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5.0 ENERGY STORAGE, STRUCTURAL, INSULATING CONCRETE

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The objective of the research of this concept was to develop a Portland Cement concrete for use in low-rise building walls that would combine the structural, thermal insulating, and heat storage capacity functions of walls. Based on knowledge of what has been done, what is required, and what the research might reasonably be expected to achieve, the goal was to develop a concrete having a unit weight of under 65 pounds per cubic foot (pcf) and compressive strength of 1500 to 2000 pounds per square inch (psi).

At least 10 mixes were to be evaluated in the program. Measurements of thermal conductivity and specific heat were to be made using those concretes most successful in achieving the desired strength/weight properties. Other thermal properties would then be determined analytically to evaluate overall thermal performance of the concrete. Because of the tendency for lower density concretes to have high drying shrinkage, which influences cracking potential, measurements of drying shrinkage were included in the program.

A wall with low heat transmission will conserve the most energy. The dynamic thermal performance of walls depends on three material properties. Generally, the lowest heat transmission is found in a wall with low thermal conductivity, high specific heat, and heavy weight. However, thermal conductivity of concrete increases with unit weight. Because heat transmission properties are more sensitive to changes in thermal conductivity than to changes in unit weight or specific heat, the lightest concrete that has sufficient structural capacity should be used to satisfy this concept.

Concrete is available in a wide range of weights and strengths. Concretes weighing 50 pcf or less are called insulating concretes. These concretes develop compressive strengths up to about 600 psi, which is too low for building walls. Concretes in the 90 to 130 pcf range are known as structural lightweight aggregate concretes. These concretes have compressive strengths in the range of 2500 to over 9000 psi, depending on materials, mix design and other factors. While these concretes have more than adequate strength for the proposed use, their thermal properties are inadequate. The third category of lightweight concretes is in the weight range of 50 to about 90 pcf. These are usually called fill concretes. Concretes in this weight range have not been widely used and their development has been somewhat neglected. It is believed that judicious development of concretes in this 50 to 90 pcf range will result in properties suitable for satisfying the requirements of the proposed concept.

In the research of this concept, expanded clay and shale coarse aggregates were used with expanded polystyrene beads and perlite fine aggregates to obtain concretes having air dry unit weights of less than 65 pcf and compressive strengths in the range of 2000 psi. Drying shrinkage measurements were started, but results are too preliminary for conclusions to be drawn at this time. Mix Nos. 7, 10, and 11 showed the most desirable combinations of low unit weight and high compressive strength. Thermal properties of specific heat and thermal conductivity were measured for these three concretes.

Dynamic thermal properties of diffusivity, lag, and reduction in amplitude of peak heat flow were estimated for concrete from Mix Nos. 7, 10, and 11. Measured values of specific heat and conductivity were used to estimate values based on results of previous thermal tests performed at Construction Technology Laboratories (CTL). Estimations indicate concrete from Mix Nos. 7, 10, and 11 have thermal lags varying from 8 to 10 hours and reduction in amplitudes of approximately 60% for the National Bureau of Standards (NBS) test cycle. However, dynamic calibrated hot box tests must be performed to verify estimated values and accurately determine thermal performance.

In the following sections, the research program conducted for this concept and future work are discussed.

5.1 RESEARCH PROGRAM

The volume of concrete largely consists of aggregates. Thus, the unit weight of a concrete mix will depend to a great extent on the unit weight of aggregates selected and the amounts used in the mix. Compressive strength depends on water-cement ratio, cement weight, aggregate properties, cement content, and desired slump. Therefore, mix design in this program is a process that balances the above factors to result in concrete having the desired strength, weight, and thermal properties. In the following sections, the materials used, the properties measured, and the prediction of the other thermal properties in the research of this concept are discussed.

5.1.1 Materials

To obtain lightweight concretes having usable structural capacity, expanded clay or shale structural lightweight aggregates are commonly used. The use of most aggregates of this type will result in concretes with unit weights of 90 to 100 pcf. Gravelite is a typical aggregate of this type. A few aggregates such as Livite provide concrete weights as low as 80 pcf.

Because the fine sizes of these aggregates are heavier than the coarse sizes, part or all of the fines have to be replaced with a much lighter aggregate to obtain the lower concrete weights described in this program. Styropor, which is expanded polystyrene beads, and perlite, which is an expanded volcanic glass, were used for this purpose. These materials weigh 1.5 and 7 pcf, respectively, as compared to about 40 to 60 pcf for expanded clay and shale fines.

The mix investigation consisted of determining mix proportions of the available materials that could result in the lowest unit weight concrete with adequate strength. Table 5.1 lists the cement and aggregate proportions, slump, air content and fresh unit weight for the 11 mixes made. Aggregate quantities are listed as cubic feet of dry loose material per cubic yard of concrete. Water was added to obtain a workable concrete with slump generally in the range of 2 to 5 in. An air entraining admixture was added to each mix, and a water-reducing agent was added to selected mixes to improve workability and durability.

5.1.2 Measured Properties

Specimens were made from selected mixes to determine of compressive strength, drying shrinkage, specific heat and thermal conductivity as described in the following sections.

TABLE 5.1. Mix Proportions

Mix No.	Material and Quantities per cu yd	Slump, in.	Air Content, %	Fresh Unit Weight, pcf
1	Cement - 500 lb Gravelite coarse - 19 cu ft Styropor - 10 cu ft	5	3.0	71.3
2	Cement - 500 lb Gravelite coarse - 18 cu ft Styropor - 12 cu ft	3	2.8	65.9
3	Cement - 550 lb Gravelite coarse - 19 cu ft Styropor - 11 cu ft	2.4	2.0	69.7
4	Cement - 550 lb Livlite coarse - 19 cu ft Livlite fine - 5 cu ft Styropor - 6 cu ft	2.1	4.0	66.0
5	Cement - 550 lb Gravelite coarse - 16 cu ft Perlite - 16 cu ft	5.7	2.0	83.3
6	Cement - 550 lb Gravelite - 15 cu ft Perlite - 17 cu ft Water Reducing Agent	4.7	2.5	77.4
7	Cement - 550 lb Livlite coarse - 19 cu ft Livlite fine - 4 cu ft Styropor - 7 cu ft Water Reducing Agent	2.1	2.3	63.8
8	Cement - 550 lb Livlite coarse - 10 cu ft Livlite fine - 6 cu ft Perlite - 16 cu ft Water Reducing Agent	3.7	4.5	64.2
9	Cement - 550 lb Livlite coarse - 18-1/2 cu ft Livlite fine - 4 cu ft Styropor - 7-1/2 cu ft Water Reducing Agent	2.6	4.0	59.5
10	Cement - 550 lb Livlite coarse - 14 cu ft Livlite fine - 5 cu ft Perlite - 13 cu ft Water Reducing Agent	4.0	4.3	68.8
11	Cement - 550 lb Livlite coarse - 19 cu ft Livlite fine - 4 cu ft Styropor - 4 cu ft Perlite - 3 cu ft	2.2	3.4	65.7

Compressive Strength

Specimens were made from most of the mixes to determine compressive strength at 7 and 28 days. The specimens consisted of 4-in. diameter by 8-in. long cylinders. All cylinders were moist cured for 7 days, at which time 3 were tested in compression and the others were stored at

73°F and 50% relative humidity (RH). At 28 days, 3 additional specimens were weighed and tested in compression. Table 5.2 shows unit weights and compressive strengths obtained on these specimens. Based on the data shown, Mix Nos. 7, 10, and 11 offered the best combination of unit weight and strength obtained in this study.

Drying Shrinkage

Drying shrinkage is a property of concrete that contributes to cracking unless adequate provision is made in the design of a structure to accommodate the shrinkage. Because lower density concretes generally have higher drying shrinkage, it was considered desirable to obtain shrinkage information on these concretes. Shrinkage specimens, 3 x 3 x 12-in. prisms, were cast with measuring pins embedded in their ends. After moist curing for 7 days, measurements using a vertical comparator were started and continued as the specimens were drying at 70°F and 50% RH. Drying shrinkage occurs slowly, and thus limited data are available due to the short duration of this program. Table 5.2 lists the data available to the age shown. The specimens will be measured over a longer period of time.

TABLE 5.2. Concrete Weight, Strength and Shrinkage

Mix No.	Unit Weight, pcf		Compressive Strength, psi		Drying Shrinkage	
	Fresh	28 day*	7 day	28 day*	%	Days of drying
1	71.3	--	No specimens made		No specimens made	
2	65.9	--	--	530	--	--
3	69.7	60.5	530	860	0.076	42
4	66.0	60.8	1270	1810	0.063	42
5	83.3	--	No specimens made		No specimens made	
6	77.4	64.3	1230	1740	0.127	42
7	63.8	60.8	1500	1990	0.071	41
8	64.2	59.9	1030	1220	0.118	41
9	59.5	59.3	1350	1760	0.060	26
10	68.8	62.7	1700	2110	0.093	26
11	65.7	62.1	1850	2440	0.063	26

*7 days moist, 21 days air dry

Thermal Properties

As mentioned previously, Mix Nos. 7, 10, and 11 offered the best combinations of unit weight and strength obtained in this study. Specific heat and thermal conductivity tests were performed on specimens from each of the three mixes.

Specific Heat. Specific heat is used to determine the storage capacity of thermal mass. Specific heat is defined as the ratio of the change in heat supplied to a body to its corresponding temperature rise divided by the mass of the body. In U.S. units, the specific heat of water is equal to 1.00 Btu/lb·°F. Therefore, specific heat may also be defined, for U.S. units, as the ratio of the amount of heat required to raise the temperature of a given mass of material one degree Fahrenheit to the amount of heat required to raise the temperature of an equal mass of water one degree Fahrenheit.

Specific heats of concrete specimens were measured using a method similar to U.S. Army Corps of Engineers Specification CRD-C123-73, "Method of Test for Specific Heat of Aggregates, Concrete, and Other Materials (Method of Mixtures)" (undated). Samples were selected from pulverized parts of two 3 x 6-in. cylinders cured one day in molds, and then at 73±3°F and 100% RH until tested.

The method used determines the specific heat of saturated materials. A different procedure was used to saturate each of the three concrete types. Crushed samples from Mix No. 7, containing perlite, were immersed in room temperature water for 4 days prior to testing. Material from Mix No. 10, containing Styropor, was boiled in water for 6 hours and then immersed in room temperature water for an additional 2-1/2 days before testing. Material from Mix No. 11, containing perlite and Styropor, was ovendried 20 hours and then vacuum saturated for 3 hours. The sample was then immersed in water for 22 hours.

Tests were performed on Mix No. 7 specimens 44 days after casting. Tests were performed on specimens from Mix Nos. 10 and 11 twenty-eight days after casting. To determine specific heat, the sample was heated in a warm bath at 115±°F and then transferred to a calorimeter containing room-temperature water. After the necessary data was obtained, the material was cooled in water at 35±1°F and again transferred to the calorimeter. Specific heat was determined by measuring the temperature change of the water in the calorimeter.

To calculate specific heat of the material in a dry state, weights of the material in the particular dry state and the saturated surface dry (SSD)[a] state must be known. Whiting, Litvin, and Goodwin (1978) used the following equation to calculate specific heat of concrete for different moisture conditions:

$$C = \frac{C_{SSD} + \gamma(Y-1)}{1 + \gamma(Y-1)} \tag{1}$$

(a) An SSD material is a saturated material with surface water removed.

where

c = specific heat of samples at any moisture content

c_{SSD} = specific heat of saturated surface dry samples

Y = moisture content expressed as a fraction of the SSD moisture content

γ = SSD moisture content.

$$\gamma = \frac{W_{SSD} - W_{OD}}{W_{SSD}} \tag{2}$$

where

W_{SSD} = SSD weight of sample

W_{OD} = ovendry weight of sample.

After testing, specific heat samples were ovendried at 175°F to determine SSD moisture contents.

Specific heat values obtained in this investigation are compared with previous perlite (Van Geem and Fiorato 1983a) and expanded shale (Van Geem and Fiorato 1983b) concrete test results in Table 5.3. Values are for concrete in saturated surface dry, air dry, and ovendry conditions. Specific heats in the air dry and ovendry conditions were calculated using Eqs. (1) and (2). Air dry unit weights were determined from 4 x 8-in. compression test cylinders. Air dry moisture contents were determined from hot wire test specimens.

Ovendry specific heats for the three mixes used in this investigation are similar. Air dry and saturated surface dry specific heats differ due to differences in moisture content. Since the specific heat of water is 1.0 Btu/lb•°F, the higher moisture content concretes have higher values of specific heat.

Thermal Conductivity. The hot wire method was used to determine apparent thermal conductivity of air-dried prisms. Concrete prisms from Mix Nos. 7, 10, and 11 were cast with a nickel-chromium constantan thermocouple embedded along their central longitudinal axis. Test specimens measured 4 x 4 x 8 in.

To test a specimen using the hot wire method, an initial thermocouple reading is taken, electrical current is supplied to the wire, and additional thermocouple readings are made at selected intervals for 10 minutes. Apparent thermal conductivity is calculated from the measured current, the resistance of the wire, and the thermocouple readings (Lentz and Monfore 1965).

Thermal conductivity was measured for 1 specimen from each of the 3 mixes. Specimens were cured in molds for 1 day, moist cured at 73±3°F and 100% RH for 6 days, and air dried at 73±3°F and 50±10% RH until the test. Specimen No. 7HW1, from Mix No. 7, was tested 40 days after casting. Specimen Nos. 10HW2 and 11HW1, from Mix Nos. 10 and 11, respectively, were tested 25 days after casting. After hot wire tests were completed, specimens were ovendried to determine moisture content. Apparent thermal conductivity values are given in Table 5.4. Values for previous tests on perlite (Van Geem and Fiorato 1983a) and expanded shale (Van Geem and Fiorato 1983b) concretes are also listed in Table 5.4.

TABLE 5.3. Specific Heat of Low Density Concrete

Mix No.	Saturated Surface Dry			Air Dry			Ovendry	
	Unit Weight, pcf	Moisture Content, % ovendry weight	Specific Heat, Btu/lb•°F	Unit Weight, pcf	Moisture Content, % ovendry weight	Specific Heat, Btu/lb•°F	Unit Weight, pcf	Specific Heat, Btu/lb•°F
Previous Perlite Concrete Test*(3)	68	62	0.444	46	9.5	0.179	42	0.100
7	70	24	0.316	61	7.1	0.208	57	0.152
10	80	39	0.390	63	9.2	0.224	57	0.152
11	84	46	0.423	62	8.1	0.220	57	0.158
Previous Expanded Shale Concrete Test**(4)	106	12	0.257	102	8.5	0.230	94	0.162

*Sample preparation included 18 hours of submersion in water and 6-1/2 hours of boiling.
**Samples submerged in water for 5 days prior to testing.

TABLE 5.4. Results from Hot Wire Thermal Conductivity Tests on Air Dry Specimens

Mix No.	Specimen No.	Air Dry Unit Weight, pcf	Air Dry Moisture Content, % ovendry weight	Measured Thermal Conductivity, $\frac{Btu \cdot in.}{hr \cdot ft^2 \cdot °F}$
Previous Perlite Concrete Test(3)	--	50*	9.5	1.9***
7	7HW1	61**	7.1	2.4
10	10HW2	63**	9.2	3.1
11	11HW1	62**	8.1	3.1
Previous Expanded Shale Concrete Test(4)	--	101*	8.5	6.7***

*Air dry unit weight of hot wire test specimen at designated moisture content
**Air dry unit weight determined from 4x8-in compression test cylinders.
***Interpolated from measured results at other moisture contents

Figure 5.1 shows that thermal conductivity of concrete increases as unit weight increases. This relationship has been documented by many investigators (Van Geem and Fiorato undated). Care must be taken when comparing thermal conductivity test results from different test methods. The hot wire method generally gives higher test results than the conventional guarded hot plate test method [American Society for Testing and Materials (ASTM) Designation: C177)]. However, the guarded hot plate method with embedded thermocouples yields higher results than the hot wire test method (Van Geem and Fiorato undated). A comparison of thermal conductivity test methods and results may be found in Van Geem and Fiorato (undated) and Van Geem, Fiorato and Musser (1983). Thermal conductivity increases with moisture content. Specimens allowed to air dry for a longer period have lower conductivity values.

5.1.3 Prediction of Other Thermal Properties

Thermal diffusivity was calculated from measured values of thermal conductivity, specific heat, and unit weight. Other dynamic thermal properties were estimated from diffusivity and previous calibrated hot box test results.

Thermal Diffusivity

Thermal diffusivity is a physical property of a material that defines the time rate of change of temperature at any point within a body. In energy applications, diffusivity defines the rate of heating of a thermal storage mass.

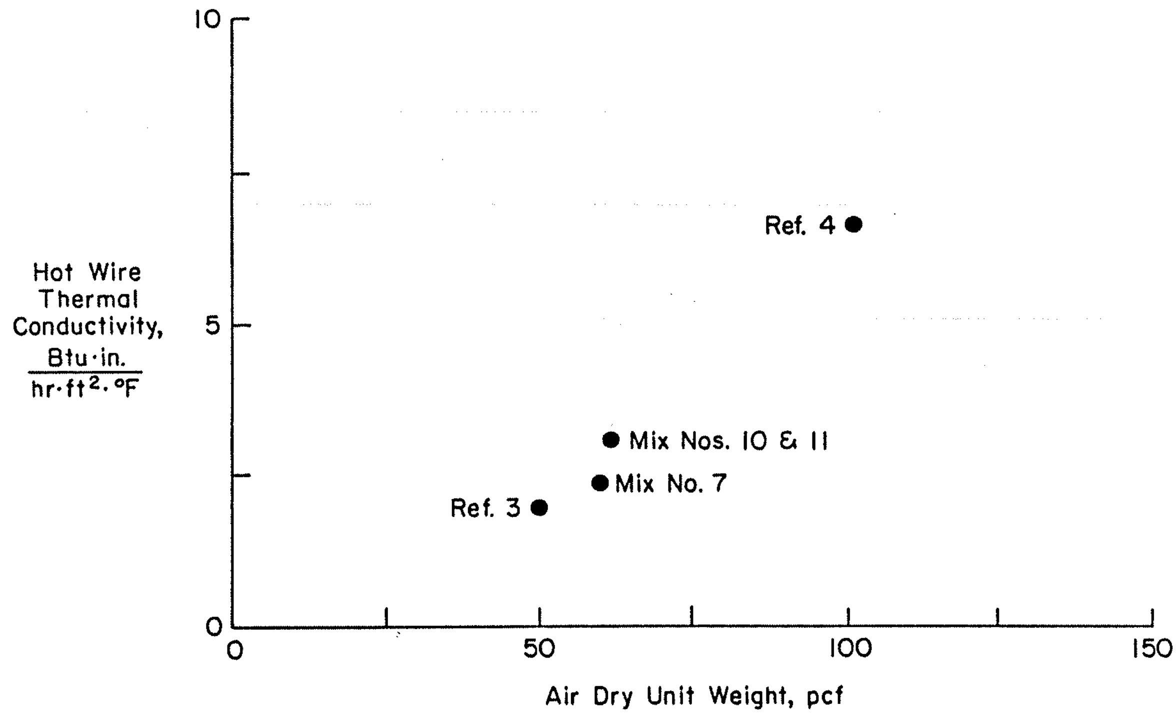

FIGURE 5.1. Results from Hot Wire Thermal Conductivity Tests on Air Dry Specimens (Ref. 3 and 4 = Van Geem and Fiorato 1983a; 1983b)

Theoretically, thermal diffusivity can be calculated from the following equation:

$$\alpha = \frac{k}{\rho \cdot c} \tag{3}$$

where

α = thermal diffusivity, ft^2/hr

k = thermal conductivity, Btu/hr·ft·°F

ρ = unit weight, pcf

c = specific heat, Btu/lb·°F.

Values of thermal diffusivity calculated for concrete Mix Nos. 7, 10, and 11 are given in Table 5.5. Values calculated from previous perlite (Van Geem and Fiorato 1983a) and expanded shale (Van Geem and Fiorato 1983b) concrete test results are also shown.

Thermal Lag and Reduction in Amplitude

Dynamic calibrated hot box tests of wall assemblies may be used to determine dynamic properties of thermal lag and reduction in amplitude. These properties were not measured as a part of this study but were estimated using results from calibrated hot box tests on perlite (Van Geem and Fiorato 1983a) and expanded shale (Van Geem and Fiorato 1983b) concrete walls.

In the late 1970s, CTL developed a calibrated hot box (ASTM 1983) to provide data on heat transmission characteristics of full-size wall assemblies under steady-state and dynamic temperature conditions. Steady-state tests are used to obtain average heat transmission

TABLE 5.5. Calculated Thermal Diffusivity

Mix No.	Air Dry Unit Weight, pcf	Air Dry Specific Heat, Btu/lb•°F	Air Dry Thermal Conductivity, $\frac{\text{Btu•in.}}{\text{hr•ft}^2\text{•°F}}$	Air Dry Moisture Content, % ovendry weight	Calculated Air Dry Thermal Diffusivity, ft^2/hr
Previous Perlite Concrete Test(3)	46*	0.179	1.9	9.5	0.019
7	61**	0.208	2.4	7.1	0.016
10	63**	0.224	3.1	9.2	0.018
11	62**	0.220	3.1	8.1	0.019
Previous Expanded Shale Test(4)	102*	0.230	6.7	8.5	0.024

*Air dry unit weight of calibrated hot box test specimen.

**Air dry unit weight of compression test cylinders.

coefficients. Dynamic tests provide data on dynamic thermal response under controlled conditions that simulate actual temperature changes in building envelopes. Dynamic response includes heat storage capacity as well as heat transmission characteristics of the wall assembly.

The facility was designed to accommodate walls with thermal resistance values ranging between 1.5 to 20 $hr \cdot ft^2 \cdot °F/Btu$. Nominal overall dimensions of test assemblies are 103 x 103 in. The outdoor chamber can be held at a constant temperature or cycled between -15°F and 130°F. Temperature cycles can be programmed to obtain the desired time-versus-temperature relationship. The indoor chamber simulates an indoor environment and can be maintained at constant room temperatures between 65°F and 80°F.

One series of tests performed in the calibrated hot box was a dynamic thermal study on three concrete wall sections (Van Geem, Fiorato and Musser 1983a). One section was a normal weight wall weighing 144 pcf, one a structural lightweight wall weighing 102 pcf, and the third a low-density wall weighing 46 pcf. Results of these tests are given in separate reports (Van Geem and Fiorato 1983a; 1983b and Van Geem, Fiorato and Julien 1983) and are summarized in a paper presented at the ASHRAE/DOE Conference in 1982 (Van Geem, Fiorato and Musser 1983). These low-density and structural lightweight concrete walls were made from the same concrete as the specimens used to determine "previous" perlite and expanded shale, respectively. Concrete test results are listed in Tables 5.3, 5.4, and 5.5.

Three diurnal test cycles were performed on the low-density and structural lightweight concrete walls. The National Bureau of Standards (NBS) test cycle was used to analyze data in this study. The NBS cycle, shown in Figure 5.2, results in an outdoor air temperature that fluctuates above and below the indoor air temperature. This causes reversal of heat flow within the wall during the 24-hour cycle.

Two parameters determined from dynamic calibrated hot box test results are thermal lag and reduction in amplitude of peak heat flow, shown in Figure 5.3. Thermal lag is the time required for the maximum or minimum indoor surface temperature to be reached after the maximum or minimum, respectively, outdoor air temperature is attained. Lag may also be defined as the time required for the maximum or minimum heat flow rate, Q_W, to be reached after the maximum or minimum heat flow rate based on steady-state prediction, Q_{SS}, is attained. The steady-state prediction is determined from wall conductance and surface temperatures. Thermal lag is indicative of both thermal resistance and heat storage capacity, since both of these factors influence the rate of heat flow (Van Geem and Fiorato 1983a).

Percent reduction in amplitude is defined as the percent reduction in measured peak heat flow when compared to peak heat flow calculated using steady-state theory. Percent reduction in amplitude varies depending on the temperature cycle applied to the wall.

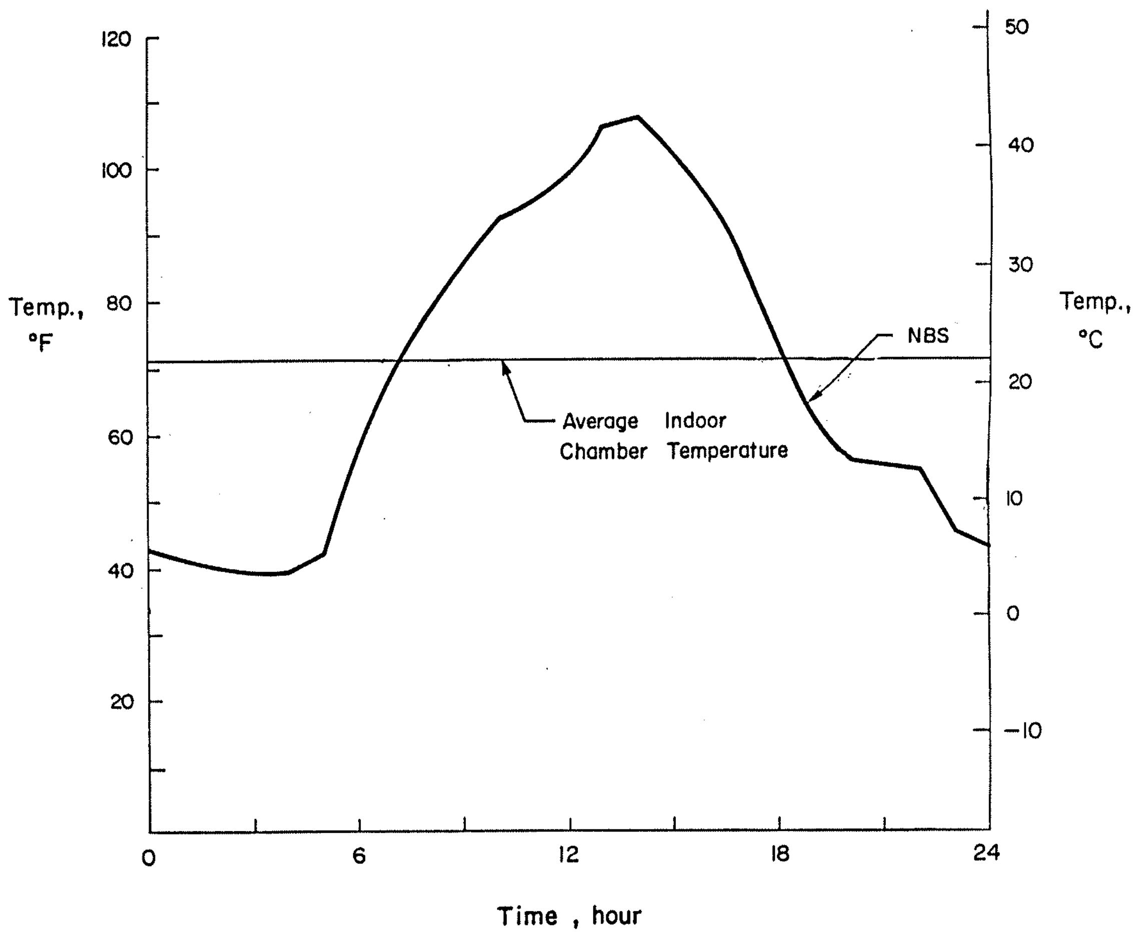

FIGURE 5.2 Outdoor Chamber Air Temperature for NBS Dynamic Test Cycle

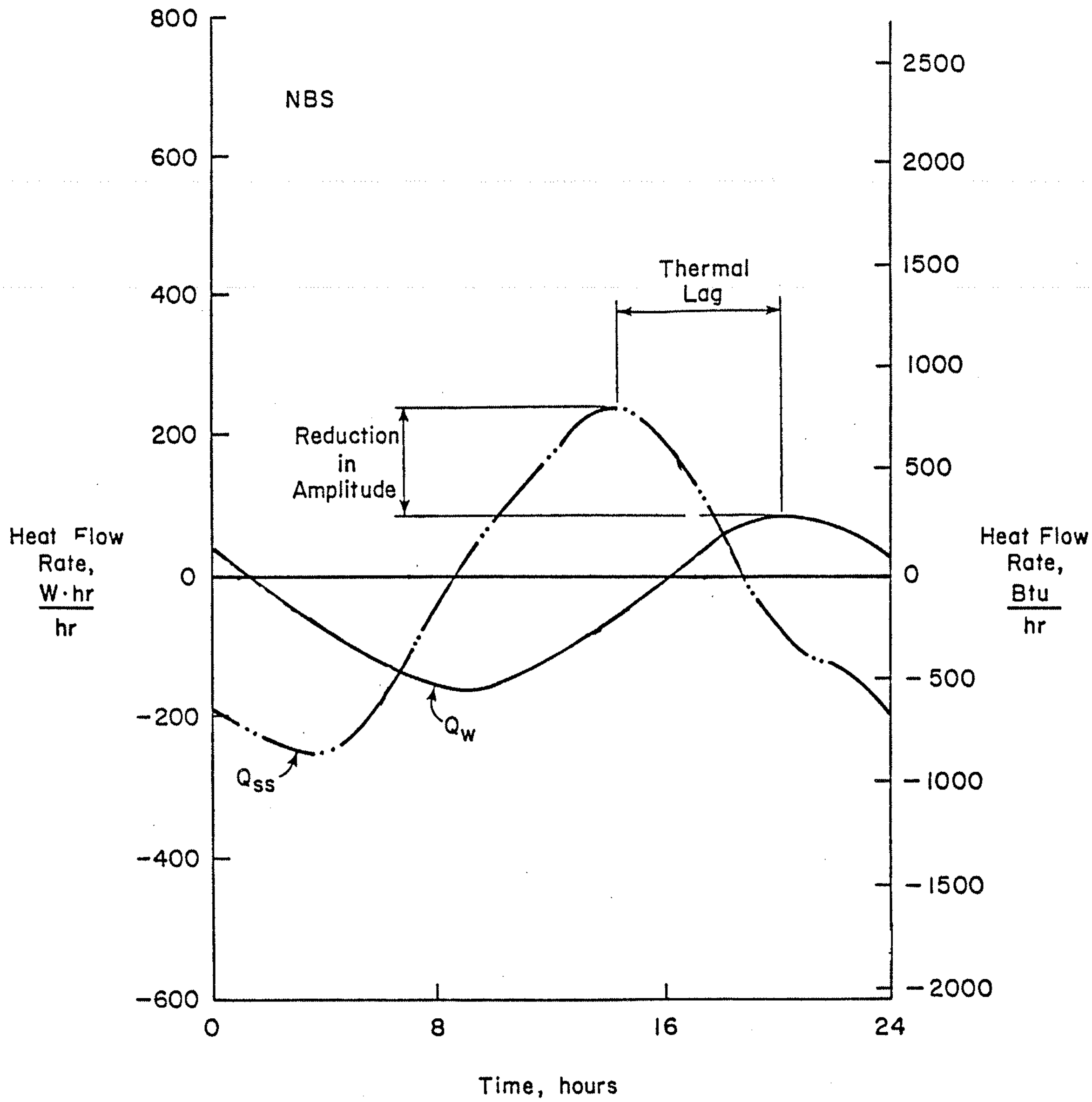

FIGURE 5.3. Thermal Lag and Reduction in Amplitude (results from structural lightweight concrete wall tests)

Under certain dynamic temperature conditions, the combination of thermal conductivity and unit weight of low-density concrete walls provides reduction and delay in peak heat flows that can result in significant energy savings. Lower peak heat flows may result in lower total energy costs for maintaining constant indoor air temperatures. Calibrated hot box tests may be used to determine actual energy requirements. Delay in peak heat flow, or thermal lag, is beneficial because the delay makes feasible the use of other inexpensive systems such as ventilation to aid in maintaining constant indoor air temperature.

Thermal lag and reduction in amplitude depend on the following parameter (Childs, Courville and Bales 1983):

$$\sqrt{\frac{L^2/\alpha}{P}} \tag{4}$$

where

L = wall thickness, ft

α = thermal diffusivity, ft^2/hr

P = time period required to complete a single cycle, hr.

Thermal lag and reduction in amplitude of concretes in this study may be estimated using the parameter presented and the results from previous calibrated hot box tests. For this chapter, time period, P, is a constant equal to 24 hours. Therefore, variations in lag and reduction in amplitude depend on $\sqrt{L^2/\alpha}$.

Table 5.6 lists values of wall thickness, diffusivity, and $\sqrt{L^2/\alpha}$ for the three concretes in this study, the previous perlite concrete test, and the previous expanded shale concrete test. Thermal lag and reduction in amplitude for concrete from Mix Nos. 7, 10, and 11 are interpolated or extrapolated from previous test results using the assumption that the parameters are linearly dependent on $\sqrt{L^2\alpha}$.

Results in Table 5.6 show that concrete from Mix Nos. 10, and 11 would perform approximately the same as the previous perlite concrete. Mix No. 7 has the most beneficial properties: high thermal lag and reduction in amplitude values. For the three mixes in this study, thermal lag varies from 8 to 10 hours, and percent reduction in amplitude values are approximately 60%.

TABLE 5.6. Thermal Lag and Reduction in Amplitude

Mix No.	L Wall Thickness, ft,	α Thermal Diffusivity ft^2/hr	$(L^2/\alpha)^{1/2}$	NBS Test Cycle	
				Average Thermal Lag, hrs	Reduction in Amplitude, %
Previous Perlite Concrete Test(3)	0.71*	0.019	5.2	8.5	61*
7	0.70**	0.016	5.5	10+	60+
10	0.70**	0.018	5.2	9+	60+
11	0.70**	0.019	5 1	8+	60+
Previous Expanded Shale Test(4)	0.69*	0.024	4.5	5.5	54*

*Measured
**Assumed
+Estimated by extrapolation

Care must be taken in using extrapolated values. Dynamic calibrated hot box tests must be performed to verify thermal lag and percent reduction in amplitude. Also, note that reduction in amplitude values is valid only for the NBS test cycle. Other test cycles will give different values for reduction in amplitude.

5.2 FUTURE WORK

While the strength/unit weight objectives of this brief program have been met, it is believed that these properties can be improved. A search must be made for additional aggregates having properties as good as, or better than, Livite. Sources must be found for lightweight fine aggregates having strength properties better than Styropor and perlite. Proper selection of such material should permit the production of lower weight concretes, resulting in improved thermal properties.

Future work should include determining the equilibrium air dry moisture content of the desirable concrete. Because specific heat and thermal conductivity vary depending on the moisture content of the concrete, the dynamic thermal properties will also vary with moisture content. Drier walls will have lower heat transmission.

Using small-scale specimens, dynamic thermal properties were estimated from properties measured. Dynamic calibrated hot box tests must be performed on full-scale specimens to adequately predict dynamic thermal performance. Thermal lag and reduction in amplitude of peak heat flow, as well as total heat flow through a wall, may be determined from calibrated hot box tests.

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