The Energy Performance of Log Homes

Documented Energy-efficiency and Thermal Mass Benefits

Prepared by the Construction Codes & Standards Committee,
Log & Timber Homes Council,
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1 FOREWARD

This white paper 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 a 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 home type.

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, and even the type of windows installed. These properties significantly benefit homeowners and help our environment by reducing energy waste - hence lowering the power plant and fuel-combustion emissions including CO_2 implicated in changing our climate. Using solid wood for mass walls adds the benefit of utilizing a renewable resource with potentially the lowest environmental impact of any common building material!

1.1 Background

Ever since building codes regarding energy conservation were established, there have been concerns about the proper representation of thermal performance of homes built using mass-wall construction. These buildings incorporate wall construction that has greater "heat capacity" or thermal mass in their walls compared to typical lightweight wood frame construction practices. There are also legitimate concerns about the ability of simple "steady-state" calculations used to size residential heating and air-conditioning equipment to properly consider the effects of thermal mass on annual utility bills for heating and air-conditioning under real-world weather conditions. The use of mass wall technologies also indicates the presence of an air barrier, since air cannot move through the solid object.

In 2001, with the accelerating growth of log home construction across the U.S., the LTHC began a comprehensive review of the available studies that document log homes' energy-efficiency and thermal mass benefits to help improve understanding in the construction codes community and the heating, ventilating and air conditioning (**HVAC**) engineering community.

The basis of this study came from 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. The original supporting data, reports and analysis remain valid today and are summarized in the reference section of this white paper.

Since the original 2003 publication, considerable evolution has occurred in the world of codes and standards. This update incorporates information from several publications of the International Code Council (**ICC**) -- **ICC 400** *Standard on the Design and Construction of Log Structures* (currently the 2022 edition), **ICC700** *National Green Building Standard.* [14, 15] (currently the 2020 edition), and the ICC International Energy Conservation Code (**IECC**, currently the 2021 edition).

The focus is on new design and construction that is striving for compliance with the above codes and standards. There are many existing log homes that did not have these documents for guidance or complied with an earlier version that allowed lower prescriptive minimum requirements. This is true for other methods of residential construction, meaning that many homes were built to the contemporary standards and codes of the time. For critics who point at "leaky" log homes, ask how well their contemporaries performed and determine which is easier to seal? To help answer this question, the LTHC has developed two other white papers that address solutions to air infiltration or maintenance issues in those dwellings.

1.2 How Log Homes Are Different

For the past 50-60 years, log homes have been primarily provided in material packages from milling/manufacturing facilities or handcrafted log yards who bring in the raw material and deliver the appropriate logs to the building site as opposed to historic structures crafted from raw logs felled nearby. As the design and construction industry evolved with technology, so did the production of log buildings. Computer aided design (CAD) replaced hand-drafted house plans and brought computer aided manufacturing (CAM) and computer numerical control (CNC) to create detailed instructions (G-code) that drive CNC machines. CAM software streamlines the machining process and automates actions like drilling and cutting, which makes it ideal for high-quality manufacturing. The solid wood structural components are visually stress graded in accordance with and under the auspices of accredited log grading agencies (i.e., the LTHC Log Grading Program). The result is a quality-controlled product shipped as a package for erection on a home site by a skilled crew to the specifications of the log home supplier.

1.2.1 Design Options

A home constructed of solid wood walls need not appear fundamentally different from conventional wood frame housing types, however designers and prospective buyers of log homes often include more contemporary design, larger south-facing windows, cathedral ceilings, and traditional "western" features such as porches and verandas in their design preferences. While many log homes are constructed as vacation, retirement, and second homes in scenic settings, there has been significant market penetration into primary housing.

1.2.2 An Alternate Method & Material

Much of this paper will compare log walls to conventional frame for a couple of very good reasons:

- The model codes -- ICC *International Residential Building Code for One- & Two-Family Construction* (**IRC**) or *International Building Code* (**IBC**) – pertain to the historically dominant building methods and materials of lightweight wood or steel framing, heavy timber, steel, concrete, and masonry.
- When building authorities are inspecting/certifying new construction, they will rely on their experience and knowledge to judge what they are observing. With log building being a much smaller share of the market, that experience and knowledge may not be present.
- Log walls and log framing systems had been reviewed for plan approval and building permits based on Section R104.11 "Alternative materials, design and methods of construction and equipment."

Log walls are a unique form of construction with definite advantages. The construction of stacked logs provides the structural integrity and thermal barrier in one assembly with one trade completing the work. This aspect of log wall construction has been recognized as a desirable element for green building. [15]

Other comparisons that distinguish log wall construction from code specifications include:

- Horizontal seams between the logs are designed and constructed to prevent air/water infiltration.
- Movement in log walls is accounted for in joinery systems and will not be compromised as when framing members change dimension (e.g., no nail pops in drywall).
- The thermal performance of log walls does not degrade from sagging insulation, damaged vapor barriers, or failure of external water screens.
- Log walls are analogous to continuous insulation, in that the thermal properties are consistent across the entire wall. There is no concealed cavity to fill with insulating material, and vertical layers of materials do not need to be applied to insure performance.

- ❑ The most common areas of air infiltration are from elements common to all dwelling construction (connections of roof to wall, wall to floor, floor to foundation, etc.) and are not log home specific. According to research studies in both Canada and the US, a log home will provide equal or better energy efficiency when compared to a stick frame home provided it is designed and built per industry standards.

1.2.3 Comparing Wall Assemblies to Insulation Products

When it comes to compliance with energy codes, our home-building/home-buying culture has been saturated with rated R-values. Granted, it is very easy to understand that a wall with R-21 insulation will be better than one with R-13 insulation but that is only an accurate assumption when comparing batt insulation in frame wall cavities. Any wall with an effective continuous wall assembly of equivalent R-value will out-perform the frame wall. For example, a structural insulated panel (**SIP**) with 4-inches of EPS foam will be rated at R-20 much more uniformly. Testing to establish a rated R-value of a solid wood wall 5" and greater in thickness has not been published, and the controversy over log wall R-value continues in today's energy code discussions.

- A quick note: A common insulation in 2x6 walls is R-19, a 6" thick batt. However, the stud cavity is 5-1/2", so when the batt is compressed, it loses R-value. This ±R-17 wall can be improved by using R-21, a 5-1/2" batt.

The on-going challenge is to demonstrate compliance of log walls with an energy code that stipulates a minimum rated R-value of the insulation product installed in the cavities of lightweight wood frame construction. When the entire frame wall assembly is considered, there may be as much as 23-27% of the assembly made up of wood products rather than insulation products, and the overall R-Value (weighted average of wall assembly) is less than the rated value of the insulation.

Today, the model energy code adopted in most jurisdictions calls for a minimum wall cavity insulation of R-13 with colder climates looking at a combination of more cavity insulation and/or continuous exterior insulation ("ci"). Still log walls (a.k.a., mass walls in the code) show greater advantage in warmer climates.

Climate Zones (CZ)	Insulation R-Value	Net (frame) whole-wall U-factor	Net (frame) whole-wall R-value	Mass wall U-factor	Mass wall R-value	Mass enhancement factor
CZ 1	13	0.084	11.90	0.197	5.08	2.35
CZ 2	13	0.084	11.90	0.165	6.06	1.96
CZ 3	20 or 13+5ci	0.06	16.67	0.098	10.20	1.63
CZ 4	20+5ci or 13+10ci	0.045	22.22	0.098	10.20	2.18
CZ 4C Marine	20+5ci or 13+10ci	0.045	22.22	0.082	12.20	1.82
CZ 5	20+5ci or 13+10ci	0.045	22.22	0.082	12.20	1.82
CZ 6	20+5ci or 13+10ci	0.045	22.22	0.06	16.67	1.33
CZ 7	20+5ci or 13+10ci	0.045	22.22	0.057	17.54	1.27
CZ 8	20+5ci or 13+10ci	0.045	22.22	0.057	17.54	1.27

• Figure 1-1 Prescriptive Values from the 2021 IECC

Another key comparison is related to moisture. Testing at Oak Ridge National Labs on wall assemblies demonstrated that air can easily pass-through batt insulation and around the insulation and framing. Advocates for adding air barriers and continuous insulation base their argument on the premise that cavity insulation cannot be installed to restrict air flow. This is a very important discussion because those air leaks are providing unrestricted passage of moisture in the form of water vapor. Yes, adding continuous insulation to the outside of wood framing requires additional consideration. In warmer climates, the code requirement for "R-5 ci" does the intended job. However, as the climate gets colder, there is a need to adjust the thickness outside to ensure that condensation does not occur within the wall assembly. Needless to say, this does not happen with solid wood.

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1.2.4 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, a lightweight wood frame home would have to be insulated to about R-13 [or even R-15 in some areas] to equal their heating and air-conditioning energy use on an annual basis. This comparison assumes similar solar orientation, 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 efficient compared to an identical wood-frame home, considering annual purchased heating and cooling energy needs.

Domestic mass timber producers, including cross-laminated timbers (CLT), are the beneficiaries of the assessment and design tools being developed in the U.S. and Europe. This is important work as producers need to be able to present scientifically assessed material to market these products efficiently and to provide code institutions with demonstrated performance claims. A study performed for 80 mass wood buildings in Finland showed up to a 50% lower measured actual heating demand than that predicted by computer simulation. Recent studies in Germany have shown that employing radiant heating and thermal comfort measures also demonstrated improved energy performance.

2 ENERGY CODES: SCIENCE, DEVELOPMENT & APPLICATION

Building science studies how heat, air and moisture effect a building assembly.

- There are three primary forms of heat transfer in a building – convection, conduction, and radiation. Convection is primarily in airspace, conduction is transmission through a material/assembly, and radiation is a surface phenomenon of exchanging energy between objects.
- Recognized as a cold draft, air infiltration is a factor in energy conservation because the outside air changes the temperature of the inside conditioned space, and the occupant responds by raising the thermostat temperature. Air movement through the building envelope also carries moisture with it.
- Moisture management looks to minimize the effects of bulk water (limited by looking at drainage planes), capillary action (limited by an air space or non-porous seal, i.e., gaskets, flashing, etc.), air transport (sealing holes in the thermal envelope – air and vapor controlled by the same seal!), and diffusion (a.k.a., vapor drive).

The focus of early energy code development was on conduction and sealing seams to minimize air infiltration. Outside of the window and door industry, "line of crack" was less of an influence on code development. Major influence and attention were invested on insulation products to reduce the conduction of heat through the building envelope – floors, walls, ceilings, windows and doors. That conduction rate was established based on steady-state testing – how long did it take heat (held at a steady temperature) to move from one side of a 1" thick sample to the other side? Traditional steady-state calculation methods and criteria still dominate the implementation of building envelope energy efficiency The concept that steady-state R-values are the best way to measure energy efficiency does not reflect the experience observed by DOE researchers, the American Society of Heating Refrigerating and Engineers (**ASHRAE**), and log homeowners.

Log walls – and mass walls in general – have received limited and conservative recognition for their thermal mass benefits. When looking solely at the steady-state R-Value, the R-1.2/inch of softwood looks weak against the R-3+/inch of insulation products, However, solid wood is a natural air barrier without plastic wraps or rigid insulation now required in the energy code. As a solid material, there is no potential for convection to occur in a stud cavity as has been evident in some batt insulation installations. And as a material of significant mass, log walls offer dynamic radiant energy exchange. Passive solar methods and radiant floor systems continue to make gains in new construction, but they are beyond the prescriptive minimum requirements for the thermal envelope.

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.

2.1 R-values as an Early Rating System

The term "steady-state" means pretty much what it says. The leading authority for evaluation of the thermal envelope in the United States is at Oak Ridge National Laboratory (**ORNL**). The definition of steady-state is provided on their website: [16]

> "The steady-state R-value is traditionally used to measure the thermal performance of building envelope components. Wall systems have been rated for their energy efficiency either by calculating the thermal resistance (R-value) of the insulation material within the wall system or by full-scale testing of a so-called clear portion of the wall system… Steady-state hot box testing requires constant temperatures on both sides of the tested specimen."

Engineers use design conditions and steady-state R-values to predict maximum loads for sizing HVAC equipment. 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 thermal envelope. This data is 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.”

“R-value” is a measure of a material’s resistance to heat flow over its thickness, or over a fixed thickness (R- per inch for example). Building assemblies – such as walls, the roof, the floor or foundation– are put together from a variety of materials, each layer or section having its own R-value. Depending on its use, a particular material (e.g., foil-faced rigid insulation), may have a different R-value for a flat, horizontal application (under a floor), sloped application (cathedral ceiling), or vertical (exterior wall). Adjusting for the application, 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. This R-value data is reported in design manuals and manufacturer’s data sheets and conforms to regulations put forth by the U.S. Federal Trade Commission (**FTC**) in the mid-1970s.

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-°F while softwoods have conductivities between 0.061- to 0.093 Btu/hr-ft-°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-°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.

Problems with establishing an accurate assembly U-factor crop up when materials with markedly different R-values are used in an assembly. Since the late-1970’s, engineering standards groups and the FTC (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. The use of construction materials with greatly dissimilar conductance creates troublesome problems with calculations (e.g., metal buildings, where metal skins and framing members can compress insulating materials when components are bolted together).

Consider the example of lightweight steel framing, where the studs conduct about 400 times more heat than the cavity insulation materials. 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 incorrect U-factors, thereby generating erroneously high estimates of overall thermal performance of the wall. 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 this 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.

As described in the sections that follow, it is not appropriate to use an R-value requirement designed for an assembly of markedly different R-values (wood framing with insulated cavities) to rate the performance of an air-tight wall assembly made from a consistent material type.

2.2 Thermal Mass – The Effect of Heat Capacity

2.2.1 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. Prominent energy efficiency standards and codes provided limited mass correction factors acting upon thermal transmittance "U-factors" until ASHRAE Standards 90.1 and 90.2, as well as several versions of the MEC, were absorbed into the IECC. Therefore, the IECC includes thermal mass correction factors and calculation methods that better reflect real-world building performance than steady-state estimates. However, these factors have been adjusted with new code development that has progressed the IECC toward the 2030 goals for net-zero energy consumption by buildings.

2.2.2 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 result of its heat capacity over a sectional area which 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). 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.

2.2.3 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-LTHC 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 structure's 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 (**NBS**).

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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]

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 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 lightweight wood 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 <u>DOE Thermal Mass Program</u> was underway, and NIST presented initial results of an instrumented field test comparing lightweight wood 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 performances 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 lightweight wood 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 were consistently over-predicting log wall heat losses. [9]

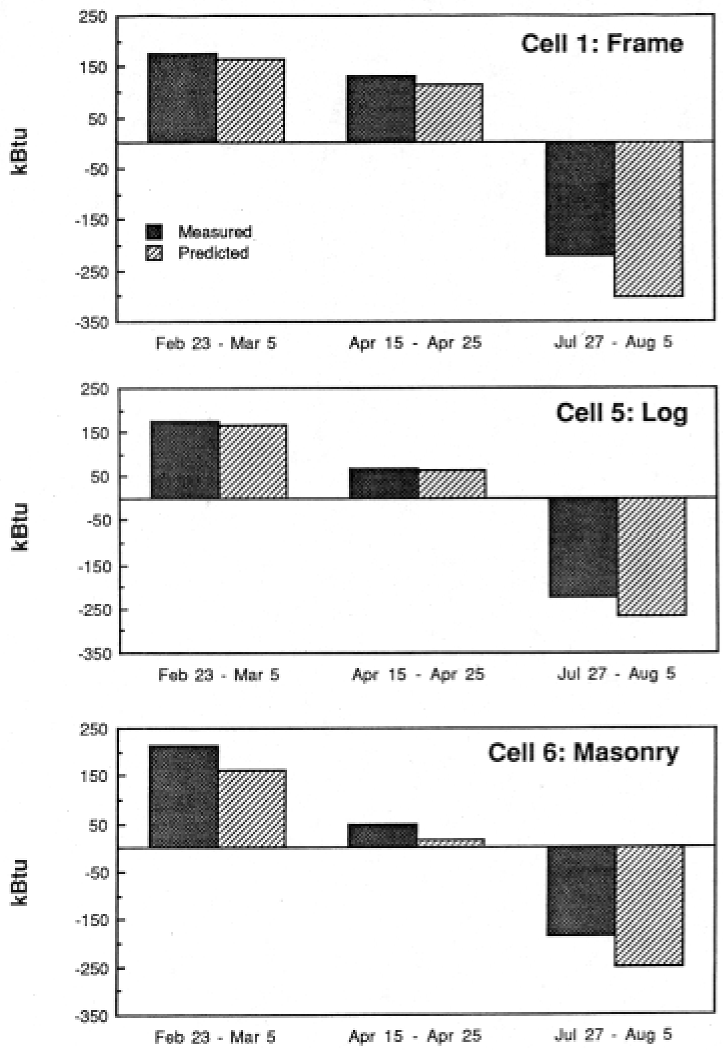
Work on measuring heat capacity effects by NIST continued through 1984, when detailed ASHRAE papers were published on both observed heating and cooling thermal mass "behavior." The log wall (“Cell #5”) in the two reports showed very good performance. It saved energy compared to the insulated frame building 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 lightweight wood 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]

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.

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 lightweight wood 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]



• Figure 2-1 NIST Test Cell Comparisons (Source: LBNL)

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)

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In addition to lightweight 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 walls (2x4 with R-11 batts; typical ½" interior wallboard and exterior sheathing). The measured air change rates of both frame and log houses were 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 1979-1985. 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.

2.3 Mass Walls in Model Energy Code

Prior to 1989, the CABO Model Energy Code (**MEC**, now the 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.

2.3.1 Introduction of Thermal Mass

REQUIRED U_w FOR WALL WITH A HEAT CAPACITY EQUAL TO OR EXCEEDING 6 Btu/ft^2 · °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/ft^2 · °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/ft^2 · °F = 0.176 kJ/(m^2 · K).

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. **Table A** illustrates the correction factors that were accepted in the 2003 IECC and connected codes like the International Residential Code (**IRC**) which are referenced by states and local jurisdictions.

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

Similarly, considerations of both a building's 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 Standard 90.2 – 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 different unique construction systems) and for the first-time simultaneous use of heating and cooling weather data as opposed to only the heating criteria.

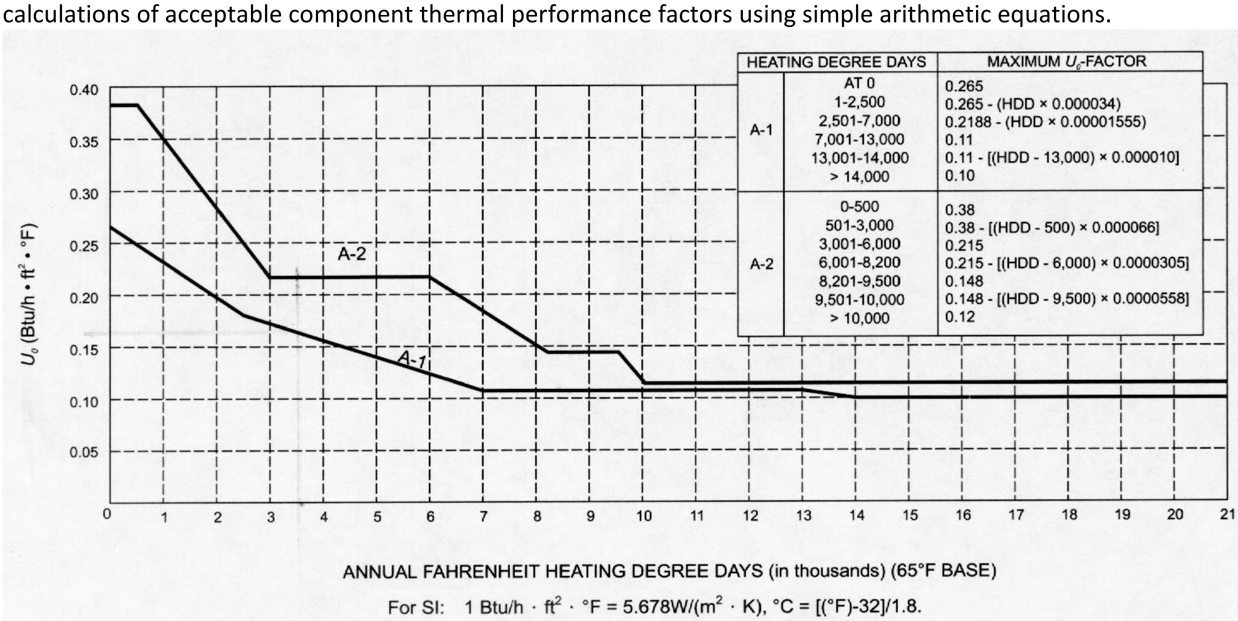
2.3.2 Calculating Thermal Mass Correction for Log Walls

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 per the 2003 IECC. The mass wall correction data are shown in 2003 IECC Chapter 5: Section 502.2.1.1.2 "Mass Walls." The 2004 Supplement IECC and editions thereafter removed this approach, however the historical reference is still valid.

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 2-2 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 2-2, 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.



- Figure 2-2 U_o – 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

2.3.3 Calculating Thermal Values

The equation shown in this section is used to calculate the overall thermal transmittance factor for the wall, from its component parts. The equation from the 2003 IECC, right, is the same as that contained in ICC400, Section 305.4.2.1. 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 wood 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 - °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 - °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.

2.3.4 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 - °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 - °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 a 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 heat capacity 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 (ICC400 defines average width as the area of the log profile divided by the stack height). 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 wood frame 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.

Airtightness 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 for as well. There also needs to be proper accounting for instances where other materials are mixed extensively in a log home's exterior structural system.

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 reductions in wall thermal mass since thinner walls have lower heat capacity.

Both 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.

2.3.5 Example: MEC Log Wall Calculation Correcting for Thermal Mass

In a 2,000 square foot log wall home, located in the U.S. Midwest, the builder determines the climate has 5200 heating degree-days. Using the overall U-factor graph (Figure 4) 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 Btu - hr/ft^2 - ^{o}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 - °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.

2.4 Model Code Updates

One obstacle to wider adoption of advanced energy standards into building codes is their relative complexity. The need for simplifying the IECC was described in DOE's Building Energy Codes Program review of the 2006 IECC – "Easier to Use and Enforce" published in May of 2007. The document states that the sweeping changes from the 2003 IECC "will shrink the 2006 IECC codebook by more than half, resulting in a code that will be easier to read, understand, use and enforce." Thermal mass was "simplified" as well by eliminating the criteria that qualified the wall assembly as a mass wall.

As an aside, it can be noted that the 2021 edition of the IECC has again grown in size and complexity.

2.4.1 The Simplified IECC

To accomplish this change, DOE submitted a public proposal to delete Chapters 1-6 and the first Appendix from the IECC and replace it in its entirety. The 2003 IECC had 216 pages; the new 2004 Supplement Edition had a mere 74. While the IECC was further modified in 2006 and 2009 editions, the pages remained at 80. Until the American Recovery and Reinvestment Act of 2009 (**ARRA**) pushed the issue, states were widely varied in their adoption of energy codes. Many states still referenced the MEC, many times updated to the current IECC. With ARRA legislation in place, states had Federal incentives to adopt the 2009 IECC. Per DOE in the "Impacts of the 2009 IECC for Residential Buildings at State Level" published in September of 2009,

> "Though there were changes in each edition of the IECC from the previous one, the IECC can be categorized into two general eras: 2003 and before, and 2004 and after. This is because the residential portion of the IECC was heavily revised in 2004. The climate zones were completely revised (reduced from 17 zones to 8 primary zones in 2004) and the building envelope requirements were restructured into a different format. The code became much more concise and much simpler to use. These changes complicate comparisons of state codes based on pre-2004 versions of the IECC to the 2009 IECC."

The 2004 IECC Supplement brought several changes including:

- ☑ New requirements to control the amount of energy consumed in cooling.
- ☑ increased wall R-value requirements for northern climates,
- ☑ created new climate zones (reduced 19 zones down to 8),
- ☑ eliminated the need to calculate the window –to–wall ratio (percentage of glazing no longer an option to choose insulation requirements for other aspects of the thermal envelope), and
- ☑ simplicity of prescriptive and UA-tradeoff paths that will tend to point to performance compliance for building systems and materials that do not fit the mold set by the new code, "simplified and improved" mass wall and steel frame provisions.

The three tables showing tradeoff for thermal mass (with insulation applied to the inside, to the outside and integral with thermal mass) were reduced to two reference values for each of the climate zones (exterior/integral or interior) in one table. In addition, and most importantly, the 2004 Supplement removed the qualification for thermal mass (at least 6 Btu/ft^2 - °F [1.06 kJ/(m^2 – K)], or 20psf density for log walls and 30psf density for concrete and masonry walls).

The following table presents the impact of the IECC changes to frame wall and mass wall U-Factors updated to include the prescriptive requirements of the 2021 IECC:

Climate Zone	Heating Degree Days	Frame Wall U-Factor								2021 Frame Walls		Mass Wall U-Factor		
		2003 (approx.)		2004 & 2006	2009	2012	2015	2018	2021	Insulation Requirement	Assembly	2003	2004 - 2009	2012 - 2021
1	9000 < CDD50°F	Varies with percent of glazing	0.085	0.082	0.082	0.082	0.084	0.084	0.084	R-13	R-11.9	Varies with percent of glazing	0.197	0.197
2	6300 < CDD50°F ≤ 9000		0.085	0.082	0.082	0.082	0.084	0.084	0.084	R-13	R-11.9		0.165	0.165
3	4500 < CDD50°F ≤ 6300 AND HDD65°F ≤ 5400		0.058	0.082	0.082	0.057	0.060	0.060	0.060	R-20 or R-13+5	R-16.7		0.141	0.098
4 except Marine	CDD50°F ≤ 4500 AND HDD65°F ≤ 5400		0.058	0.082	0.082	0.057	0.060	0.060	0.045	R-20+5ci or R-13+10ci	R-22.2		0.141	0.098
5 and Marine 4	5400 < HDD65°F ≤ 7200		0.052	0.060	0.057	0.057	0.060	0.060	0.045	R-20 or R-13+5	R-22.2		0.082	0.082
6	7200 < HDD65°F ≤ 9000		0.052	0.060	0.057	0.048	0.045	0.045	0.045	R-20+5 or R-13+10	R-22.2		0.06	0.06
7 and 8	9000 < HDD65°F		0.046	0.057	0.057	0.048	0.045	0.045	0.045	R-20+5 or R-13+10	R-22.2		0.057	0.057

- Table C Changes to Wall Requirements in the Consecutive Issues of the IECC

It is interesting that after all of the changes, these values have nearly reverted to the 2003 IECC.

Even with the simplifications in the IECC, the issue remains that many building officials are still looking for the required R-value to meet the prescriptive code. Without discussion and explanation, there is little recognition that insulating solid wood and masonry walls is a different process than insulating typical frame construction. Therefore, standard practices employed for affordable and cost-effective thermal protection improvements of wood frame walls are unreasonable, onerous, and not equitably applied to log walls, an alternative method and material of construction. In other words, if a house is conventionally framed, as most homes in the U.S. are, code compliance has specific direction, but it fails to provide that direction when faced with an alternative wall assembly.

Keeping to the theory that codes and standards need to promote correct and expeditious interpretation, ICC400 provides a table of assembly U-factors (305.3.1.1, calculated at 12% moisture content) that correspond to the equivalent Mass Wall U-Factor. The application of U-factor to log walls is a truer application of the code than meeting the prescribed Mass Wall R-values which are appropriate for concrete and masonry walls.

2.4.2 Introduction of Air Barriers

As mentioned earlier, building science is not new, but has had a significant impact on the newer developments in the IECC. It influenced the recognition of climate zones, and the variables affecting building in those zones. The placement of vapor barriers is one such discussion, as hot-humid climates place entirely different vapor drive pressures on the thermal envelope than cold climates. The hygroscopic nature of solid wood walls allows them to work magnificently in all climate zones!

The attention to air infiltration brought focus on proper installation of insulation to avoid gaps, to proper sealing around windows and other penetrations through the building envelope, and the concept of a continuous layer that seals across all seams in building construction. The goal to eliminate energy consumption from conditioning outside air was termed as "airtight." Code compliance changed from visual inspection to blower door testing. The requirements changed from general statements to 7 air changes per hour when the house is pressurized to 50

Pascal (7ACH50). That has now changed to 5ACH50 in warm Climate Zones (1, 2) and 3ACH50 in the rest of the country (climate zones 3-8).

This requirement for an air-tight thermal envelope addresses the claim that up to 30% of building energy loss is to air infiltration, but it also raised a major concern for building occupant health. The same infiltration that cost energy dollars also ventilated the indoor environment, removing moisture, contaminants, etc. Now, that must be done through exhaust fans (already in the code for bathrooms and high humidity-prone areas of the home). Exhausting indoor air then creates a negative pressure that will be relieved by … leaks in the thermal envelope? A balanced mechanical system of fresh supply air (e.g., using heat exchangers called energy recovery ventilators, ERVs and heat recovery ventilators, HRVs) compensating for the exhausted air minimizes the introduction of air pulled from undesirable areas of the home and those that may carry contaminants.

2.4.3 Home Energy Rating Systems

Third-party verification of building performance has evolved significantly over the last decade. Certified Home Energy Rating Systems (HERS) raters are rigorously trained by two organizations, the Building Performance Institute (BPI) [17] and RESNET [18].

The significance of HERS indexes was realized when this approach to demonstrating building energy performance was introduced to the 2015 IECC. Added as a new section R406, Energy Rating Index, building officials who are working with the 2015 IECC can accept reports from certified BPI and RESNET raters to demonstrate compliance with the code.

The Energy Rating Index (ERI) was established as an overall examination of the building that integrates thermal envelope, mechanical efficiency (not a factor in the prescriptive path), air tightness, and reduction of distribution losses (e.g., duct testing). The 2006 IECC provides the basis for the index, meaning that the worst possible rating (an index of 100) meets the minimum requirements of the 2006 energy code. However, the thermal envelope requirements must meet or exceed the minimum requirements of the 2009 IECC. With the goal of an ERI of 51 to 55 (varies with climate zone), this path for demonstrating compliance with the energy code is on track with DOE's goals of building energy performance.

This is also a significant benefit to log buildings. For many years, members of the Log & Timber Homes Council have been encouraged to perform HERS ratings on new projects. Many HERS reports have been completed and shared with code officials to demonstrate that log homes can achieve Energy Star certification. This includes the new requirements for aggressive control of air infiltration! Properly designed and constructed log homes can achieve the required ERI, including 3 air changes/hour under 50 Pascals of pressure (required in cold climates).

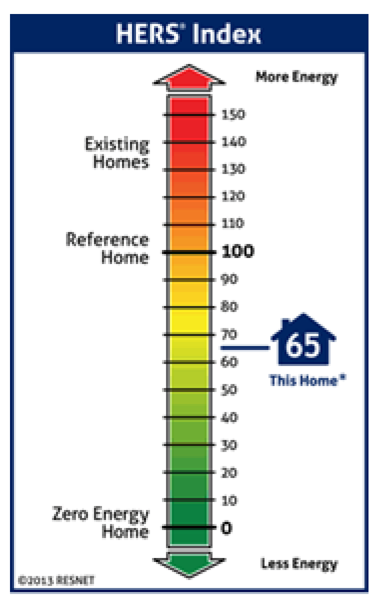
The benefits of home energy ratings are well documented as described by the following from RESNET:

2.4.3.1 "How Does the HERS Index Work?"

To calculate a home's HERS Index Score, a certified RESNET Home Energy Rater will do a home energy rating and compare the data against a 'reference home' – a design modeled home of the same size and shape as the actual home, so the HERS Index Score is always relative to the size, shape and type of house you live in. The lower the number, the more energy efficient the home.

The U.S. Department of Energy has determined that a typical resale home scores 130 on the HERS Index while a standard new home is rated at 100.

- A home with a HERS Index Score of 70 is 30% more energy efficient than a standard new home.
- A home with a HERS Index Score of 130 is 30% less energy efficient than a standard new home.



*Sample rating representation.

Developed by the Residential Energy Services Network and introduced in 2006, the HERS Index is the industry standard by which a home's energy efficiency is measured. Government agencies such as the Department of Energy (DOE), Department of Housing and Urban Development (HUD) and the Environmental Protection Agency (EPA, www.epa.gov) recognize the HERS Index as an option for demonstrating code compliance .

2.4.4 Distribution Systems

Until the 2021 edition, the IECC has not included provisions for improved efficiency in HVAC equipment since the 2009 edition. It has continued to advance improvements in energy loss through distribution systems. Whether delivering conditioned air or water, distribution losses can have a significant impact on HVAC performance. This is why duct insulation requirements have been bolstered by the call for duct testing. Likewise, pipe insulation and proper sizing of pipes is striving to shorten the response time of hot water to its intended source.

In 2021, with the building thermal envelope and air infiltration requirements at their peak, IECC Section R408 Additional Efficiency Package Options were written. The options include by exceeding REScheck minimum design by at least 5%, by using more efficient HVAC equipment (back to 2003?) and domestic hot water, more efficient ductwork, or improved air sealing and ventilation.

2.4.5 Lighting

Addressing another area of energy consumption, the IECC requries lamps and light fixtures that require less energy, virtually making incandescent lamps obsolete. Today’s new construction must have high-efficacy lamps. In addition, permanently installed lighting fixtures must be controlled by a dimmer, an occupant sensor, or other control that will reduce the wattage load.

3 LOG BUILDING STANDARDS, CODES AND ENERGY-EFFICIENCY CRITERIA

3.1 ICC400 Standard on the Design & Construction of Log Structures

With many different methods used to build log structures, it was an accomplishment when the industry came together with the ICC to develop a consensus standard. Published by ICC in 2007, ICC400 *Standard on the Design and Construction of Log Structures* establishes criteria for all methods of log home construction with consideration for structural and thermal performance, including settling allowance and fire resistance. ICC400 provides a single reference for log design, construction, and inspection that reflects the nature of these unique structures rather than requiring them to comply with standards written for lumber and frame construction practices.

In 2000, the International Log Builders' Association (**ILBA**) was working to complete its *Log Building Standards for Residential, Handcrafted, Interlocking, Scribe-fit Construction*. Founded in 1974, ILBA is a worldwide organization dedicated to furthering the craft of handcrafted log building, to the advancement of log builders, and to the promotion of the highest standards of their trade. ILBA writes and distributes educational materials, provides educational services related to the craft of log building, and establishes scholarship trust funds.

With the desire for broader acceptance of their standard, the ILBA approached the National Evaluation Service, Inc. (**NES**). This was about the time that the regional model codes were merging into the ICC. Around the same time, the LTHC had developed a guideline for the U.S. Dept. of Housing and Urban Development (**HUD**) for review and approval of log buildings for Federal financing programs. After a joint meeting between representatives from IBLA, NES, and the LTHC, a decision was made to develop an ICC standard for log construction. Through ICC, the call for a committee to develop a consensus standard on log construction was released.

ICC established the Consensus Committee on Log Structures (**IS-LOG**) in 2002. The goal was to create uniformity in evaluation applicable to all log building systems, providing a quick reference for technical data, and promoting broader acceptance with growth of ICC adoption at various levels of government.

As an ICC Standard, the document goes through a 5-year review and update cycle. The first update was completed in time for publication in 2012, which was critical for inclusion in the 2012 I-Codes.

3.1.1 The Significance of ICC400

Log structures employ alternative methods of construction that are fully covered by ICC400. It gives the code official an important tool for inspection and understanding log construction, including thermal performance. Carefully written to cover all forms of log construction, the standard explains how to respond to design conditions, but it does not establish those conditions.

The significance of ICC400 is that, for the first time, the log home industry has a recognized, ANSI-approved consensus standard that represents industry standards and guidelines for this form of construction. This standard applies to all methods of log wall construction and is referenced in the IBC and IRC as noted above. The benefit regarding the issue of energy code compliance is that ICC400 also offers a venue for continued improvement. This means that an effort to establish a better approach needs to be established, which is one of the purposes of this paper. In response, the LTHC has undertaken an effort to reference ICC400 in the IECC and to update Section 305 so that ICC400 becomes the primary standard without subrogation to other codes.

Its sections are summarized below:

Chapter 1 – Administrative Provisions explains that ICC400 pertains only to log structures and notes that all other requirements covered by other ICC codes are not included and are therefore the same as for conventional construction:

- ❑ Project planning & preparation
- ❑ Design loads and deflection criteria
- ❑ Plumb, square and level construction
- ❑ Receiving, handling, and protecting materials

Chapter 2 – Definitions became a key section for negotiating the meaning of log construction. The committee agreed on a definition of a log for this standard as follows:

Log. Wood member that has been stress graded and grade marked or grade certified using rules of an accredited inspection agency in accordance with ASTM D3957, D3737, or D245 and is incorporated into a structure.

Chapter 3 – General Requirements evolved into a substantial review of the elements of log building that most engineers do not have at their fingertips. It calls for all logs to be stress graded and requires the grading agency to provide certification of moisture content where a log building system relies on controlling moisture content for performance purposes. This chapter includes specific design stress values associated with two log grading agencies (this information was not previously published). Notching and boring limitations usually adopted from the American Forest & Paper Association's *National Design Specification for Wood Construction* (**AF&PA NDS**) were modified to represent the normal joinery conditions found in log structures.

In section 303, ICC400 begins to stipulate requirements by offering options for compliance – prescriptive path, calculated/engineered path, or tested/performance path. This approach is provided to establish the fire-resistance rating of a log wall (section 303), the necessary provisions for settling (section 304) to ensure that the wall remains airtight, and evaluation of the thermal envelope (section 305).

302.2.3.6 Log thickness. For calculation purposes, the log thickness (W_L) shall equal the average cross-sectional area divided by the stack height.

Chapter 4 – Structural Provisions is no less important than any of its preceding chapters. AF&PA's Wood Frame Construction Manual (**WFCM**) was used as a model for the structure of this section of the standard. Engineered provisions were developed to ensure that a load path is maintained for the structure, including connections and resistance of both gravity and lateral loads.

3.1.2 Reference within the I-Codes

ICC400 is referenced in the 2009 & later editions of the ICC I-codes.

- ❑ IBC Ch. 23 Wood, 2301.2 General design requirements: "4. Log Structures. The design and construction of log structures shall be in accordance with the provisions of the International Code Council's IS-LOG Standard ICC-400."
- ❑ IRC Ch. 3 Building Planning, R301 Design Criteria: R301.1.1 Alternative provisions: "3. International Code Council (ICC) ICC-400 IS-LOG Standard for the Design and Construction of Log Structures."
- ❑ IBC and IRC sections reference ICC400 relating to the requirement for grading of structural log members.
- ❑ 2015 IRC section R703 Exterior Covering includes an exception for log walls designed and constructed in accordance with the provisions of ICC400.

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- The IECC now includes references other than mass walls:
  - The 2012 IECC added a footnote to Table R402.4.1.1 referring to ICC 400.
  - The 2018 IECC added an exception to R402.1, "Log homes designed in accordance with ICC 400. The exception applies only to section 402.1.1 through 402.1.5. Sections 402.2 and beyond apply to all building designs.

3.1.3 ICC400 Section 305, Thermal Envelope

When originally written, Section 305 used existing code references (the 2003 IECC) to generate the process for compliance. With green building and other above-code programs developing, a path was generated for the performance path that complies with the latest versions of the IECC.

The ICC400-2007 effort identified how wood species vary in how they conduct heat (e.g., R-value) due to differences in specific gravity and moisture content. With the advent of the DOE climate zone map in the 2004 IECC and associated equilibrium moisture contents, there was an impact on both settling allowance (Section 304) and thermal values. Employing the climate zones redefined by DOE, the moisture content of the log wall in service is established as follows:

- MCs = 10% for Dry climate
- MCs = 13% for Moist climates
- MCs = 15% for Marine climates
- MCs = 14% for Warm-Humid climates
- MCs = 12% for all other climates

Section 305 was not only a culmination of scientific data on how wood performs in different climate conditions, but it provided the basis for further improvement to REScheck®, the energy code compliance software written for the DOE (available for free download at www.energycodes.gov). This approach is reflected in that the user can select from a variety of wood species and the average log wall thickness. The program calculates by climate region to establish the U-factor for the wall.

Relative to thermal mass, the ASHRAE approach published in the 2003 IECC was the only option to establishing and qualifying mass walls until ICC400 included it in Section 305.4. Section 305.4.1 is a prescriptive path that refers to the IECC which since the 2006 IECC defines mass walls, including solid wood walls. ICC400 Section 305.4.2 provides for a test method to establish the thermal mass benefit. Then, 305.4.3 offers the calculation for heat capacity that was established by ASHRAE.

Each edition of ICC400 has been updated with the intent of being current with the changes to the IECC in Chapter 4 and IRC Chapter 11. The standard offers prescriptive, calculated/engineered and performance/testing paths for substantiating the performance of log walls, and trade-off packages for each Climate Zone. Therefore, the thermal envelope of log homes would be evaluated as follows:

- **THERMAL:** **Section 305 Thermal Envelope** presents requirements for weather protection and determination of thermal properties, offering prescriptive, calculation, and performance options. **TABLE 305.3.1.2 Insulation and Fenestration Requirements by Component** provides one such prescriptive option.
- **AIR INFILTRATION:** Guidance is provided in **Section 306 Infiltration**, 305.1 Weather protection, and 304 Provisions for Settling in Log. The same blower door requirement of the IECC shall apply to log walls as for any other method of construction.
- **VAPOR RETARDERS:** As noted in Exception 3 of IRC Section R702.7 Vapor retarders, "Construction where moisture or its freezing will not damage the materials." There is no cavity to protect in a log wall, and all joinery is covered by ICC 400.
- **EXTERIOR COVERING:** The Exception in IRC Section R703.1 General refers to "Log walls designed and constructed in accordance with the provisions of ICC 400." The standard covers all discussion of weather resistance, drainage planes, etc.

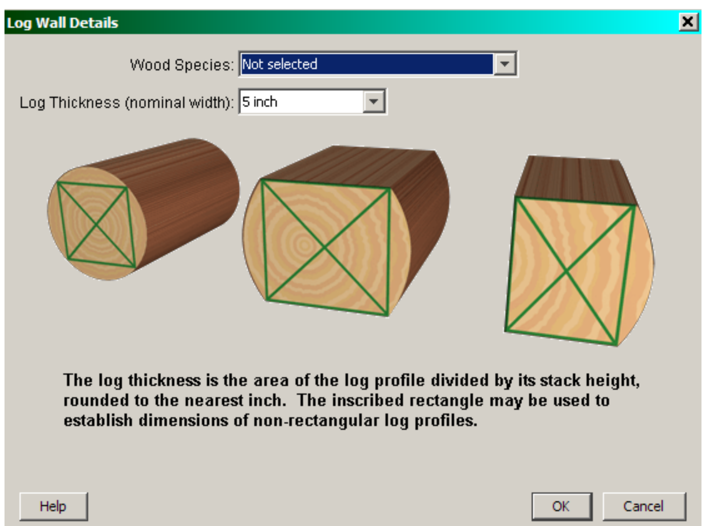
3.1.3.1 *Using REScheck® for the UA Trade-off Path*

RES*check*® is the most widely used software to demonstrate compliance with state and local energy codes. Its reports are widely accepted by building officials. The program and support are sponsored by the DOE and are free to download from www.energycodes.gov. Formerly called ***MECcheck*** and used to demonstrate compliance with the MEC, REScheck has been continually updated to support the IRC, the IECC, and several state codes. REScheck residential compliance methods offer two ways to demonstrate compliance: the trade-off approach and the prescriptive packages approach. The desktop version of REScheck works with the 2009 to 2015 IECC. For jurisdictions requiring later code versions than 2015, the web-based program will be required.

In 2004, log wall criteria were revised to calculate thermal parameters based on the variables documented in ICC400-2007 and the Wood Handbook (USDA 1999). The Technical Support Document (**TSD**) released with REScheck 3.7.1 describes how the mass wall criteria was implemented.

“Prior versions of REScheck required users to input only the log wall width and the insulation R-value. REScheck then implemented an average calculated density used to compare the wall with the thermal mass requirements of the IECC. For a wall to receive the mass wall credit in the IECC, it needed a heat capacity (HC) of 6 Btu/ft² F, which generally requires a weight of 20 lb/ft². Lighter walls with 5" and 6" diameters did not receive the credit, demonstrating the compliance difficulties of smaller log walls.”

REScheck was expanded for log walls to include average widths from 5” to 10” in one-inch increments, and then in two-inch increments to 16” wide logs. Because of this incremental approach, the log width is referred to as nominal with the intent to use the closest average width (determined by dividing the area of the log profile by its stack height). In addition, REScheck lists 31 different wood species that can be selected.



• Figure 3-1 - REScheck Log Specification Window

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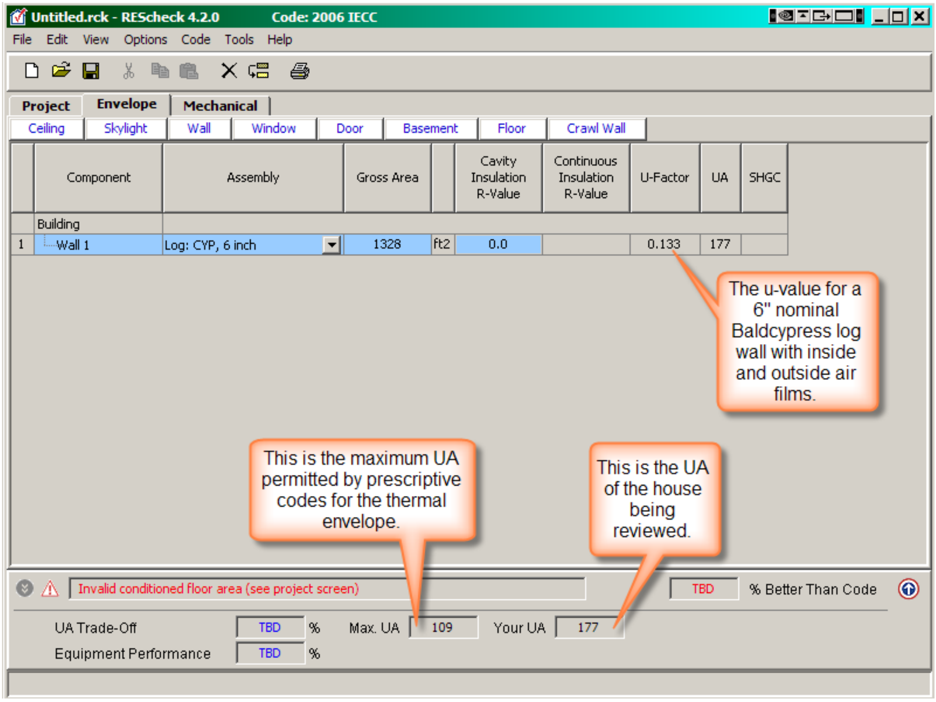


• Figure 3-2 - REScheck Envelope Screen

The calculated conductivity and assumed specific gravity for species found in the revised RES*check* (3.7 and later) are shown in Table A.20 of REScheck Technical Support Document 4.2 (available at http://www.energycodes.gov/rescheck/pdfs/rescheck_tsd4.2.pdf). This document explains that the computed R-value and thermal mass benefit in REScheck is based on in-service moisture content which varies by climate zone as redefined in the IECC 2004 Supplement.

REScheck Release 4.3.1 correctly applies the thermal mass credit for all log wall construction as stipulated in the 2009 IECC.

3.1.4 ICC400 304 Settling Provisions and Air Infiltration

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. This is a critical design element for any log building system and is addressed in three locations – Section 304, 305.1 Weather protection, and 306 Infiltration.

Log walls are a more structurally durable 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 change dimension. 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% relative humidity) 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 air conditioning system.

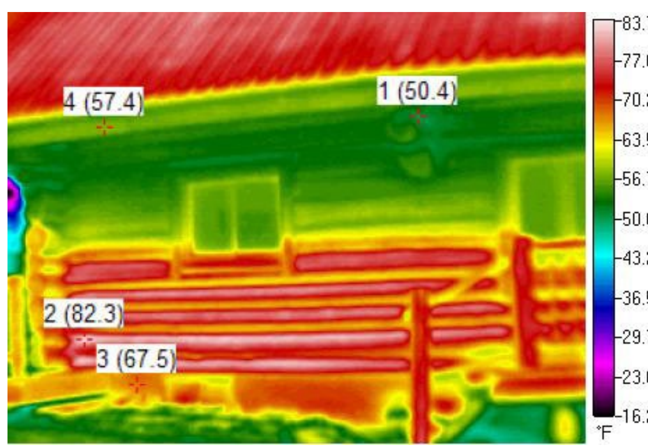
In colder months, permitting excess moisture into log walls can reduce their resistance to heat flow (R-value). This increases somewhat the overall demand for mechanical heating in buildings with poor air-leakage and moisture controls. Alternatively, should humidity levels drop too low – into the 30- to 20% range for example – not only can human respiratory discomfort result but drying in logs can lead to shrinkage with symptoms of check-cracks and/or separations between joints, which may further elevate 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. The evaluation and inspection of the responses to the movement of logs and log walls is contained in ICC400.

The success of the log home industry in designing joinery that is compliant with ICC400 is becoming more commonly demonstrated through home energy audits using blower door testing and/or thermal imaging studies. Certified home energy raters have noted that the log homes are no more conducive to air leakage than any other type of construction – the sources of leakage are universal. However, the following list identifies particular areas for inspection and care during construction to insure performance:

- The ridge area of vaulted ceilings (typical of all timber frame roofs);
- The joint between the top (plate) log and the roof;
- The protrusion of logs through the exterior walls (both frame walls and log walls);
- The connections between the floor and a bottom plate log, or the foundation and the sill log;
- The connection of the log with contiguous frame wall assemblies (e.g., dormers, gable ends, extensions, etc.);
- The window/door-to-wall log interfaces;
- The log-corner interface; and
- Installation of insulation over deck/plank ceilings.

Building analysis using thermal imaging is providing as much information about solar gain on log walls as it is about air infiltration. The photos below show solar gain in diffuse sunlight at an exterior temperature of 45°F (65°F interior).



The Energy Performance of Log Homes
Log Structures & ICC700 National Green Building Standard

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 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 lightweight wood frame 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).*
- ☑ *Log walls reduce global warming and reduce greenhouse gases through*
  - ❖ *Maintaining the carbon stored in the forest in the log wall, log homes store more carbon than any other method of wall construction.*
  - ❖ *Providing the structural shell and thermal envelope with a system that does not involve fossil fuel-intensive products (e.g., steel, concrete).*
  - ❖ *Waste products from log construction can be recycled into fuel replacing the need for fossil fuels, reducing the release of CO_2.*

The actual "green" measure of a log home is a function of several elements, all of which are assessed over the course of planning, constructing, and final verification of the completed building project prior to occupancy. This measure can be made by implementing a variety of green building standards, but the ICC700 *National Green Building Standard* is preferred by the LTHC. Co-sponsored by its parent organization, the NAHB (NAHB), and ICC, this ANSI-approved consensus standard was written for residential construction for builders, building officials, and other design professionals. NAHB has developed their *National Green Building Certification Program* based on this standard. For more information, go to www.nahbgreen.org.

The Energy Performance of Log Homes

The frequent updates to an ICC Standard (normally a 5-year update cycle) have been required to ensure that the "above code" nature of the standard maintains performance better than the minimum requirements specified in the latest IECC, which has a 3-year development cycle

The certification of a completed building project is achieved by reaching the minimum point levels in each of six chapters of ICC700. It is possible to benefit from multiple buildings and subdivisions that are green certified. Land development is covered in Chapter 4. The six chapters by which each project is verified for green points (by an independent third-party accredited to do so by the NAHB Research Center) are listed below. Note that it is not sufficient to meet only those chapters, but to also have overflow points from any of those chapters (see Additional points). The green certification will be based on the lowest score in each chapter and the total points in a column. For example, if the project scores 450, it warrants a Silver certification, but it will only qualify for Bronze if only 30 points are achieved for Chapter 7, Energy Efficiency.

Green Building Categories			Performance Level Points[1,2]			
			BRONZE	SILVER	GOLD	EMERALD
1.	Chapter 5	Lot Design, Preparation, and Development	39	66	93	119
2.	Chapter 6	Resource Efficiency	45	79	113	146
3.	Chapter 7	Energy Efficiency	30	60	100	120
4.	Chapter 8	Water Efficiency	14	26	41	60
5.	Chapter 9	Indoor Environmental Quality	36	65	100	140
6.	Chapter 10	Operation, Maintenance and Building Owner Education	8	10	11	12
7.		Additional Points from any category	50	100	100	100
		Total Points:	222	406	558	697

Threshold Point Ratings for Green Buildings

Green Building Categories			Rating Level Points [a] [b]			
			BRONZE	SILVER	GOLD	EMERALD
1.	Chapter 5	Lot Design, Preparation, and Development	50	64	93	121
2.	Chapter 6	Resource Efficiency	43	59	89	119
3.	Chapter 7	Energy Efficiency	30	45	60	70
4.	Chapter 8	Water Efficiency	25	39	67	92
5.	Chapter 9	Indoor Environmental Quality	25	42	69	97
6.	Chapter 10	Operation, Maintenance, and Building Owner Education	8	10	11	12
7.		Additional Points from Any Category	50	75	100	100
		Total Points:	231	334	489	611

(a) In addition to the threshold number of points in each category, all mandatory provisions of each category shall be implemented.

(b) For dwelling units greater than 4,000 sq. ft. (372 m²), the number of points in Category 7 (Additional Points from Any Category) shall be increased in accordance with Section 601.1. The "Total Points" shall be increased by the same number of points.

As many as 90 points can be obtained by adhering to the requirements of the EPA programs -- Energy Star®, WaterSense®, and Indoor AirPlus®. These points can be gained by specifying, installing, and verifying certified products and systems. It is important to note that all green building programs are "above code" programs – that means that the IECC's and/or IRC's minimum code requirements are mandatory for certification as a green building.

Most building systems are supplied to a builder or building site without control of that site. Therefore, the log package cannot impact the design, preparation, and development of the building lot. This is entirely the responsibility of the builder/homeowner. Other builder-related practices that can achieve points include the management of materials on site (recycling, reusing, or otherwise limiting waste removed to landfill).

As a building material and method of assembly, logs are relatively limited to Chapter 6, Resource Efficiency -- material specification, design specification, and extent of manufacturing in its content. A key theme is a simple concept – do not contribute to a landfill.

Design elements are difficult to generalize about, as log homes are typically custom-built. However, points can be achieved for

- Using building dimensions and/or layouts that are intended to reduce material cuts and waste (possible 13 points);
- Stacking floors (up to 8 points for going up, not out – reducing the building footprint and minimizing site disturbance);
- Adding porches to protect entry doors from the weather will provide 3 points for the main entry and an additional point for each additional entry;
- Incorporating roof overhangs of at least 12" will earn 4 points in dryer climates, with 18" and 24" eave overhangs required where annual precipitation is greater;
- Foundation drainage, gutters and downspouts, and other methods to move water away from the structure will increase durability, reduce maintenance, and generate points.

The most common areas where log structures can achieve points are identified below. There are many other sections that can be beneficial to a log home, but water efficiency, air quality, and other topics are beyond the scope of this discussion.

3.2.1 Construction Documents (601.4, 602.12)

Log home construction projects range greatly in process. However, it is extremely green to plan your project up front. There are several areas where advanced planning and documentation generates points. Detailed framing plans, material takeoffs, and on-site cut lists are an example of this. Providing this guidance to the builder reduces time and material waste and is therefore given 4 points.

Another 6 points can be achieved by providing a complete set of construction plans that include flashing details around windows and doors (including drip cap), at roof valleys, at roof/wall and chimney junctions, etc. Showing drip edge at overhangs is a plus.

3.2.2 Prefabricated components (601.5)

Points are assessed in this section for the use pre-cut or pre-assembled building systems or methods for 90% of structure. The goal here is to eliminate waste on the jobsite, where it is more difficult to manage than in a manufacturing facility. The verification of this is complete by a lack of cutting waste on the job, a set of installation layout instructions, etc. This section can provide 12 points for hand-crafted or factory pre-cut logs for walls (4 pts.), floor framing (4 pts.), and roof framing (4 pts.).

3.2.3 Structural Log Wall Systems (601.9)

Systems that provide sufficient structural and thermal characteristics used for at least 75% of the gross exterior wall area of the building are awarded 4 points under section 601.9. Log walls are one of the options for this section. As previously noted, log walls provide "surface as finish" saving material and labor costs since added layers of other building materials are not required.

3.2.4 Reused or Salvaged Materials (603)

One segment of the log home and timber frame market uses timbers salvaged from buildings that are being taken down. Section 603 offers points (1-19 points) for practices that reclaim materials. This also includes other finish products remanufactured from timber salvage efforts ranging from demolition to buried or submerged timber recovery.

3.2.5 Bio-based Products (606)

Using building materials derived from renewable resources is the theme in this section. Certified solid wood and engineered wood products are common to log structures. The problem throughout the wood products industry is that of certification to the requirements of organizations such as the American Forest Foundation's American Tree Farm System®, the Forest Stewardship Council (FSC), or the Sustainable Forest Initiative® Program (SFI). Despite the fact that wood products offer great environmental benefits, many points in this section cannot be achieved without additional certification. This certification can be responsible for additional cost, as the industry continues to learn more about this option for green building programs.

3.2.6 Manufactured energy (606.3)

This section states that up to six (6) points can be achieved by using materials for major components of the building which are made with primary energy derived for manufacturing from renewable sources, combustible waste sources, or renewable energy credits (RECs) are used. The sources provide at least 33% of the primary manufacturing process energy.

3.2.7 Regional Materials (609.1)

Today's log homes still tend to be erected from regionally available materials (indigenous 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. 2 points are available for each material type.

3.2.8 Life Cycle Analysis (610)

Several points can be achieved in Chapter 6 by using life cycle analysis (LCA) for the whole building. Utilizing an LCA tool and reporting the results in the owner's manual can gain up to 15 points. LCA for a product or assembly such as a log building system can gain up to another 10 points for section 610.1.2.

4 BEST PRACTICES FOR ENERGY EFFICIENCY

4.1 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.

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 enclose a home, without undue sacrifices of energy efficiency. There remains sufficient thermal mass to help moderate 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.

4.2 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 number 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 airtightness (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).*

4.2.1 Insulation ("R"-value)

4.2.1.1 Insulating a Mass Wall

It is important to note that the placement of insulation in or on a mass wall impacts thermal mass performance. 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, straw-bale 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 masonry wall with an interior foam or mineral fibrous insulation layer behind sheetrock. The code also recognizes this effect. A long-standing footnote in the IECC notes: "b. When more than half the insulation is on the interior, the mass wall U-factors shall be a maximum of 0.17 in Climate Zone 1, 0.14 in Climate Zone 2, 0.12 in Climate Zone 3, 0.087 in Climate Zone 4 except Marine, 0.065 in Climate Zone 5 and Marine 4, and 0.057 in Climate Zones 6 through 8." In essence, the mass wall effect is negated by interior insulation.

4.2.1.2 Roof Insulation

Regardless of the wall system used, the code stipulates minimum levels of floor/foundation and roof insulation. These minimums are approaching their return on investment (ROI). Studies have identified the ROI for roof insulation to be R-60 in cold climates (CZ 6-8). Some advocates are building with higher levels of roof insulation, but the energy savings is not likely to offset the additional cost.

In climates dominated by cooling degree days rather than heating degree days, roof insulation is still important to separate the conditioned cooler inside air from the hot outside air. An important consideration here may be light colored roofing to reflect sunlight, and a radiant barrier in the attic to help deflect heat. Remember that to be effective, radiant barriers need an air space.

4.2.1.3 Floor/Foundation

Floor and foundation insulations are not as clear to summarize due to the wide variety of designs and climates. There is a greater economic benefit to building a heated basement/crawlspace (insulated foundation stem walls) than insulating the floor. That conditioned space allows more flexibility in the location of HVAC equipment and distribution. Foundation systems such as insulated concrete forms (ICF) or prefabricated insulated panels have provided good results for all types of home construction. Remember that heated slabs require an additional R-5 underneath them (e.g., the IECC requires R-10 in Climate Zones 4-8, but heated slabs would be R-15).

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 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 thermostat.

4.2.2 Windows and Doors

The size and location of glazing areas influence thermal mass effects via solar gain and conduction heat loss. . 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.

Log home designs often include more than the 15% average window to wall area ratio discussed in code development. Therefore, using Energy Star® rated windows and doors (above-code) will help offset UA trade-off calculations for a nominal 6" log wall.

4.2.3 Passive Solar Glazing

A "passive solar" home using log or masonry walls may perform better than a lightweight wood frame 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.

4.2.4 Envelope Airtightness

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 and heat as well as wind.

4.2.5 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, the effect is 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.

4.2.6 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.

4.2.7 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 is considered by energy engineers when performing computer simulations but is not considered in much detail for basic HVAC equipment sizing.

4.3 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:

- ☑ Locate air distribution duct systems inside the conditioned space of the building;
- ☑ Conduct computer aided analysis to properly size mechanical equipment;
- ☑ Provide return ducts to reduce pressure differences between rooms within H/AC zones;
- ☑ Select mechanical equipment that meets the EPA/DOE **Energy Star®** label criteria;
- ☑ Properly commission the system including basic measurements to ensure good performance; and
- ☑ 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 offset the somewhat lower steady-state R-values of the log walls. In cold climate regions, look for furnaces rated to AFUE 90 or higher and heat pump equipment rated to SEER14/HSPF8.

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 airflows. The home systems commissioning plan should be included in specifications for project bidders.

4.3.1 HVAC Controls with Thermal Mass

The increasing use of radiant floor systems has educated our use of HVAC controls. While set-back thermostats tend to provide good energy savings with forced air and hot water systems that deliver heat rather quickly to the zone of the house calling for it, they are not beneficial to systems using radiant heat. Radiant systems are better managed by setting thermostats at a lower, comfortable temperature and keeping it constant.

4.3.2 Wood Stoves

There is a radiant heat benefit to using wood stoves in log homes. The log walls will absorb the radiant heat generated by the stove while the space is heated by convection of the air around the stove and pipe. As the fire dies down, the radiation from the log walls contributes to the indoor comfort until more wood is added.

4.4 Role of Construction Supervision in Energy Performance

The best analytical calculations indicating a modern building "meets or exceeds energy code" levels can only be attained through proper field implementation of the selected efficiency measures during construction. A trained crew that is properly supervised to install building products according to the manufacturer's specifications is key to ensuring good performance.

An example of this issue is when lightweight wood frame walls are insulated with fibrous materials. If the insulating crews are not trained or supervised properly and have little incentive or third-party oversight, there may be installation issues causing materials to have gaps, tears, excessive compression, or even omitted materials. Other building layers like gypsum drywall can rapidly conceal the errors.

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).

Whether blessed with an excellent building crew or not, the LTHC supports the concepts of utilizing the National Green Building Program and/or Energy Star® certifications. Both programs incorporate an inspection at the rough frame stage and another at final inspection. A blower door test at both inspections can be of tremendous value in sealing the home. Surveys have indicated that involvement in these certification programs have brought increased awareness on the job site, resulting in the benefit of greater occupant satisfaction.

5 CONCLUSION

5.1.1 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 lightweight wood 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 lightweight wood frame wall in a temperate climate.
2. The homogeneous assembly of the log wall has fewer thermal short-circuits than lightweight wood- or steel frame 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.

5.1.2 In Review

The log home is an American construction concept with significant history. Some of the oldest occupied structures in North America are log buildings, indicating their fundamental durability when properly designed, constructed, and maintained. Compliance with the consensus standard for this type of construction makes log homes structurally sound, energy efficient, and durable.

There is a large body of engineering technical literature supporting the validity of performance adjustments 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 solid log home construction, these whole-building performance benefits range between 2.5% to over 15% in most US climates. This means, a log home with log walls of 6-inch average thickness (R-9, U-0.111 per ICC400 Table 305.3.1.1) will provide equivalent performance for heating and cooling as compared to a lightweight wood frame home of otherwise identical design with R-15 cavity insulation, 7/16” OSB or plywood, ½” gypsum wallboard, and uninsulated vinyl siding (U-0.647). Note that a log wall with a minimum 6” thickness is equivalent to a one-hour rated fire wall (ICC400 303.2.1).

More importantly, log walls do not have the same potential for thermal degradation as frame walls – such as insulation settling in the cavity leaving a void at the top of the wall or installations with gaps between insulation and framing. Air-tight construction is being achieved and recorded in Energy Star® certifications and other HERS reports. A tight log home, like any type of construction, requires an attention to detail in design and construction. A properly sealed home is more energy efficient and will be more durable. A heat exchange ventilation system is recommended to provide a balanced system of exhausting moisture and contaminants and supplying fresh, conditioned air.

Log homes are constructed of natural and renewable materials that are inherently more environmentally efficient than processed lumber in construction. Credit toward green building certification may be achieved through several methods common with log construction. A long-term benefit of log and timber building is that when the home is demolished or de-constructed for its component parts, the logs/timbers can be reused in another home of similar construction rather than going to landfills.

All told, the log home has been shown to be a competitively energy efficient, durable, and environmentally useful alternative to traditional construction methods. Both consumers and the environment will benefit from the increasing recognition of log homes as green and energy efficient dwellings.

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BPI is the nation's premier building performance credentialing, quality assurance and standards setting organization. BPI develops technical standards using an open, transparent, consensus-based process built on sound building science. From these standards, we develop professional certifications for individuals, companywide credentials for BPI GoldStar Contractors, home energy rating systems and quality assurance services that help raise the bar in home performance contracting. BPI is approved by the American National Standards Institute, Inc. (ANSI) as an accredited developer of American National Standards and as a certifying body for personnel credentials.

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5.4 WEB SITES

NAHB Log & Timber Homes Council 1201 15th Street NW Washington, DC 20005 USA -- (800) 368-5242	*http://www.nahb.org/loghomes/* *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/*
Midwest Energy Efficiency Alliance (MEEA)	http://www.mwalliance.org/
Northeast Energy Efficiency Partnerships (NEEP)	http://www.neep.org/
Northwest Energy Efficiency Alliance (NEEA)	http://www.neea.org/
Southeast Energy Efficiency Alliance (SEEA)	http://www.seealliance.org/
South-Central Partnership for Energy Efficiency as a Resource (SPEER)	https://eepartnership.org
Southwest Energy Efficiency Project (SWEEP)	http://www.swenergy.org/