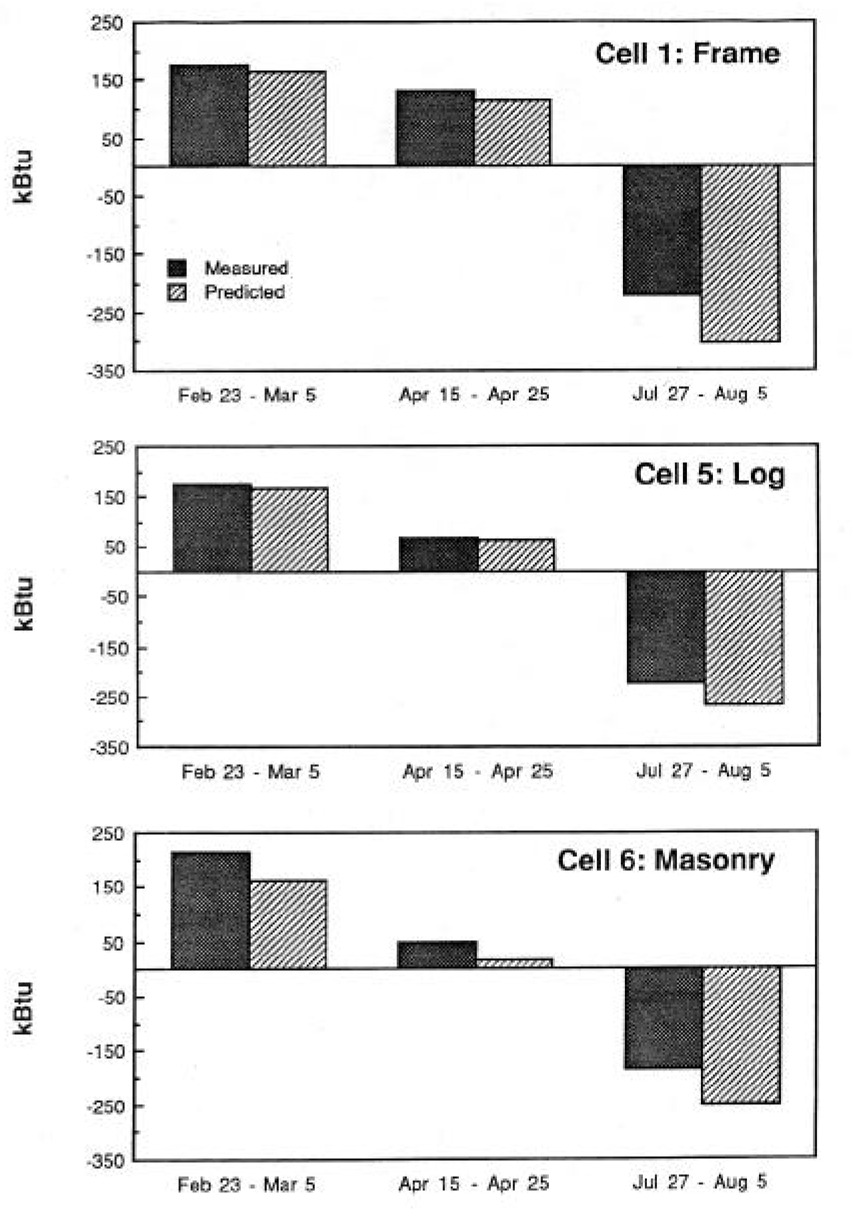
Figure 1 illustrates the seasonal loads for heating and cooling, predicted by BLAST for the NIST test site. Both the log and masonry houses perform better than the insulated frame case. The log wall case seems to also have the closest agreement between measured and predicted results produced by the BLAST computer program.



• Figure 1 NIST Test Cell Comparisons (Source: LBNL)

In addition, NIST researchers determined that mass wall buildings could better utilize night vent cooling (summer) and thermostat setback (winter) performance than frame wall buildings, and interior insulated masonry buildings. The mass coupled with the indoor conditioned spaces, and became involved with the thermostat controlling the comfort levels. Excess heat could be stored in the mass during the day in summer, and later removed by night-flush ventilation reducing the AC demand on the following day.

Another key finding was that actual loads measured for the insulated light frame building behaved as if it had "insufficient" mass. That is, when weather conditions changed abruptly the thermostat of the light frame building tended to overshoot actual amounts of heating or cooling energy that otherwise would have satisfied similar comfort needs in a mass-wall building of similar design. This was a fascinating insight that only would have come to light through observing energy use in an instrumented building. Previous work had largely thrown out such observations as "computer error." (10, 11)

From 1982 to 1984, the New Mexico Energy Research and Development Institute (NM-ERDI) operated another instrumented test home site in Tesuque Pueblo, New Mexico, under the DOE Thermal Mass program. Located halfway between Santa Fe and Albuquerque in a high desert climate, the "Southwest Thermal Mass Study" conducted detailed energy monitoring on test houses built with identical roof, foundation and windows, varying only in their wall construction. (12)

In addition to wood frame, log walls and concrete block construction, three traditional Southwestern adobe wall houses were constructed with increasingly thick walls, up to 15 inches thick. Roofs were insulated to R-30, the foundations to R-15.4, and the same size, U-factor, and shading coefficient windows were installed after first calibrating the test houses with no fenestration (windows and doors) installed. The 15-inch adobe walled super-massive house also served as the base case to perform some normalization studies on the test data. Normalization is a statistical process to verify the level of errors in a set of data.

The log wall research house used 7-inch walls (R-9 calculated) while the insulated wood frame test house used 4.5-inch thick (2x4 with typical ½ " interior wallboard and exterior sheathing) R11 insulated walls, corrected for framing versus cavity-insulated areas. The measured air change rates of both frame and log houses was about 0.1 air changes per hour. (*Note: Typical homes have air change rates of 0.35 to 0.5 per hour, so the test buildings were very tight.)*

According to the NM-ERDI report both the log wall and insulated frame houses had identical calculated steady state building load coefficients (50.1 Watts per degree C). Despite identical steady state load coefficients, the log wall house used the least heating energy of all the test houses. The log walled test house showed 27% lower heating demand during spring 1983 than the higher R-value frame house. (12)

The verification of major building energy simulation tools largely marked the culmination of the DOE Thermal Mass Study. The DOE program quietly wound down at ORNL without issuance of an overall final report. Ultimately however, the thermal mass research results did help get heat capacity benefits recognized in standards and model codes, however only at a very rudimentary and conservative level.

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Conclusions from DOE Sponsored Thermal Mass Studies

Throughout the literature reviewed on log wall thermal performance several key findings come forward.

1) Log walls, despite lower-appearing steady state R-values, have been shown to provide equal or superior annual heating and cooling performance when compared to frame walls of higher steady state R-values. Example: a log wall with a calculated steady state R-9 value performs similarly for both heating and A/C loads to an R-13 to R-15 insulated light-frame wall in a temperate climate.
2) The homogeneous assembly of the log wall has fewer thermal short-circuits than lightweight wood- or steel framed walls. This property leads to closer agreement between steady state calculated thermal transmittance levels and their actual thermal performance. Both calibrated testing and sophisticated computer modeling have confirmed this observation.
3) Studies indicate that log construction thermal mass "integral" to its assembly is nearly as effective as exterior insulation on concrete and masonry walls, per unit of insulation and heat capacity. In a log wall, its "insulation" is mixed with the heat capacity and provides dual functionality of both structure and thermal protection.
4) Concrete, block and brick walls have higher heat capacity but also have higher heat flow conductivity compared to solid wood wall sections. Hence masonry walls may require adding conventional insulation to meet code in most U.S. climates versus comparable log walls where the insulating material is the structural material.
5) The greatest thermal mass effect has been observed for exterior insulated mass walls. Interior insulation applied to a mass wall severely decreases its heat capacity benefits. To get the most advantage from thermally massive construction, insulation materials should either be placed on the exterior of walls, or mixed within the structural section such as with log construction.

BUILDING STANDARDS, CODES AND ENERGY-EFFICIENCY CRITERIA

Steady-state Thermal Criteria for Walls in Standards and Codes

Log walls – and mass walls in general – have since 1989 received limited and conservative recognition for their thermal mass benefits. Some limited recognition of the differences in cost effectiveness for thermal protection systems that improve mass walls' performance has also been advanced by ASHRAE. However, traditional steady state calculation methods and criteria still dominate the implementation of building envelope energy efficiency in the codes and standards.

One obstacle to wider adoption of advanced energy standards into building codes is their relative complexity. Thermal mass is a more involved concept than R-value, and makes for confusion and lengthy explanations to building officials who have limited time to digest "new" concepts. Engineers need to be armed with advanced calculations verified in both lab and field measurements, then report their results of building simulations in a very straightforward way to building officials.

Insulating solid wood and masonry walls is a different process than insulating typical frame construction. However, for many years economics was not employed in setting standards in building codes. This resulted in disconnects between reasonable thermal protection improvements that were affordable and cost-effective and onerous requirements that were not equitably applied to some construction approaches while not required for others.

Log walls have been shown to be more likely to provide predictable measured steady state thermal transmittance values compared to calculated values for light frame walls, particularly the increasingly popular steel-frame construction which has serious thermal bridging challenges.

It is vital to provide useful, accurate and simple information supporting this fact to building code officials and standards writers on a continual basis, so that misinformation is removed from practices responsible for building design and permitting, as well as HVAC sizing practices.

ASHRAE based Standards – Situation Analysis

"Model Energy Codes" – 1983 to Present:

Prior to 1989, the CABO Model Energy Code [now- International Energy Conservation Code (IECC)] did not contain adjustments for considering heat capacity influences on annual heating and cooling in buildings. All wall assemblies were treated as if they had similar performance, and the compliance calculations in the model code were entirely based on steady state assumptions about material physical properties.

This changed with the 1989 edition of the MEC, when researcher Jeff Christian of ORNL successfully submitted, defended and got passed new thermal mass correction factor tables based largely on work done in the DOE Thermal Mass Program 1979-1985. Table A illustrates the correction factors that are now accepted in the IECC, and connected codes like the International Residential Code (IRC) which is now becoming more widely referenced by states and local jurisdictions.

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REQUIRED U_w FOR WALL WITH A HEAT CAPACITY EQUAL TO OR EXCEEDING 6 Btu/ft² · °F WITH INTEGRAL INSULATION (INSULATION AND MASS MIXED, SUCH AS A LOG WALL)

HEATING DEGREE DAYS	U_w REQUIRED FOR WALLS WITH A HEAT CAPACITY LESS THAN 6 Btu/ft² · °F AS DETERMINED BY USING EQUATION 5-1 AND FIGURE 502.2(1)										
	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.04
0-2,000	0.33	0.31	0.28	0.25	0.23	0.20	0.17	0.15	0.12	0.09	0.07
2,001-4,000	0.32	0.30	0.27	0.24	0.22	0.19	0.17	0.14	0.11	0.09	0.06
4,001-5,500	0.30	0.28	0.26	0.23	0.21	0.18	0.16	0.13	0.11	0.08	0.06
5,501-6,500	0.28	0.26	0.24	0.21	0.19	0.17	0.14	0.12	0.10	0.08	0.05
6,501-8,000	0.26	0.24	0.22	0.20	0.18	0.15	0.13	0.11	0.09	0.07	0.05
> 8,001	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.04

For SI: °C = [(°F)-32]/1.8, 1 Btu/ft² · °F = 0.176 kJ/(m² · K).

- Table A Required Uw (U-factor of opaque walls) for wall having sufficient heat capacity.

Similarly, considerations of both a buildings thermal protection system and the relative economics of delivering the needed thermal protection levels, were used in developing mass wall curves for the ASHRAE Standard 90.2-1993 "Energy Efficient Design of New Low-rise Residential Buildings." In this standard – adopted in late 1993 but never widely implemented in model codes due to complexity and opposition by builder groups – a combined approach was used to generate compliance information. The effort was based both on building economics (relative life cycle cost scales for difference unique construction systems) and for the first time simultaneous use of heating and cooling weather data as opposed to only the heating criteria.

Properly Calculating Thermal Mass Correction for Log Walls

Using the thermal mass correction information in Table A can be tricky. This section will help to clarify the correct approach to calculating and reporting heat capacity (thermal mass) corrections to building code officials. The mass wall correction data are shown in IECC Chapter 5: Section 502.2.1.1.2 "Mass Walls."

However, prior to discussing mass wall corrections, it is important to understand how they are used in model-code overall compliance calculations of residential walls. The 502.2 IECC section covers compliance by analyzing individual components of the building's thermal shell – walls, roof, ceilings, foundation, etc.

Analysis begins with consideration of the combined thermal transmittance of the exterior walls of the building, over the total gross surface area including both the opaque wall sections, and the windows and doors. Where there is more than one type of structural wall, window, or door used, their relative areas and thermal transmittance factors must be expanded to include the specific information needed for accurate calculations. For example, if a house has both log walls and a masonry wall in its exterior shell, then the proportional areas and thermal transmittance factors for both types of walls need to be included, not simply lumped together.

To obtain the initial value for the required overall thermal transmittance value for walls, Figure 2 is consulted, along with the relevant heating degree-day (HDD) value for the climate location where the building is being erected. The curves and line-segment equations are shown in Figure 2, where the horizontal axis is the climate description in HDD and the vertical axis is the overall wall U-factor – U_o. The U_o is then utilized in more detailed calculations of acceptable component thermal performance factors using simple arithmetic equations.

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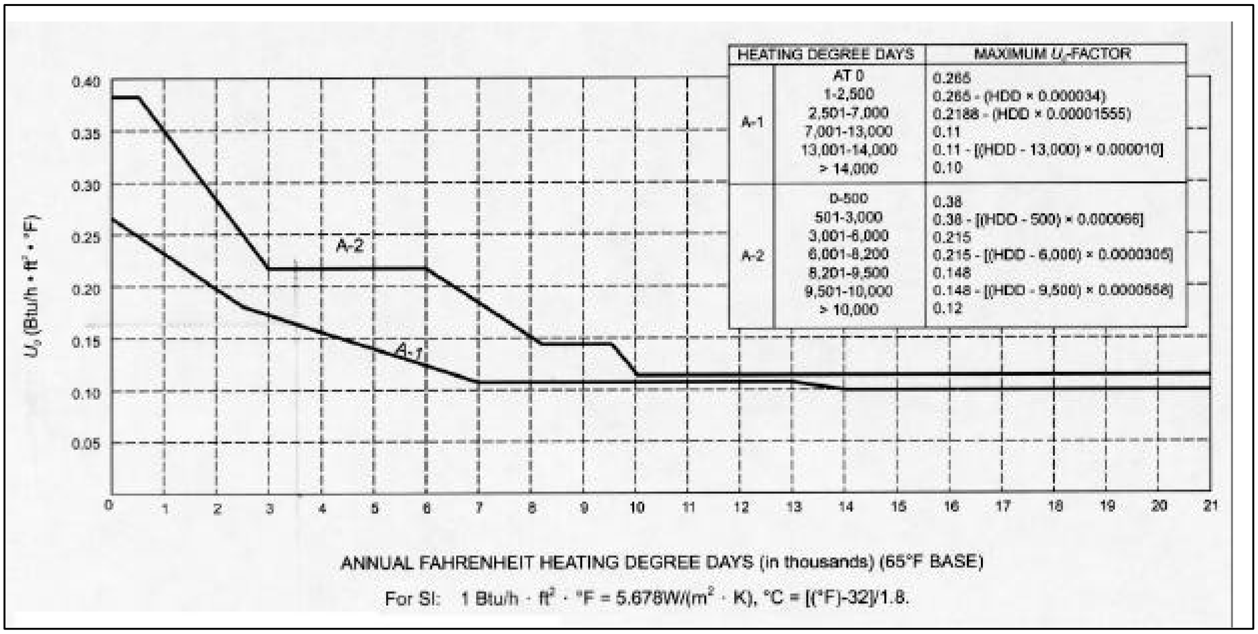

• Figure 2 Uo – Overall U-factor Compliance Lines, by Heating Degree Days (A-1 = One and Two-family Dwellings, A-2 = Other Low-rise Residential Buildings)

Calculating Wall Thermal Values

The equation shown in this section is used to calculate the overall thermal transmittance factor for the wall, from its component parts. Note that this equation includes all the typical component parts of a building wall, however it pertains to the above grade walls. A separate approach for below grade foundation walls is included elsewhere in the model code, and not discussed here.

To use this equation for determining the appropriate U_W factor for an "equivalent" mass wall compared to the basic lightweight frame wall of typical U.S. home construction, the next step is to calculate and verify the log walls to be used have sufficient heat capacity.

In the model code, when a wall has sufficient heat capacity – at least 6 Btu/ft^2 - ^{o}F [1.06 kJ/(m^2 – K)] – then it provides sufficient thermal protection to be "deemed to comply" with the model code in lieu of the more highly insulated frame wall (having a corresponding lower numerical U-factor). The calculation starts with a compliance frame wall requirement, then backs-into the allowable U-factor for a mass wall. This is because the heat capacity correction is based on comparisons of the effective thermal protection of the wall with higher heat capacity, versus a lightweight wall according to the research discussed previously in this paper.

$$U_o = \frac{(U_w \times A_w) + (U_g \times A_g) + (U_d \times A_d)}{A_o}$$

where:

U_o = The average thermal transmittance of the gross area of the exterior walls.

A_o = The gross area of exterior walls.

U_w = The combined thermal transmittance of the various paths of heat transfer through the opaque exterior wall area.

A_w = Area of exterior walls that are opaque.

U_g = The combined thermal transmittance of all glazing within the gross area of exterior walls.

A_g = The area of all glazing within the gross area of exterior walls.

U_d = The combined thermal transmittance of all opaque doors within the gross area of exterior walls.

A_d = The area of all opaque doors within the gross area of exterior walls.

Notes: (1) When more than one type of wall, window or door is used, the U and A terms for those items shall be expanded into subelements as:

$$(U_{w1} A_{w1}) + (U_{w2} A_{w2}) + (U_{w3} A_{w3}) + \ldots \text{(etc.)}$$

(2) Access doors or hatches in a wall assembly shall be included as a subelement of the wall assembly.

In the model code, a compliance note within the thermal envelope calculation section says:

> "…solid wood walls having a mass greater than or equal to 20 pounds per square foot have heat capacities equal to or exceeding 6 Btu/ft^2 - ^{o}F [1.06 kJ/(m^2 – K)] of exterior wall area."

Despite this note, most code approval submittals will still require direct calculation of the log wall's heat capacity. It is better to make the calculations in advance rather than risk getting held up on energy approvals due to submitting insufficiently detailed documentation.

The Energy Performance of Log Homes

Calculating Wall Assembly Heat Capacity

The construction materials' heat capacity of an exterior wall is calculated as follows:

HC = (Wall thickness * Density) * Specific Heat

Where:

HC denotes the heat capacity of the exterior wall in Btu/ft^2 - ^{o}F [1.06 kJ/(m^2 - K)];

Note: *Wall thickness is entered in feet for this equation*;

Material Density in lb/ft^3 [kg/m^3];

Specific Heat of wood = 0.39 Btu/lb - ^{o}F [kJ/(kj – K)] #

ASHRAE Fundamentals Handbook, 2001 (See Table B.)

* denotes a multiplication operation

According to ASHRAE, wood species have the following physical and thermal properties, relevant to these calculations (Table B). Hence, referring to the table, an SPF log wall of 8 inches diameter would provide an average value of R- 9.84 at an HC of at least 9.5 according to ASHRAE design data. So, in the example climate a log wall could easily comply with the model code requirements without having to step up to higher performance doors or windows. Additional calculations could be made to optimize the windows and doors for least cost while still meeting or exceeding the requirements.

WOODS (12% moisture content)	Density (lb/cf)	Conductivity (*k*)	R per Inch (1/*k*)	Specific Heat (lb/F)
Hardwoods				
Oak	41.2-46.8	1.12-1.25	0.89-0.80	0.39[s]
Birch	42.6-45.4	1.16-1.22	0.87-0.82	
Maple	39.8-44.0	1.09-1.19	0.92-0.84	
Ash	38.4-41.9	1.06-1.14	0.94-0.88	
Softwoods				
Southern pine	35.6-41.2	1.00-1.12	1.00-0.89	0.39[s]
Douglas fir-Larch	33.5-36.3	0.95-1.01	1.06-0.99	
Southern cypress	31.4-32.1	0.90-0.92	1.11-1.09	
Hem-Fir, Spruce-Pine-Fir	24.5-31.4	0.74-0.90	1.35-1.11	
West coast woods, Cedars	21.7-31.4	0.68-0.90	1.48-1.11	
California redwood	24.5-28.0	0.74-0.82	1.35-1.22	

• Table B Thermal Physical Properties of Wood Species (Source: ASHRAE Fundamentals Handbook, 2001)

The user of the HC formula must know the net log wall thickness, and appropriately correct it for any physical attributes that influence its actual overall thickness from a thermal standpoint. For example if a whole log is used, where the diameter is larger than the meeting points between courses, a net thickness must be calculated. This caution is not dissimilar from knowing the amount of framing and its conductance in lightweight "stick" wall construction at corners, plates, headers, etc. The framing elements have about three times higher heat transmittance than the insulation materials in the stud cavities. These effects are accentuated for steel-frame walls, due to the extremely high thermal conductance of steel. Included in the model code there are correction factors that account for the "thermal bridging" of steel studs.

The Energy Performance of Log Homes

Air-tightness is very important in log wall homes, to help control heating and cooling loads. Where large quantities of chinking materials are used in finishing the exterior walls then appropriate corrections should be made for their physical properties. Chinking materials are likely to have different thermal transmittance and heat capacities than those of the solid wood wall sections. If insulating layers are laminated or installed in a composite log wall system, these properties must be accounted as well. Where other materials are mixed extensively in a log home's exterior structural system, these also need to be properly accounted.

Here is an example of why careful assessment of all materials and layers is important. Let's say a natural log wall (round but debarked and de-tapered) has a 10-inch nominal diameter. However, if the meeting points between courses are only four or five inches across – such was where planning is done to make joints between courses more uniform – the net thickness of the overall wall is not really 10 inches; it may be substantially less, perhaps only 8 inches depending on actual system geometry. Since both the R-value of the wall and the heat capacity are sensitive to thickness, then the net overall thickness needs to be accurately estimated and appropriate adjustments made if needed prior to making U-factor calculations and thermal mass corrections.

The overall impacts of actual surface contours of a natural log wall include:

1) Potential reduction in R-value (thinner wall provides less material to resist heat flow); and
2) Potential reduction in wall thermal mass since thinner walls have lower heat capacity.

Both of these issues can result in changes to expected energy performance characteristics that need to be accounted for in the required calculations. For a totally fair set of calculations that accurately reflect the performance of any building wall, appropriate corrections for physical properties and actual component geometry are essential.

Example: Log Wall Calculation Correcting for Thermal Mass

In a 2,000 square foot log wall home, located in the Mid-west, the builder determines the climate has 5200 heating degree-days. Using the overall U-factor graph (Figure 2) the required overall U-factor is found to be 0.138 Btu - hr/ft^2 - ^{o}F. Recalling that the Uo value includes all wall, window, and door surfaces, the builder makes a basic listing of the homes' components and their surface areas.

Example Building Take-off's Listing

	Area	U-factor
Gross wall area (A_o)	1,200	0.138 (U overall, allowable)
Window area (A_g)	180	0.42 (U_g typ. Low-E Window)
Door area, 2 doors (A_d)	44	0.25 (U_d insulated doors)
Opaque wall area (A_w)	976	? (U_w compliant frame wall)

First the frame wall U-factor is determined, from which the corrected log wall U-factor will be derived using values in Table A. Using the simple U_o calculation we can solve for the compliant frame wall U-factor prototype needed to meet the model code, as follows:

$$U_o = \frac{(U_w * A_w) + (U_g * A_g) + (U_d * A_d)}{A_o}$$

using the known quantities:

$$0.138 = \frac{(U_W * 976) + (0.42 * 180) + (0.25 * 44)}{1{,}200}$$

then solving for U_W:

$$U_W = \frac{(0.138 * 1{,}200) - [(0.42 * 180) + (0.25 * 44)]}{976}$$

the initial frame wall required opaque area U-factor to meet the model code is calculated:

$$U_W = 0.081 \text{ Btu - hr/ft}^2 \text{ - }^{o}\text{F}$$

In this example house an R-13 cavity insulation level (including 1 inch exterior sheathing and typical dry-wall inside finishes) would satisfy the frame wall Uw requirement in the model code. The user then needs to correct for the use of a high heat capacity log wall used over the same surface area of the home.

Looking back at the heat capacity correction factors for log walls (Table A), the nominal U_W factor is used to select the appropriate base U_W column (shown in bold print); then the user reads across the appropriate climate category row (in this case selecting the 4,100 to 5,500 HDD category) to obtain the compliant log wall "equivalent" U_W value.

In this example the log wall would be required to have a Uw value of U-0.11 Btu - hr/ft^2 - ^{o}F. This means a log wall assembly with a net value of "R- 9" qualifies for the model code criteria that otherwise would require a stick framed house to use R-13 cavity insulation. The table permits selection of the log wall Uw value that will provide equivalent annual heating and cooling performance, similar to if the home had been built with a code-compliant light-frame wall.

Typical Log Home Energy Requirements

Thermal Envelope – Wall, Roof, Foundation, Glazing

Energy standards in building codes have always recognized regional differences in climate as discussed previously. Thermal protection – insulation, air-tightness, and window performance – recommendations vary over different climate locations, due to the impact of weather on heating and cooling demand. The same thermal protection levels are neither required by code, nor economically justified, everywhere in the country.

Tables C1 and C2 illustrate examples of some typical levels of thermal protection for log homes in four simplified U.S. climatic regions. Table C1 illustrates example energy packages for different thickness log walls in several climate areas. A complementary table C2 is presented where a 6 inch log wall is used across all climate zones, and other elements of the packages are "adjusted" to result in similar energy efficiency given the "fixed" wall system described.

Builders should use the table as a starting point for further considerations of basic energy efficiency levels. Information on compliant packages for code approval should be produced for specific locations. ***Note:*** *these tables may not be used for code compliance submittals, and are examples only.*

The Energy Performance of Log Homes

Table C –1

Representative Home Thermal Protection Levels, Including Log Homes

Envelope Section	**Cold Region > 6500 HDD**	**Temperate Mixed > 3500 HDD**	**Warm climate < 3500 HDD**	**Hot, and Hot-Humid climates**
Log Walls (Range of net inches wall thickness)	10 - 12	7 - 8	6	6
Frame Walls (R-value)	R-21	R-15, R-13	R-13, R-11	R-13 or R-7 CBS
Attic insulation	R-49	R-38	R-30	R-30 + RBS
Cathedral ceilings	R-38	R-30	R-30	R-19 + RBS
Windows (U, *SHGC*)	< 0.26; *0.56*	< 0.42; *0.52*	< 0.48; *0.45*	0.56; *0.41*
Doors	R-14	R-10 or R-5	R-5 or R-2.5	R-5 or R-2.5
Foundations				
Basement walls	R-19	R-19	R-13	NA
crawl space, floor	R-38	R-30	R-30	R-19
slab on grade	R-10 perimeter	R-5 perimeter	R-4 perimeter	Not required
Air-sealing *	Very tight	Tight	Well sealed	Sealed
Mechanical System Efficiency	National Standard	National Standard	National Standard	National Standard
Ventilation #	Mechanical, heat recovery type	Mechanical Recommended	Basic ventilation	Mechanical Recommended

* Blower door testing highly recommended to verify appropriate air-leakage levels

\# Ventilation systems should be installed in tightly sealed homes in cold climates to control energy waste while ensuring adequate indoor air quality.

HDD – Heating Degree Days base 65 ^{o}F

SHGC – Solar heat gain coefficient (listed on window labels like "NFRC" and ***EnergyStar***)

RBS – Radiant barrier system in attic

CBS – concrete block system, exterior insulated (typical in Florida, and Gulf Coast)

< Denotes "less than"; > denotes "greater than"

Note: Use of this table shall not abridge any locally mandated codes or standards.

The Energy Performance of Log Homes

Table C –2

Nominal 6-inch Log Home Energy Efficiency Packages

	Cold Region > 6500 HDD	**Temperate Mixed > 3500 HDD**	**Warm climate < 3500 HDD**	**Hot, and Hot-Humid climates**
Log Walls (net inches minimum thickness)	6	6	6	6
Attic insulation	R-60	R-49	R-38	R-30 + RBS
Cathedral ceilings	R-38	R-38	R-30	R-19 + RBS
Windows (U, *SHGC*)	< 0.26; *0.56*	< 0.42; *0.52*	< 0.48; *0.45*	0.56; *0.41*
Doors	R-14	R-10 or R-5	R-5 or R-2.5	R-5 or R-2.5
Foundations				
Basement walls	R-19	R-19	R-13	NA
crawl space, floor	R-38	R-30	R-30	R-19
slab on grade	R-10 perimeter	R-5 perimeter	R-4 perimeter	Not required
Air-sealing *	Very tight	Tight	Well sealed	Sealed
Mechanical System Efficiency	Very High Efficiency AFUE 90+ SEER14/HSPF 8	High Efficiency AFUE 88 SEER13/HSPF7.5	National Standard	National Standard
Ventilation #	Mechanical, heat recovery type	Mechanical Recommended	Basic ventilation	Mechanical Recommended

* Blower door testing highly recommended to verify appropriate air-leakage levels

Ventilation systems should be installed in tightly sealed homes in cold climates to control energy waste while ensuring adequate indoor air quality.

HDD – Heating Degree Days base 65 ^{o}F

SHGC – Solar heat gain coefficient (listed on window labels like "NFRC" and ***EnergyStar***)

RBS – Radiant barrier system in attic

CBS – concrete block system, exterior insulated (typical in Florida, and Gulf Coast)

< Denotes "less than"; > denotes "greater than"

Note: For a 6 inch log to have sufficient Heat Capacity (HC) to be eligible for thermal mass credits, the density of the wood species must equal or exceed 31 pounds per cubit foot.)

Note: Use of this table shall not abridge any locally mandated codes or standards.

MISCALCULATION EFFECTS: INSULATION, AIR-LEAKAGE, AND THERMAL MASS VALUES

Materials R-value Calculations Versus Laboratory Measurements

Since the late-1970's engineering standards groups and the Federal Trade Commission (See: "R-value Rule" -- Reference 13) have been concerned with errors and fraud in claims for thermal protection systems, particularly the misuse of the R-value for steady state thermal resistance to heat flows. The issue becomes more complex when building structural systems are conceived that have multiple materials, each with a different rate of heat flow compared to other "paths" for heat flow in the system.

Wood materials have heat transmission rates in between those of metals (very high) and thermal insulation materials. For example, steel has a high thermal conductivity of 26.2 Btu/hr-ft-^{o}F while softwoods have conductivities between 0.061- to 0.093 Btu/hr-ft-^{o}F, depending on species. Hence, steel framing is from 280 – to 430 times more conductive than wood. Thermal insulating products like mineral fibrous materials and cellulose insulation have conductivities ranging from 0.022 - to 0.07 Btu/hr-ft-^{o}F, depending on the type of material examined (ASHRAE Fundamentals Handbook, 2001. Ch. 25, Ch. 38). So insulation is up to three-times less conductive as the wood framing surrounding structural cavities.

The simple steady state methods for calculating system thermal transmittance (U-factor) based on individual component R-values can be highly error prone. The use of construction materials with greatly dissimilar conductance creates troublesome problems with calculations. In particular metal buildings, where metal skins and framing members can compress insulating materials when components are bolted together.

Another example is steel stud light framing, where the studs conduct about 400 times more heat than the cavity insulation materials. In the model codes and standards, there are significant correction factors that are applied to steel stud construction to correct for the excess heat flow that can occur through such walls.

In response to these concerns ASHRAE conducted studies to compare calculated heat flows with heat flows tested for the same building systems, in accredited laboratory facilities. These findings led to the publication of the Heat Transmission Coefficients manual by ASHRAE, based on research conducted by the University of Massachusetts engineering department.

The ASHRAE Fundamentals Handbook now requires at least two accredited lab sources for heat transmission data for special building assemblies, and code officials are cautioned to prefer these data to calculations unless submitted by professional engineers. A special building assembly includes complicated configurations of building materials for which it is difficult to produce meaningful thermal transmittance calculations due to the presence of heat-flow pathways with greatly different conductance.

Climate Design Issues

Log homes benefit more from thermal mass in temperate and mild climates (1). The research data has confirmed that in both very cold (heating dominates utility costs) and very hot (air-conditioning dominates utility costs) locations, the energy-saving effectiveness of heat capacity in a building envelope is reduced. However, climate conditions exist in most of the U.S. where homes have both a heating and a cooling load resulting in significant space conditioning energy use during a given typical year.

The Energy Performance of Log Homes

In colder regions of the country, log walls may be designed of thicker timbers to improve their basic R-value. Boosting thickness also adds heat capacity to the home. More heat capacity means larger windows installed facing South more effectively collect solar energy for passive heating of the interior spaces. The walls protect the interior from cold, and the admitted sunlight is stored and later released for heating. The log walls typically provide enough thermal mass that extra heat storage surfaces are not needed, reducing overall construction costs. A log home in a cold climate will benefit from good attention to air-sealing, and high efficiency heating equipment. The ductwork should be installed inside the conditioned spaces of the building for best performance

In milder "temperate" climates, a proportionally thinner log wall may be used to frame a home, without undue sacrifices of energy efficiency. There remains sufficient thermal mass to help temper temperature swings, and less glazing is needed for passive heating. In a mild climate, overhangs for window areas are useful to help control solar gains in spring, summer and fall, reducing air-conditioning costs. The interior mass surfaces can store heat during the day for later release by night ventilation of the interior. This same effect helps smooth air-conditioning demands during the day, and may even be sufficient to move the demand for electric power several hours into off-peak times when less expensive power may be available under "time-of-day" rates.

In a hot climate, log walls should be protected from direct sunlight by overhangs, or finished in lighter colors to reflect sunlight. Overly thin walls can begin to admit sufficient heat so as to raise air-conditioning costs somewhat. In a hot and humid area, it is important to reduce the air-leakage of the home, so excess moist outdoor air does not infiltrate the building. Windows should be installed that control solar heat gain into the home. A properly sized high efficiency air-conditioner and sealed ductwork will help stabilize indoor humidity levels.

There are many variables affecting overall building energy performance, and care should be taken to select appropriate climate-specific solutions for efficient design at affordable costs to consumers.

Air Leakage, Relative Humidity, and Construction Defects

In log wall buildings like any structural framing, attention to details in design and construction will lessen the amounts of unwanted air leakage. Air-leakage should be minimized since it is a key source of energy waste, indoor pollution, and potentially damaging moisture.

Log walls are a more structurally durable framing approach if interior humidity levels are kept within a stable range. Should humidity levels widely fluctuate on a short-term basis, solid wood members tend to swell or contract. These expansions and contractions can be especially significant under large step-changes in moisture levels at the surfaces of the wood, since wood can both adsorb liquid water and absorb moisture vapor. A well-designed exterior sealant approach, and chinking sealant system between log courses, can help mitigate both bulk moisture entry into the logs and reduce the entry of excess water vapor via the log sections into the building interior.

When excess humidity builds up in a structure, operation of the HVAC system can exacerbate moisture problems. In the summer, if there is excess moisture (elevated indoor humidity above 55 – to 60% RH) then air-conditioning systems may operate less efficiently and in extreme cases their heat exchange "air-coils" may ice up, defeating the function of the AC system.

The Energy Performance of Log Homes

In colder months, permitting excess moisture into log walls can reduce their resistance to heat flow (R-value). This increases somewhat the overall demand for mechanical heating in buildings with poor air-leakage and moisture controls. Alternatively, should humidity levels drop too low – into the 30- to 20% range for example – not only can human respiratory discomfort result but shrinkage drying in logs can lead to check-cracks, separations between joints, further elevating air leakage into the building. This air-leakage is an insidious cycle; if air leakage increases in winter when outdoor air is both cold and dry, then cracks and joints can expand further due to excessive drying of components – leading to more air leakage!

The best way to defeat the combined problems of air-leakage and moisture infiltration is through good system design and construction details that control the air infiltration via construction joints, cracks and penetrations. Log home manufacturers have devised some innovative systems that are more airtight. These designs include tongue and groove milling, foam compressible gaskets, and composite systems of solid wood and insulation materials. All of these approaches significantly reduce air leakage via thermal and construction defects, compared to direct butt-jointed log courses with large quantities of chinking compounds inserted to fill the gaps.

Heating, Air-conditioning, Distribution Systems

Like any modern building, log homes benefit from effective design, installation and checkout of their HVAC systems. Some of the best basic building science advice is to design and install residential heating and cooling systems with the following basic criteria:

1) Locate air distribution duct systems inside the conditioned space of the building;
2) Conduct computer aided analysis to properly size mechanical equipment;
3) Provide return ducts to reduce pressure differences between rooms within H/AC zones;
4) Select mechanical equipment that meets the EPA/DOE **EnergyStar** label criteria;
5) Properly commission the system including basic measurements to ensure good performance; and
6) Provide the owner with an information booklet on how to operate and maintain the system.

The ductwork should be located indoors and care should be taken during installation to properly seal all joints and seams of the ducts to reduce air-leakage. Field-testing has found up to 40% of HVAC system airflows can be lost in poorly sealed ductwork, wasting energy and causing equipment to wear out prematurely.

Over sizing heating and A/C components in any building is inefficient and adds unnecessary construction cost. Rules of thumb for sizing residential HVAC equipment have no place in log home design, since the thermal mass and increased ability to utilize free heat from the sun (passive solar heating) are important to good long term performance and lower utility bills. Log homes need HVAC equipment that has been properly sized for optimal performance. Right-sized furnaces, boilers and heat-pump equipment will cycle less, and be more effective at providing indoor comfort. Also, very deep thermostat setback is not recommended for homes with high thermal mass.

The duct system should provide a return air pathway from each major room to the primary equipment air-handler. Central returns have been shown to create comfort problems and pressure differences. Building physics shows that without return ducts, when doors are closed for privacy large pressure differences can set up in buildings that induce indoor air quality problems and lower energy efficiency. This can be especially true of rooms with large surface areas exposed to outdoor conditions, where pressure differences attempt to increase air-leakage through construction defects in walls.

High efficiency mechanical equipment is one of the best marginal investments for any home, and especially in log wall homes. On rare occasions where extreme conditions of cold or hot weather occur, then more efficient equipment helps moderate utility bills, and help offset the somewhat lower steady state R-values of the log walls.

Installing a properly designed HVAC system is incomplete without requiring a thorough checkout or "commissioning" of the house as a system. In particular a commissioning plan should include duct leakage testing, making sure A/C or heat pump systems have proper refrigerant levels, checking that modes of the thermostat are working, and that forced-air systems obtain proper air-flow readings in the air-handler unit to ensure adequate but not excessive air-flows. The home systems commissioning plan should be included in specifications for project bidders.

Role of Construction Supervision in Energy Performance

The best analytical calculations indicating a modern building "meets or exceeds energy code" levels can only be as good as the field implementation of the selected efficiency measures during construction. A trained crew that is properly supervised to install building products according to the manufacturers specifications is the only way to ensure good performance.

An example of this issue is when stick-frame walls are insulated with mineral-fibrous materials. Often the insulating crews are in a hurry, since they are compensated on a piecework basis. Since volume of material installed over time measures their compensation, they may have little incentive to install the materials without gaps, tears, excessive compression, or even omitted materials. Other building layers like gypsum drywall can rapidly conceal the errors; so they are not readily observed, that is until the homebuyer gets their first big heating or air-conditioning bill following occupancy.

Another example is air-leakage reduction strategies. A common issue on construction sites is "Whose job is it to seal the building?" Is it the responsibility of the framing crew, the insulators, the dry-wall installer, or who else? Unless there is a designated responsible party for the air sealing, it is not likely to get done properly, if at all.

Insulation errors and poor air sealing can account for up to 50% excess energy consumption. So it is no wonder that designers and installers of heating and air-conditioning systems have been lead to considerable over-sizing of mechanical equipment. One poor set of practices compounds another, leading to both increased first cost (overly large more expensive furnaces, boilers, AC, or heat-pumps) and increased energy consumption (more heat loss or gain).

INTERACTIONS OF BUILDING ENERGY FEATURES

Energy efficiency features interact with the thermal mass effect in residential buildings, as observed in the literature cited earlier in this report. Major considerations influencing the amount of benefits that can reasonably be derived from log wall heat capacity include:

- ☐ *Insulation levels (“R”-value);*
- ☐ *Windows and doors (thermal and air-leakage qualities);*
- ☐ *Passive solar glazing (how much south-facing glass is installed);*
- ☐ *Foundation design (amount of coupling to the ground);*
- ☐ *Envelope air-tightness (unwanted air leakages);*
- ☐ *Duct work leakage (pressure differences);*
- ☐ *Ventilation (mechanical venting, natural venting, leakage rates); and*
- ☐ *Interior thermal capacity (mass of furnishings, etc. inside the space).*

Insulation (“R”-value)

Insulation quantity and placement in the wall section is a significant factor influencing the level of thermal mass benefits from heat capacity. Exterior insulated massive walls perform best according to the data. Their performance benefits are closely followed by "integral" insulated cases -- such as log walls -- where the insulating materials are mixed with the heat capacity materials. Other integral cases include aerated-autoclaved masonry block, structural-insulated panels, strawbale walls, and hybrid composite materials.

The poorest case of heat capacity benefits is when the mass wall is insulated on the interior, where the insulation is between the conditioned spaces and the structure element with the heat capacity. An example is a brick wall with an interior foam or mineral fibrous insulation layer behind sheet-rock.

Windows and Doors

The size and location of glazing areas that can both let in solar heat and cause heat loss and gain by conduction (temperature differences) will influence thermal mass effects. A high-mass building can accept larger amounts of glazing area without uncomfortable "overheating" and temperature swings, because it can temporarily store extra heat in the surfaces having elevated heat capacity for later release either to warm the space, or to be ventilated to outdoors.

Passive Solar Glazing

A "passive solar" home using log or masonry walls may perform better than a lightweight solar home with the same amount of glass due to the virtue of interior surfaces of structural walls smoothing delivery and rejection of extra heat.

Foundation Design

A building with a slab on grade foundation may show less benefits of thermal mass in its walls due to the heat sink of its floor and coupling of the indoor space (and H A/C thermostat) to a bigger mass "the floor." Conversely, buildings with basements and crawlspaces floored with wood frame constructions furnish less thermal mass internally, so the walls will have greater influence over the comfort conditions "seen" by the H A/C thermostat.

The Energy Performance of Log Homes

Envelope Air-tightness

Buildings with excessive air leakage (infiltration) will likely show poorer overall energy efficiency for heating and cooling, which may mask thermal mass benefits to a large degree. High rates of air leakage in buildings not only wastes energy but also can cause indoor air quality problems, moisture build up, excessive "dusty" conditions, and poor comfort balance for occupants. Infiltration effects on thermal mass performance will be highly variable by climate since the indoor spaces in a leaky home are more connected to outdoor weather features, particularly severe cold an heat as well as wind.

Ductwork leakage (pressure differences*)*

According to field studies leaky ductwork can cause 40% energy waste in heating and cooling seasons. It is difficult to generalize the influence of poor duct design and construction on how a building might benefit from heat capacity. However, even if poor ducts cost a homeowner only about 20% more for heating and cooling compared to well sealed and insulated ducts, that is still right in the same order of magnitude as one may expect from annual thermal mass benefits. One may expect a home with duct loss problems not to benefit as much from thermal mass since the thermostat would constantly be correcting indoor comfort conditions to account for the leakage.

Ventilation

A properly air sealed building with a mechanical ventilation system should never greatly penalize heat capacity benefits. Research shows that if night-flush (economizer) cooling is used elevated heat capacity in a building's structural walls can actually increase the overall annual energy savings by reducing air conditioning demand in summer. Heat stored in the mass walls is flushed out by vigorous controlled ventilation on the following night, instead of keeping on running the air-conditioner if outdoor temperature and humidity conditions are suitable.

Interior thermal capacity

The amount of additional heat storage capacity inside a building due to furnishings, partition walls, brick fireplaces, floor slabs and ceramic tile, and other contents can add up to a significant amount of thermal mass in its own right. A home filled with concrete floors, brick partition walls, tile or granite counters, etc. will "see" less effects from heat capacity in walls.

However, by the same token such contents help store "passive solar heat" for later use permitting larger window areas to be installed without fear of overheating. Heat capacity of contents are considered by energy engineers when performing computer simulations, but are not considered in much detail for basic HVAC equipment sizing.

CONCLUSION

The log home is a fundamental American construction concept. Some of the oldest occupied structures in North America are log buildings, indicating their fundamental durability when properly designed and constructed. Modern manufacturing methods are bringing new technologies to bear in making log homes increasingly energy efficient and even more long lasting.

There is a large engineering technical literature supporting the validity of granting performance adjustments or "credits", as they are sometimes called, for thermal mass in structural walls of buildings. When the annual heating and cooling benefits of mass are analyzed for single-family homes, it is important to realize that the overall assessment of net benefits should be the focus of study. In some cases increased energy use may occur during one part of the year (days, months) versus another period, while net-net the building may be shown to use less overall space conditioning energy on an annual basis.

For homes these whole-building performance benefits fall into a range of 2.5% to over 15% for most US climates. This means, a log home having 30% to 40% lower numerical R-value's will provide equivalent performance for heating and cooling when using numerically lower steady state R-values in its walls than will a stick-framed home of otherwise identical design.

Exceptions are areas with especially cold or especially hot weather, where the benefits of wall heat capacity are reduced according to engineering studies. There are extreme climates where thermal mass has little or no benefit, such as those with greater than about 8,500 Heating Degree-Days (HDD) and those with very high Cooling-Degree Hours (CDH74).

Log homes are constructed of natural and renewable materials that are inherently more environmentally efficient than processed lumber in construction. Using logs can be a "green building" method especially when the timber is produced locally (typically the case), or the log home producer uses wind or fire-killed timber as the log source. There are also manufactured log-type wall systems of composite design where smaller dimensional wood and insulating materials are combined to provide a log-like construction unit.

Another inadvertent environmental benefit of log home building is that in the distant future, when the log home is demolished or de-constructed for its component parts, the logs will provide value as a source of quality timber for producing other lumber and wood products unlike stick frame construction which is often demolished and shipped direct to landfills.

All told, the log home has been shown to be a competitively energy efficient, durable, and environmentally useful alternative to typical stick frame construction. Technical progress will continue to evolve log homes that are even better performers. Both consumers and the environment will benefit from the increasing recognition of log homes as green and efficient dwellings.

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For more information, refer to

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INFORMATION WEB SITES

NAHB Log Homes Council, 1201 15th Street NW Washington, DC 20005 USA -- (800) 368-5242	*http://www.loghomes.org/*
Log Home Living Magazine	*http://www.loghomeliving.com/*
EnergyStar program (US EPA/DOE)	*http://www.energystar.gov/*
U.S. Department of Energy, Office of Building Technology, State and Community Programs	*http://www.energycodes.gov/*

