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THE THERMAL MASS ADVANTAGE OF MASONRY IN ENERGY CODES AND STANDARDS

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ABSTRACT

The U.S. Energy Policy Act of 1992 mandated that the local energy codes for commercial buildings meet or exceed the requirements of ASHRAE Standard 90.1. This, in effect, made ASHRAE 90.1 requirements the U.S. energy baseline. Canada's energy code is also influenced by the ASHRAE standard. This standard specifies requirements for energy conservation and use within commercial buildings, and includes criteria for lighting, HVAC systems, and heat loss through walls.

In the ASHRAE 90.1 standard, credits are given for the thermal mass effects of concrete and masonry walls. The mass effects depend on the climate, wall heat capacity, and insulation position. The thermal mass of the concrete and masonry stores and later releases heat energy which eliminates large temperature swings within the interior of the building. Thermal mass is also effective in commercial buildings because it moderates internal loads generated by occupants, lighting, and equipment.

INTRODUCTION

Ever since the Arab oil embargo of 1973 and the ensuing energy crisis, conservation of energy has become a major concern of industry and government. In an effort to avoid future energy crises, the United States developed the first energy policy shortly after the 1973 embargo. The energy policy was tied to state and local building codes by specifying

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minimum R-values for building envelopes. The thermal performance of lightweight building materials is adequately represented by the R-value alone. However, since concrete and masonry store and later release heat energy, the R-value is not an accurate measure of their thermal performance.

Prescriptive requirements in early energy codes penalized concrete and masonry by strictly specifying minimum R-values. Current energy codes, however, account for the ability of concrete and masonry to store and later release thermal energy.

ENERGY CODES

ASHRAE/IESNA Standard 90.1-1989 (ASHRAE, 1989) is an energy code for new commercial buildings and ASHRAE Standard 90.2-1993 (ASHRAE, 1993) is an energy code for new residential buildings. These standards were developed using a consensus process by committees within the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). The standards, which are continually updated, encompass all aspects of building design and energy usage. The total building is considered from proper sizing of the HVAC system to lighting requirements to minimum levels of insulation in walls and roofs.

In 1992, the United States Congress passed the U.S. Energy Policy Act. This legislation required each state to implement an energy code that meets or exceeds the requirements of ASHRAE Standard 90.1 for commercial buildings. States were given two years to implement the change or show reasonable progress in implementing the change. The legislation also required that each state determine whether its energy code for residential buildings meets or exceeds the requirements of the Model Energy Code (Council of America Building Officials, 1992). It is possible that the Model Energy Code will soon adopt the ASHRAE 90.2 Standard, essentially making both ASHRAE standards the federally mandated energy policy in the United States.

The ASHRAE standards have been written with input from engineers and architects from the United States and Canada, and include criteria and climate data for both countries.

Although Canada does not have a national energy policy, some of the individual provinces have their own energy policies. Quebec and Ontario both use the ASHRAE Standard 90.1 for commercial buildings.

THERMAL MASS

As previously discussed, the R-value alone does not accurately predict the thermal performance of concrete and masonry walls. This is because the R-value is a measure of resistance to heat flow during constant temperature. A typical 150-mm (6-inch) insulated frame wall may have an R-value of 2.3 $m^2 \cdot K/W$ (13 $hr \cdot ft^2 \cdot {}^\circ F/Btu$), while a typical 200-mm (8-inch) concrete wall will have an R-value of 0.2 $m^2 \cdot K/W$ (1.3 $hr \cdot ft^2 \cdot {}^\circ F/Btu$). Simply comparing the R-values of these walls will falsely imply that the concrete wall loses 10 times more heat than the insulated frame wall.

Thermal mass is a property that enables building materials to absorb, store, and later release significant amounts of heat. Buildings constructed of concrete and masonry have a unique energy-saving advantage because of their inherent thermal mass. These materials absorb energy slowly and hold it for much longer periods of time than do less massive materials. This delays and reduces heat transfer through a thermal mass building component, leading to three important results. First, there are fewer spikes in the heating and cooling requirements, since thermal mass slows the response time and moderates indoor temperature fluctuations. Second, a massive building uses less energy than a similar low mass building due to the reduced heat transfer through the massive elements. Third, thermal mass can shift energy demand to off-peak time periods when energy rates are lower.

When comparing the thermal performance of concrete and masonry walls with that of frame walls, both the thermal mass and R-values must be considered. Early energy codes specified R-values only, and this is why concrete and masonry walls were "penalized".

The thermal performance of walls can be measured in a calibrated hot box test (ASTM C976). This test method is used to determine the thermal mass and the R-value of a wall assembly. To measure the R-value, the wall assembly is placed in the testing apparatus, and each side is subjected to constant, but different temperatures. The R-value is then calculated from the temperature difference and the heat flow across the specimen. The effect of thermal mass is determined in a similar manner, except the temperature on one side of the wall assembly is fluctuated to represent actual outdoor conditions. Due to the high cost of testing, and the usefulness of computers, this type of testing has been largely replaced by computer simulations.

Figure 1 presents a typical test result from a calibrated hot box test of an uninsulated concrete block wall. The vertical axis represents the heat flow through the wall, while the horizontal axis represents the time of testing. The calculated heat flow represents the thermal performance based on R-values only, neglecting thermal mass effects. The measured heat flow includes thermal mass effects. As can be seen in the figure the actual measured values include a decrease in the total heat flow as well as a shift of the peak heat flow. Both the shift and the reduction of maximum heat flow are important for a number of reasons. First, the reduction in peak heat flow is important because this shows the importance of the thermal mass effect. Another important point is the reduction in total heat flow, as measured by the area under each curve. This is important because less heat is actually being lost through the wall when the thermal mass is considered. Finally, the thermal lag is important because energy consumption is shifted to off-peak times which may reduce fuel expenses or shift loads to times when heating or cooling is not necessary.

Table 1 presents the result of calibrated hot box tests for a number of wall configurations. Presented are the wall configurations, the calculated R-value, the thermal lag, the reduction in amplitude, and the calculated and measured total heat fluxes. It is interesting to compare the insulated frame wall to the insulated brick and block cavity wall. The R-value of the insulated frame wall was higher than that of the insulated cavity wall, however, less heat flowed through the insulated cavity wall. Thermal lag, reduction in amplitude, and total energy use for any wall is dependent on the climate, building, and building use.

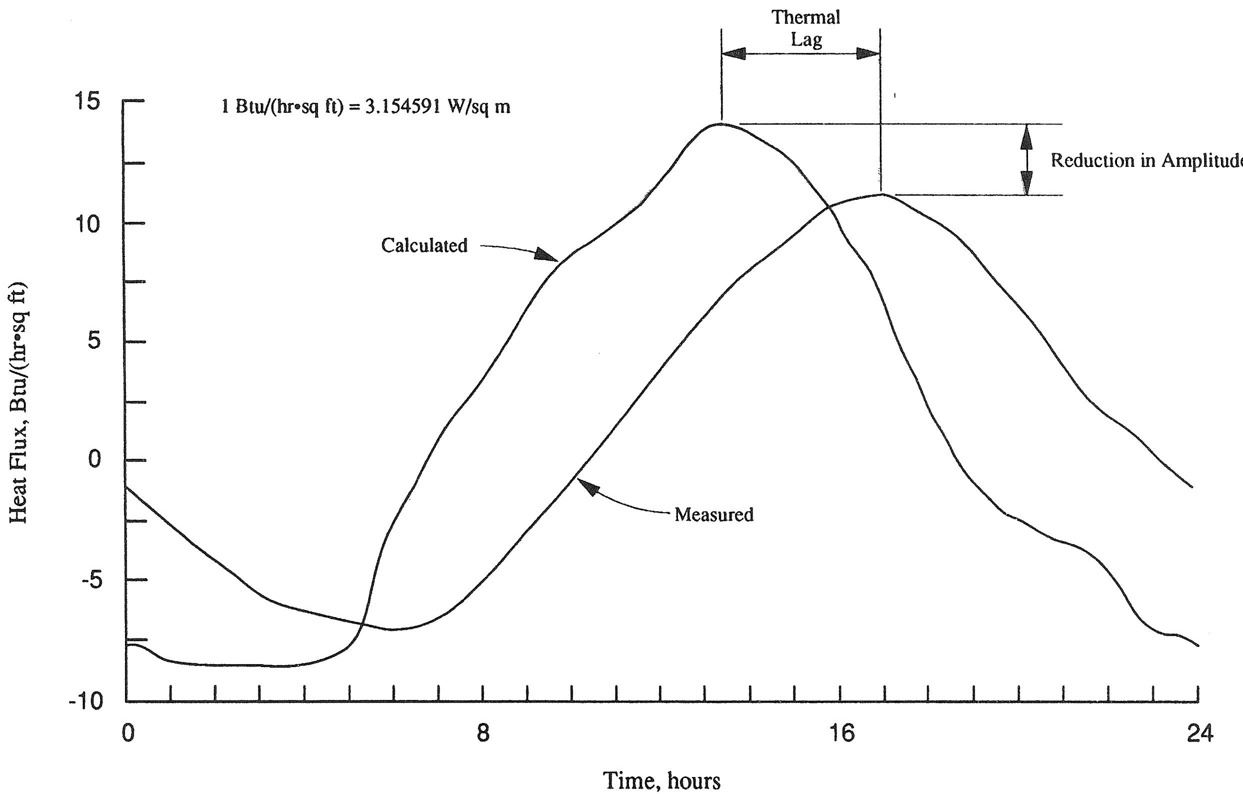

Figure 1 - Heat Flux Measured using a Calibrated Hot Box and Calculated from R-values for an Uninsulated Concrete Block Wall.

Table 1 - Results of Calibrated Hot Box Tests for Various Wall Types

Wall Description	Measured Thickness in.	Measured R-value hr·sq ft·°F/Btu	Thermal Lag, hours	Reduction in Amplitude, percent	Measured Heat Flow Btu/sq ft	Calculated Heat Flow Btu/sq ft
Medium Weight Hollow Core Concrete Block	7.6	2.8	3.0	18	133	169
Medium Weight Hollow Core Concrete Block with Expanded Perlite Loose-Fill Insulation in Cores	7.6	4.3	3.5	28	72	101
Uninsulated Cavity Wall: 6-in. Hollow Core Concrete Block and 4-in. Clay Brick Separated by a 2.8-in. Air Space	12.1	3.5	5.5	43	70	121
Insulated Cavity Wall: 6-in. Hollow Core Concrete Block and 4-in. Clay Brick Separated by 2.8-in. of Expanded Perlite Loose-Fill Insulation	12.1	9.4	7.0	50	22	39
2x4-in. Wood Frame with R-11 Fiberglass Batt Insulation between Studs, Gypsum Wallboard on Inside Surface, and Plywood Cedar Siding on Outside Surface	4.8	12.0	1.5	7.5	38	43

Notes : 1 inch = 25.4 mm
1 hr·sq ft·°F/Btu = 0.1761102 sq m·K/W
1 Btu/sq ft = 11.35653 kJ/sq m

In low-rise residential buildings, heating and cooling loads are primarily determined by the thermal performance of the building envelope. In those buildings the effects of thermal mass are most pronounced in climates where the outdoor temperature is both greater than the indoor temperature during the day, and less than the indoor temperature at night. In this situation, heat energy warms the cool concrete walls during the day, and then the stored heat energy warms the interior of the building at night and also escapes into the cool surroundings at night. This situation is termed a reversal in heat flow. In commercial buildings, loads are influenced more by internal heat gains from occupants, lighting, and equipment. Because exposed thermal mass can absorb intermittent heat gains, thermal mass is generally more effective in commercial buildings than in low-rise residential buildings. Utilizing these principals, it is possible to design and build cost effective buildings utilizing thermal mass for most climates in the United States and Canada.

ENERGY CODE COMPLIANCE

Thermal mass effects for concrete and masonry wall components are addressed in the ASHRAE 90.1 standard. Credits are available in most climates for this type of construction. In the standard there are three paths for showing that a wall or roof meets the criteria of the standard. These paths are the prescriptive, performance, and the cost budget method. Each succeeding compliance path is more complex than the others. For example the performance method is more complex than the prescriptive method.

The prescriptive compliance path is the simplest path to show that a building component meets the minimum requirements of the ASHRAE 90.1 standard. This method uses tables to determine the required R-values for walls and roofs. In the standard, these tables are called Alternate Compliance Packages or ACP tables. There are a total of 38 ACP tables, and each table contains a listing of locations in which the requirements of the table apply. In these tables, the minimum R-value is based on the heat capacity of the wall. There are four categories of heat capacity: 0 to 0.88, 0.88 to 1.76, 1.76 to 2.64, and greater than 2.64 $kJ/(m^2 \cdot K)$ (0 to 5, 5 to 10, 10 to 15, and greater than 15 $Btu/(ft^2 \cdot °F)$), and two categories of insulation position (interior or exterior). The required R-value is determined by knowing the heat capacity of the wall and where the insulation is located.

The performance path of compliance is slightly more difficult to use than the prescriptive path. This method uses a relatively simple computer program that is supplied with the ASHRAE 90.1 standard. The computer program is call ENVSTD, and allows wall construction options to be manipulated in order to meet the standard. For example, lesser amounts of insulation can be traded for other energy conserving options such as more energy efficient windows. The program allows the exact heat capacity to be used, and any value up to 17.6 $kJ/(m^2 \cdot K)$ (100 $Btu/(ft^2 \cdot °F)$) can be entered. Additional credits are only available for values up to 3.70 $kJ/(m^2 \cdot K)$ (21 $Btu/(ft^2 \cdot °F)$). The program allows for three types of insulation position: interior, exterior, or integral.

The most complex method of compliance is the cost budget method. This method compares a building that complies with the standard with a design building to see if it complies. This method is usually used to determine if a new type of construction material, or a novel building design will meet the energy standard.

A majority of the engineers, architects, and contractors use either the prescriptive or the performance path of compliance. As an example, consider the design of a new concrete building for McMaster University which meets the prescriptive requirements of ASHRAE 90.1. The city in the ACP Tables closest to McMaster University is Toronto, Ontario, Canada. Toronto is contained in ACP Table No. 32. For this example assume that the new building has 200-mm (8-inch) thick normal weight concrete walls with exterior insulation. The heat capacity of the concrete is its unit weight on a weight per unit area basis multiplied by the specific heat. The specific heat of normal-weight concrete can generally be assumed to be 0.84 kJ/(kg·K) (0.20 Btu/(lb·°F)). Since normal-weight concrete in generally 2400 kg/m^3 (150 lb/ft^3), the heat capacity in this case is 3.53 $kJ/(m^2·K)$ (20 $Btu/(ft^2·°F)$). The required R-value is 1.8 $m^2·K/W$ (10 $hr·ft^2·°F/Btu$) for the concrete wall with exterior insulation. Insulation with an R-value of 1.53 $m^2·K/W$ (8.7 $hr·ft^2·°F/Btu$) must be added to the concrete to achieve a wall R-value of 1.8 $m^2·K/W$ (10 $hr·ft^2·°F/Btu$). If this building was constructed using wood framed walls, the required R-value would be 2.45 $m^2·K/W$ (13.9 $hr·ft^2·°F/Btu$). The R-value requirement of the mass wall is 28 percent less than of the framed wall.

A building of this type can be modelled for any location in Canada and the United States. Table 2 compares the required R-values using the prescriptive path for four types of construction at many locations in Canada and the United States. The four wall types are a simple wood framed wall, a simple wood framed wall with an exterior wythe of clay brick, a 200-mm (8-inch) thick normal weight concrete wall with interior insulation, and a similar concrete wall with exterior insulation. Insulation on the exterior side of mass is generally more effective than interior insulation in reducing heating and cooling loads. This is demonstrated in Table 2 by the lower R-value requirements of concrete walls with exterior insulation.

CONCLUSIONS

Since the passage of the Energy Policy Act of 1992, ASHRAE Standard 90.1 has become the energy policy of the United States for commercial buildings. Some Canadian Provinces currently use the ASHRAE standard, and it is expected that as the remaining Provinces develop energy codes, these policies will use the ASHRAE standard.

The thermal performance of concrete and masonry are not accurately represented by R-values alone. In most climates, thermal mass effects allow for less insulation to be used in concrete and masonry construction to achieve the required level of insulation.

The ASHRAE 90.1 standard considers the thermal mass effects of concrete and masonry walls, and allows building designers to meet the energy codes by using less insulation than required for non-mass walls.

Table 2 - Minimum Required R-values (hr·sq ft·°F/Btu) for Different Wall Types in Selected Cities

City	ACP Table	Frame Wall	Frame Wall with Brick Wythe	Concrete Wall with Interior Insulation	Concrete Wall with Exterior Insulation
Albany, NY	31	13.2	12.7	11.2	10.0
Albuquerque, NM	23	10.0	9.1	6.3	4.8
Anchorage, AK	37	17.2	16.9	16.4	11.8
Atlanta, GA	8	7.7	6.7	4.2	3.4
Boise, ID	28	12.2	10.9	8.3	6.3
Calgary, AB	36	17.2	16.9	16.4	14.5
Chicago, IL	26	12.2	11.8	10.5	9.1
Dauphin, MB	38	22.2	21.7	21.3	20.0
Denver, CO	28	12.2	10.9	8.3	6.3
Des Moines, IA	31	13.2	12.7	11.2	10.0
Detroit, MI	26	12.2	11.8	10.5	9.1
Fort Smith, NW	38	22.2	21.7	21.3	20.0
Helena, MT	32	13.9	13.3	11.9	10.0
Las Vegas, NV	14	6.3	5.3	3.6	3.2
Los Angeles, CA	6	4.5	2.7	1.3	1.3
Minneapolis, MN	33	15.4	14.9	14.1	12.0
Minot, ND	36	17.2	16.9	16.4	14.5
Montreal, PQ	33	15.4	14.9	14.1	12.0
Moose Jaw, SK	36	17.2	16.9	16.4	14.5
New York City, NY	25	8.3	7.7	5.9	4.8
Ottawa, ON	33	15.4	14.9	14.1	12.0
Peace River, AB	38	22.2	21.7	21.3	20.0
Phoenix, AZ	18	4.2	3.6	2.4	2.4
Pittsburg, PA	26	12.2	11.8	10.5	9.1
Portage La Prarie, MB	36	17.2	16.9	16.4	14.5
Prince Rupert, BC	37	17.2	16.9	16.4	11.8
Red Deer, AB	36	17.2	16.9	16.4	14.5
Sable Island, NS	27	12.5	11.9	10.3	8.3
San Francisco, CA	4	7.1	5.0	2.3	1.9
Sandspit, BC	27	12.5	11.9	10.3	8.3
Saskatoon, SK	38	22.2	21.7	21.3	20.0
Seattle, WA	19	10.9	10.4	9.1	7.1
St Johns, NF	37	17.2	16.9	16.4	11.8
St Louis, MO	29	10.8	10.1	8.3	7.1
Tampa, FL	12	7.7	5.9	3.7	3.1
Toronto, ON	32	13.9	13.3	11.9	10.0
Traverse City, MI	32	13.9	13.3	11.9	10.0
Vancouver, BC	19	10.9	10.4	9.1	7.1
Windsor, ON	31	13.2	12.7	11.2	10.0
Winnipeg, MB	38	22.2	21.7	21.3	20.0
Yarmouth, NS	32	13.9	13.3	11.9	10.0
Yorktown, SK	38	22.2	21.7	21.3	20.0

Note : Heat capacities for the brick wythe and concrete walls are assumed to be 6 and 20 Btu/(sq ft·°F), respectively.

Table 2 - Minimum Required R-values (sq m·K/W) for Different Wall Types in Selected Cities

City	ACP Table	Frame Wall	Frame Wall with Brick Wythe	Concrete Wall with Interior Insulation	Concrete Wall with Exterior Insulation
Albany, NY	31	2.3	2.2	2.0	1.8
Albuquerque, NM	23	1.8	1.6	1.1	0.8
Anchorage, AK	37	3.0	3.0	2.9	2.1
Atlanta, GA	8	1.4	1.2	0.7	0.6
Boise, ID	28	2.1	1.9	1.5	1.1
Calgary, AB	36	3.0	3.0	2.9	2.6
Chicago, IL	26	2.1	2.1	1.9	1.6
Dauphin, MB	38	3.9	3.8	3.7	3.5
Denver, CO	28	2.1	1.9	1.5	1.1
Des Moines, IA	31	2.3	2.2	2.0	1.8
Detroit, MI	26	2.1	2.1	1.9	1.6
Fort Smith, NW	38	3.9	3.8	3.7	3.5
Helena, MT	32	2.4	2.3	2.1	1.8
Las Vegas, NV	14	1.1	0.9	0.6	0.6
Los Angeles, CA	6	0.8	0.5	0.2	0.2
Minneapolis, MN	33	2.7	2.6	2.5	2.1
Minot, ND	36	3.0	3.0	2.9	2.6
Montreal, PQ	33	2.7	2.6	2.5	2.1
Moose Jaw, SK	36	3.0	3.0	2.9	2.6
New York City, NY	25	1.5	1.4	1.0	0.8
Ottawa, ON	33	2.7	2.6	2.5	2.1
Peace River, AB	38	3.9	3.8	3.7	3.5
Phoenix, AZ	18	0.7	0.6	0.4	0.4
Pittsburg, PA	26	2.1	2.1	1.9	1.6
Portage La Prarie, MB	36	3.0	3.0	2.9	2.6
Prince Rupert, BC	37	3.0	3.0	2.9	2.1
Red Deer, AB	36	3.0	3.0	2.9	2.6
Sable Island, NS	27	2.2	2.1	1.8	1.5
San Francisco, CA	4	1.3	0.9	0.4	0.3
Sandspit, BC	27	2.2	2.1	1.8	1.5
Saskatoon, SK	38	3.9	3.8	3.7	3.5
Seattle, WA	19	1.9	1.8	1.6	1.3
St Johns, NF	37	3.0	3.0	2.9	2.1
St Louis, MO	29	1.9	1.8	1.5	1.3
Tampa, FL	12	1.4	1.0	0.7	0.6
Toronto, ON	32	2.4	2.3	2.1	1.8
Traverse City, MI	32	2.4	2.3	2.1	1.8
Vancouver, BC	19	1.9	1.8	1.6	1.3
Windsor, ON	31	2.3	2.2	2.0	1.8
Winnipeg, MB	38	3.9	3.8	3.7	3.5
Yarmouth, NS	32	2.4	2.3	2.1	1.8
Yorktown, SK	38	3.9	3.8	3.7	3.5

Note : Heat capacities for the brick wythe and concrete walls are assumed to be 1.06 and 3.52 kJ/(sq m·K), respectively.

REFERENCES

ASHRAE/IESNA 90.1-1989 (1989), "ASHRAE Standard for Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings", ASHRAE, Atlanta, Georgia.

ASHRAE 90.2-1993, (1993), "ASHRAE Standard for Energy Efficient Design of New Low-Rise Residential Buildings", ASHRAE, Atlanta, Georgia.

Model Energy Code, 1992 Edition (1992), Council of America Building Officials, Pike Falls Church, Virginia.