The Experimental Long-Term Performance of Some Thermal Foundation Systems

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ABSTRACT

Four basement and two shallow-foundation test modules encompassing seven thermal foundation systems have been tested at a foundation test facility over four heating seasons. The results show that basement exterior or interior full-wall extruded polystyrene insulation reduces heating energy consumption by more than 50% compared with an uninsulated basement, while, on a seasonal basis, the interior insulated envelope transports at least 50% less water vapor than the exterior insulated envelope. Decreasing basement interior insulation to the upper half-wall increases the module thermal energy consumption and envelope water vapor transport by more than 50%. An insulated shallow foundation reduces whole-building thermal energy consumption by 15% compared with an uninsulated foundation.

INTRODUCTION

A foundation test facility (FTF) located in Minnesota was established with the primary purpose of demonstrating objectively and unambiguously that foundation insulation produces significant energy savings, particularly in a cold Minnesota climate. Initially, four basement test modules were commissioned in 1988, followed by two shallow-foundation modules in 1991, encompassing a test period of four heating seasons. Seven different thermal foundation systems have been tested to date, producing a large volume of transient and long-term experimental data. The results reported here concentrate upon the long-term moisture transport and thermal behavior of the test modules.

TEST FACILITY AND EXPERIMENTAL DESIGN

A site plan showing the relative location of the six test modules is given in Figure 1. The staggered arrangement and spacing of the modules are designed to ensure that microclimatic variations between modules are minimized for the wind conditions prevailing at the site. All six modules share a common heated test cavity floor area that measures 19 ft, 4 in. (5.89 m) square.

Basement Module Design

As indicated in Figure 2, the basement modules have a test cavity height of 7 ft, 8 in. (2.34 m), with 1.5 ft (457.2 mm) of the wall protruding above grade. The floor consists of a 4 in. (101.6 mm) thick, unreinforced concrete slab divided into nine uniform squares by caulked, cracking control cuts, while sealed expansion strips are located at the slab/wall interface. Nine squares were chosen as a practical minimum for preventing uncontrolled crack formation in the floor. The north basement module is designated as a reference for data normalization and has unreinforced, homogeneous 12-in. (304.8-mm) thick poured concrete walls bearing directly on the ground without any intervening spread footings. The remaining three basement modules are all of standard 12-in. (304.8-mm) masonry block construction with spread footings (Figure 2). The cores of the masonry blocks have remained unfilled for all the testing performed to date.

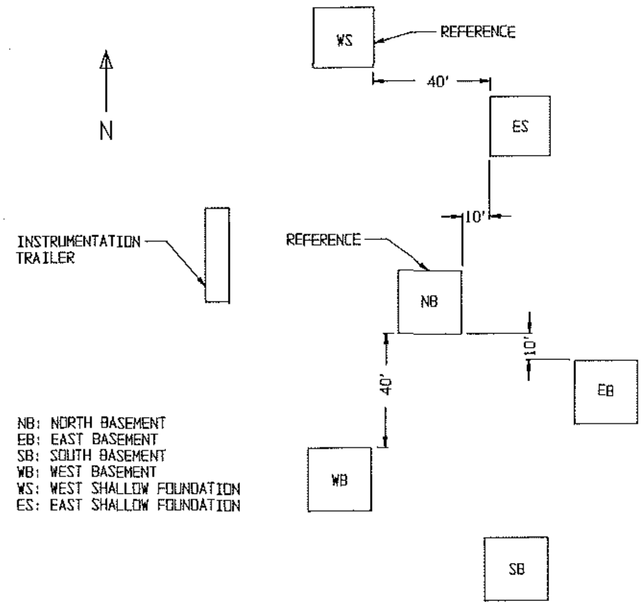

Figure 1 *General site plan—all modules.*

The test cavity in each basement module is covered identically with a thermal guard cavity fabricated from stressed-skin, expanded polystyrene cored panels. The guard cavity is controlled to have the same temperature as the test cavity beneath, reducing the heat transfer through the test cavity ceiling to a practical minimum approaching the adiabatic ideal. Since all the modules are electrically heated, this arrangement causes each test cavity to function as a calorimeter so that the net electrical energy consumption of the test cavity is a direct and unambiguous measure-

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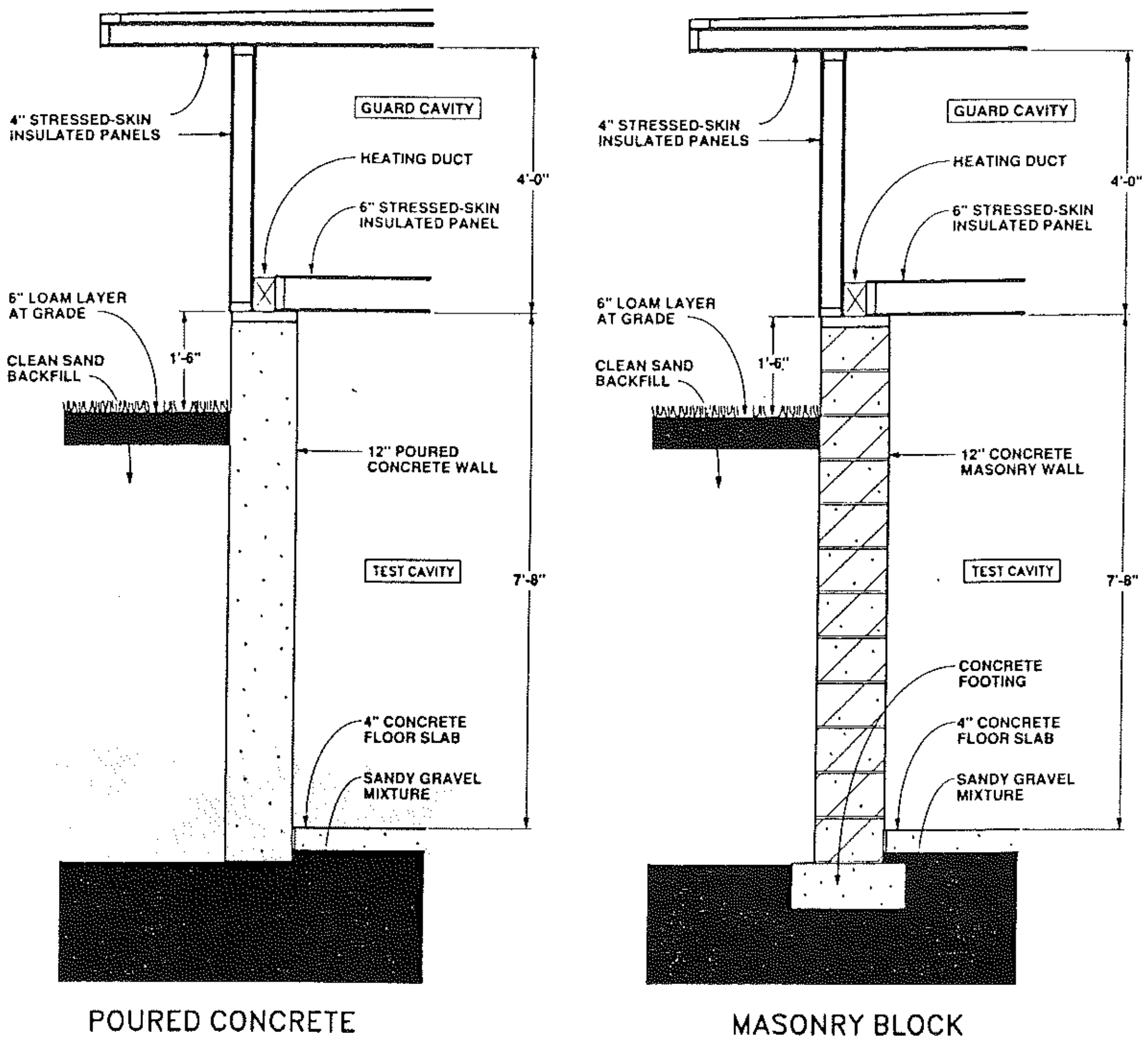


Figure 2 *Construction cross sections—basement modules.*

ment of the basement foundation system's energy performance. Furthermore, each basement module is equipped with a small dehumidifier that operates continuously so that the maximum achievable rate of condensate removal in each module is approximately equal.

The surrounding ground is engineered to be the same for all the basements over a square area extending at least 10 ft (3.05 m) beyond the perimeter of each module. The upper 6 in. (152.4 mm) consists of agricultural loam (to support a natural grass cover), which is underlain by a uniform, well-draining sand to the depth of the footings. The test site has a uniform sand/gravel soil composition below this level, and the water table is estimated to be about 80 ft (24.38 m) below grade.

Shallow-Foundation Module Design

The design of the shallow-foundation (SF) test modules is depicted in Figure 3. Both modules have nominally 8 in. (203.2 mm) thick poured concrete stem walls bearing directly on the ground, with the upper 8 in. (203.2 mm) of the wall extending above grade. The west SF module is designated as the reference for data normalization and has its stem wall base positioned 42 in. (106.7 cm) below grade in conformity with the standard requirements for frost heave protection. In contrast, the east SF module employs a shallow 2-ft (609.6-mm) stem wall with its base positioned 16 in. (406.4 mm) below grade. This stem wall is protected against frost penetration by 2 in. (50.8 mm) of rigid extruded polystyrene insulation on the wall exterior together with horizontal wing insulation of like material extending 2 ft (609.6 mm) away from the base of the wall. The vertical/wing insulation butt joint is protected by a stacked pair of extruded polystyrene insulation strips (Figure 3) that prevent water leakage through the joint while allowing angular and horizontal displacement of the wing to occur without producing any damage.

Both SF modules have 4 in. (101.6 mm) thick floor slabs of unreinforced, poured concrete. As with the basement modules, the slabs are divided into nine sections by caulked, cracking control cuts while the slabs are separated from the stem walls by expansion strips. It also may be noted that to facilitate simulation code validation, the reference SF module has a floating slab for geometric

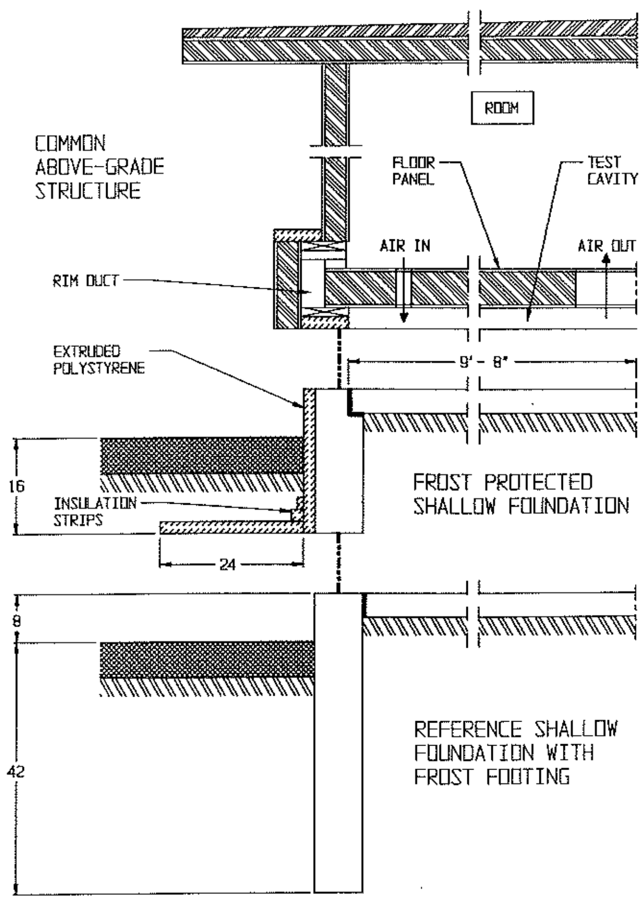


Figure 3 *Construction cross sections—shallow-foundation modules.*

simplicity (in comparison with the supported slab of the insulated SF module).

Both SF modules are identical above the surface level of the slabs. The above-grade structures consist entirely of the same stressed-skin, expanded polystyrene cored panels used for the basement modules. As the modules are heated electrically, a simple watt-hour meter measurement allows the overall thermal performance of each module to be determined.

The slab of each module has its upper surface exposed to a 3.5 in. (88.9 mm) high test cavity through which room-temperature air is circulated. For the purpose of ensuring radially uniform flow, the test cavity is divided into 12 axially symmetric angular sectors so that each sector is fitted with separate, vertical draft pressurization fans at its outer edge. The airflows from the 12 sectors merge at the center of the test cavity into a common vertical outlet duct that directs the air upward through a mass flow rate measurement station and thence over a set of heating coils. The air is exhausted to the room via a diffuser near the top of the module. Room air is also forced through a rim duct surrounding the floor panel above the test cavity, constraining the panel heat flows to be vertical by minimizing horizontal heat loss through the edge of the floor panel. Temperature transducers are located strategically at all the test cavity entrances, along each airflow path within the cavity, and at the common cavity exit. Together with the overall mass flow rate, these temperatures are monitored continuously by a digital control and data acquisition system. These data permit the unsteady flow energy balance of the test cavity to be integrated numerically in real time, enabling the slab/cavity surface heat transfer to be determined.

The ground surrounding both SF modules has been engineered to provide a uniform heat transfer environment. A square area extending 10 ft (3.05 m) beyond the stem walls was excavated to a depth of 42 in. (106.7 cm) and backfilled with the same uniform well-draining sand and 6-in. (152.4-mm) agricultural loam surface cover (outside the stem walls) used for the basement modules.

Long-Term Experimental Measurements

The long-term data reported here consist of manual readings gathered on an approximately weekly basis from the basement and SF modules. These data are in addition to, and verifications of, the extensive transient data gathered automatically on a continuous basis. All the modules were maintained at a constant internal temperature of 68°F (20°C) during the heating season test periods. The manual basement module data are composed of

- incremental test cavity electrical energy (watt-hour meter),
- incremental condensate mass removed from the test cavity (digital mass balance),
- test cavity relative humidity (dehumidifier dial gauge), and
- test and guard cavity temperatures (digital thermostat displays).

The manual shallow foundation readings include

- incremental energy consumption (watt-hour meter);
- incremental forced slab heat transfer, that is, the heat transferred to the slab during periods when the ventilation system is active (pulse counter driven by digital control system); and
- module temperature (digital thermostat display).

RESULTS

The matrix of foundation types and heating season test periods may be inferred from Table 1, which describes the thermal energy performance of the modules. Only those locations with numerical entries form part of the test matrix. The data in Table 1 are normalized with respect to heated cavity floor area for the sake of comparison with other published data.

TABLE 1
Thermal Foundation Energy Performance

Module Description	Average Daily Heating Season Thermal Energy Consumption Btu/ft^2/day (Wh/m^2/day)			
	1988/89	1989/90	1990/91	1991/92
North reference basement: uninsulated, poured concrete	470.92 (1485.6)	399.66 (1260.8)	402.40 (1269.4)	385.69 (1216.7)
East basement: uninsulated, masonry block	478.49 (1509.5)	416.26 (1313.1)	417.90 (1318.3)	406.12 (1281.1)
South basement: R-10[a] (RSI 1.76[b]) full-wall exterior insulation, masonry block	209.76 (661.7)	188.46 (594.5)	173.94 (548.7)	168.05 (530.1)
West basement: R-10 (RSI 1.76) full-wall interior insulation, masonry block	—	194.63 (614.0)	186.46 (588.2)	—
West basement: R-10 (RSI 1.76) half-wall interior insulation, masonry block	—	—	—	311.50 (982.6)
West reference slab: uninsulated, 42-in. (106.7-cm) frost footing	—	—	—	255.67 (806.5)
East slab: insulated 16-in. (406.4-mm) shallow foundation	—	—	—	215.66 (680.3)

[a]R-value has units of ft$^2\cdot$°F·h/Btu.
[b]RSI value has units of m$^2\cdot$K/W.

During the first heating season (1988/89), the west masonry block module (later fitted with interior insulation) was left uninsulated and used to quantify the experimental error inherent in the design of the FTF. Nominally, any two modules with the same foundation system subjected to the same boundary conditions should yield identical performance, in particular, the uninsulated west and east masonry block basement modules, which are positioned farthest apart (Figure 1).

A "perturbation" or dynamic method was used to determine the experimental error, as this is a severe test including transient ambient temperature boundary conditions. Continuous preheating of all four basement modules at a constant heat input rate of 5,118 Btu/h (1,500 W) began in late December 1988. Toward the end of February 1989, preheating was terminated and constant rate dehumidification and controlled heating at 68°F (20°C) was initiated. However, the west basement module remained unheated and without dehumidification for a period of 48 hours before space conditioning commenced. The resulting transient performance of the east and west basement modules is depicted in Figure 4. As the heating season progressed, the difference in the daily energy consumption decreased to a value consistently less than 2%. This test provides a measure of the systematic error in the FTF design, implying that energy performance comparisons between the modules have an uncertainty of about ±2%. Furthermore, the shape of the energy consumption curves of the modules in Figure 4 is similar, showing that when subjected to the same boundary conditions, the modules yield similar transient thermal responses.

It may be noted from Table 1 that the relative energy performance of the basement modules is repeatable over several heating seasons, each with a different duration and heating demand. Normalizing the seasonal energy consumption of the basement modules to that of the north reference basement module yields the bar chart of Figure 5. The range bars for the east, south, and west basement modules show the minimum/maximum span of individual heating season normalized values about the multiseasonal average. The largest divergence from the mean is 2.5%, which occurred for the south basement module (with full-wall exterior insulation) during the 1989-90 heating season. Within the context of this repeatability, the uninsulated masonry block module has a physically significant basement envelope heat transfer that is 4% greater than that of its poured concrete counterpart. This is in contrast to the nominally higher thermal resistance quoted for masonry block compared with poured concrete (ASHRAE 1981) and is caused by heat being transported advectively from the warm wall bottom to the cold wall top by buoyancy-driven flows within the hollow masonry block walls (Svec and Goodrich 1986). The modules insulated with exterior and interior full-wall R-10 ft$^2\cdot$°F.h/Btu (RSI 1.76 m$^2\cdot$K/W) insulation require 57% and 54% less heating energy, respectively, than their uninsulated masonry block counterpart, an economically significant savings. On a seasonal basis, the exterior insulation placement requires 3% less thermal energy than the interior placement, slightly more than the systematic error. However, from Figure 6, over a significant part of the 1990-91 heating season, the average daily energy consumption between the south and west insulated modules differed by substantially more than 2%, reaching a peak difference of 12.4% in mid-January 1991. Hence, even though some of this difference may be explained by slightly different above-grade wall exposures (owing to a small settlement of the soil over time around the west basement module), the data indicate that exterior

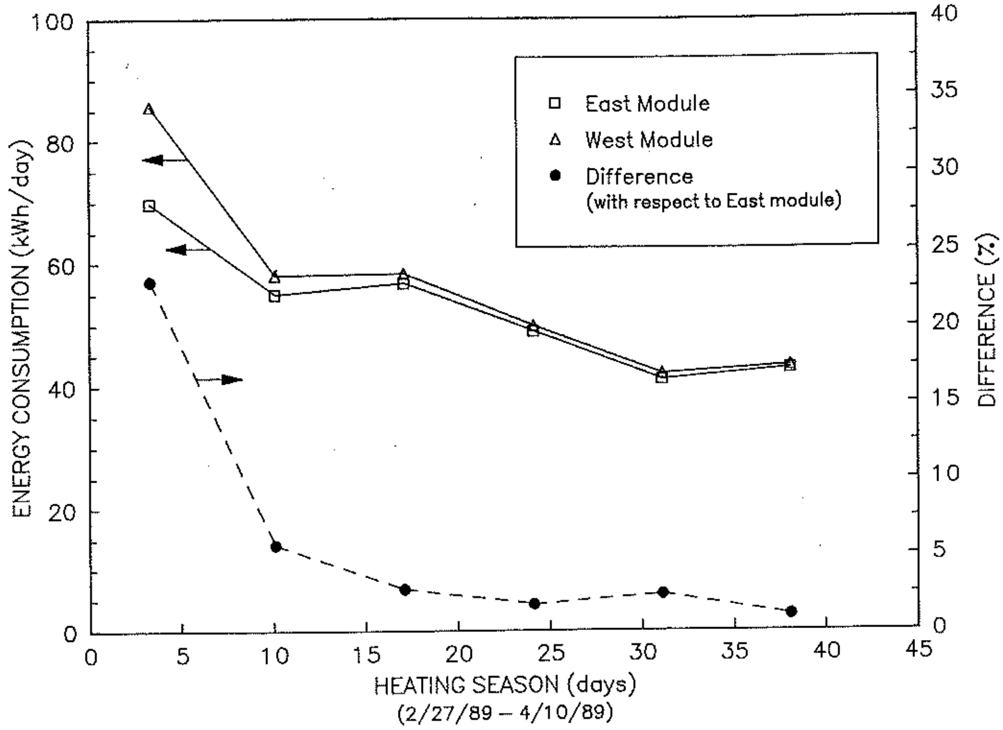
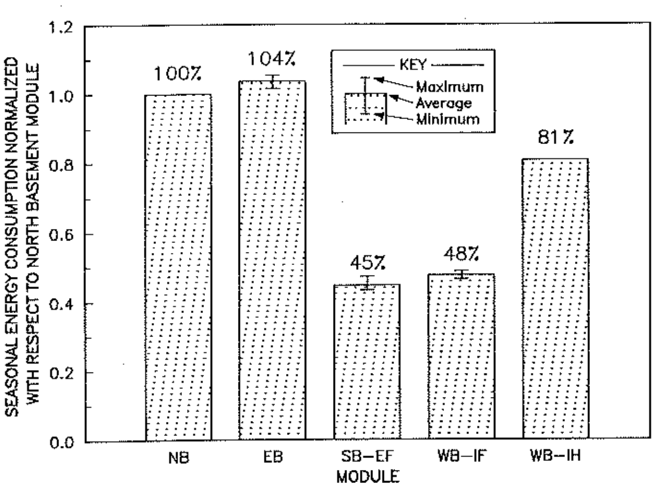
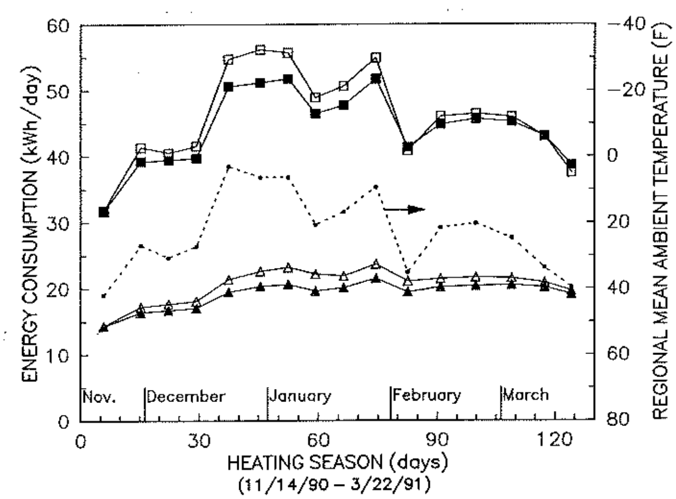


Figure 4 *Thermal performance difference, uninsulated masonry block basement modules.*



MODULE	HEATING SEASONS	WALL MATERIAL	WALL INSULATION
NB	4	Concrete	None
EB	4	Block	None
SB–EF	4	Block	Exterior R10 – Full wall
WB–IF	2	Block	Interior R10 – Full wall
WB–IH	1	Block	Interior R10 – Half wall

Figure 5 *Seasonal thermal performance of basement modules.*



SYMBOL	MODULE	WALL MATERIAL	WALL INSULATION
■	NB	Concrete	None
□	EB	Block	None
▲	SB–EF	Block	Exterior R10 – Full wall
△	WB–IF	Block	Interior R10 – Full wall
···◆···	Regional mean ambient temperature		

Figure 6 *Average energy consumption rate, 1990-91 heating season.*

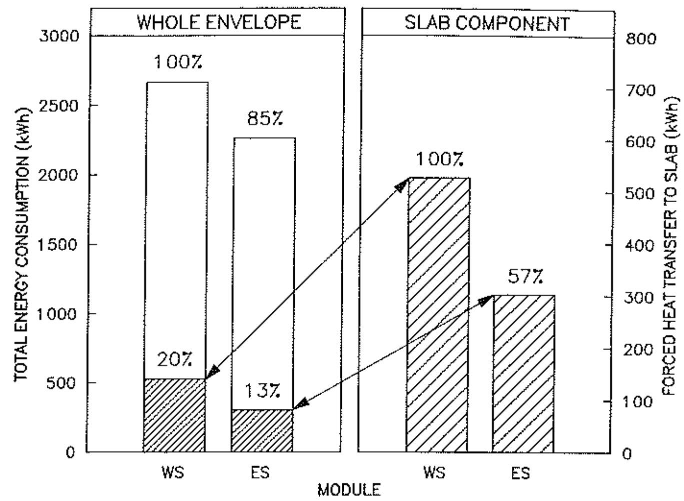
basement foundation insulation placement is thermally superior to interior placement, albeit by a small margin on a seasonal basis.

In contrast, Figure 5 shows that decreasing the interior insulation from full-wall to half-wall coverage in the west basement module reduced the energy savings by more than half (from 54% to 23%) compared with the uninsulated east basement module. This reduction is caused not only by a difference in the diffusive thermal transport in the ground but also by enhanced cavity wall advection heat pumping where the upper half-wall interior insulation serves to increase the vertical wall temperature gradient driving the buoyant flow (Svec and Goodrich 1986). The relative contribution of these mechanisms to the nonlinear increase in basement wall heat transfer is not yet well understood analytically, particularly in three dimensions.

For the 1990-91 heating season in particular, Figure 6 confirms the seasonal results of Figure 5 on a transient basis. Also plotted on this graph is the regional mean ambient temperature, measured *not* at the FTF but at the local weather station, some 12 miles (16.1 km) distant. Note the reversed scale of the mean ambient temperature (maximum on the abscissa axis) and the strong correlation between the regional ambient temperature and the daily energy consumption of the modules (a decrease in mean ambient temperature corresponding with an increase in average daily energy consumption). Hence, for the weekly averaging period used to calculate the daily energy consumption, local microclimatic divergences from the representative regional temperatures do not appear to be of major qualitative significance. This lends credence to energy analysis and design techniques that rely on regional weather data, provided that the calculations are performed for large enough energy aggregation time increments.

It also may be noted that the insulation on the south and west basement modules damps the response of the energy consumption to ambient temperature transients compared with the uninsulated poured concrete and masonry block modules. Evidently, over a weekly averaging period, the surrounding ground does not provide significant damping nor does it introduce an observable phase delay between the temperature and energy consumption transients. These observations do not substantiate the argument that shallow below-grade construction protects the conditioned space from ambient temperature variations by virtue of the surrounding ground alone (in comparison with below-grade spaces completely isolated from the ambient environment [Shipp et al. 1980]). However, it is the combination of the below-grade placement with the full-wall thermal insulation that achieves the moderating effect.

The thermal performance of the two shallow-foundation test modules for the 1991-92 heating season is shown in Figure 7. The insulated stem wall shallow-foundation module requires 15% less thermal energy than its uninsulated frost footing counterpart to maintain a constant interior temperature of 68°F (20°C). When air is forced through the test cavity above the slab by the ventilation system,



MODULE	FOOTING DEPTH	WALL MATERIAL	WALL INSULATION
WS	42 inches	Concrete	None
ES	16 inches	Concrete	Exterior R10 with horizontal wings

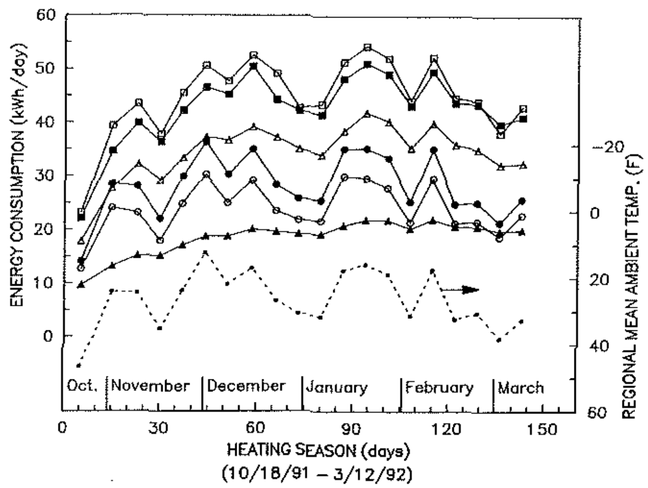
1991/92 Heating Season: (10/18/91 – 3/12/92)

Figure 7 *Thermal performance of shallow-foundation modules, 1990-91 heating season.*

20% of the thermal energy input to the uninsulated west module is lost to the slab compared with a loss of 13% for the insulated east module. Comparing these forced slab heat losses reveals that the insulated shallow foundation is 43% more energy conservative than its uninsulated counterpart. It can also be reported that over the relatively mild 1991-92 heating season (with a mean ambient temperature of about 27°F [-2.8°C]) with both modules being heated continuously, the transient temperature data gathered show that no frost penetrated beneath the footings of either module.

As in Figure 6, the transient thermal performance of all six modules is shown for the 1991-92 heating season in Figure 8, as is the regional mean ambient temperature. Once again, the strong correlation between the regional mean temperature and the average daily energy consumption is evident, not only for the basement, but also for the shallow-foundation modules. Comparing the west basement module's transient energy consumption profiles in Figures 6 and 8 shows the impact of reducing the interior wall insulation by half. The damping effect of the insulation on the ambient temperature transients is considerably reduced, implying that the damping is also a nonlinear function of the insulated wall surface area. Hence, from energy conservation and from occupant comfort perspectives, anything less than full-wall interior insulation on unfilled masonry block walls does not appear to be physically (as opposed to economically) justified.

Figure 8 reveals that the energy consumption performance of both above-grade modules is apparently superior



SYMBOL	MODULE	MODULE TYPE	FOOTING DEPTH	WALL MATERIAL	WALL INSULATION
■	NB	Full basement	72 inches	Concrete	None
□	EB	Full basement	72 inches	Block	None
▲	SB–EF	Full basement	72 inches	Block	Exterior R10
△	WB–IH	Full basement	72 inches	Block	Interior R10 – upper half wall
●	WS	Grade slab with stem walls	42 inches	Concrete	None
○	ES	Grade slab with stem walls	16 inches	Concrete	Exterior R10 with horizontal wings
···•···	Regional mean ambient temperature				

Figure 8 Average energy consumption rate, 1990-91 heating season.

to all the below-grade modules except the fully insulated south module. Noting that the envelopes of the basement and SF modules are nominally comparable in terms of infiltration resistance and that their heated volumes are within 7.5% of each other (2,866 ft^3 [81.2 m^3] and 2,670 ft^3 [75.61 m^3] for the basement and SF modules, respectively), the seasonal energy consumption per unit of envelope heat transfer area is given in Table 2. The tabulated data show that the insulated east shallow-foundation module is 7% more energy conservative per unit of envelope heat transfer area than the basement test cavity with exterior insulation. This difference includes the impact of the smaller heat transfer area in the basement module test cavities, which have nominally adiabatic ceilings.

Comparing the transient response of the shallow foundation and basement modules to ambient temperature variations shows that the earth surrounding the basement modules does provide an increase in damping (note the shape of the energy consumption profiles for the uninsulated basements compared with those of the shallow-foundation modules in January, for example). However, as noted for Figure 6, compared with the significant damping provided by the synergistic combination of full-wall insulation and below-grade placement, the damping effect of the ground alone is small.

As mentioned previously, all the basement modules are fitted with small-capacity dehumidifiers that operate continuously providing approximately the same maximum water vapor condensation capacity. It may be noted that the low levels of interior relative humidity experienced in the shallow-foundation modules (typically less than 40%) make dehumidification in these modules unnecessary. This shows the advantage of above-grade construction in reducing envelope soil gas transport, simply by virtue of the diminished earth-contact surface area. The advantage is emphasized by the data because none of the modules is fitted with a below-grade vapor barrier. Table 3 describes the condensate removed from the basement modules expressed as a daily average over the heating season.

Normalizing the condensate removal data with respect to the north basement module yields Figure 9. The range bars on the data for the east, south, and west basement modules (the latter with full-wall interior insulation) indicate the minimum/maximum span of individual heating season normalized values about the multiseasonal mean. A maximum divergence of 7% from the mean is observed for the east masonry block module during the 1991-92 heating season. While still reasonable, the repeatability of the condensate removal data is not as good as that of the energy performance data, which showed a maximum seasonal divergence of 2.5% (Figure 5).

As no sources of moisture exist within the modules, there is a net transport of water vapor from the surrounding soil and atmosphere into the modules. In terms of this flow regime, Figure 9 reveals that under continuous dehumidification conditions (that is, no on/off dehumidifier cycling

TABLE 2
1991-92 Seasonal Envelope Heat Transfer

Module Description	Heating Season Envelope Heat Transfer Btu/ft^2 (kWh/m^2)
North reference basement: uninsulated, poured concrete	68.80 (21.81)
East basement: uninsulated, masonry block	72.44 (22.97)
South basement: R-10[a] (RSI 1.76[b]) full-wall exterior insulation, masonry block	29.98 (9.50)
West basement: R-10 (RSI 1.76) half-wall interior insulation, masonry block	55.57 (17.62)
West reference slab: uninsulated, 42-in. (106.7-cm) frost footing	32.91 (10.43)
East slab: insulated 16-in. (406.4-mm) shallow foundation	27.76 (8.80)

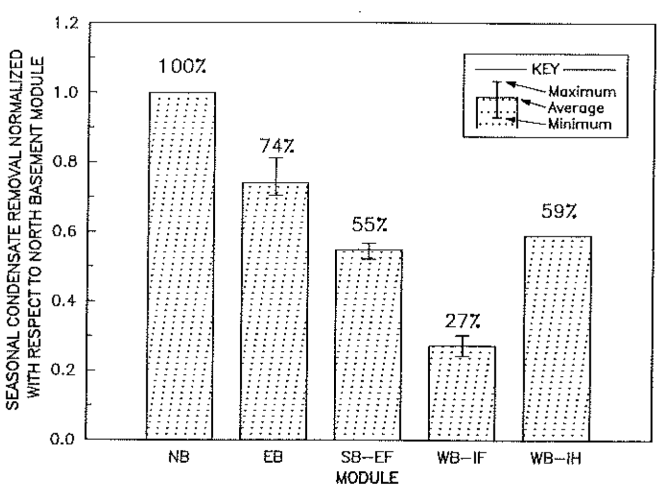
[a]R-value has units of $ft^2 \cdot {}^\circ F \cdot h/Btu$.
[b]RSI value has units of $m^2 \cdot K/W$.

TABLE 3
Basement Foundation Module Condensate Removal

Module Description	Average Daily Heating Season Condensate Removal quart/day (liter/day)		
	1989-90	1990-91	1991-92
North reference basement: uninsulated, poured concrete	1.61 (1.52)	1.47 (1.39)	1.26 (1.19)
East basement: uninsulated, masonry block	1.13 (1.07)	1.03 (0.98)	1.02 (0.96)
South basement: R-10[a] (RSI 1.76[b]) full-wall exterior insulation, masonry block	0.91 (0.86)	0.76 (0.72)	0.70 (0.66)
West basement: R-10 (RSI 1.76) full-wall interior insulation, masonry block	0.39 (0.37)	0.44 (0.42)	—
West basement: R-10 (RSI 1.76) half-wall interior insulation, masonry block	—	—	0.74 (0.70)

[a]R-value has units of $ft^2 \cdot {}^\circ F \cdot h/Btu$.
[b]RSI value has units of $m^2 \cdot K/W$.

occurs to maintain a set humidity), the uninsulated masonry block module allows 26% less water vapor transport through the envelope than the reference module with poured concrete walls. A comparison of the masonry block modules with full-wall insulation shows that the interior insulation placement allows 51% less water vapor transport through the envelope than an exterior placement. Furthermore, reducing the interior insulation coverage to the upper half of the wall produces a disproportionate increase (119%, or more than double) in the envelope water vapor transport. Under these conditions, the module with full-wall exterior insulation is 7% more impervious to envelope water vapor transport. It also should be noted that during the entire duration of the module tests, no discernible trace of liquid water has been encountered on the interior wall or floor surfaces of any of the basement modules, even prior to the onset of continuous dehumidification.



MODULE	HEATING SEASONS	WALL MATERIAL	WALL INSULATION
NB	3	Concrete	None
EB	3	Block	None
SB–EF	3	Block	Exterior R10 – Full wall
WB–IF	2	Block	Interior R10 – Full wall
WB–IH	1	Block	Interior R10 – Half wall

Figure 9 *Seasonal condensate removal from basement modules.*

The multiseasonal cumulative condensate-removal behavior shown in Figure 9 is echoed, in particular, on a transient basis for the 1990-91 heating season, as depicted in Figure 10, which shows the daily condensate-removal rate averaged on a weekly basis. With these rates of condensate removal, the modules displayed the relative humidities depicted in Figure 11. It must be pointed out that the relative humidity data have qualitative significance only, because these data are gleaned from the dehumidifier panel dial gauges, which are judged to have poor accuracy (perhaps ± 5 % at best). Nevertheless, Figure 11 indicates that, during most of the heating season, a constant rate of dehumidification produced a lower relative humidity in the basement module with full-wall interior insulation than in its counterpart with exterior insulation. The relative humidities in the insulated modules were lower than those in the uninsulated modules.

After the interior insulation was reduced by half, the relative daily condensate-removal rate behavior between the insulated basement modules during the 1991-92 heating season changed significantly, as shown in Figure 12. The daily condensate removal rates of the insulated modules are similar over the heating season, yielding a slightly greater condensate accumulation for the half-wall interior insulated module (Figure 9). It also may be noted that the relative condensate-removal rate patterns for the uninsulated and exterior insulated modules are similar for the 1990-91 and 1991-92 heating seasons despite rather different seasonal precipitation profiles. This confirms the essential viability of the FTF experimental design in permitting the relative moisture transport performance of various thermal foundation systems to be evaluated.

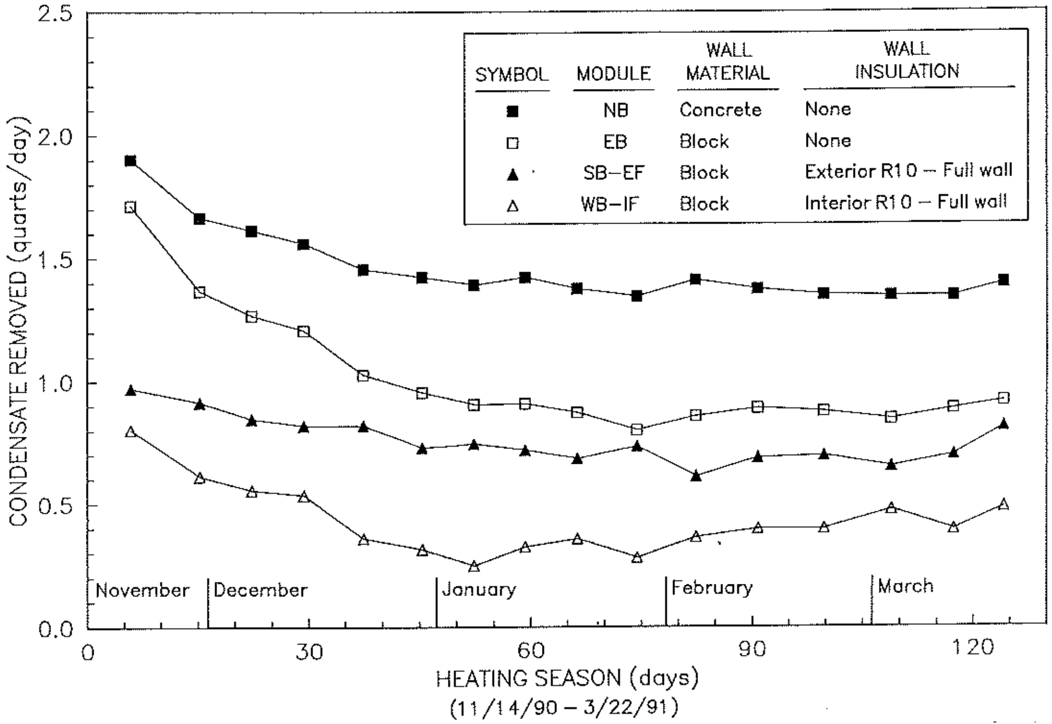


Figure 10 ***Average condensate removal rate, 1990-91 heating season.***

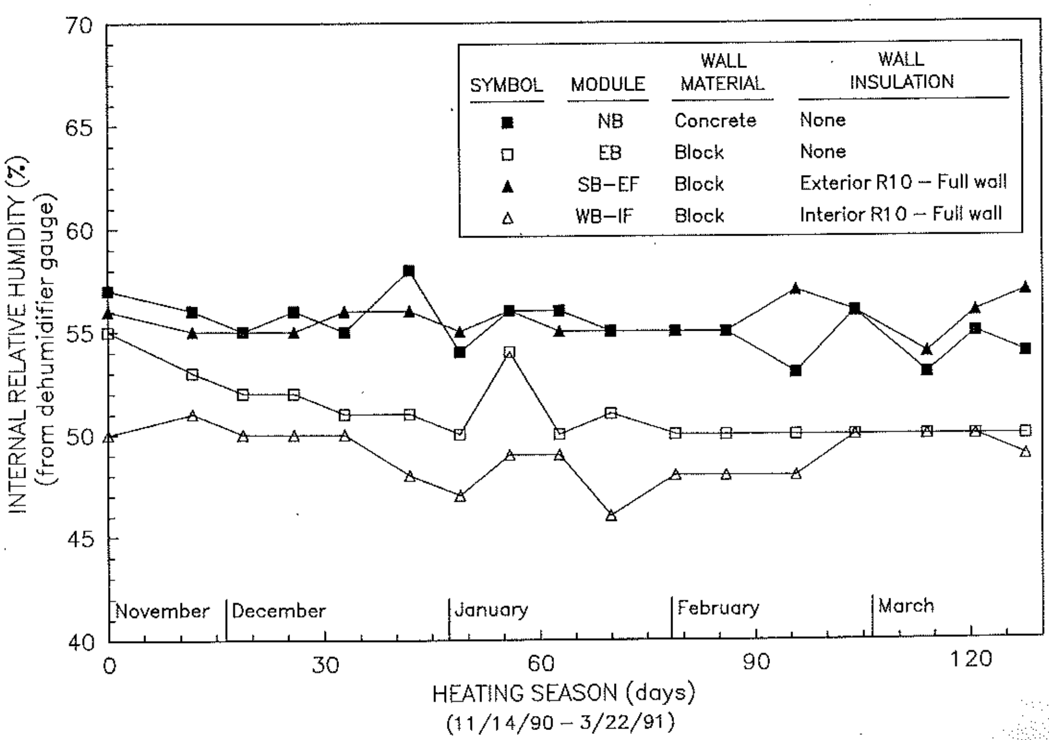


Figure 11 ***Relative humidity profiles, 1990-91 heating season.***

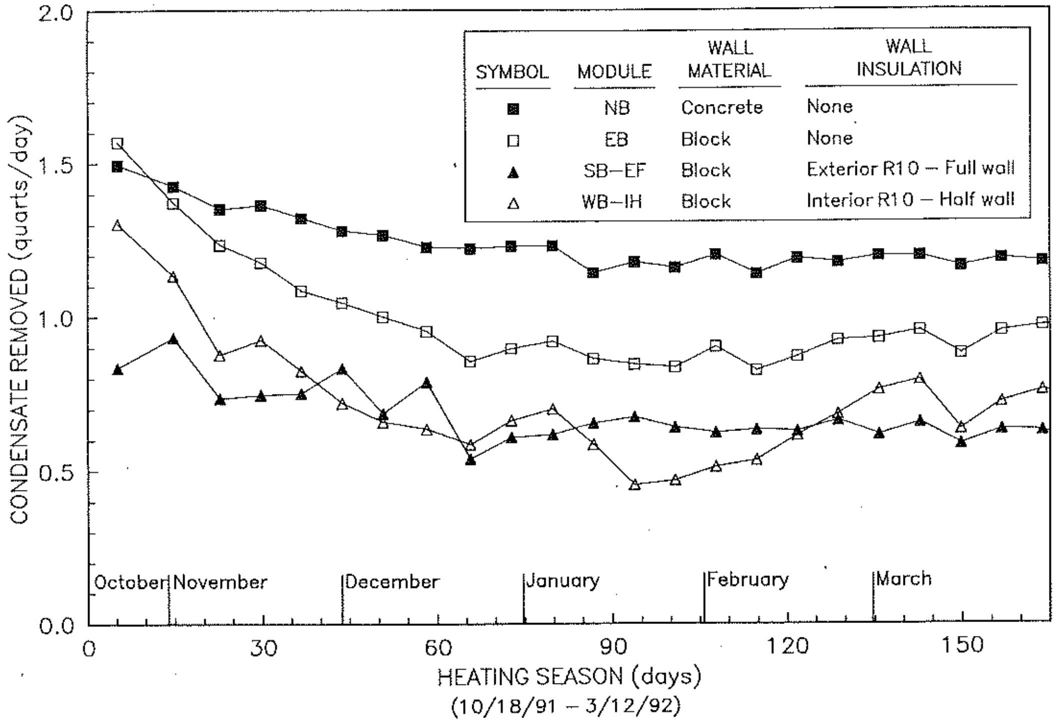


Figure 12 *Average condensate removal rate, 1990-91 heating season.*

These results prompt the obvious question as to why interior placement of full-wall basement foundation insulation yields much-reduced seasonal envelope water vapor transport compared with an exterior insulation placement, while both placements give similar seasonal energy conservation performance. The reasons for this behavior are tied to the complexities of the three-dimensional, multi-phase, multi-component continuum mechanics of the liquid and gaseous flows occurring within the masonry block wall cavities and the surrounding soil. However, the averaged seasonal data presented here are insufficient to shed any meaningful light on these complexities, contextually reducing any proffered explanation to the level of speculation. Development of a computer-simulation-based method for analyzing the detailed continuum mechanics of the modules is in progress with the intent of providing an adequate theoretical basis for understanding and explaining the experimental results.

CONCLUSION

The results produced by the FTF unambiguously quantify the thermal performance of seven different thermal foundation systems. Exterior or interior full-wall extruded polystyrene insulation of heated basement cavities consistently reduces the heating energy consumption by more than 50% compared with an uninsulated basement cavity. Similarly, an insulated shallow foundation reduces the whole-building thermal energy consumption by 15% compared with an uninsulated foundation. On a seasonal basis, the experimental data indicate that interior full-wall extruded polystyrene insulation yields a more than 50% decrease in envelope water vapor transport compared with an exterior placement of the same insulation. Also, on a seasonal basis, decreasing the interior insulation coverage to the upper half-wall more than doubles the envelope's thermal energy and water vapor transport.

ACKNOWLEDGMENTS

The results reported have been obtained from projects carried out by the Underground Space Center, University of Minnesota. These projects were supported by EXXON oil overcharge funds administered by the U.S. Department of Energy and the Minnesota Department of Public Service and by oil overcharge funds distributed through the Minnesota Department of Administration. While gratefully acknowledging this support, the authors assume complete responsibility for the contents herein.

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