# Energy Benefits of Application of Massive Walls in Residential Buildings

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**ABSTRACT**

*Thermal mass effects occur in buildings containing walls, floors, and ceilings made of logs, heavy masonry, and concrete. In certain climates, massive building envelopes—such as masonry, concrete, earth, and insulating concrete forms (ICFs)—can be utilized as one of the simplest ways of reducing building heating and cooling loads. Very often such savings can be achieved in the design stage of the building and on a relatively low-cost basis. Such reductions in building envelope heat losses combined with optimized material configuration and the proper amount of thermal insulation in the building envelope help to reduce the building cooling and heating energy demands and building-related $CO_2$ emission into the atmosphere.*

*This paper presents a comparative study of the energy performance of lightweight and massive wall systems. An overview of historic and current U.S. field experiments is discussed and a theoretical energy performance analysis of a series of wall assemblies for residential buildings is also presented. Potential energy savings are calculated for ten U. S. climates. Research presented demonstrates that in some U. S. locations, heating and cooling energy demands for buildings containing massive walls with relatively high R-values can be lower than those in similar buildings constructed using lightweight wall technologies.*

## INTRODUCTION

Several massive building envelope technologies (masonry and concrete systems) are gaining acceptance by U.S. builders today. It is believed that building envelopes made of concrete, earth, insulating concrete forms (ICFs), and solid wood (log) may be helpful in lowering building heating and cooling loads. For centuries, the vast majority of European and Middle Eastern residential buildings have been built using massive wall technologies. They have made life without air conditioners relatively comfortable even in countries with hot climates such as Spain, Italy, or Greece.

Numerous historic and current field studies have demonstrated that in some U.S. locations, heating and cooling energy demands in buildings containing massive walls with high R-values could be lower than those in similar buildings constructed using lightweight wall technologies. This better performance results from the thermal mass encapsulated in the building, reducing temperature swings and absorbing energy surpluses both from solar gains and from heat produced by internal energy sources such as lighting, computers, and appliances. In addition, massive building envelope components delay and flatten thermal waves caused by exterior temperature swings.

Since all U.S. thermal building standards including ASHRAE Standards 90.1 and 90.2 and the Model Energy Code are linked primarily to the steady-state clear wall R-value, calculating heating and cooling needs of a house built with high-mass walls is not straightforward. The steady-state R-value traditionally used to measure energy performance does not accurately reflect the dynamic thermal behavior of massive building envelope systems. This makes it difficult to convince builders, investors, code officials, etc., about the improved energy performance of massive building envelope systems. Such a situation opens the door for many companies to claim unrealistically high energy performance data for their wall technologies.

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The main objective of this work is to provide a comparative study of the energy performance of massive wall technologies. Since the majority of U.S. residential buildings are built using lightweight wood-framed technologies, all energy performance comparisons in this paper are made against lightweight wood-framed buildings. An overview of several historic and current U.S. field experiments is given. These experiments were performed in a wide range of U.S. climates utilizing several building sizes and shapes. Theoretical energy performance analysis is presented for a series of four wall assemblies. The wall material configurations of these assemblies represent most massive wall systems utilized in U.S. residential buildings. Theoretical and experimental results presented in this paper should enable approximate energy performance evaluations for the most popular massive wall configurations.

## EXPERIMENTAL ENERGY STUDIES PERFORMED ON MASSIVE RESIDENTIAL BUILDINGS

In this section, a selection of historic and current field experiments are discussed. Some early experiments were initiated in late 1970s as a result of the energy crisis and focused on application of passive solar techniques in residential buildings. Passive solar designers used glazing and thermal mass to utilize solar energy and stabilize interior air temperature. A Los Alamos National Laboratory team headed by J. D. Balcomb and R. D. McFarland investigated the energy performance of several passive solar wall systems and various thermal mass storage materials. All systems were tested in field conditions in 2.6 × 1.9 × 2.9 m (100 × 80 × 120 in.) insulated lightweight containers (Balcomb and McFarland 1978). The only thermal mass provided was by the tested solar systems. Several materials were tested as potential energy storage during these experiments. The most common was the application of conventional masonry blocks or solid concrete walls. However, Los Alamos researchers also studied the energy performance of water and phase change materials as energy storage means. The results from these experiments demonstrated that passive solar systems had great potential to reduce energy consumption in residential buildings. They were published in the *Passive Solar Design Handbook* (Balcomb and McFarland 1983) and *Passive Solar Construction Handbook* (Winters 1981), which have been widely used as references in the designing of passive solar houses.

Other experiments focused on more conventional applications. These field studies demonstrated the potential energy demand reductions in buildings containing massive walls, floors, or roofs. It was observed and documented that heating and cooling energies in massive houses can be far lower than those in similar buildings constructed using lightweight wall technologies. This better performance resulted because the thermal mass encapsulated in the walls reduces temperature swings and absorbs energy surpluses both from solar gains and from heat produced by internal energy sources such as lighting, computers, and other appliances.

In June 1982, ORNL hosted the Building Thermal Mass Seminar (Courville and Bales 1982). This seminar gathered a very interesting collection of results from theoretical and experimental studies on building thermal mass. Experimental work of T. Kusuda, D. Burch, and G.N. Walton from the National Institute of Standards (NIST), A.E. Fiorato from the Construction Technology Lab, and P.H. Shipp from Owens Corning, created a solid foundation for the future studies in this field. During the seminar, several presenters indicated a possibility of potential energy savings in houses using massive building envelope components.

Almost two decades ago, several thermal mass field experiments were carried out for DOE by researchers in Gaithersburg, Maryland; Santa Fe, New Mexico; and Oak Ridge, Tennessee (Burch et al. 1984a, 1984b, 1984c; Robertson and Christian 1985; Christian 1983, 1984, 1985). The primary focus of these projects was to collect reliable performance data for structures that emphasized exterior wall thermal mass effects. Several principal data-collecting efforts are described below.

Burch built four one-room test huts 6 × 6 m (20 × 20 ft) at the National Institute of Standards and Technology (NIST) to compare the seasonal energy performance of wood-framed, masonry, and log constructions. Site weather data were collected for periods during winter, spring, and summer. The buildings were of identical construction except for the walls and were operated at the same thermostat setting. This study conclusively demonstrated the effect of thermal mass on space heating and cooling loads. Significant energy savings were noted for the house with a higher internal thermal mass.

During the same study, the impact of thermal mass on the night temperature setback savings was investigated. It was believed that night temperature setbacks might cause a significant reduction in the setback energy savings in massive buildings. The following observations were made during this project:

- When thermostat setpoint temperature was suddenly reduced by a fixed amount, the indoor temperature decreased from a higher to a lower level. During that period, the heating plant remained off. Thermal mass in buildings increased the time for the indoor temperature to decrease during the setback period.
- Similarly, during the morning period when the indoor temperature setpoint was increased, the presence of thermal mass extended the time to reach setpoint. The output capacity of the heating plant was sufficiently large that the temperature setup was short compared to setback.

The net effect of thermal mass in buildings containing heavyweight components was believed to cause the average indoor temperature and difference across the building envelope to be maintained at a more elevated level. As a result, night temperature setback caused the envelope heat-loss rate to be higher in massive buildings. All of this supported a

***Figure 1*** *ORNL/Habitat test houses.*

common belief that night temperature setbacks in massive buildings caused a reduction in the setback energy savings. Burch investigated this penalty in setback energy savings and his research confirmed the fact that such a reduction took place. However, the magnitude of this phenomenon was very insignificant. For example, for a typical residence the difference in setback energy savings in the massive house and traditional wood-framed house was predicted to be only 0.3%.

Robertson and Christian (1985) investigated eight one-room test buildings 6 × 6 m (20 × 20 ft) that were constructed in the desert near Santa Fe, New Mexico, to determine the influence of thermal mass in exterior walls. The buildings were identical except for the walls (adobe, concrete masonry, wood-framed, and log). Data were collected for two heating seasons from midwinter to late spring. This study demonstrated that on small windowless massive test huts, energy consumption can be up to 5% lower than in lightweight building. It is important to point out that during this study, the massive walls had about three to four times lower R-value than wood-framed walls (wood-framed wall R-value was about R-13 vs. R-2 to R-5 for adobe, concrete masonry, and log walls). This gives a completely different meaning to the 5% energy savings that were reported.

During the years 1982 to 1984, Christian monitored an occupied 372 $m^2$ (4000 $ft^2$) dormitory constructed of massive building materials in Oak Ridge, Tennessee. This study demonstrated the potential for energy savings in buildings using massive envelope materials. Whole building energy simulations were performed employing the DOE-2.1B computer model. This computer model was calibrated using experimental data collected and analyzed during the testing period of the dormitory. Later, massive building envelope components in the computer model were replaced by wood-framed components. Predicted energy demands with the wood frame were compared with the energy required with the massive building components. Final comparisons showed a potential 10% savings in cooling energy and a 13% savings in heating energy.

In 1999 a field investigation on thermal mass effect in residential buildings was performed by the NAHB Research Center (NAHB RC 1999). NAHB RC evaluated three side-by-side homes with 102 $m^2$ (1098 $ft^2$) of floor area to compare the energy performance of insulated concrete form (ICF) wall systems versus traditional wood-framed construction. All three homes had identical orientation, window area, roof construction, footprint, ductwork, and air handler systems. This research provided more experimental evidence of the superior energy performance of buildings constructed using massive wall materials. A 20% difference in energy consumption was noticed between the ICF house and the conventional wood-framed house. In the final report, NHAB researchers concluded that this 20% difference was caused by the R-7 difference in wall R-values (ICF wall R-value was about R-20, conventional 2 × 4 wood stud wall R-value was about R-13). However, simulation data developed by ORNL for a similar 121 $m^2$ (1300 $ft^2$) one-story house suggest that for the same climate a difference between R-20 and R-13 should yield a maximum 8% to 9% difference in annual whole building energy consumption. This suggests that most likely thermal mass related energy savings during the NAHB ICF study were in the neighborhood of 11%.

Currently, a field investigation of the effect of thermal mass in residential buildings is being performed by the ORNL Buildings Technology Center with support from the Insulated Concrete Forms Association and the local Habitat for Humanity. The goal is to evaluate the relative energy performance of insulated concrete form (ICF) wall systems. A major task of the project is to field monitor the energy efficiency of a typical ICF residential building side by side with another house that has traditional 2 × 4 wood-framed walls installed on concrete masonry unit foundations (see Figure 1). The interior floor space and floor plan are identical as are the ceiling and floor construction, heating/cooling system, and ductwork for the single-story, 111 $m^2$ (1200 $ft^2$) houses.

The field monitoring of the houses began in mid-June 2000 and will continue for a calendar year, during which time the houses will be unoccupied with the heating/cooling systems operated on identical schedules. This will allow a strong experimental basis for the differences in energy consumption due to the differing outside wall constructions.

The purpose of the monitoring for one year is to provide data sufficient to validate annual energy models of the two houses in the Knoxville climate. Developed computer models will be used to investigate benefits of the ICF construction in climates different from the field test climate of east Tennessee. A detailed report from this project will be available at the end of 2001.

## THERMAL MASS BENEFIT—METHODOLOGY

Evaluation of the dynamic thermal performance of massive wall systems combines experimental and theoretical analysis. For complex three-dimensional building envelope components, it is based on dynamic three-dimensional finite difference simulations, whole building energy computer modeling, dynamic guarded hot box tests, and, sometimes, comparative field performance investigations (Kosny et al. 1998b). Dynamic hot box tests serve to calibrate detailed computer models. However, all these costly and time-consuming steps are not necessary for all wall assemblies. For simple one-dimensional walls, only theoretical analysis can be performed without compromising accuracy.

Masonry or concrete walls having a mass greater than or equal to 146 kg/m$^2$ (30 lb/ft$^2$) and solid wood walls having a mass greater than or equal to 98 kg/m$^2$ (20 lb/ft$^2$) are defined by the Model Energy Code (CABO 1995; Christian 1991) as massive walls. They have heat capacities equal to or exceeding 266 J/m$^2$K (6 Btu/ft$^2$·°F). The same classification is used in this work.

Since 95% of U.S. residential buildings is constructed using lightweight building envelope technologies, energy performance of wood-framed walls is utilized as a base for performance comparisons in this work. A wide range of traditional wood-framed wall assemblies is considered, with R-values from 0.4 to 6.9 Km$^2$/W (2.3 to 39.0 h·ft$^2$·°F/Btu). Energy performance data, generated by whole building energy simulations for residential buildings containing wood-framed walls, are compared against similar data generated for four basic types of massive walls. Each wall type consists of the same materials, concrete and insulating foam. Within the same type of walls, all sequences of materials are the same; however, individual material thicknesses change to match necessary R-values. Massive wall R-values range in this work from R - 0.88 m$^2$K/W (5.0 h·ft$^2$·°F/Btu) to R - 3.03 m$^2$ K/W (17.2 h·ft$^2$·°F/Btu). Four basic material configurations are considered for massive walls:

- Exterior thermal insulation, interior mass **(Intmass)**
- Exterior mass, interior thermal insulation **(Extmass)**
- Exterior mass, core thermal insulation, interior mass **(CIC)**
- Exterior thermal insulation, core mass, interior thermal insulation **(ICI)**

The four types of massive walls listed above approximate most of the currently used multilayer massive wall configurations. For example, the first two wall configurations may represent any masonry block wall insulated with rigid foam sheathing. The last wall configuration may represent insulated concrete form (ICF) walls. Therefore, results presented in this work can be used for approximate energy calculations of most massive wall systems.

## General Procedure

The DOE-2.1E computer code is utilized to simulate single-family residences in representative U.S. climates. Heating and cooling energies calculated for residences with massive walls are compared to the heating and cooling energies for identical buildings simulated with lightweight wood-frame exterior walls. To find a relation between wall R-value and heating and cooling energies, a lightweight ranch-type building is simulated on 12 different wood-frame walls with R-values from 0.4 to 6.9 Km$^2$/W (2.3 to 39.0 h·ft$^2$·°F/Btu). This simulation is performed on ten U.S. climates using TMY2 weather files for a total of 120 simulations. The energy output data generated by these whole building simulations are used to estimate the R-value equivalents that would be needed in conventional wood-frame construction to produce the same energy demand as for the house with massive walls in each of the ten climates. The resulting values account for not only the steady-state R-value but also the inherent thermal mass benefit. This procedure is similar to that used to create the thermal mass benefits tables in the Model Energy Code (CABO 1995). The thermal mass benefit is a function of the climate. The R-value equivalent for massive systems is obtained by comparing the energy performance of the massive wall with the lightweight wood-frame walls (Kosny et al. 1998a; Kosny et al. 1998b) and should be understood only as the R-value needed by a house with wood-framed walls to match the annual energy required by an identical house containing massive walls.

To enable simple comparisons of dynamic energy performances of wall systems, ORNL's BTC introduced in 1995 the Dynamic Benefit for Massive Systems model (DBMS) (Kosny at al. 1998a). DBMS is a dimensionless multiplier of steady-state R-value. The product of DBMS and steady-state R-value is called "Dynamic R-value Equivalent for Massive Systems." It should be used only as an answer to the question: *"What wall R-value should a house with wood frame walls have to obtain the same space heating and cooling energy consumption as a similar house containing massive walls?"*

## Dynamic Whole Building Energy Modeling of Residential Buildings

Comparative analysis of the space heating and cooling energies from two identical residences, one with massive walls and the other containing lightweight wood-frame exterior walls, was introduced in the Model Energy Code for development of thermal requirements for massive wall and was adopted by the authors. The DOE-2.1E computer code was utilized to simulate three single-family residences in ten representative U.S. climates. Two single-story ranch-style houses of approximately 74 m$^2$ (800 ft$^2$) and 143 m$^2$ (1540 ft$^2$) floor area were accompanied by a two-story 279 m$^2$ (3000 ft$^2$) house. Over 10,000 whole building energy simulations were performed during this study. The heating and cooling energies generated from these building simulations served to estimate the R-value equivalents for massive walls. A list of cities and basic climatic data are presented in Table 1.

The Sherman-Grimsrud infiltration method, which is an option in the DOE 2.1E whole-building simulation model (Sherman and Grimsrud 1980), is used in all whole building simulations. An average total leakage area of 0.0005 expressed as a fraction of the floor area is assumed. This is the considered average for a single-zone wood-framed residential

**TABLE 1**
**Ten U.S. Climates Used for DOE 2.1E Computer Modeling**

| Cities | HDD 18.3ºC(65ºF) | CDD 23.3ºC(74ºF) |
|---|---|---|
| Atlanta | 1705 (3070) | 9335 (16803) |
| Bakersfield | 1182 (2127) | 16641 (29954) |
| Boulder | 3037 (5466) | 4269 (7684) |
| Chicago | 3588 (6459) | 3670 (6606) |
| Fort Worth | 1344 (2420) | 20163 (36294) |
| Miami | 110 (198) | 21889 (39401) |
| Minneapolis | 4450 (8010) | 3781 (6806) |
| Phoenix | 802 (1444) | 30224 (54404) |
| Seattle | 2602 (4684) | 498 (897) |
| Sterling (Washington D.C.) | 2781 (5005) | 4286 (7715) |

**TABLE 2**
**Thermal Properties of Material for Multilayer Walls**

| Material | Thermal conductivity, W/mK (Btu-in./h·ft$^2$·ºF) | Density, kg/m$^3$ (lb/ft$^3$) | Specific heat, kJ/kgK (Btu/lb·ºF) |
|---|---|---|---|
| Concrete | 1.44 (10.0) | 2240 (140) | 0.84 (0.20) |
| Insulating foam | 0.036 (0.25) | 25.6 (1.6) | 1.21 (0.29) |
| Gypsum board | 0.16 (1.11) | 800 (50) | 1.09 (0.26) |
| Stucco | 0.72 (5.00) | 1856 (116) | 0.84 (0.20) |

structure. This number cannot be converted directly to average air changes per hour because it is used in an equation driven by hourly wind speed and temperature difference between the inside and ambient, which varies for the six climates analyzed for this study. However, for the ten climates, this represents an air change per hour range that will not fall below an annual average of 0.35 ACH.

The total space heating and cooling energies for 12 light-weight wood-frame walls were calculated using DOE-2.1E simulations. Regression analysis was performed to analyze the relation between the steady-state clear wall R-values of wood-stud walls and the total building annual energies for ten U.S. climates. For all ten climates, the correlation was strong ($r^2$ of about 0.99).

## DYNAMIC THERMAL PERFORMANCE OF SIMPLE MULTILAYER WALL ASSEMBLIES

The whole building energy calculation program DOE-2 E was utilized to simulate residential buildings containing simple multilayer wall assemblies. Simple walls without thermal bridges can be accurately represented by one-dimensional models such as DOE-2 (Kossecka and Kosny 1998; Kosny et al. 2000; ASHRAE 2001). Four sets of massive walls representing different sequences of concrete and foam layers were simulated. Each set consisted of four walls of the same material sequence. These four wall sets (sixteen walls total) represented the majority of existing massive wall material configurations used in construction today. For all wall configurations analyzed in this section, the same material properties were used and are presented in Table 2.

These walls had different thicknesses of concrete and insulation layers. For each analyzed material configuration, four different sets of thicknesses were considered and were organized according to their R-value;

- R - 3.03 m$^2$·K/W (17.2 h·ft$^2$·ºF/Btu), in total: 10.6 cm (4 in.) of foam, 15.2 cm. (6 in.) of concrete.
- R - 2.29 m$^2$·K/W (13.0 h·ft$^2$·ºF/Btu), in total: 7.6 cm (3 in.) of foam, 10.2 cm. (4 in.) of concrete.
- R - 1.58 m$^2$·K/W (9.0 h·ft$^2$·ºF/Btu), in total: 5.2 cm (2 in.) of foam, 10.2 cm. (4 in.) of concrete.
- R - 0.88 m$^2$·K/W (5.0 h·ft$^2$·ºF/Btu), in total: 2.5 cm (1 in.) of foam, 10.2 cm. (4 in.) of concrete.

Due to the limited size of this paper, only some examples of the results are presented below. Detailed results for all considered houses are scheduled to be available at the end of

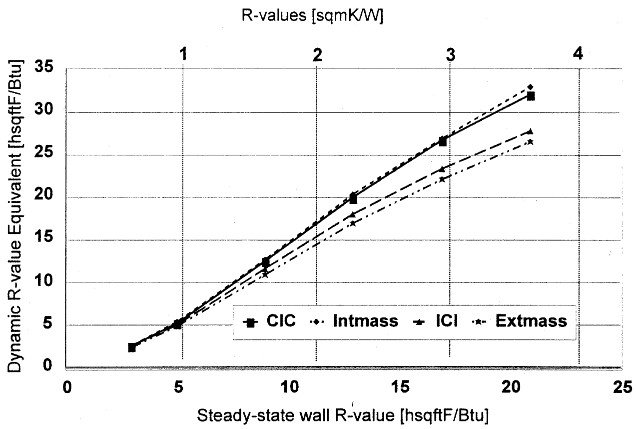


**Figure 2** *Dynamic R-value equivalents for Washington, D.C., for 1540 ft² one-story ranch house.*

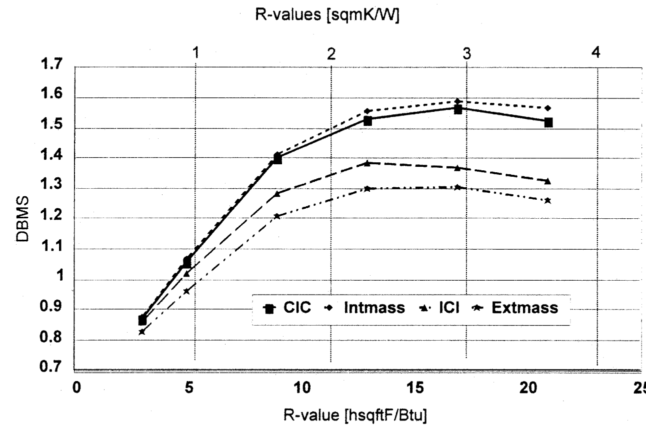


**Figure 3** *DBMS values for Washington, D.C., for 143 m² (1540 ft²) one-story ranch house.*

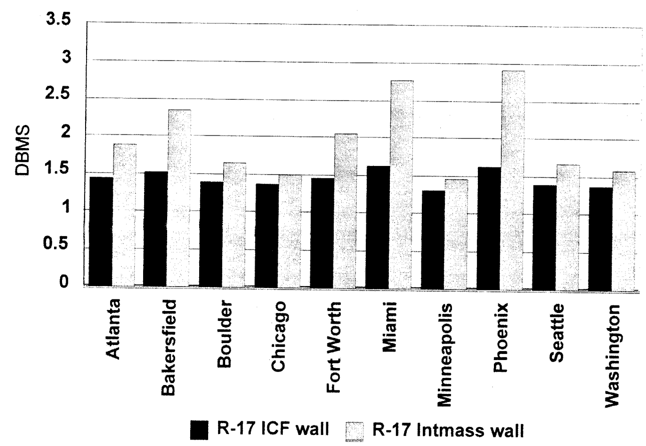


**Figure 4** *DBMS values for two massive wall systems in ten U.S. climates for 143 m² (1540 ft²) one-story ranch house.*

2001 under the following Internet address: http://www.ornl.gov/roofs+walls/.

Figure 2 depicts an example of the relationships between wall steady-state R-value and dynamic R-value equivalents for the Washington, D.C., climate. A one-story ranch house of 143 m² (1540 ft²) (Hasting 1977; Huang et al. 1987) is chosen to illustrate the dynamic energy performance of a one-story residential building. Similar relations were observed for all considered climatic conditions and for all sizes and types of buildings. These data show that the most effective wall assemblies were walls with thermal mass (concrete) being in good contact with the interior of the building (Intmass and CIC). Walls where the insulation material is concentrated on the interior side (Extmass) were the worst performing wall assemblies. Wall configurations with the concrete wall core and insulation placed on both sides of the wall (ICI) performed slightly better than Extmass configurations. However, their performance was significantly worse than CIC and Intmass configurations. The ICI configuration can be used for approximate analysis of the very popular insulated concrete form (ICF) constructions, since ICF walls consist of the internal concrete core placed between shells made of insulating foam.

The relationship between DBMS and wall R-value is not linear. For CIC and Extmass configurations, DBMS is relatively close to 1.0. Figure 3 depicts DBMS values for a 143 m² (1540 ft²) one-story residential building in the Washington, D.C., climate. As in Figure 2, CIC and Intmass walls outperformed other wall systems. Walls where the insulation material is concentrated on the interior side of the wall have the smallest DBMS values. DBMS values for walls with the concrete core and insulation placed on both sides fell between these configurations. It was observed for all simulated cases that the DBMS was at its maximum for wall R-values between 2.3 and 3.0 m²·K/W (13 and 17 h·ft²·°F/Btu).

Figure 4 shows the relationship between wall material configurations and DBMS for ten climates. A one-story ranch house and two R- 3 m²·K/W (17 h·ft²·°F/Btu) walls were considered. One wall had a concrete core with insulation placed on both sides, and the second wall was built with concrete on the interior side and insulation on the exterior. The first wall exemplifies popular ICF systems used in the U.S. and Canada. The second wall could represent a concrete block wall insulated with external rigid foam sheathing. Figure 4 clearly demonstrates significant differences in energy performance between the two wall systems. The wall with external foam insulation (Intmass on Figure 4) was much more effective than the ICF wall. The most favorable climates for both wall systems were in Phoenix and Miami and the worst locations were Minneapolis and Chicago. However, even for the worst locations, the DBMS values were close to 1.5. The range of DBMS values for walls with exterior foam insulation (from 1.4 to 2.8) is much wider than a very flat chart of DBMS values for the ICF wall system (oscillating around 1.5). This is caused by different distributions of mass and thermal insulation in these walls, generating significant differences in DBMS values for the same climate.

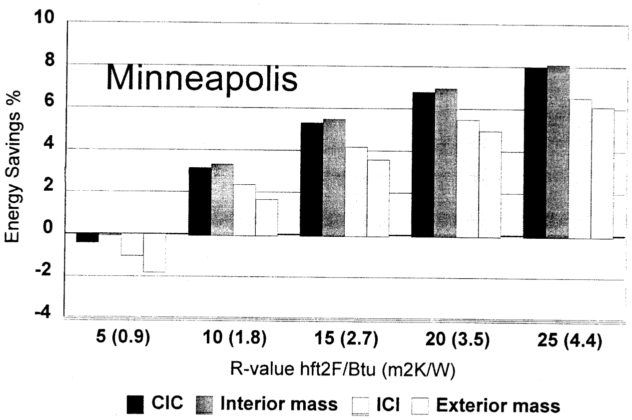


*Figure 5* *A portion of the whole building energy that can be saved in Minneapolis, Minnesota, by replacement of conventional wood-framed walls by massive wall technologies.*

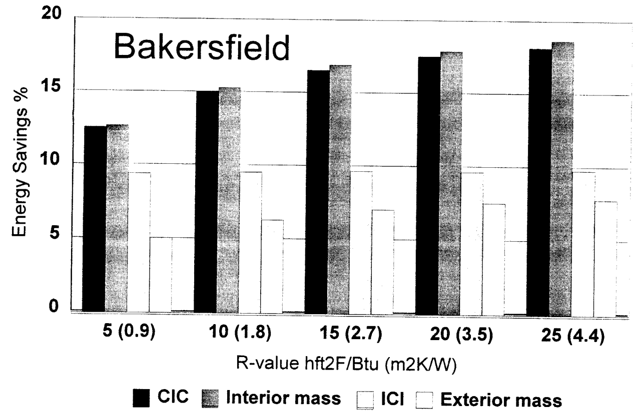


*Figure 6* *A portion of the whole building energy that can be saved in Bakersfield, California, by replacement of conventional wood-framed walls by massive wall technologies.*

## POTENTIAL ENERGY SAVINGS IN HOUSES WITH MASSIVE WALL SYSTEMS

In certain climates, buildings containing massive building envelopes—such as concrete, earth, insulating concrete forms (ICFs), and solid wood (log) — can be more energy efficient than similar conventional wood-framed houses. This was well known by Native Americans who commonly used adobe structures in the past. Also, European residential buildings have been built for centuries using massive wall technologies. Several studies performed in the last decade or so have compared energy performance of buildings containing massive walls with similar buildings constructed using lightweight wall technologies (Burch 1984a, 1984b, 1984c; Robertson and Christian 1985; Christian 1983, 1984, 1985). These experiments required construction of identical houses having the same floor plane, shape, orientation, HVAC equipment, etc. One of the most difficult conditions for such comparisons was the requirement of identical R-values for all building envelope components in all compared buildings. Many experimental studies did not fulfill this requirement, making necessary the deployment of whole building energy simulation models. Investigation of differences in energy consumption between massive and lightweight buildings can help in the analysis of potential benefits of using massive building envelope components. Two examples of energy consumption comparisons are presented below for Minneapolis, Minnesota, (heating climate), and Bakersfield, California (cooling climate).

Annual whole building energy savings, attainable when lightweight walls are replaced by massive walls of the same R-value, were calculated for a 143 $m^2$ (1540 $ft^2$) one-story ranch house located in Minneapolis, Minnesota. These energy savings were defined as the difference between energies required to heat and cool the house containing massive walls vs. the same house constructed with wood-frame technology. Energy savings for this house were estimated between 3 and 7 MBtu/year for R-1.8 to 4.4 $m^2 \cdot K/W$ (10 to 25 $h \cdot ft^2 \cdot {}^oF/Btu$) walls. This is approximately 1900-4400 Btu/year per $ft^2$ of floor area of the residential building.

Figure 5 depicts the percentage annual energy savings for a massive house located in Minneapolis (heating climate). Data presented in Figure 5 show that it is possible for buildings with high R-value walls to save up to 8% of annual energy consumption when traditional wood stud walls are replaced by massive wall systems. It is interesting to note that low R-value massive walls may actually increase energy consumption in this location.

Figure 6 shows similar energy savings comparisons as shown in Figure 5 but for buildings located in Bakersfield, California (cooling climate). Data presented in Figure 6 demonstrate that during the design process, an architect may save 5% to 18% of future whole building energy use simply by replacing traditional lightweight walls with massive systems.

Insulated concrete forms (ICF) have been gaining acceptance by U. S. builders during the last decade. These massive building envelope technologies are using foam forms that are filled with concrete at the building site. Since most of these systems have a similar configuration of materials, foam/concrete/foam, it was possible to develop a single chart that shows approximate energy savings available when conventional wood-framed walls are replaced by ICF walls in residential buildings. Figure 7 depicts the potential energy savings available in ten U. S. locations for ICF wall systems. This figure represents combined data from all three simulated houses. It shows the average whole building energy savings potential in houses with 74 - 279 $m^2$ (800-3000 $ft^2$) of floor area. For individual building size and shape, these data may vary within ″2%. Assuming that the average ICF wall R-value is between R- 2.6 and 3.5 $m^2 \cdot K/W$ (15 and 20 $h \cdot ft^2 \cdot {}^oF/Btu$), average potential whole building energy savings (ICF house vs. conventional wood-framed house) for all U.S. locations are between 6% and 8%.

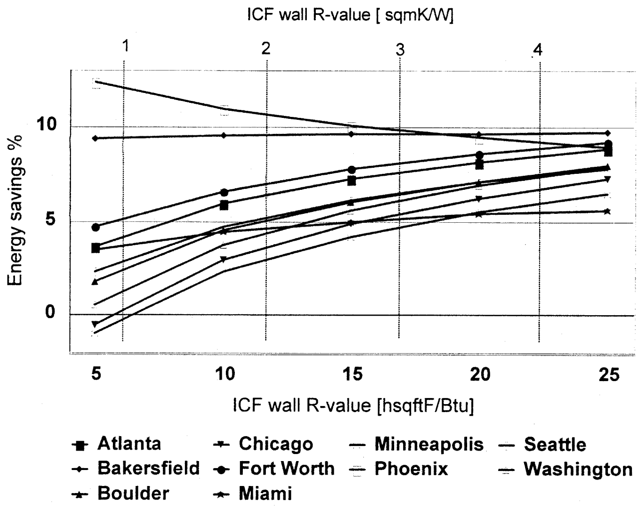


***Figure 7*** *Potential energy savings available in ten U.S. locations for ICF wall systems.*

## CONCLUSIONS

Experimental and theoretical analysis of the energy performance of lightweight and massive wall systems was presented in this paper. Dynamic thermal performance of 16 wall assemblies was investigated for residential buildings and the potential energy savings were presented for ten U.S. climates. It was found that some massive building envelope technologies can help in the reduction of building annual energies.

Several comparative field experiments have demonstrated that in many U. S. locations, heating and cooling energy demands in buildings containing massive walls of relatively high R-values can be lower than those in similar buildings constructed using equivalent R-value with lightweight wall technologies.

The thermal mass benefit is a function of wall material configuration, climate, and building size, configuration, and orientation. From ten analyzed U.S. locations, the most beneficial for application of thermal mass are Phoenix, Arizona, and Bakersfield, California.

Comparative analysis of 16 different material configurations showed that the most effective wall assembly was the wall with thermal mass (concrete) applied in good contact with the interior of the building. Walls where the insulation material was concentrated on the interior side performed much worse. Wall configurations with the concrete wall core and insulation placed on both sides of the wall performed slightly better; however, their performance was significantly worse than walls containing foam core and concrete shells on both sides.

Potential whole building energy savings, available when lightweight walls are replaced by massive walls of the same R-value, were calculated for 143 $m^2$ (1540 $ft^2$) one-story ranch houses located in Minneapolis, Minnesota, and Bakersfield, California. For high R-value walls, up to 8% of the whole building energy could be saved in Minneapolis and 18% in Bakersfield when wood-framed walls were replaced by massive wall systems. Thermal mass layers must be in good contact with the interior of the building in these walls.

Whole building possible energy savings in houses built with ICF walls were estimated as well. Three houses with 74 to 279 $m^2$ (800-3000 $ft^2$) of floor area were simulated for this purpose. It was found that for ten U.S. locations, ICF walls of R-2.6 and 3.5 $m^2 \cdot K/W$ (15 and 20 $h \cdot ft^2 \cdot °F/Btu$), the average potential whole building energy savings (ICF house vs. conventional wood-framed house) can be between 6% and 8%.

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