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A FEASIBILITY STUDY ON THE USE OF FOAM IN PLACE URETHANE INSULATION IN MASONRY CAVITY WALLS

by

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Champaign, Illinois 61820

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A thorough survey of manufacturers, system suppliers, and installation contractors of foam products was conducted to determine the physical properties and technical nature of the application. Building codes and standard military and federal specifications were researched to investigate the acceptance of urethane foam insulation in masonry cavity walls.

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This investigation revealed that rigid urethane foam has impressive physical properties. It has an excellent thermal efficiency and a high strength-low weight ratio, and its closed cell nature gives it good moisture resistance and stability. Although small-scale ASTM tests give urethane a non-burning rating, Factory Mutual Research Corporation demonstrated that urethane will support combustion when the ignition source is removed. However, Factory Mutual concludes that foamed-in-place urethane that completely fills a wall cavity does not significantly contribute to the fire hazard of a building.

Major drawbacks of the application include adverse effects of hot and cold temperatures, moisture, and humidity on foam quality, health and safety problems in installation, and high application costs.

Foamed-in-place urethane is not recommended as masonry cavity wall insulation in standard military construction. The disadvantages of the foam outweigh its advantages, particularly since the foam has no economic advantage for such construction.

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FOREWORD

The investigation of the feasibility of the use of foam-in-place urethane insulation in masonry walls was performed by the Chicago District of the Corps of Engineers and the Construction Engineering Research Laboratory (CERL) under the direction of the Office of the Chief of Engineers. This work was performed under work unit 006 of task 02 of OMA project "Engineering Criteria for Design and Construction."

CERL personnel directly concerned with this study were Messrs. A. J. Geswein, W. E. Kindel, R. Neathammer, and Lt. J. Dyckmans. Chicago District Personnel were Messrs. A. C. Martino, G. Frankish, and K. Zukauskas. The OCE technical monitor was W. R. Darnell, Directorate of Military Construction, Engineering Division. This report was prepared by Mr. A. C. Martino.

Figures 1, 2, and 3 in this report are taken from "Rigid Urethane Foams" (1964) with the permission of the Union Carbide Corporation. Figure 11 is taken from the Society of the Plastics Industry bulletin, "Guide for the Safe Handling and Use of Urethane Foam Systems" (1969).

CONTENTS

A FEASIBILITY STUDY ON THE USE OF FOAM-IN-PLACE URETHANE INSULATION IN MASONRY CAVITY WALLS

1 INTRODUCTION

Background. In the 1940's rigid urethane foam was introduced as a commercial product. It was developed when Germany needed strong aircraft wing tips and rudders--needed them fast and in the face of great material shortages. The promise that rigid urethane foams would be the key to rapid production provided the incentive for a high priority development program. Soon materials and techniques were perfected to the point where a simple mix of urethane foam chemicals could be poured into a metal mold, where it would quickly expand, adhere, and cure to a strong, lightweight structure.

In the United States, largescale commercial interest in urethane technology did not develop until 1956, when the utility and economy of the ingredient chemicals were established. But, even then, the majority of commercial interest centered on flexible urethane foams. These foams were readily accepted, and are now mainly used as durable, resilient and economical cushioning materials.

Recently, many industries have devoted their time, energy, and development potential to rigid urethane foam. Its insulating efficiency, buoyancy and ability to add strength with low weight have made it the most functional of the new rigid cellular plastics. It is now a basic material in many key industrial segments—commercial refrigeration, transportation, home appliances, packaging, and building construction.

As a construction material, it is used in slab or board stock, as well as in foamed-in-place systems. Its primary applications have been as (a) an insulation board on pipes, roof decks, and walls because of its thermal properties and (b) as a core material in sandwich panels because of its low weight-high strength ratio. It is also being examined in light of all its properties for applications in a complete space-enclosing system.*

Purpose and Scope. This report examines the technical and economic feasibility of foamed-in-place urethane insulation in masonry cavity walls, especially in military construction. The report draws conclusions from a search of documented literature on the material and its application and from a survey of manufacturers, system suppliers, and installation contractors of foam products (survey results in Appendix I).

A Department of the Army standard facility, Headquarters Building, Regimental/Brigade, is used in this report as an example of military cavity wall construction for the economic evaluation of rigid urethane foam insulation. Urethane is compared with insulating materials

* The Monsanto "Home of the Future" on display at Disneyland's Tomorrowland since 1957 is built of rigid urethane foam prefab modules that were factory cast and site assembled. It is being studied as a possible answer to the need for a large-scale program of mass-produced, low-cost housing. It features urethane as its structural, thermal, and finish (both interior and exterior) material.

designated in the standard specifications for this structure.* The facility is studied with each insulation system in temperature zones of 20° F, 0° F, and +20° F.

2 PROPERTIES OF RIGID URETHANE FOAM

Rigid urethane foam is an inflexible cellular plastic. It is formed by the reaction of two liquids, an isocyanate component and resin blend, in the presence of a gas-producing blowing agent, usually freon water or carbon dioxide. It is made up of many tiny closed cells, each containing the gaseous agent. Physically, the foam is a permanent dispersion of a gas in a rigid plastic, and as such, both the gas and the plastic contribute importantly to the final foam properties.

*Standard Technical Specification 30-02-66-64-CE for the Headquarters Building, Regimental/Brigade, reads as follows for the insulation of exterior masonry walls (see 3A-10):

a. Exterior masonry walls are designed for a coefficient of heat transmission of "U" value through the completed construction inside air to outside air not in excess of 0.27 BTU per hour, per square foot per degree F. Temperature difference when determined for winter conditions in accordance with recognized methods in agreement with ASHRAE Guide and Data Book. The Contractor will be required to furnish a certificate attesting that the exterior wall construction proposed will, when constructed, attain the required "U" value.

b. At the option of the Contractor, any one of or combination of the following may be used

(1) Where exterior wythe is brick, a lightweight type aggregate may be used in manufacturing concrete masonry units providing the "K" value of the unit will in the wall furnish the required "U" value.

(2) Where exterior and interior wythe is concrete masonry, use of light-weight aggregate as stated in (1) above.

(3) Where neither of above methods will furnish the required "U" value, light-weight or regular weight aggregate masonry units may be used in combination with filling cavity of cavity-type wall with waterproof vermiculite or applying a board type insulation completely covering and applied against the inner cavity face of the interior wythe of masonry. The material used shall be as specified below.

c. Vermiculite shall be a water repellent type and will conform to the Vermiculite Institute Standard for Vermiculite Water-Repellant Masonry Fill Insulation. "K" factor of 0.45 will be used for water repellant vermiculite.

d. Board type insulation will be 1" thick, non-combustible, with waterproof facing on one face or otherwise treated to be water-repellant, and shall be vermin-proof. The published "K" value for the board will be used.

Density. The density of rigid urethane foam is determined by the ratio of gas to plastic and therefore can be controlled in its formulation. Normally foams contain between 20 to 80 times the volume of gas as plastic and are applied at densities of 1.5 to 3.0 pounds per cubic foot (pcf). Since it is actual practice to use rigid urethane foams at densities close to 2.0 pcf in masonry cavity walls, the properties reported throughout this report are standardized at this density, an overall installed density of 2 pcf is achieved by using pressurization techniques in the formulation and installation of the foam. As demonstrated by Figures 1, 2, and 3, density has a nearly direct correlation with heat transfer and other mechanical properties. However, water permeability remains constant for densities greater than 3 pcf.

Thermal Coefficient. The coefficient of heat transfer ("K" value) of foam depends primarily on the blowing agent, the cell size, and the environment. A 2 pcf density foam blow with freon at 75°F will have an initial "K" value of about 0.12 BTU in/hr/ft²/°F. This value will be maintained if the foam is contained in an almost closed cavity and not subjected to atmospheric temperature and pressure. But if the foam is open to the atmosphere, a gradual increase will occur with aging until a maximum value of about 0.16 BTU in/hr/ft²/°F is attained because of air infusion. Foam system suppliers recommend a "K" value of 0.14 or 0.15 to be used for design purposes.

The thermal conductivity of rigid urethane foam as compared to other insulating materials is shown in Figure 4. Rigid urethane foam is 133% more efficient than its nearest competitor, styrene form.

Water Absorption and Vapor Permeability. Water-absorption and water-vapor permeability are dependent on the percentage of closed cells in the rigid urethane foam. Standard American Society for Testing and Materials (ASTM) tests

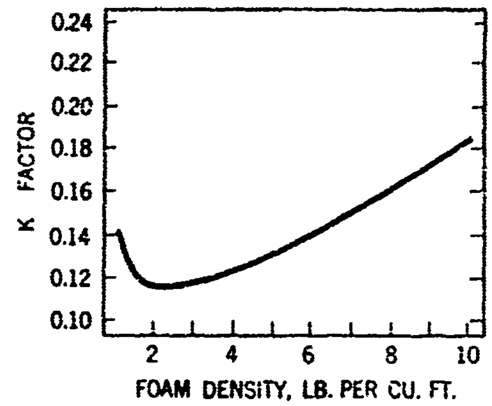

Figure 1. Effect of density on heat-transfer properties.

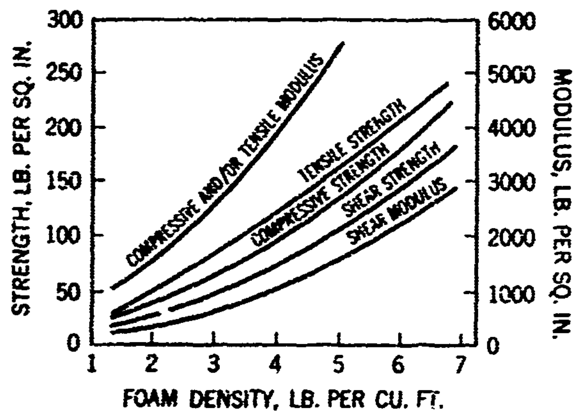

Figure 2. Effect of density on mechanical properties.

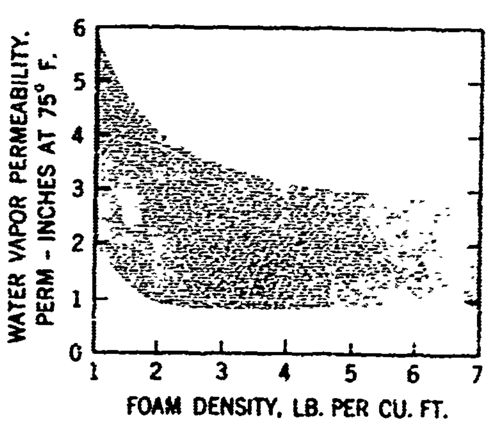

Figure 3. Effect of density on water vapor permeability.

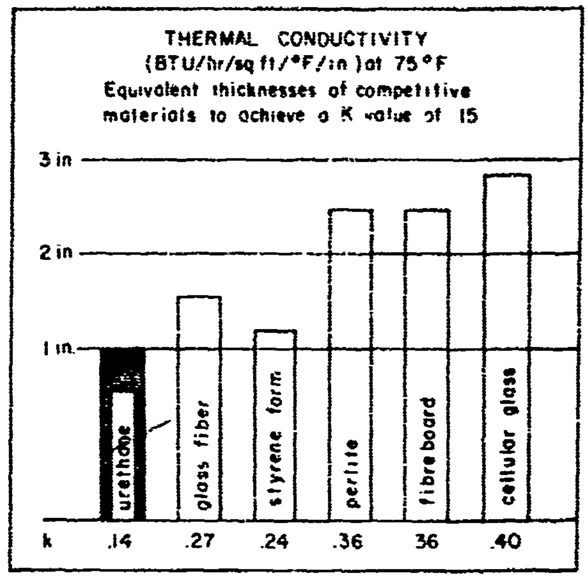

Figure 4. Comparable termal conductivities of rigid urethane foam and other commonly used insulation materials.

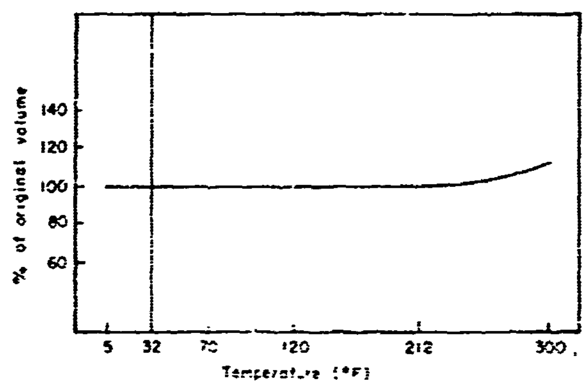

Figure 5. Ratio of volume change to temperature in rigid urethane foam.

were performed on 2 pcf density foam. The water absorption (determined by ASTM D2127 with the foam under a 2 in. head for two days) was 0.04 lbs/ft² by weight and 1.1% by volume. Water permeability (ASTM 335) was 2.0 perm-in.

Dimensional Stability. A rigid urethane foam installed with a density of 2 pcf exhibits volume change as shown in Figure 5.

A maximum minus 1.5% volume change is experienced for low temperature work, and a maximum plus 2% volume change is experienced at dry heat and humidity aging. The total range of linear change measured under ASTM test procedure D2126, Proc B and Proc E, is illustrated in Table 1.

Table 1
Dimensional Stability of Rigid Urethane Foam

Aging Condition	Aging Duration	Average Linear Change
-20° F (Proc B)	1 day	-0.7%
	7 days	-1.1%
	28 days	-1.5%
160° F (Proc E)	1 day	+0.6%
	7 days	+1.0%
	28 days	+2.0%

Fire Properties. Several foam manufacturers have tested the fire properties of rigid urethane according to ASTM tests E 84* and D1692-59T. The results are shown in Table 2; scores are related to those from asbestos board (rating 0) and 5/8-inch red oak (rating 100).

Although the foam appears to be nonburning in small-scale ASTM tests, a parallel laboratory test conducted by Factory Mutual Research Corporation demonstrates that combustion will continue when the Bunsen burner ignition source is removed. But Factory Mutual concluded that rigid foamed-in-place urethane when completely filling a wall cavity "does not of itself add a significant fire hazard to the building."[1]

Table 2
Fire Properties of Rigid Urethane Foam

ASTM No.	Test	Value
E 84	Flame spread	30
	Fuel contributed	15
	Smoke developed	325
D1692	Flame Resistance:	
	distance burned, inches	.09
	time to extinguish, seconds	45

*ASTM E 84 (tunnel test) is also Underwriter's Laboratories test 723, National Fire Protection Association Test 225, and Uniform Building Code 42-1.

The Factory Mutual tests evaluated the effects of extreme heat and direct flames at a temperature of about 2000° F on urethane foam insulation in cavity walls. They also examined the possible toxicity of gases released from urethane during foaming or by excessive heat or fire. Both the flammability and toxicity hazards were found to be negligible.**

Mechanical Properties. The cellular structure of rigid urethane foam gives it excellent high strength-low weight balance. The solids in a 2 pcf foam occupy only 3 percent of the foam's total volume, but provide a stable cellular structure. Table 3 lists the mechanical properties of rigid urethane foam.

Table 3
Mechanical Properties of Rigid Urethane Foam at 740°

	ASTM Test	Values (psi)
Compressive Strength		
Parallel	D1621	40
Perpendicular	D1621	20
Compressive Modulus		
Parallel	D1621	500
Perpendicular	D1621	250
Tensile Strength		
Parallel	D1623	46
Perpendicular	D1623	35
Shear Strength (Parallel)	C273	26

[1] R. B. Boyd and Wayne Crandlemere, "An Evaluation of Fire Safety of Rigid Foamed Polyurethane as a Wall Cavity Insulation" (Factory Mutual Research Corporation, 1969), p. 4.

**For the foam to decompose to yield toxic gases, the temperature inside the room would have to be high enough to heat the foam to about 482° F. The temperature in the room would be too high for human survival.

3 APPLICATION

Techniques. The rigid urethane foam is either poured or frothed into the masonry cavity. The prime application considerations are to eliminate all entrapped air, achieve complete distribution of foam and achieve uniform density.

In the pour-in-place procedure the two ingredient liquids and blowing agent are mixed on the job and poured directly into the cavity (Fig. 6). In a matter of minutes this mixture foams to 30 times its original volume and sets into its installed form. The proper technique is to pour enough foaming composition to give a maximum foam rise of 2 to 3 feet, allow the material to rise and set, then deposit another layer of foaming composition and allow it to rise and set, and so on until the cavity is filled. The multiple pour technique is used to reduce the pressure exerted on the masonry wythes by the expanding foam.

Frothing is a modification of the pour-in-place installation method in which the mixture is dispensed partially pre-expanded–like aerosol cream (Fig. 7). Frothing requires special equipment and an extra blowing agent for immediate pre-expansion. Final expansion then occurs as the chemical reaction goes to completion. It is generally agreed that frothing allows easier and more uniform filling of cavities than pouring. In the frothing technique, the original liquids are expanded to roughly ten times the volume as the blend exits from the mixing chamber. This semi-liquid is extremely mobile and can be

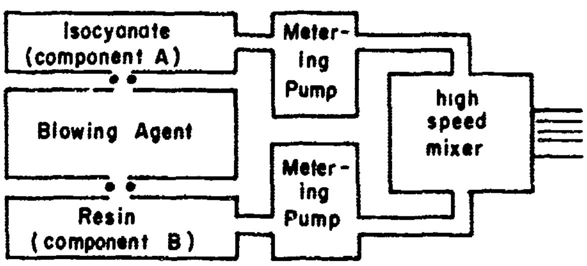

Figure 6. Pour-in-place application of rigid urethane foam.

Table 4
Health and Safety Considerations for Urethane Foam Component Chemicals

Component	Composition	Skin Irritant	Sensitizing Effect On Respiratory System
Isocyanate	Primarily Free Isocyanate Chemicals	Yes	Yes
Resin blend	Polyol	No	No
	Amines and/or Metallic Catalysts	Yes	Yes (Some)
	Fluorocarbon and/or Water	No	No
	Silicone Surfactants	No	No
Catalyst blend	Amines	Yes	Yes
	Water	No	No

directed by the force of light exit pressure to give maximum ditribution. About 20 to 30 seconds after the froth is deposited in the cavity, additional expansion results and brings total expansion of the liquids to about thirty times the original volume. This secondary expansion completes the filling of the space and consolidates the foam. The cell structure of the installed foam is relatively undistorted, and a more stable foam at a lower density results.

Health and Safety. Care must be taken in the foaming process since isocyanate vapors are toxic in heavy concentration. Although the vapor is quickly dissipated in fresh air and is readily detectable, fresh air or cartridge masks are recommended before and during foaming. Care should also be taken to avoid prolonged contact with the skin since the isocyanate, resin blend, and catalyst components contain skin irritants. The components, either in liquid or vapor form, can cause damage to the eyes; so

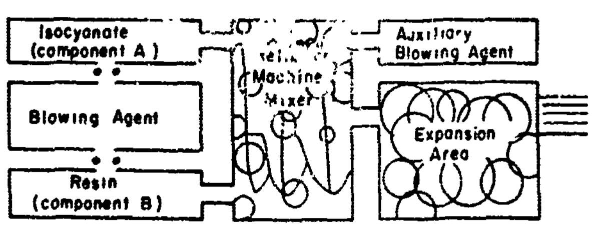

Figure 7. Froth-in-place application of rigid urethane foam.

safety goggles must be worn in all operations. The major component chemicals deserving safety considerations are indicated in Table 4.

Operators must be experienced foam technicians and equipment must be frequently cleaned and checked for metering accuracy. The machinery must never be left untended when there is a possibility of ignition of hardened foam deposits, as by an electrical source.

Environmental Effects. The major urethane foam components are sensitive to the climate and must be sealed tightly and stored in a controlled environment when not in actual use. Atmospheric moisture will cause a crust to develop on the surface of the isocyanate, thereby rendering it unfit, and change the reaction condition of the polyol in the resin blend. In addition, temperatures above 85°F may cause gas loss and density change in the catalyst.

When urethane chemicals react and the foaming process starts, the expanding mass must bond securely to the substrate surfaces to be totally effective. To ensure this, the substrates must be dry, warm, and oil free. (In general, any surface suitable for painting is suitable for foaming.) An accumulation of water in the cavity or a humidity level which causes condensation of moisture on the substrates can adversely affect the foam by causing substrate bind or improper adhesion. The temperature of the substrate surfaces and the environment should be between 65°F to 85°F to ensure full expansion, adhesion, and cure of the urethane.*

4 ACCEPTANCE

Building Codes. The nation's building codes are bodies of law which state what construction is acceptable in terms of space, strength and fire behavior. To use rigid urethane foam as insulation in a masonry cavity wall, it must be demonstrated that it meets the performances and tests outlined for plastics by the building codes.

Under the Uniform Building Code of the International Conference of Builders, an approved plastic is one which has "a flame-spread rating of 225 or less and a smoke density not greater than that obtained from the burning of untreated wood under similar conditions when tested in accordance with U.B.C. Standard No. 42-1-64 in the way intended for use. The products of combustion shall be no more toxic than the burning of untreated wood under similar conditions."[2] Rigid urethane foam has acceptable fire properties as specified by these criteria, as demonstrated in the section "Fire Properties" above.

Under the Basic Code of Building Officials Conference of America, the Souther Building Code, and the Model Code drafted by the Society of the Plastics Industry, Inc., "an approved plastic is one which by the ASTM D635 test** does not burn faster than 2.5 inches per minute."[3] There are no documented results for an ASTM D635 test on urethane, but a similar testing procedure, ASTM D1692-59T, yields a 0.9 inch burn distance (non-burning rating) for rigid urethane foam.

Department of Defense Construction Criteria Manual. Construction criteria manual, DOD 4270.1-M, requires all insulation to have a

*Actually, foam can be applied in temperatures ranging from 0°F to 115°F by adjusting the component formulation, but an ideal temperature to ensure a perfect application should be between 65°F to 85°F.

[2] "Uniform Building Code" (Internation Conference of Building Officials, 1964).

**In the test, one end of a 1/4" × 1/2" × 5" urethane sample is held horizontally, and the other end is ignited by a 30-second application of a 1-inch high blue flame of a Bunsen burner. If the sample extinguishes upon removal of the burner, another 30-second application is made.

[3] P. B. Akin, "Fire Testing and Building Codes" in "Proceedings: Society of the Plastics Industry National Plastics Conference in Chicago" (1968).

Table 5
Tests and Values Required for Rigid Urethane Foam by Standard Specifications

ASTM Test	Units	HHH-I-00530 (GSA-FSS)	MIL-I-24172 (SHIPS)	MIL-P-21929A (SHIPS)	Typical Urethane Values
		SPECIFICATION REQUIREMENTS			
C 177 Thermal Conductivity	Max BTU/in/ft² /h/°F	0.17	0.16		0.12–0.14
C 355 Water-Vapor Transmissibility	Max perm-in	2.0	2.0		2.0
D 1621 Compressive Strength	Min psi	16	20	20	30 40
D 1692 Flammability		Self-exting.	non-burning		non-burning
D 2127 Water Absorption	Max % (vol)	4%	5%		1.1
	Max lb/ft² (weight)	·		.12	0.04

flame-spread rating of not higher than 25 without evidence of continued progressive combustion. The insulation should be of such composition that surfaces exposed by cutting would have neither a flame-spread rating higher than 25 nor evidence of continued progressive combustion. Smoke development rating should not be higher than 50. Data in Table 2 indicate that urethane foams will not meet these criteria.

Standard Specifications. Following are three applicable standard specifications on the use of urethane foam materials: (a) federal specification HHH-I-00530 (GSA-FSS), interim 25 April 1963, (b) military specification MIL-I-24172 (SHIPS) of 4 October 1965, and (c) military specification MIL-P-21929A (SHIPS) of 20 August 1962.

Table 5 lists the ASTM tests and physical results required by these specifications. To facilitate investigation of how rigid urethane foam is rated by these standards, the last column of the table exhibits the ASTM test results documented in Part 2 of this report.

5 ECONOMIC ANALYSIS

Installation Costs. The economic feasibility of using foamed-in-place urethane insulation in masonry cavity walls was analyzed by costing it for a typical building and comparing costs with alternate insulation materials. The building selected is a Department of the Army standard facility, Headquarters Building, Regimental/Brigade. It is a three story structure with gross dimensions of 40'-8" by 80'-8". Its perimeter walls are composed of a single wythe of face brick, a 2-3/8" wide cavity, and a single wythe of 4" concrete block. See Figure 8 for a typical wall section.

Table 6
Comparison of Installation Costs

Insulation System	General Construction Cost ($)	Heating Equipment Cost ($)	Total Cost ($)	$/ft² of Walls
I No insulation				
−20° F Zone	18,900	1750	20,650	5.16
0° F Zone	18,900	1500	20,400	5.10
+20° F Zone	18,900	1100	20,000	5.00
II Vermiculite or perlite insulation				
−20° F Zone	19,800	1500	21,300	5.33
0° F Zone	19,800	1300	21,100	5.28
+20° F Zone	19,800	1100	20,800	5.20
III 1-in. Foam glass board insulation				
−20° F Zone	20,400	1500	21,900	5.48
0° F Zone	20,400	1300	21,700	5.43
+20° F Zone	20,400	1100	21,400	5.35
IV 1-in. Fiberglass or polystyrene insulation				
−20° F Zone	20,100	1500	21,600	5.40
0° F Zone	20,100	1300	21,400	5.35
+20° F Zone	20,100	1100	21,100	5.28
V 1-in. Paper-backed urethane insulation				
−20° F Zone	20,400	1500	21,900	5.48
0° F Zone	20,400	1300	21,700	5.43
+20° F Zone	20,400	1100	21,400	5.35
VI Foamed-in-place urethane insulation				
−20° F Zone	22,800	1500	24,300	6.08
0° F Zone	22,800	1300	24,100	6.03
+20° F Zone	22,800	1100	23,800	5.95

Standard specifications 30-02-66-64-CE states that the exterior masonry walls of the facility must be so designed as to achieve a maximum "U" value of 0.27 either with the masonry alone or by adding loose fill or 1 in thick board-type insulation in the cavity of the wall.* Table 6 presents an economic comparison between rigid urethane foam and the various optional insulation materials based on 4000 ft² of wall space.

* See Standard Technical Specification 30-02-66-64-CE, footnoted on p. 2 of this report.

The estimates for each application were developed for temperature zones of −20° F, 0° F, and +20° F. Appendix II contains a complete analysis of installation costs.

Operating Costs. The various cavity wall insulation types were compared for thermal performance by analyzing the gas heating equipment and operating costs related to each system. The estimates for each application were then amortized over ten and twenty-five year periods. Ten

Table 7
Present Worths of Operating Costs for 10 and 25 Years Based on 0% Discount Rate

	Insulation System	–20° Zone	0° Zone	+20° Zone
		10 Year Operating Costs / 25 Year Operating Costs ($)		
I	No insulation	13500 33750	11600 29000	8500 21250
II	Vermiculite or perlite insulation	12000 30000	10300 25750	7600 19000
III	1-in. Foamglass board insulation	12100 30250	10400 26000	19000 19250
IV	1-in. Fiberglass or polystyrene insulation	12100 30250	10400 26000	7700 19250
V	1-in. Paper-backed urethane insulation	12100 30250	10400 26000	7700 19250
VI	Foamed-in-place urethane insulation	11400 28500	9800 24500	7300 18250

Table 8
Present Worths of Operating Costs for 10 and 25 Years Based on 6% Discount Rate

	Insulation System	–20° Zone	0° Zone	+20° Zone
		10 Year Operating Costs / 25 Year Operating Costs ($)		
I	No insulation	9900 17300	8500 14800	6300 10900
II	Vermiculite or perlite insulation	8800 15300	7600 13200	5600 9700
III	1-in. Foamglass board insulation	8900 15500	7700 13300	5700 9800
IV	1-in. Fiberglass or polystyrene insulation	8900 15500	7700 13300	5700 9800
V	1-in. Paper-backed urethane insulation	8900 15500	7700 13300	5700 9600
VI	Foamed-in-place urethane insulation	8400 14600	7200 12500	5400 9300

and twenty-five year costs were translated to present day value by multiplying first year operating costs by appropriate worth factors. These costs are given in Appendix III for discount rates of 0%, 6% and 10%. Tables 7, 8, and 9 illustrate the results of this investigation.

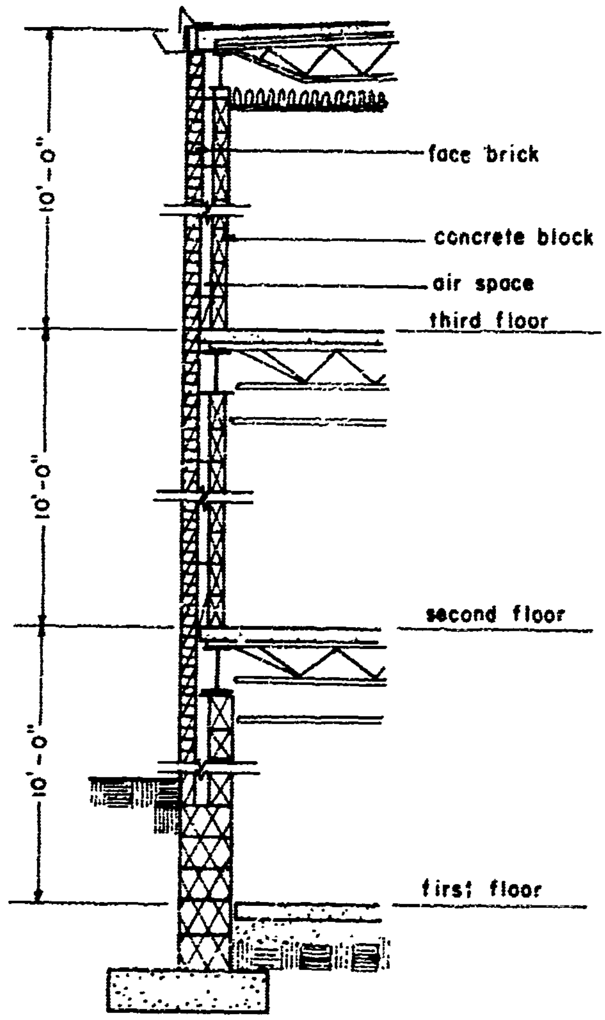

Figure 8. Typical wall section of Regimental/Brigade Headquarters Building.

Cooling cost estimates are given in Appendix IV. Since there was no significant difference in cooling costs for the various insulation system, the results are not reported here.

Total Costs. Combined installation and operating costs are illustrated in Tables 10, 11, and 12.

Comments on Economic Analysis. The preceding tables indicate that the use of foamed-in-place urethane insulation in the cavity of the masonry walls of the standard Regimental/Brigade Headquarters Building has no economic advantage over other available types of insulation. However, this indication is significantly affected by several variables including (1) discount rate, (2) assumed service life of the building, and (3) unit cost of the urethane insulation.

The effect of the discount rate is readily apparent from a comparison of Tables 7 through

Table 9
Present Worths of Operating Costs for 10 and 25 Years Based on 10% Discount Rate

	Insulation System	10 Year Operating Costs / 25 Year Operating Costs ($) −20° Zone	0° Zone	+20° Zone
I	No insulation	8300 2300	7100 10500	5200 7700
II	Vermiculite or perlite insulation	7400 10900	6300 9300	4700 6900
III	1-in. Foamglass board insulation	7400 11000	6400 9400	4700 7000
IV	1-in. Fiberglass or polystyrene insulation	7400 11000	6400 9400	4700 7000
V	1-in. Paper-backed urethane insulation	7400 11000	6400 9400	4700 7000
VI	Foamed-in-place urethane insulation	7000 10300	6000 8900	4500 6600

Table 10
Present Worths of Total Costs Based on 0% Discount Rate

	Insulation System	Total 10 Year Costs / Total 25 Year Costs ($) −20° Zone	0° Zone	+20° Zone
I	No insulation	34150 54400	32000 49400	28500 41250
II	Vermiculite or perlite insulation	33300 51300	31400 46850	28400 39800
III	1-in. Foamglass board insulation	34000 52150	32100 47700	29100 40650
IV	1-in. Fiberglass or polystyrene insulation	33700 51850	31800 47400	28800 40350
V	1-in. Paper-backed urethane insulation	34000 52150	32100 47000	29100 40650
VI	Foamed-in-place urethane insulation	35700 52800	34100 48600	31600 42050

Table 11
Present Worths of Total Costs Based on 6% Discount Rate

	Insulation System	Total 10 Year Costs / Total 25 Year Costs ($) −20° Zone	0° Zone	+20° Zone
I	No insulation	30550 37950	28900 35200	26300 30900
II	Vermiculite or perlite insulation	30100 36600	28700 34300	26400 30500
III	1-in. Foamglass board insulation	30800 37400	29400 35000	27100 31200
IV	1-in. Fiberglass or polystyrene insulation	30500 37100	29100 34700	26800 30900
V	1-in. Paper-backed urethane insulation	30800 37400	29400 35000	27100 31200
VI	Foamed-in-place urethane insulation	32700 38900	31300 36600	29200 33100

Table 12
Present Worths of Total Costs Based on 10% Discount Rate

	Insulation System	Total 10 Year Costs / Total 25 Year Costs ($) −20° Zone	0° Zone	+20° Zone
I	No insulation	28950 32950	27500 30900	25200 27700
II	Vermiculite or perlite insulation	28700 32200	27400 30400	25500 27700
III	1-in. Foamglass board insulation	29300 32900	28100 31100	26100 28400
IV	1-in. Fiberglass or polystyrene insulation	29000 32600	27800 30800	25800 28100
V	1-in. Paper-backed urethane insulation	29300 32900	28100 31100	26100 28400
VI	Foamed-in-place urethane insulation	31300 34600	30100 33000	28300 30400

12. A low discount rate improves the position of solutions with a higher first cost and lower operating costs. Evaluations are shown for 0%, 6% and 10% discount rates to illustrate the results of rate variation. The rate of 6% was also chosen since it approximates the current commercial discount rate; 10%, since it is the government discount.

The assumed service life of the building is also important. Ten and twenty-five year lifes were selected to correspond with semi-permanent and permanent military construction. However, many military facilities remain in service for longer than twenty-five years. In a building with a forty year life, the economic disadvantage of foamed-in-place urethane would be almost eliminated.

Another factor to be questioned is the cost of installation. The unit cost for foamed-in-place urethane used in Appendix II is near the high end of a wide range of cost data submitted by various suppliers. A change in the assumed price from $1.50 per pound in place to $1.10 per pound in place (which is near the middle of the range) would also eliminate most of the cost disadvantage of the urethane insulation. It is reasonable to expect that the cost of this material will become relatively less as commercial application increases.

6 CONCLUSIONS

This investigation on the use of foamed-in-place urethane insulation in masonry cavity walls revealed that the urethane foam itself has impressive physical properties, but experiences many drawbacks in application. The following conclusions on the use of foamed-in place urethane insulation in masonry walls are based on the investigation into the nature of the material and the application of the product to a typical building.

1. The material is applied at a 2 pcf density for its best advantages.
2. Urethane foam has the lowest "K" value (0.12–0.16) of any commonly used insulation material.
3. The closed cell content of the foam gives it excellent water resistive properties.
4. The material exhibits a remarkable strength-weight ratio.
5. Although small-scale ASTM tests classify rigid urethane foam as non-burning, a parallel laboratory test by Factory Mutual Research Corporation shows that it will support combustion when its ignition source is removed. However, when foamed-in-place urethane completely fills the wall cavity, it does not add significant flammability or toxicity hazard. Nevertheless, urethane foam does not have acceptable smoke development properties as required by Department of Defense Construction Criteria Manual, DOD 4270.1-M.
6. Vapors released in the foaming process are toxic in heavy concentration. Health and safety precautions must be observed.
7. Temperature of the substrate surfaces and the environment should be between 65°F to 85°F, and substrates should be dry to ensure full expansion, adhesion, and cure of the urethane.
8. Major building codes and standard specifications require that all plastics used in construction must meet certain standards designated by ASTM or private testing programs. Rigid urethane foam performs adequately in all of the required tests for which there are documented results.
9. Initial cost of foamed-in-place urethane insulation exceeds that of other commonly used insulation materials.

10. The sample facility with foamed-in-place urethane insulation realized annual operating cost savings of approximately 15% over the same facility without insulation.

11. The total costs of the rigid urethane foam system for the sample facility are competitive with the total costs for the commonly used cavity wall insulations if the service life of the facility is 40 years or more.

In view of the absence of a significant economic advantage and in view of hazards to health and safety in application, it is recommended that foamed-in-place urethane insulation not be used in the masonry cavity walls of typical military construction. However, future developments in urethane technology may improve the fire resistance and reduce the unit cost relative to other types of insulation. If so, foamed-in-place urethane may become the most effective method of insulating cavity walls.

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APPENDIX I SURVEY RESULTS

The following survey questions were asked of 31 foam manufacturers, system suppliers, and installation contractors.* Following each question is a summary of answers from the 23 respondents. Of the 23, twelve claimed no involvement in the application under study.

1. What are the problems in maintaining foam quality during field application? *The main quality control problems are rigid atmospheric and substrate temperature-humidity requirements, equipment malfunctions, and inexperienced operators.*

2. How do temperature and humidity affect the placement of urethane foam in the field? *Atmospheric and substrate temperatures below 65°F or above 85°F affect expansion of urethane foam and alter its properties. High atmospheric humidity or wet substrates affect the foam's adhesion to the cavity surfaces.*

3. What are the properties of foam-in-place urethane?
   Density: a nominal 2.0 pcf density is used as a matter of practice; it is believed that the foam achieves its best properties for this application at 2.0 pcf.
   Coefficient of heat transfer: 0.12 to 0.16 BTU/in/ft²/hr/°F; either 0.14 or 0.15 is used for design purposes.
   Vapor permeability. 1 to 3 perms.
   Dimensional stability: minus 1% volume change for low temperature work, plus 2% for dry heat aging, and plus 2% for humidity aging.
   Flammability: self-extinguishing, 2-in burn according to ASTM D1692.
   Water absorption: 0.03 to 0.04 lbs/ft², or approximately 1% by volume.

4. How do these properties vary as the foam ages? *The above properties will be maintained if the foam components are properly stored in a controlled environment.*

5. What is the cost per pound of urethane foam? *The cost range is 40¢ ± 10%, depending on the quantity and location.*

6. What is the installed cost per pound of the foam for field applications? *The installed cost range is $1.10 ± 10%.*

7. Can you relate any case histories of foam-in-place urethane as a cavity wall insulation? *Generally, respondents had little practical experience with the use of foam-in-place urethane in masonry cavity walls.*

8. Do you have a listing of insulation contractors now using the foam-in-place method? *Five submitted short lists of five or fewer contractors that were using this process in 1969.*

The following are the survey questions asked of 11 foaming equipment suppliers. Following each question is a summary of the answers from the eight respondents.

1. Is your foaming equipment available for use in field application? *Yes.*

2. Can the equipment be adapted to pouring, spraying, and frothing? *Yes.*

3. What are the major problems encountered in field applications? *Inexperienced operators, machine maintenance, and rigid environmental requirements.*

4. How do temperature and humidity affect these problems in the field? *Moisture in the air will react with urethane materials, and the resultant reaction is capable of seizing pumps and plugging ports and filters.*

5. Do you have a listing of insulation contractors now using your equipment to foam urethane in-place? *Three submitted short lists of five or fewer contractors that were using the process in 1969.*

6. Can you supply us with literature, including costs, on the equipment you handle that is suitable for field application of urethane? *Price lists and descriptive brochures were sent, but the prices are now obsolete.*

*The mailing lists for both surveys were formulated from the 1966-67 Directory of the Society of the Plastics Industry.

APPENDIX II GENERAL CONSTRUTION AND HEATING EQUIPMENT COSTS

To compare the schemes without reference to geographical variances, a location factor of 100 is used throughout the cost analysis in this appendix.

Insulation systems are referred to by the following Roman numerals in the tables:

Scheme I. no insulation.

Scheme II. vermiculite or perlite. Material cost: .04/bf X 9502bf = 380. Labor cost: .02/bf X 9502bf = 190.

Scheme III. foam glass board. Material cost: .16/ft² X 4001ft² = 640. Labor cost: .08/ft² X 4001ft² = 320.

Scheme IV. fiberglass or polystyrene. Material cost: .11/ft² X 4001ft² = 440. Labor cost: .07/ft² X 4001ft² = 280.

Scheme V. paper-backed urethane. Material cost: .18/ft² X 4001ft² = 720. Labor cost: .07/ft² X 4001ft² = 280.

Scheme VI. foamed-in-place urethane. Material cost: .40/lb X 1584 lbs = 634. Labor cost: 1.10/lb X 1584 lbs = 1742.

Table A

Heating Equipment Costs *(Dollars except bracketed figures)*

	SCHEME I			SCHEME II		
	−20° zone	0° zone	+20° zone	−20° zone	0° zone	+20° zone
Heating load (BTU/hr)	[451900]	[353400]	[254900]	[397840]	[311350]	[224870]
Gas boiler cost	1005	869	600	869	734	561
[Hours labor] /labor cost (hrs × 6.83 + 20% ins)	[7] 58	[6.5] 52	[5.5] 46	[6.5] 53	[6] 49	[5] 41
Overhead (10%), subcontractor profit (10%), general contractor profit (10%), and bond (1%): approximate total 34%	361	313	220	313	266	205
Subtotal	1424	1234	866	1235	1049	807
Approximate Total (with 15% contingencies)	1750	1500	1100	1500	1300	1000

	SCHEMES III, IV, V			SCHEME VI		
	−20° zone	0° zone	+20° zone	−20° zone	0° zone	+20° zone
Heating load (BTU/hr)	[401220]	[313980]	[226740]	[377570]	[295590]	[213600]
Gas boiler cost	869	734	561	869	734	561
[Hours labor] /labor cost (hrs × 6.83 + 20% ins)	[6.5] 53	[6] 49	[5] 41	[6.5] 53	[6] 49	[5] 41
Overhead (10%), subcontractor profit (10%), general contractor profit (10%), and bond (1%): approximate total 34%	313	266	205	313	266	205
Subtotal	1235	1049	807	1235	1049	807
Approximate Total (with 15% contingencies)	1500	1300	1000	1500	1300	1000

Table B
Total Construction Costs (unit cost x .4001 ft²)

UNIT COSTS ($)	Scheme I	Scheme II	Scheme III	Scheme IV	Scheme V	Scheme VI
4" conc block wall						
material: .30/ft²	1200	1200	1200	1200	1200	1200
labor: .85/ft²	3401	3401	3401	3401	3401	3401
4" brick wall						
material: .55/ft²	2201	2201	2201	2201	2201	2201
labor: 1.05/ft²	4201	4201	4201	4201	4201	3401
Clean brick wall						
material: .02/ft²	80	80	80	80	80	80
labor: .12/ft²	480	480	480	480	480	480
Clean conc block wall						
material: .005/ft²	20	20	20	20	20	20
labor: .02/ft²	80	80	80	80	80	80
Insulation*						
material*	–	380	640	440	720	634
labor*	–	190	320	280	280	1742
Insurance (13% of labor)	1061	1086	1103	1097	1097	1288
Overhead (10% of total)	1273	1332	1373	1348	1378	1533
Profit (10% of total)	1400	1465	1510	1483	1512	1686
Bonds (1% of total)	154	161	166	163	167	185
Subtotal	15550	16277	16775	16477	16817	18731
TOTAL (plus 15% contingencies and 5.8% S&E)	18900	19800	20400	20100	20400	22800

*Insulation costs are listed at the beginning of Appendix II.

APPENDIX III HEAT COSTS

The following formula was used to calculate the quantity of gas used for a heating season: $F = U \times N \times D \times C_f$[1], where F is the quantity of gas in therms; U, the unit fuel consumption (0.0049); N, the heating load; D, the degree days*, and C_f, the temperature correction factor (–20° zone, $C_f = 0.778$; 0° zone, $C_f = 1.000$; +20° zone, $C_f = 1.4$). The following monthly unit prices were used for calculating gas costs (to compare the schemes without reference to geographical location, unit prices were derived by averaging typical unit prices for each temperature zone):

first 10 therms or less	$2.20
next 20 therms	.132/therm
next 70 therms	.121/therm
next 200 therms	.110/therm
excess therms	.008/therm

Annual heating costs are computed with typical "U" factors of the six insulation schemes studied. Scheme I (no insulation) has a "U" factor of 0.27, scheme II (vermiculite or perlite insulation), 0.11: schemes III, IV, and V (rigid board insulation), 0.12 and scheme VI (foamed-in-place urethane insulation), 0.05.

[1] "ASHRAE Guide and Data Book" (American Society of Heating, Refrigeration, and Air Conditioning Engineers, 1966), p. 243–244.

*Typical "degree days" for the individual temperature zones were taken from "Climates of the States" (Weather Bureau, 1966) for the following locations: Helena, Montana (–20° zone), Twin Falls, Idaho (0° zone), and Medford, Oregon (+20° zone).

Table A
Annual Heating Costs in –20°F Temperature Zone

		Scheme I		Scheme II		Schemes III, IV, V		Scheme VI	
Month	°Days	Therms	Cost/M	Therms	Cost/M	Therms	Cost/M	Therms	Cost/M
Jan	1469	2529	231.46	2227	204.88	2246	206.55	2113	194.85
Feb	1165	2006	185.43	1766	164.31	1781	165.63	1676	156.39
Mar	1017	1751	163.00	1543	144.60	1555	145.75	1463	137.65
Apr	654	1126	108.00	991	96.11	1000	96.91	941	41.71
May	399	687	69.36	605	62.15	610	62.59	574	59.42
Jun	197	339	38.74	299	35.20	301	35.40	283	33.44
Jul	36	62	8.71	55	7.86	55	7.86	52	7.50
Aug	66	114	14.85	100	13.31	101	13.42	95	12.70
Sep	320	551	57.35	485	51.59	489	51.94	460	49.39
Oct	617	1062	102.37	935	91.19	943	91.89	888	87.05
Nov	999	1770	160.27	1514	142.14	1527	143.28	1437	135.36
Dec	1311	2257	207.52	1987	183.76	2004	185.26	1886	174.87
ANNUAL COST			$1350.00		$1200.00	--	$1210.00	–	$1140.00

Table B
Annual Heating Costs in 0°F Temperature Zone

		Scheme I		Scheme II		Schemes III, IV, V		Scheme VI	
Month	°Days	Therms	Cost/M	Therms	Cost/M	Therms	Cost/M	Therms	Cost/M
Jan	1324	2293	210.69	2020	186.67	2036	188.07	1918	177.69
Feb	1058	1832	170.12	1614	150.94	1628	152.17	1532	143.72
Mar	905	1567	146.80	1381	130.43	1392	131.40	1311	124.27
Apr	555	961	93.47	847	83.44	854	84.06	804	79.66
May	319	552	57.48	481	51.23	491	52.11	462	49.56
Jun	141	244	29.15	215	25.96	217	26.18	204	24.75
Jul	0	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0	0
Sep	172	298	35.09	262	31.13	265	31.46	249	29.70
Oct	493	854	84.06	752	75.08	758	75.61	714	71.38
Nov	600	1558	146.01	1373	129.73	1385	130.79	1304	123.66
Dec	1166	2019	186.58	1779	165.46	1794	166.78	1689	157.54
ANNUAL COST			$1160.00	–	$1030.00	-	$1040.00	–	$980.00

Table C
Annual Heating Costs in +20°F Temperature Zone

		Scheme I		Scheme II		Schemes III, IV, V		Scheme VI	
Month	°Days	Therms	Cost/M	Therms	Cost/M	Therms	Cost/M	Therms	Cost/M
Jan	918	1605	150.15	1416	133.51	1427	134.49	1345	127.27
Feb	697	1219	116.18	1075	103.57	1084	104.30	1021	98.75
Mar	642	1123	107.73	990	96.03	998	96.73	941	91.71
Apr	432	755	75.35	666	67.57	672	68.04	633	64.61
May	242	423	45.13	373	41.73	376	41.99	355	40.15
Jun	78	136	17.27	120	15.51	121	15.62	114	14.85
Jul	0	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0	0
Sep	78	136	17.27	120	15.51	121	15.62	114	14.85
Oct	372	650	66.11	574	53.26	578	59.77	595	61.27
Nov	678	1186	113.27	1046	100.95	1054	101.66	993	96.29
Dec	871	1523	142.93	1344	127.18	1354	128.06	1276	121.20
ANNUAL COST		-	$850.00	–	$760.00	-	$770.00	–	$730.00

APPENDIX IV COOLING COSTS

Electricity cost estimates for a cooling season are shown below. The maximum cooling load for the building without insulation is 255,511 BTU/hr, whereas the maximum cooling load for the building with urethane cavity wall insulation is 247,293 BTU/hr. The reduction is 3%. Because of the graduated unit price structure of electricity, the reduction in cooling costs will be less than 3% (less than $7/season). Since the cost difference is negligible, the cooling costs have not been included in the report proper.

Table A
Cooling Conditions at Time of Peak Load (1500 Hours Suntime)

	Dry Bulb Temperature (°F)	Wet Bulb Temperature (°F)	Relative Humidity (%)	Dew Point (°F)	Grams Moisture per Pound Dry Air
Outside	95	78	48	72	117.7
Room	80	67	50	60	76.7
Difference	15	–	–	--	40.0

Table B
Cooling Load Estimate for a Building Without Insulation

Item	Factor	No. of Units	BTU/hr
Sensible Load:			
N Glass (ft²)	27	112	3030
E Glass (ft²)	27	170	4580
S Glass (ft²)	40	144	5760
W Glass (ft²)	138	192	26500
N Wall (ft²)	0.27	514	139
E Wall (ft²)	4.9	849	4130
S Wall (ft²)	1.9	693	1810
W Wall (ft²)	2.4	1024	2490
Insulated panels	4.3	122	527
Roof/ceiling (ft²)	5.3	2415	12800
Partition (ft²)	3.0	1927	5867
People (number)	200	40	8000
Lights (watts)	34	2034	69000
SUBTOTAL			147283
Safety factor	0.10		14728
SUBTOTAL			162011
Latent Load:			
People (number)	275	40	11000
SUBTOTAL			173011
OA Sensible (ft³/min)		1810	29300
OA Latent (ft³/min)		1810	53200
TOTAL LOAD			255511

Table C
Cooling Load Estimate for a Building With Urethane Insulation

Item	Factor	No. of Units	BTU/hr
Sensible Load:			
N Glass (ft²)	27	112	3030
E Glass (ft²)	27	170	4580
S Glass (ft²)	40	144	5760
W Glass (ft²)	138	192	26500
N Wall (ft²)	0.02*	514	10
E Wall (ft²)	0.36*	849	305
S Wall (ft²)	0.14*	693	98
W Wall (ft²)	0.18*	1024	184
Insulated panels	4.3	122	527
Roof/ceiling (ft²)	5.3	2415	12800
Partition (ft²)	3.0	1927	5867
People (number)	200	40	8000
Lights (watts)	34	20304	69000
SUBTOTAL			139812
Safety factor	0.10		13981
SUBTOTAL			153793
Latent Load:			
People (number)	275	40	11000
SUBTOTAL			164793
OA Sensible (ft³/min)		1810	29300
OA Latent (ft³/min)		1810	53200
TOTAL LOAD			247293

*Modified factors.