NBS TECHNICAL NOTE 946

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Urea-Formaldehyde Based Foam Insulations:

An Assessment of Their Properties and Performance

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Disclaimer:

Certain trade names and company products are identified in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the products are necessarily the best available for the purpose.

UREA-FORMALDEHYDE BASED FOAM INSULATIONS: AN ASSESSMENT OF THEIR PROPERTIES AND PERFORMANCE

by

Walter J. Rossiter, Jr., Robert G. Mathey,
Douglas M. Burch, and E. Thomas Pierce

The properties and performance of urea-formaldehyde based foams pertinent to their use as insulation in buildings were assessed based essentially on existing information. Pertinent materials properties were identified and guidelines prepared for the suggested values of these properties along with corresponding methods of test. For certain materials properties information was not found to enable suggested values of these properties. The factors affecting performance of urea-formaldehyde based foam insulations were also identified and discussed. Some performance factors could not be adequately evaluated because of insufficient or contradictory data in the literature. Methods of foam application were studied and suggested general application guidelines were prepared.

The advantages and disadvantages of using urea-formaldehyde based foam insulations were discussed and problem areas identified. Recommendations were made pertaining to the use and assessment of urea-formaldehyde based foam insulations for residential construction.

Keywords: Cellular plastics; foam insulation; insulation; materials properties; performance; urea-formaldehyde.

1. INTRODUCTION

1.1 Background

The energy crisis has increased interest in the use of cellular plastics for insulation because of their thermal insulation characteristics and their ability to be used on irregularly shaped surfaces or in spaces where access is difficult. There have been problems associated with cellular plastics used in residential construction; however, it is believed that by proper formulation, design, and application many of these problems can be resolved.

Urea-formaldehyde based foam is one of the oldest of the cellular plastics, having been known since 1933 [1][1/]. The principal application of urea-formaldehyde based foam is as thermal insulation in new and existing building construction. Although it has been commercially available in the United States since the 1950's [2], its use as an insulation has not been extensive. It has been more widely used in Northern Europe for nearly 20 years [3], primarily in the cavities of masonry walls. However, with the energy crisis and the need to conserve energy, the use of urea-formaldehyde based foam insulation in the United States has been increasing. In recent years in the United States it has been applied mostly as a thermal insulation for retrofitting walls of residences.

Although urea-formaldehyde based foam insulation has been considered a generic material, there are differences in composition and properties of the various foams available in the United States. Additives, fillers, extenders and plasticizers may be added to the foam to improve or alter some of its properties such as to increase the compressive strength of the foam, to reduce brittleness, to mask odors and to discourage vermin. Different types of apparatus are used to produce the foam and mechanically mix the component materials at the job site, which may result in some differences in cell structure and cell size.

Guidelines are presently not available in the United States for the evaluation and use of urea-formaldehyde based foam insulations. Much of the information available about the foams in the literature is contradictory. There are no material, product or industry standards. The American Society for Testing and Materials (ASTM) has appointed a task group to initiate development of a standard for urea-formaldehyde based foam insulations. Because of the potential benefits in energy conservation to be gained through its proper use and application, the U.S. Department of Housing and Urban Development (HUD) requested the U.S. National Bureau of Standards (NBS) to assess the current state-of-the-art of urea-formaldehyde based foam technology. This study for HUD was intended to summarize existing information on the properties and application of urea-formaldehyde based foams that are pertinent to their use as insulation in buildings, and to determine whether or not sufficient experience and research data exist to serve as a basis for recommending guidelines for their use and application.

1.2 Objectives of the Report

The objectives of this report are:

1) to present currently available information on which the assessment of urea-formaldehyde based foam insulations may be based;

2) to identify the properties of urea-formaldehyde based foams which affect their performance as thermal insulation;

1/ Figures in brackets indicate references listed in Section 12.

3) to recommend guidelines for suggested materials properties and to identify existing test methods for measuring these properties; and

4) to recommend general guidelines for the proper application of the foam.

1.3 Scope of the Project

The project was limited to an assessment of urea-formaldehyde based foams as thermal and sound insulation for buildings. Other uses, such as the insulation of refrigerated trucks, have not been considered.

There are three types of systems by which urea-formaldehyde based foams are generated. In one, the urea-formaldehyde based resin is transported to the job site as an aqueous solution. In another, the resin is brought to the job site as a powder and mixed with water on-site. In the third, the resin is brought to the job site as a concentrated solution where it is diluted with water prior to application. This report is limited to an assessment of the first type of system (aqueous solution), since the powder-water mixtures and concentrated solutions are not generally used in the United States at the present time.

1.4 Sources of Information

As requested by HUD, the assessment of the properties and performance of urea-formaldehyde based foam insulations was based essentially upon existing information and not NBS laboratory studies. NBS did conduct limited tests to observe the effect of the combination of high temperature and humidity on urea-formaldehyde based foams. Shrinkage of a foam in a residential building at their facilities was also observed.

There were four major sources from which the information was gathered. The first source was the chemical and engineering literature. A second source was building research organizations in foreign countries where the foams have had more use than in the United States. Information was received from Canada, the United Kingdom, the Netherlands, France, and West Germany that included research reports, material standards and application standards. A third source was the four major United States producers of urea-formaldehyde based foam insulations. Producers cooperated with NBS by supplying product information, application guidelines and test reports on their products from independent testing laboratories. The final source was third parties who were familiar with urea-formaldehyde based foams, including testing laboratories, researchers and building code officials. The information was collated and assessed by a team of NBS researchers consisting of a chemist, materials engineer, mechanical engineer, and a physicist.

2. SYNOPSIS OF THE MAJOR FINDINGS

This study involved a comprehensive survey to assess urea-formaldehyde based foams and their performance as thermal insulation. The assessment was based on information and data obtained from a review of the literature complemented by private communications and test results. Detailed discussions of findings and data are presented in subsequent sections of the report to substantiate the information and guidelines for materials properties given in the synopsis.

There are a number of advantages associated with urea-formaldehyde based foam insulations. First of all, the use of the foams as cavity wall insulation conserves energy through reduced fuel consumption. It is unfortunate, however, that few studies evaluating energy savings are available in the literature.

Secondly, urea-formaldehyde based foams are easy to install. Installation techniques have been developed by the major resin producers who have also initiated training programs for their applicators. Conscientious conformance to the installation guidelines by applicators should reduce the risk of faulty application to a minimum.

The component materials from which the foams are produced are easy to transport and handle since they are available as aqueous solutions in 55 gallon (0.21 m^3) drums. Because they are aqueous solutions, clean-up of application equipment is easily accomplished with water. In addition, it has been reported that the materials offer little risk of a health hazard to the applicator provided contact of the materials with the eyes and skin is avoided.

A fourth advantage is that the properly installed foam offers no excessive safety hazard to the occupants of the building. Based on a current method for evaluating the fire resistance properties of foam plastics, urea-formaldehyde based foams present no excessive risk of fire. It must be remembered that the foam is combustible as defined by ASTM E 176-73[1/]. The fumes from burning foam have been shown to be no more toxic than burning plywood or northern white pine products when tested in the laboratory according to a current test for determining smoke toxicity. The validity of the smoke toxicity test has not been established. Based on the results of fire and toxicity tests, some proprietary foams have been accepted for use by certain building code organizations.

Some proprietary foams have been subjected to inhalation toxicity tests and were classified as being non-toxic.

1/ Combustible is defined as capable of undergoing combustion (any chemical process that produces light and heat either as glow or flames) in air, at pressures and temperatures that might occur during a fire in a building, or in a more severe environment when specified.

The foams present no attraction as a feed for vermin and are normally resistant to mold growth.

The foams are being used abroad to a greater extent than in the United States. As a consequence, certain European countries and Canada have or are in the process of developing standards for the foams. These documents are referred to frequently in this report.

Finally, from the available information it appears that the likelihood of a formaldehyde odor problem occurring in residences after foaming is slight. The evidence indicates that there has only been a minor incidence of the problem. However, if an odor problem does occur, it could be major, especially if the foam has to be removed to eliminate the odor.

A number of disadvantages associated with the foams have also been identified. First, some material and performance properties have not been determined. Those properties which have been determined and agreed upon in the literature include density, mechanical strength, and water absorption. A design value for the thermal conductivity of the foam has been recommended in Section 7.20. For other performance properties, there are insufficient data available from which performance may be adequately evaluated. Performance properties in this category include the effect of the foams on other building materials, the resistance of the foams to freezing and thawing, water vapor transmission, the effect of absorbed water on the thermal conductivity of the foams, shrinkage of the foams, maximum service temperature and the effect of high temperature and high humidity.

For some properties of the foams the data in the literature are contradictory. A notable example is the maximum service temperature which is reported to range from 120°F (49°C) to 320°F (160°C). It is difficult to assess any property from a literature survey where the range of values are widespread.

The final disadvantage is that no standards or specifications exist in the United States for urea-formaldehyde based foams. Standards are written to assure a minimum level of quality in a material. At the present, no means of assuring a minimum level of quality of urea-formaldehyde based foams are available. The ASTM has appointed a task group to initiate development of a standard for these foams.

In addition to determining advantages and disadvantages associated with urea-formaldehyde based foams, two major problem areas have also been identified. The problem areas deal with shrinkage of the foam and its resistance to high temperature and high humidity. Evidence from preliminary tests conducted at the National Bureau of Standards supports information from the literature that these aspects of the performance of the foams may be suspect. In considering shrinkage, the evidence has shown that one urea-formaldehyde based foam in a test house has continued to shrink 20 months after application without any indication of stabilizing. The magnitude of the linear shrinkage after 20 months was observed to be 7.3 percent. With regard to the resistance of the foams to high temperature and high humidity, the preliminary results have shown that 3 out of 4 different foam specimens disintegrated after 7 weeks exposure to 122°F (50°C) and 92% rh. When comparable foam specimens were exposed to 104°F (40°C) and 92% rh, the same 3 out of the 4 specimens disintegrated after 14 weeks. Prior to disintegration of the three specimens, all the specimens underwent shrinkage, loss of weight and slight discoloration.

Both of these NBS preliminary observations raise serious questions concerning the durability of the foams when used under certain conditions. Field data are not available which demonstrate how long after application the shrinkage process continues or the amount of the shrinkage of the foams which may be expected in building constructions. Field data are also not available to document the performance of the foams in areas of the United States which are exposed to hot and humid weather conditions. Field surveys are needed to gather data that will show the in-service performance of the foams. Until such surveys are conducted, the question of durability will remain largely unanswered.

2.1 Guidelines for Materials Properties

The pertinent materials properties were identified and guidelines for the suggested values of these properties are presented in table 1 along with methods of test. For certain materials properties, information was not found to enable the suggestion of property values.

Values of the properties of urea-formaldehyde based foams as published in the literature are given in Sections 4 and 5 of this report. Factors affecting performance of the foams which are in many cases related to materials properties are discussed in Section 7. The information in these three sections was considered in preparing the suggested guidelines for material properties given in table 1.

Table 1. Suggested Guidelines for Materials Properties[1/]

Material Property	Suggested Value	Method of Test
Cell consistency	Uniform cell size without voids	Visual observation
Cell content (porosity)	Percent open cells not established	ASTM D 2856-70
Cell size	Range of cell size not established	Microscopic examination
Decomposition temperature	392°F (200°C), minimum	Oven test for one hour
Density, dry	0.6 to 0.9 lb/ft^3 (10 to 14 kg/m^3)	ASTM D 1622-63 (1975)
Density, wet	Approximately 2.5 lb/ft^3 (40 kg/m^3)	Weigh a foam filled plastic bag of known volume
Flammability	Flame spread classification should not exceed 25	ASTM E 84-76a, test specimen thickness comparable to application thickness
Freeze-thaw resistance	Not established	Not established
Mechanical properties		
Compressive strength	Not established	ASTM D 1621-73
Flexural strength	Not established	Not established
Friability	Not established	Not established
Tensile strength	Not established	ASTM D 1623-72
Mold resistance	No growth	ASTM G 21-70 (1975)
Shrinkage, linear during curing	4 percent maximum in 28 days	Sample size and test conditions not established
Shrinkage, linear long-term	Not established	Not established
Temperature and humidity resistance	Not established	ASTM D 2126-76, maximum temperature and humidity not established
Thermal conductivity	0.24 Btu in/h ft^2 °F (0.035 W/m·K)	ASTM C 177-72, mean temperature 75°F (24°C)
Toxicity		
Inhalation	Classified as non-toxic	Federal Hazardous Substances Act, Section 191(f)(2)-1961
Burning foam	No more toxic than fumes from burning wood	Not established
Water absorption	Not established; absorption through capillarity is slight	ASTM D 2842-69 (1975)
Water vapor permeability	Maximum value not established	ASTM C 355-64 (1973)
Vermin resistance	Not a feed for vermin	Not established

1/ These guidelines were suggested by the authors based on an assessment of available information.

3. GENERATION OF UREA-FORMALDEHYDE BASED FOAM INSULATIONS

As a building insulation, urea-formaldehyde based foam is generated on-site using portable equipment to foam a partially polymerized urea-formaldehyde based resin mechanically which then reacts chemically (cures) in place. This process has been described in the literature [1, 3, 4, 5].

Three major ingredients are used in the generation of the foam: urea-formaldehyde based resin, a surfactant (generally called a foaming agent) which includes an acid catalyst or hardening agent, and air. The resin and foaming agent-catalyst mixture are transported to the job site as aqueous solutions in two separate containers.

The equipment for generating the foam generally consists of a compressed air pump and a mixing or foaming gun. In the United States the foaming agent-catalyst mixture is in general pumped into the gun where compressed air mixes with it and mechanically expands it into foam consisting of small bubbles. The bubbles are then coated in the nozzle of the gun with the urea-formaldehyde based resin which has been pumped through a separate line into the gun. The foam, consisting of resin coated bubbles, is forced out of the gun under pressure at which time it contains about 75 percent water by weight.

After the urea-formaldehyde based resin mixes with the catalyst on the surface of the foam bubbles, the resin immediately begins to cure. The resin coated bubbles exit from the nozzle of the gun as a white, fully expanded lather which has a consistency typically described as resembling a foam shaving cream. Normally, within less than a minute after leaving the gun, the resin has partially cured into a stiff, self-supporting foam. Complete chemical curing of the foam generally occurs within weeks after application. The rate of chemical curing is dependent upon factors such as temperature and foam formulation. The water, present initially during foaming, dries out at a rate which is dependent upon temperature humidity and the type of construction to which the foam is applied.

The chemical formulations used in the production of urea-formaldehyde based foams are proprietary and are not reported in the literature. It is known that minor components are often added to the basic formulations in order to improve or alter the foam properties. For example, components may be added to lessen the friability of the foam or to mask an odor of formaldehyde. For purposes of this report, a knowledge of the chemical compositions of the foam formulations is not necessary, since the performance of the foam insulation is of primary importance. The foam is produced on the job by mechanical mixing and stabilized by a chemical reaction. Therefore, proper foam producing ingredients, proper use of the foaming equipment and proper application are critical in producing an acceptable product. If basic principles governing chemical reactions, which are intrinsic to the foaming process, are violated, an unacceptable product may result. In this regard the quality of the foam is dependent upon a number of application parameters such as:

- the quality of the ingredients
- the ratios of the ingredients
- the mixing of the ingredients
- the viscosities of the ingredients
- the age or shelf-life of the ingredients
- the temperature at which the foaming takes place.

4. PROPERTIES OF UREA-FORMALDEHYDE BASED FOAMS

4.1 The Literature

As part of the assessment of the performance properties of urea-formaldehyde based foam insulations, an extensive literature search was conducted. The primary sources examined for literature citations were the chemical and engineering abstract services and the files of the U.S. National Technical Information Service (NTIS). A number of publications concerning urea-formaldehyde foam insulation were obtained from the literature survey. Many articles were qualitative, describing the foaming process, and the advantages and disadvantages of using the foam. Other articles were quantitative, listing values of the mechanical, chemical, and physical properties. These property values, as reported in the literature, were tabulated and are given in table 2. For many of these properties, neither the test methods nor the test conditions were specified. It can be seen from table 2 that much of the published data on the material properties of urea-formaldehyde based foams cover a wide range and in some cases are contradictory. A possible explanation for this is that the foams and test conditions may not have been identical. The foams may not be identical because of differences in source and foaming equipment used to produce them.

4.2 Test Reports

The major manufacturers[1/] of urea-formaldehyde based foam insulations cooperated with the National Bureau of Standards by providing copies of reports of tests in which properties of urea-formaldehyde based foams were measured. These tests were in general conducted by independent testing laboratories under the sponsorship of the urea-formaldehyde based foam manufacturers. Additional reports were obtained from other research and testing laboratories which had conducted laboratory tests on urea-formaldehyde based foams. Values of properties of urea-formaldehyde based foams as measured by independent testing and research laboratories are also presented in table 2 along with the property values obtained from the chemical and engineering literature.

1/ The major manufacturers of urea-formaldehyde based foam insulations are listed in Appendix A.

4.3 The Properties

Those properties of urea-formaldehyde based foams for which numerical values were found in the literature or were given in test reports include:

- Cell size
- Cell structure
- Coefficient of linear expansion
- Compressive strength
- Density
- Flammability
- Flexural modulus
- Freeze-thaw cycling resistance
- Shrinkage
- Thermal conductivity
- Thermal stability
- Water absorption
- Water vapor transmission.

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports

PROPERTY	VALUE[1/]	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Cell Size	8×10^{-4} to 2×10^{-2} in (2×10^{-2} to 5×10^{-1} mm)	*[2/]	-	-	L.[3/]	6
	4×10^{-5} to 1×10^{-2} in (1×10^{-3} to 3×10^{-2} mm)	*	-	-	L.	7
Cell Structure	99.3% open	*	-	-	L.	6
	99% open	*	-	-	L.	8
	80% closed 20% open	*	-	-	L.	9
	60% closed 40% open	*	-	-	L.	7
Coefficient of Linear Expansion	5×10^{-5}/°F (9×10^{-5}/°C)	*	-	-	L.	10
	no contraction	*	Sample cooled from 68°F to 5°F (20°C to -15°C)	-	T.R.[4/]	11
Compressive Strength	25 lb/in^2 (172 kPa)	*	-	-	L.	10
	5 lb/in^2 (34 kPa)	ASTM D 1621	-	Compressive strength at 10% deflection	L.	12

1/ Values in parentheses are in S.I. units.
2/ The asterisk indicates that the test method was not described in the quoted reference.
3/ L. indicates that the quoted reference is a literature citation.
4/ T.R. indicates that the quoted reference is a test report citation.

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports (cont.)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Density	0.40 to 0.45 lb/ft^3 (6.4 to 7.2 kg/m^3)	*	-	-	L.	6
	1 to 4 lb/ft^3 (16 to 64 kg/m^3)	*	-	-	L.	10
	2 to 10 lb/ft^3 (32 to 160 kg/m^3)	*	-	-	L.	10
	0.5 to 10 lb/ft^3 (8 to 160 kg/m^3)	*	-	-	L.	2
	0.6 to 1.2 lb/ft^3 (10 to 19 kg/m^3)	*	-	-	L.	1
	0.5 lb/ft^3 (8 kg/m^3)	*	-	-	L.	13,14
	0.7 lb/ft^3 (11 kg/m^3)	*	dry foam	-	L.	15,16
	2.5 lb/ft^3 (40 kg/m^3)	*	freshly prepared wet foam	-	L.	15
	0.8 lb/ft^3 (13 kg/m^3)	*	-	-	T.R.	11
Flammability 5/						
flame spread	25	ASTM E 84	-	-	L.	9,15,16
smoke density	0-5	ASTM E 84	-	-	L.	9,15,16
fuel contributed	10	ASTM E 84	-	-	L.	15

5/ The ASTM E 84 tunnel test is recommended as one way to judge the fire performance of insulations, since other test methods relating to primary safety properties such as ignitability and rate of heat release are not fully developed [17]. ASTM E 84 is a laboratory test of a material and is not intended to show the hazard presented by the material under actual fire conditions. In general plastic foams are difficult to evaluate by ASTM E 84.

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports (cont.)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Flammability						
flame spread fuel contributed	15 15	Factory Mutual Calorimeter Test	2.5 in (64 mm) thick foam between 0.5 in (13 mm) thick paper-faced gypsum wall board	-	T.R.	18
flame spread smoke density fuel contributed	15 30 10	ASTM E 84-68	3.5 in (89 mm) thickness 1.98 lb/ft^3 (32 kg/m^3) density	-	T.R.	19
flame spread smoke density fuel contributed	20-35 15 0	UL 723	1.5 in (38 mm) thickness 0.5 to 0.7 lb/ft^3 (8 to 11 kg/m^3) density	-	T.R.	20
flame spread smoke density fuel contributed	15 5 0	UL 723	4 in (102 mm) thickness 0.5 to 0.7 lb/ft^3 (8 to 11 kg/m^3) density	-	T.R.	20
flame spread smoke density fuel contributed	5 5 0	ASTM E 84-70	1.5 in (38 mm) thickness	-	T.R.	21
flame spread smoke density fuel contributed	25 0-5 10	ASTM E 84-61	2 in (51 mm) thickness	-	T.R.	22
flame spread smoke density fuel contributed	0 0 0	ASTM E 84	tests were conducted on specimens 1.5, 2.5 and 2.5 in (38, 64 and 64 mm) thickness	results were identical for all 3 specimens	T.R.	23

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports (cont.)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Flammability						
flame spread smoke density fuel contributed	10 18 0	ASTM E 84-70	1.5 in (38 mm) thickness	-	T.R.	24
flame spread smoke density fuel contributed	5 0 0	ASTM E 84-70	2.5 in (64 mm) thickness 0.85 lb/ft^3 (14 kg/m^3) density	results of three tests	T.R.	25
Flexural Modulus	1600 lb/in^2 (11 MPa)	*	-	-	L.	10
Flexural Strength	20 lb/in^2 (138 kPa)	*	--	-	L.	10
Freeze-Thaw Cycling Resistance	no damage after 25 cycles	foam cycle between 59 and 5°F (15 and -15°C)	foam was reportedly saturated with water	report does not define how the water content of the foam was determined	L.	11
Shrinkage						
linear, during cure at ambient conditions	10-12% 3%	*	low density specimen normal density	-	L.	14
	1-3%	*	-	-	L.	7
	1.8-3.0%	*	- -	-	L.	15

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports (cont.)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Shrinkage						
linear, during cure at ambient conditions	2%	test on simulated stud frame wall panel	-	linear shrinkage after 114 days	T.R.	26
	1.8%	*	-	-	T.R.	11
	2.1% (length) 2.8% (width)	*	sample at 73°F (23°C) and 50% rh for 1 week	specimen was in an "open cavity"	T.R.	27
	1.5% (length) 1.7% (width)	*	sample at 73°F (23°C) and 50% rh for 1 week	specimen was in an "closed cavity"	T.R.	27
Shrinkage						
linear, at conditions other than ambient	4.6% 4.4%	ASTM D 2126 Procedure C	sample at 100°F (38°C) and 100% rh for 4 days	changes in length or width for duplicate specimens	T.R.	28
	6.7% 10.0%	ASTM D 2126 Procedure C	sample at 100°F (38°C) and 100% rh for 4 days	changes in thickness for duplicate specimens	T.R.	28
	30% (length) 30% (width) 45% (thick)	ASTM D 2126-66	sample at 158°F (70°C) and 90-100% rh for 10 days	specimens could not be handled at the end of test	T.R.	29
	5.9% (length) 5.3% (width) 6.4% (thick)	ASTM D 2126-66	sample at 200°F (93°C) for 10 days (humidity not reported)	-	T.R.	29

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports (cont.)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Thermal Conductivity Btu in/ft^2 h °F (W/m·K)	0.18 (0.026)	ASTM C 177	35°F (2°C) mean temperature	-	L.	15
	0.2 (0.029)	ASTM C 177	70°F (21°C) mean temperature	-	L.	15
	0.18-0.22 (0.026-0.032)	*	-	-	L.	30
	0.2 (0.029)	*	80°F (27°C) mean temperature	-	L.	7,16
	0.20 (0.029)	*	-	-	L.	10,31
	0.208 (0.0300)	*	-	-	L.	9
	0.21 (0.030)	*	density 0.5 lb/ft^3 (8 kg/m^3)	-	L.	14
	0.22 (0.032)	*	-	-	L.	4,10
	0.22-0.24 (0.032-0.035)	*	-	-	L.	13
	0.24 (0.035)	*	-	-	L.	8
	0.245 (0.0353)	*	-	-	L.	32

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports (cont.)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Thermal Conductivity Btu in/ft^2 h °F (W/m·K)	0.25 (0.036)	*	-	-	L.	10
	0.28 (0.040)	*	-	-	L.	33
	0.24-0.29 (0.035-0.042)	*	-	-	L.	34
	0.26 (0.037)	Dynatech Rapid K testing apparatus	density 0.73 lb/ft^3 (12 kg/m^3) test temperature 71°F (22°C)	average of 4 measurements, values varied from about 0.25 to 0.27 (0.036 to 0.039)	L.	35
	0.26 (0.037)	Dynatech Rapid K testing apparatus	density 0.73 lb/ft^3 (12 kg/m^3) test temperature 40°F (4°C)	average of 4 measurements, values varied from about 0.24 to 0.28 (0.035 to 0.040)	L.	35
	0.25 (0.036)	Dynatech Rapid K testing apparatus	density of 0.73 lb/ft^3 (12 kg/m^3) test temperature 20°F (-7°C)	average of 4 measurements, values varied from about 0.24 to 0.26 (0.035 to 0.037)	L.	35
	0.201 (0.0290)	ASTM C 177	density 0.7 lb/ft^3 (11 kg/m^3) mean temperature 79°F (26°C)	-	T.R.	36

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports (cont.)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Thermal Conductivity Btu in/ft^2 h °F (W/m·K)	0.207 (0.0298)	ASTM C 177-45	density 0.75 lb/ft^3 (12 kg/m^3) mean temperature 79°F (26°C)	-	T.R.	37
	0.223 (0.0322)	ASTM C 177	thickness 1.5 in (38 mm) mean temperature 77°F (25°C)	-	T.R.	38
	0.225 (0.0324)	ASTM C 518-70	density 1.07 lb/ft^3 (17 kg/m^3) mean temperature 72°F (22°C)	-	T.R.	39
	0.225 (0.0324)	ASTM C 518-70	density 0.86 lb/ft^3 (14 kg/m^3) mean temperature 72°F (22°C)	-	T.R.	39
	0.23 (0.033)	ASTM C 518-70	density 1.05 lb/ft^3 (17 kg/m^3) mean temperature 72°F (22°C)	-	T.R.	39
	0.235 (0.0339)	ASTM C 518-70	density 0.64 lb/ft^3 (10 kg/m^3) mean temperature 72°F (22°C)	-	T.R.	39
	0.245 (0.0353)	ASTM C 518-70	density 0.48 lb/ft^3 (8 kg/m^3) mean temperature 72°F (22°C)	-	T.R.	39
	0.239 (0.0345)	ASTM C 177-71	density 0.66 lb/ft^3 (11 kg/m^3) mean temperature 75°F (24°C)	-	T.R.	40

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports (cont.)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Thermal Conductivity Btu in/ft^2 h °F (W/m·K)	0.213 (0.0307)	ASTM C 177-71	density 0.66 lb/ft^3 (11 kg/m^3) mean temperature 25°F (-4°C)	-	T.R.	40
	0.21 (0.030)	ASTM C 518-70	density 0.64 lb/ft^3 (10 kg/m^3) mean temperature 32°F (0°C)	-	T.R.	39
	0.22 (0.032)	ASTM C 177	mean temperature 77°F (25°C)	-	T.R.	41
	0.246 (0.0354)	ASTM C 177	density 0.44 lb/ft^3 (7 kg/m^3) mean temperature 75°F (24°C)	-	T.R.	29
	0.265 (0.0382)	ASTM C 518	density 0.44 lb/ft^3 (10 kg/m^3) mean temperature 35°F (2°C)	-	T.R.	29
	0.228 (0.0329)	ASTM C 177	thickness 1.5 in (38 mm) mean temperature 64°F (18°C)	-	T.R.	42
	0.216 (0.0311)	ASTM C 177	thickness 1.5 in (38 mm) mean temperature 31°F (-1°C)	-	T.R.	42
	0.207 (0.0298)	ASTM C 177	thickness 1.5 in (38 mm) mean temperature -7°F (-22°C)	-	T.R.	42
	0.246 (0.0354)	ASTM C 177-71	density 0.60 lb/ft^3 (9.6 kg/m^3) mean temperature 75.7°F (24.3°C)	measured at NBS	T.R.	43

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports (cont.)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Thermal Stability						
maximum service temperature	120°F (49°C)	*	-	-	L.	2,12
	150°F (65°C)	*	-	-	L.	6
	212°F (100°C)	*	-	-	L.	10,13
	270°F (132°C)	*	-	-	L.	4
	320°F (160°C)	*	-	-	L.	3
service range	-20° to 120°F (-29 to 49°C)	*	-	-	L.	9
	-300° to 210°F (-184 to 99°C)	*	-	-	L.	7
decomposition	415°F (213°C)	*	-	foam decomposition begins	T.R.	11
	428°F (220°C)	*	-	foam decomposition begins	L.	44
Water Absorption	2% (volume)	*	7 days immersion	-	L.	8
	10% (volume)	*	24 hours immersion	-	L.	7
	28% (volume)	*	14-16 days immersion	-	L.	7
	1581% (weight)	ASTM C 272	2 hours immersion at 3 in (76 mm) water depth	-	T.R.	45
	3800% (weight) 42% (volume)	*	immersion in water	-	T.R.	11

Table 2. Properties of Urea-Formaldehyde Based Foams as Reported in the Literature and Test Reports (cont.)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	CITATION	REFERENCE
Water Absorption	32% (weight) 0.35% (volume)	*	95% rh conditioning	-	T.R.	11
	18% (weight) 0.2% (volume)	*	60% rh conditioning	-	T.R.	11
	0.2% (volume)	*	60% rh and 68°F (20°C)	-	L.	46
Water Vapor Transmission						
permeance	35 to 40 perms (20 to 23 x 10^{-10} kg/Pa·s·m^2)	*	90% rh 100°F (38°C)	thickness not given	L.	4
	32 to 38 perms (18 to 22 x 10^{-10} kg/Pa·s·m^2)	ASTM C 355	-	thickness not given	L.	15
	35.9 perms (20.6 x 10^{-10} kg/Pa·s·m^2)	ASTM C 355	50% rh 75°F (24°C) density 0.72 lb/ft^3 (11.5 kg/m^3) thickness 1.25 in (32 mm)	-	T.R.	47
	70.5 perms (40.5 x 10^{-10} kg/Pa·s·m^2)	*	density 1.41 lb/ft^3 (22.6 kg/m^3)	thickness not given	T.R.	45
	32 to 38 perms (18 to 22 x 10^{-10} kg/Pa·s·m^2)	ASTM E 96	wet cup 50% rh 73°F (23°C) thickness 1.5 in (38 mm)	-	T.R.	48
permeability	4.9 perm-in (7.2 x 10^{-12} kg/Pa·s·m) 4.5 perm-in (6.6 x 10^{-12} kg/Pa·s·m)	ASTM C 355	50% rh 73°F (23°C)	-	T.R.	49
	15.55 perm-in (22.7 x 10^{-12} kg/Pa·s·m) 16.96 perm-in (24.8 x 10^{-12} kg/Pa·s·m)	ASTM C 355	-	-	T.R.	50
	30 to 100 perm-in (44 to 146 x 10^{-12} kg/Pa·s·m)	ASTM C 355	-	-	L.	12

5. FOREIGN STANDARDS AND RELATED TECHNICAL DOCUMENTATION

Since urea-formaldehyde based foams have been used as insulation more extensively in Northern European countries and in Canada than in the United States, information was requested from foreign building research institutes on the material and performance properties of the foams. Building research institutes in Canada, the United Kingdom, France, West Germany and the Netherlands were contacted. The addresses of these institutes are given in Appendix B. Information requested include the availability of foreign standards or specifications and other technical publications, problems encountered with using the foams and steps taken to correct problems.

A number of documents were received in response to the NBS inquiries. These documents include a Dutch standard as well as a proposed revision of the standard [51], a proposed West German standard [52], a proposed application standard from Canada [53], technical guidelines from Sweden [54], and Agrément Certificates from the United Kingdom. In addition, it was learned that the Canadian Government is preparing a draft for a materials standard. These foreign publications represent the most extensive published information presently available concerning the material properties and application procedures for urea-formaldehyde based foam insulations. A synopsis of the material and performance properties of urea-formaldehyde based foam insulations given in foreign standards and related technical publications is presented in table 3. It can be seen from this table that certain properties of the foams are not included in all of the documents.

The various foreign documents are not all of the same type. The Dutch and West German documents are standards. As such, they specify values of the material and performance properties required of the foams and in general give test methods by which these values are measured. The Swedish document is not a standard. Rather it is a set of guidelines for using the foams and a resume of the properties expected of the foams. In this document there are no test methods described by which the material properties can be measured.

The British Agrément Certificate is a third type of document, which differs from the Dutch, West German and Swedish documents. Under the Agrément system, a technical committee examines the properties of the construction material produced by a specific company and determines its suitability for the intended use. If the material is accepted as being suitable, an Agrément Certificate is issued. Material and performance properties are normally described in the Agrément Certificate. Agrément Certificates have been issued to many companies for urea-formaldehyde based foam insulations. The foam properties described in a typical Agrément Certificate are included in table 3 [55].

It is noted that urea-formaldehyde based foam insulations in Northern European countries are used primarily in, and often restricted to, masonry cavity wall construction. For example, the Dutch standard and the British Agrément Certificates apply only to masonry walls.

Table 3. Synopsis of the Material and Performance Properties of Urea-Formaldehyde Based Foams Given in the Foreign Standards and Related Technical Publications

Material or Performance Property	Country of Origin of the Document			
	The Netherlands [51]	West Germany [52]	Sweden [54]	The United Kingdom [55]
Density	0.5 lb/ft^3 (8 kg/m^3) minimum	dry - 0.63 lb/ft^3 (10 kg/m^3) minimum wet - 2.5 lb/ft^3 (40 kg/m^3) minimum	0.44 to 0.63 lb/ft^3 (7 to 10 kg/m^3) average	approximately 0.53 lb/ft^3 (8.5 kg/m^3)
Heat Resistance	no change, heating to 158°F (70°C) no decomposition below 320°F (160°C)	must not change more than 4% linearly after 7 days at 212°F (100°C)	decomposes at 392°F (200°C)	--
Water Absorption	foam block on water must not sink more than 25% of its height within 4 weeks	foam cube on water must not sink more than 50% of its height within 7 days	8% by weight at 35% rh, 15% by weight at 85% rh; absorbs large quantities under pressure	will not transmit water by capillary action
Water Vapor Transmission (Permeability)	--	--	about 6 grains/h ft in Hg (1×10^{-4} mg/s·m·Pa)	will allow water to be vented through the foam
Shrinkage - linear	8% maximum after drying	4% maximum after 28 days	8-10%; stopped after a year of storage	subject to slight shrinkage and cracking during drying
Thermal Conductivity	--	no greater than 0.23 Btu in/h ft^2 °F (0.033 W/m·K)	between 0.24 and 0.28 Btu in/h ft2 °F (0.035 to 0.040 W/m·K)	0.21 Btu in/h ft^2 °F (0.03 W/m·K)
Effective Thermal Conductivity	must not be greater than 0.35 Btu in/h ft^2 °F (0.050 W/m.K) in a test wall	--	assumed about 0.48 Btu in/h ft^2 °F (0.067 W/m·K) in building constructions	--
Corrosion	cavity rods, embedded in foam, must not show more evidence of corrosion than rods not embedded in foam	--	properly formulated, does not affect hooks, nails or other metal parts in buildings	no detrimental effect on wall ties or other metal fittings

Table 3. Synopsis of the Material and Performance Properties of Urea-Formaldehyde Based Foams Given in the Foreign Standards and Related Technical Publications (cont.)

Material or Performance Property	Country of Origin of the Document			
	The Netherlands [51]	West Germany [52]	Sweden [54]	The United Kingdom [55]
Mold Resistance	must be resistant to attack	must be resistant to attack	not affected by rot fungi	--
Resistance of a Foamed Wall to Water Penetration	no evidence of moisture penetration on the inside of a masonry test wall	--	--	foam installation is limited in areas of the country which are subject to severe rain exposure
Formaldehyde Concentration	2 weeks after foaming, concentration no greater than 0.5 ppm; 2 months after foaming, concentration no greater than 0.02 ppm	--	--	may occur for approximately 4 weeks after installation, does not present a toxic hazard
Flammability	--	flame spread classification is required	inflammable	does not reduce the fire resistance properties of the wall
Consistency	--	must show a uniform structure and be coherent	--	--
Reactivity of Components	must set up between 20 and 50 s	must react sufficiently within 60 s	--	gel time should be approximately 60 s
Resistance to Aging	--	must be resistant	--	sufficiently stable to remain effective as an insulant for the life of the building

6. BUILDING CODES

Information about the use of urea-formaldehyde based foam insulations in residential construction was requested from officials representing model building code and other organizations in the United States. The information received from these organizations is presented in this Section of the report.

Specific requirements for plastic foams given in the Basic Building Code (Building Officials and Code Administrators)[1/], Uniform Building Code (International Conference of Building Officials) and the Standard Building Code (Southern Building Code Congress, Inc.) deal primarily with fire safety. Approved foam plastics are to have a flame spread classification of seventy-five (75) or less and a smoke density no greater than four hundred fifty (450) when tested in accordance with ASTM E 84. Other fire-resistance requirements are based on ignition temperature, wall and corner tests. When wall tests are required, testing is to be carried out according to ASTM E 119.

The Basic, Uniform and Standard Building Codes require that foam plastics used on the inside of buildings in walls or ceilings be fully protected by a thermal barrier of fire-resistive materials having a finish rating of not less than fifteen (15) minutes.

The Basic Building Code (Building Officials and Code Administrators International, Inc.) treats all plastic foams the same and applies the requirements of the Code to all foams including urea-formaldehyde.

Two producers of urea-formaldehyde based foam insulations have applied for recognition of compliance with the Uniform Building Code. One of the foam insulations has been approved. Briefly, the approval states that the foam is applied through a patented gun in which the foaming takes place. The dry density of the foam is approximately 0.7 lb/ft^3 (11 kg/m^3). The foam may only be applied as a cavity fill and not exceed 3.5 in (89 mm) in thickness. The material may be installed in fire-resistive wood stud walls without affecting the fire resistance. When installed in steel stud walls, the assembly is to be considered as combustible, non-rated construction. All surfaces to receive the fill material must be clean, dry and free from agents tending to reduce good bonding qualities. The insulation cannot be located in areas where temperatures will exceed 210°F (99°C). The approval further states that application can be at any temperature provided that the components brought to the foaming apparatus are between 55 and 85°F (13 and 29°C). The insulation is rated as a combustible material. It is assigned a Class I flame spread classification when the thickness does not exceed 2 in (51 mm). For thicknesses over 2 in (51 mm) and not exceeding 3.5 in (89 mm), it is assigned a Class III flame spread classification.

1/ Addresses of the model building code and other organizations referred to in this section of the report are given in Appendix C.

The International Conference of Building Officials noted that there were two reported cases of odor problems in California. They stated that occupants were forced to leave their buildings for a period of time due to odors associated with formaldehyde. In addition the question was raised as to whether urea-formaldehyde foam might result in breakdown of aluminum wiring. No evidence was presented to indicate that this problem existed. The International Conference of Building Officials also noted that the question has been raised concerning all foams as to what effects they may have on electrical wiring within wall cavities where heat cannot be dissipated.

The New York City Housing and Development Administration granted acceptance to three producers of urea-formaldehyde based foam insulation. For one acceptance, qualification was based on the ASTM E84-61 test with a maximum flame spread rating of 25, a smoke developed rating not to exceed 50 and a toxicity test. The other two acceptances were based on the ASTM E136-65 test and a toxicity test. In the toxicity test the products of combustion produced by burning of the insulation were required to be no more toxic than comparable concentrations given off by wood or paper when burned under comparable conditions.

These insulation materials were accepted by the New York City Housing and Development Administration within the past three years. There has been no significant feedback concerning performance or possible problems encountered during this time.

The Society of the Plastics Industry, Inc. was not aware of any companies among their membership, with the exception of one subsidiary of a large corporation, who supply or install urea-formaldehyde based foam insulation. The Society has not developed any objective data for evaluating the foam.

Urea-formaldehyde based foam insulations are not referred to as a generic material by the building codes. Rather, acceptance for the use of these types of insulation materials by building code organizations has been granted only for materials considered proprietary.

7. FACTORS AFFECTING THE PERFORMANCE OF UREA-FORMALDEHYDE BASED FOAM INSULATIONS

A list of the factors considered to affect the performance of urea-formaldehyde based foam insulations was compiled from extensive information obtained from many sources. Each factor is discussed based primarily on literature information, test reports, foreign standards and preliminary National Bureau of Standards test results. For some factors there is a lack of published information so that discussions of these aspects of performance are limited. The discussions of the factors affecting performance provide the basis of the assessment of urea-formaldehyde based foam insulations.

The factors considered to affect the performance of urea-formaldehyde based foam insulations discussed in this section are:

- cell structure
- consistency (discussed in Section 7.1, cell content)
- density
- dimensional stability (discussed in Section 7.16, shrinkage)
- durability
- electrical properties
- effect on energy conservation
- effect on other building materials
  - gypsum plaster and wallboard
  - metals
  - paints and coatings
  - wood
- flammability and combustibility
- friability (discussed in Section 7.9, mechanical properties)
- freeze-thaw resistance
- mechanical properties
- mold and vermin resistance
- odor (due to formaldehyde gas)
- photodegradation
- reactivity of the foam ingredients
- service temperature range and decomposition temperature
- shrinkage
- specific heat
- sound absorption and acoustic properties
- temperature and humidity
- thermal conductivity
- toxicity
- water absorption
- water vapor transmission (permeability).

Other factors were identified but not included in this list since they were not considered to affect performance of the foam as a thermal insulation. Factors considered not to affect performance include adhesion to other materials, resistance to chemicals and coefficient of thermal expansion.

7.1 Cell Structure

It is the low density, cellular structure of urea-formaldehyde based foams that accounts for their low thermal conductivity. The air content of the foams has been reported as approximately 99% by volume [6, 8]. There is disagreement in the literature as to the cell structure. The foams have been described as consisting of completely open cells [6, 8], or as having closed cell contents of 60% [7] or 80% [9]. Reasons for these published differences between closed and open cell content are not known. The cell structure can be altered by changes in the foaming technique [56]. The cell structure will influence other performance parameters such as air, water and water vapor transmission.

The size of the cells has been reported as being within the range 8×10^{-4} to 2×10^{-2} in (2×10^{-2} to 5×10^{-1} mm) [6], or 4×10^{-5} to 1×10^{-3} in (1×10^{-3} to 3×10^{-2} mm) [7]. Small cell size contributes to the low thermal conductivity of the foam, since small cells result in less convectional currents within the foam [57]. Cell size has significance for the foam applicator. He must maintain and regulate his foaming apparatus to assure small cells. Large cells or voids will result in a less thermally efficient foam. Foam manufacturers generally instruct their applicators to check the appearance of the foam for cell uniformity. In this respect, the proposed West German standard has a requirement for the consistency of the cells [52].

7.2 Density

Urea-formaldehyde based foams are applied wet at a density of approximately 2.5 lb/ft^3 (40 kg/m^3) [15]. After application, the wet foam dries at a rate which is dependent upon temperature and humidity conditions, and also the composition and construction of the wall cavity. Foam manufacturers instruct their applicators to check the wet density of the foam immediately prior to application since the wet density generally is indicative of the dry density.

The density of the dry foam has been reported in the literature to be normally in the range of 0.5 to 0.7 lb/ft^3 (8 to 11 kg/m^3) [13-16]. The Dutch and West German standards require that the dry foams have a minimum density of 0.5 lb/ft^3 (8 kg/m^3) and 0.6 lb/ft^3 (10 kg/m^3), respectively [51, 52]. The major U.S. manufacturers' recommendations for dry density range from 0.6 to 0.9 lb/ft^3 (10 to 14 kg/m^3).

Table 2 shows that the density of dry urea-formaldehyde based foams has been reported to vary within the range 0.4 to 10 lb/ft^3 (6 to 160 kg/m^3). This wide range of densities results from the various techniques available for foam production, and is not typical of the density range of foamed-in-place insulation.

Dry density may be used as an easily measured indicator that the foam has been applied according to the manufacturers' recommendations. Foams whose dry densities lie well beyond the manufacturers recommended range may have been misapplied and, as a result, may not perform adequately. Density by itself should not be used as a criterion for performance since it is possible that a foam with a density within the recommended range may perform poorly.

7.3 Durability

Durability may be defined as the capability of a material to resist deterioration so that its performance remains above a minimum acceptable level for its intended service life. The durability of a material may be ascertained through in-service performance or estimated by accelerated aging tests. In the survey of literature only one report was found[1/] which considered foam durability [11]. In this German report, a proprietary foam in a pipe chase in one building was inspected 9 1/2 years after installation. The foam was described as showing no signs of decomposition and it had shrunk away from the pipe chase wall. At the present time, reliable information on the durability of urea-formaldehyde foam, or its ability to perform over a long period of time as an efficient thermal insulation, is not available.

From the literature, the reader may get the impression that once the foam is in place, it remains there indefinitely without deteriorating. Such a suggestion has been made by the British Agrément Board [55]. Once the foam is injected into walls, it is generally not observed; thus, its in-service performance is not documented and remains unknown. A comprehensive survey is needed to determine the conditions of the foam in walls after a number of years of service in various regions of the United States.

7.4 Electrical Properties

Urea-formaldehyde based foams may be injected into cavity walls which contain electrical wiring and junction boxes. Evidence has not been found in this survey to show that a safety hazard exists. The dry foam is considered an electrical insulator.

1/ The authors received a report in Dutch from the Bouwcentrum, Holland too late for inclusion in this NBS Technical Note. This report by E. K. H. Wulkan, entitled "Onderzoek van een 6 1/2 jaar oud monster UF-schuim, afkomstig uit een spouwmuur," describes tests on a foam removed from a cavity 6 1/2 years after installation.

Because of the quantity of water in the foam during application, the wet foam may conduct electricity. Freshly applied, wet foam may present a risk to the applicator if recommended safety precautions are not followed. At least one of the major U.S. manufacturers recommends that electrical lines of 220 volts or above be turned off during application. A similar recommendation is included in the proposed Canadian application standard [53]. Power lines of 110 volts are normally not considered to present a hazard to the applicator, and are not usually shut off during application. However, if the applicator is standing on wet ground during installation, a risk of shock may exist. Under these conditions, it is advised to shut off 110 volt power lines.

Although the dry foam presents no safety hazard due to electrical conduction, the installed foam should not come in contact with heat-dissipating objects such as light fixtures, motors, fans, blowers, heaters, flues and chimneys [17]. Insulation of any type in contact with heating-dissipating objects could hinder heat dissipation and cause heat build-up, thus, creating a risk of fire.

7.5 Effect on Other Building Materials

The effect of installed urea-formaldehyde based foam on the performance of other building materials in contact with or adjacent to the foam is not adequately documented in the literature. Materials which may conceivably be adversely affected by the foam or its installation include gypsum plaster and wallboard, metals, paints or coatings, and wood.

7.5.1 Gypsum Plaster and Wallboard

The effect of water in freshly applied urea-formaldehyde based foams on gypsum plaster and wallboard has not been discussed in the literature. No evidence was found in this survey to indicate that problems existed.

A problem may occur if water in the freshly applied foam accumulates in the bottom of the cavity of a gypsum faced wall by drainage through the foam. This possibility was recognized by the Canadian Government and a water drainage test was included in their proposed application standard [53]. The test method consists of applying foam in a plastic bag and two hours after application opening the bottom of the bag and examining for the presence of water. The test requires that water should not be present, even as droplets, although the surface of the bag and the foam may feel damp.

7.5.2 Metals

When injected into a wall cavity, it is conceivable that the foams may cause corrosion of metal objects such as ties or electrical junction boxes due to the water and acid catalyst in the foams. The problem of corrosion has been discussed in the literature, but the results are inconclusive and contradictory. The foam has been described as non-corrosive [8, 58] or as capable of causing corrosion in some cases [12]. This latter reference further mentioned that improved foams are available that have reduced corrosive properties or none at all.

These references [8, 12, 58] did not describe any test method for measuring the corrosive properties of the foam. No standard test method was found during this survey. Baumann has described [44] briefly the corrosive action on various metals. His test method consisted of placing the metals in contact with moist foam for various periods of time, after which the metals were examined for evidence of corrosion. The extent of corrosion was compared to that occurring on metals stored without contact with the foam. From his experiments Baumann concluded that the foam material itself does not cause corrosion on metals used in buildings.

Baumann's conclusion is consistent with the statements published by Swedish and British Government Agencies. The Swedish State Planning Organization has stated that, when properly formulated, foam will not cause corrosion of metals in buildings [54]. The British Agrément Board Certificates have stated without qualification that foams have no detrimental effect on metals [55]. Contrary to these statements, some U.S. manufacturers of urea-formaldehyde based foams recommend that foam inadvertently sprayed on aluminum building components should immediately be removed by thoroughly rinsing with water.

The Dutch Government has considered the corrosion problem important enough to include a requirement for corrosion testing in their standard [51]. It is required that a galvanized steel rod embedded in fresh foam show no more effect of corrosion than a similar rod not embedded in the foam. They have not, however, developed a satisfactory test method for determining the potential corrosive action [51].

7.5.3 Paints and Coatings

The water present in the foam during application may increase the risk of blistering and peeling of paints or coatings on wall surfaces. The amount of water contained in the fresh foam is about 0.5 lb/ft^2 (0.2 kg/m^2) of wall surface area for a wall cavity approximately 3 1/2 in (88 mm) thick. As the foam dries, the water will normally migrate to the exterior of the house in the winter and to the interior in the summer. In either case if the paint on the surface of the wall is a good vapor barrier, the paint may blister. In cases where blistering of the paint may be a potential problem, adequate means should be provided to allow the water in the foam to vent to the atmosphere. Such means may consist of inserting properly designed vent plugs in the holes drilled in the walls during application, although the effectiveness of vent plugs has not been shown.

A study at the National Bureau of Standards conducted on a wood-frame house has shown that water present in the foam during application migrated during the winter into the exterior wood-fiber sheathing and wood siding as the foam dried [43]. Blistering of the exterior paint was observed in this study.

7.5.4 Wood

There has been some concern expressed that water present in the foam during application may cause rotting of wood members in wood frame housing. Data and in particular field experience are lacking to evaluate the rate of drying of the foam and the effect of the wet foam on wood. This topic has received little discussion in the literature. The Swedish State Institute for Construction Research has stated that under conditions where the wall would not dry out, the wood could conceivably rot [59]. They did not have sufficient experience to evaluate the risk, and thus gave no guidelines.

In field tests of the wood-frame house at the National Bureau of Standards, it was observed that a wall filled with foam during the winter remained partially wet during the spring and dried out the following summer [43]. Examination of a wall section 16 months after foaming showed no evidence of wood rot at a location 3 ft (0.9 m) above ground level, even though the wall retained some moisture for four to five months. Additional data of this type would be desirable.

7.6 Effect on Energy Conservation

There was little information available on the amount of energy conserved due to the application of urea-formaldehyde based foam insulations in residential construction. One study was sponsored by the U.S. Department of Housing and Urban Development on energy conservation in public housing during the winter of 1975-1976 in Atlanta, Georgia [60]. In this study, a comparison of the amount of energy used in heating was made between five buildings retrofitted with a urea-formaldehyde based foam insulation and five uninsulated buildings in the same housing complex. The foam was applied in the 2 in (51 mm) cavity of brick-block masonry walls. The preliminary analysis indicated that the amount of fuel saved was about 30 percent in the retrofitted houses. Since the final results have not been published, it is not known what other retrofit measures may have been included in the study such as storm windows and doors, caulking and weather stripping.

A detailed study of energy conservation in one residence located in Hertfordshire, England was conducted by the U.K. Building Research Establishment [61]. The average mean temperature in Hertfordshire is 50°F (10°C). The cavity of the brick-block masonry walls in a three bedroom house were filled with urea-formaldehyde foam. Approximately 85 percent of the 220 ft^2 (21 m^2) window area was double glazed one year before the walls were insulated. The gas fuel consumption was measured for one year before and after application of the foam and a reduction of 23 percent was reported. The savings in fuel consumption was also reported as approximately 30 percent for periods when the mean external temperature was between 32 and 54°F (0 and 12°C).

7.7 Flammability and Combustibility

Urea-formaldehyde based foam insulations are organic materials composed of nitrogen, hydrogen, carbon and oxygen and are combustible as defined by ASTM E 176-73[1/] and release heat when burned. The heat of combustion of one foam has been measured and is given in table 4 along with the heats of combustion of other insulations [62]. It can be seen that the urea-formaldehyde based foam has a lower heat of combustion per unit weight than polystyrene and polyurethane foams but a higher heat of combustion than mineral wool and glass fiber insulations. In the case of insulation which may be used in different densities and thicknesses, it is more appropriate to consider heat of combustion per unit area for the thickness and density used. Misleading published statements have been made in the past referring to urea-formaldehyde based foam insulations as "noncombustible," "self-extinguishing," and the like. These descriptions of the fire resistance of the foams are inaccurate and should be disregarded.

1/ The definition of combustible is given in Section 2 of this report.

Table 4. Approximate Heats of Combustion of Some Thermal Insulations [62]

Insulation Material	Heat of Combustion	
	Btu/lb	MJ/kg
Mineral Wool 1/	0-1,000	0-2.3
Fibrous Glass 1/	1,000-3,000	2.3-6.9
Urea-Formaldehyde Based Foam	6,000	13
Polyurethane Foam	11,000	25
Polystyrene Foam	17,000	39

1/ The heat of combustion depends upon the amount of organic binder in the insulation.

The flammability of the foams has been of great concern to the industry. It is often through an examination of the flammability characteristics that a building code jurisdiction will grant approval for use of the foam. As a consequence, many reports describing the results of fire testing of foams were available.

The most commonly employed test method for urea-formaldehyde based foams has been the ASTM E 84 flame spread test which is similar to UL 723. The test gives a numerical classification to a material as to its surface flame spread, smoke density and fuel contribution. The test is a laboratory evaluation of the material and is not intended to show the hazard presented by the material under actual fire conditions. In general, plastic foams are difficult to evaluate by ASTM E 84. Some hazards associated with plastic foams having numerical flame spread classifications derived from this test method may be significantly greater than those which would be expected of other products with the same numerical classification. This test has been recommended as one way to judge the fire performance of insulations, since other test methods relating to primary safety properties such as ignitability and rate of heat release are not fully developed [17]. Information on the rate of heat release of foam insulation and on the performance of foams in full-scale room fire tests would be very useful. For fire safety validation of non-bearing walls and ceilings containing plastic foam, at least one model building code refers to the use of full scale corner tests or room burnout tests [63].

It has been recommended that the flame spread classification for a foam plastic insulation should not exceed 25 when tested according to ASTM E 84 [17]. The behavior of urea-formaldehyde based foams in the flame spread test, as described in the references cited in this report, is favorable in that it is usually less than the recommended flame spread classification of 25, as shown in table 2. In one instance the flame spread classification of a test specimen was 35, while in all other cases it was 25 or less. There was some variation in the test results given in table 2 which may in part be attributed to differences in foam density, thickness and formulation.

The flammability of a foam as demonstrated by ASTM E 84 test varies with the water content at the time of testing. A freshly prepared specimen will show a lower flame spread classification than an older specimen. Water in the fresh foam reduces its flame spread classification. As the foam dries, the flame spread classification increases. The results of two fire tests of foam specimens as a function of the age of the specimens are given in tables 5 and 6 [64, 65]. In the tests, the flame spread classification increased with the age of the foam for a period of two weeks in one test and eight weeks in the other. It is noted that the classification did not exceed the recommended value of 25 in either test.

This recommended classification of 25 is more stringent than the requirement of the model codes for flame spread (see Section 6). The model codes require that foam plastics have a flame spread classification of 75 or less, and also a smoke density no greater than 450. In addition, the model codes stipulate that a foam plastic must be covered by a thermal barrier of fire-resistive material having a finish rating of not less than 15 minutes. Since urea-formaldehyde based foam is designed for injecting into cavity walls, unexposed urea-formaldehyde based foam in a residence would not, in normal circumstances, be a problem. Although there are other technical reasons such as friability and light sensitivity for not using urea-formaldehyde based foam in an exposed application, from a fire safety point of view, it must always be covered as recommended by the model codes.

Based on this survey, flammability does not appear to be a major concern of the Europeans. A flammability requirement has not been specified in the Dutch standard [51]. A British Agrément Certificate has stated that the foam which is only permitted in masonry cavity walls does not reduce the fire properties of the wall [55]. The West German standard has a requirement for flame spread classification [52].

This survey has not uncovered any evidence that shows urea-formaldehyde based foams increase the fire hazard. These foams burn, but based on one current method of evaluation, they in general meet the recommended flame spread of 25 [17].

A second hazard due to the flammability of urea-formaldehyde based foams is the toxicity of gases released when the foam burns. There is no standard test method currently available for determining the toxicity of combustion products. One test procedure exposes laboratory rats for six hours to a given concentration of combustion products to determine the effects of the products on the rats. After exposure, surviving rats are observed for fourteen days for any ill effects. The reliability of this test procedure for determining the toxicity of combustion products is not fully known. Nevertheless, the test has been used as an indication of the relative toxicity of the combustion products of various materials. It is noted that the state-of-the-art of toxicity testing of combustion products is rapidly developing and future developments may invalidate present test results.

Table 5. Results of Fire Testing on Urea-Formaldehyde Based Foam Specimens as a Function of the Age of the Foam [64]

Foam Age 1,2/	Foam Density 3/ lb/ft3 (kg/m3)		Test Results 4,5,6/	
			Flame Spread	Smoke Developed
0.25 h	-	-	12.8	0
0.25 h	-	-	12.8	0
1 h	-	-	12.8	0
1 h	-	-	10.3	0
4 h	-	-	12.8	0
4 h	-	-	12.8	0
8 h	-	-	12.8	7.0
24 h	0.93 (14.9)	0.83 (13.3)	10.3	29.6
2 wk	0.59 (9.4)	0.53 (8.5)	17.9	48.1
4 wk	0.59 (9.4)	0.52 (8.3)	17.9	154.1

1/ Duplicate specimens were tested at specified time intervals.
2/ Aged specimens were stored at 70 ± 5°F (21 ± 3°C) and 35 to 40% rh.
3/ This is not the density of the fire test specimens. Additional block samples of unidentified dimensions were prepared at the same time as the fire test specimens. Density determinations were conducted on the block samples. Density measurements were made on duplicate specimens.
4/ Test was conducted according to the procedure described in UL 723, "Test Method for Fire Classification of Building Materials."
5/ Test specimens were 3 in (76 mm) thick.
6/ All the test specimens displayed an apparent negative fuel contributed classification, which was expressed as not determinable.

Table 6. Additional Results of Fire Testing on Urea-Formaldehyde Based Foam Specimens as a Function of the Age of the Foam [65]

Foam Age1,2/	Foam Density3/ lb/ft^3 (kg/m^3)	Test Results4,5,6/	
		Flame Spread	Smoke Developed
Fresh	2.00 (32.0)	-	-
24 h	-	0	0
24 h		0	0
2 wk	0.61 (9.8)	12.8	88.6
2 wk		17.9	111.1
4 wk	0.55 (8.8)	12.8	92.2
4 wk		15.4	139.5
6 wk	0.52 (8.3)	17.9	110.0
6 wk		20.5	108.0
8 wk	-	20.5	50.0
8 wk		23.1	91.2
12 wk	-	20.5	100.8
12 wk		20.5	90.5
18 wk	-	17.9	122.8
18 wk		20.5	66.5
24 wk	-	17.9	69.1
24 wk		20.5	90.4

1/ Duplicate specimens were tested at each time period.
2/ Aged specimens were stored at 70 ± 5°F (21 ± 3°C) and 35 to 40% rh.
3/ This is not the density of the fire test specimens. Density determinations were made on additional foam samples in such a manner as to approximate the densities of the fire test specimens.
4/ Test was conducted according to the procedure described in UL 723, "Test Method for Fire Classification of Building Materials."
5/ Test specimens were 3 in (76 mm) thick.
6/ All the test specimens displayed an apparent negative fuel contributed classification, which was expressed as not determinable.

This type of toxicity test has been conducted using urea-formaldehyde based foam insulations in which laboratory rats were exposed to either the fumes of burning foam or of burning wood or plywood. One test was carried out on each of three proprietary products. Under the test conditions, the burning foams appeared no more toxic than the burning wood or plywood. In one case, within 24 hours two of 10 rats exposed to foam fumes died while four of 10 rats exposed to burning plywood fumes died [66]. In a second test, within 24 hours, two of 10 rats died when exposed to the fumes of burning foam, while four of 10 rats died from burning plywood fumes [67]. In another test, none of the 10 rats exposed to the foam fumes died, while within one hour six of 10 rats exposed to the fumes of northern white pine died [68].

7.8 Freeze-Thaw Resistance

The question has arisen as to whether or not freeze-thaw cycling can cause deterioration of the foams, especially if the foams are wet. This question has been mainly ignored in publications which discuss performance parameters. One report described a test in which a foam specimen saturated with water was cycled between 59 and 5°F (15 and -15°C) for 25 cycles [11]. No damage reportedly occurred to the foam during testing. This report did not describe the conditions under which the foam was "saturated with water," and the results may thus be open to question. No other reports describing freeze-thaw cycling were found in the literature.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) has been applying foams, on an experimental basis, in buildings in Alaska. Freeze-thaw cycling resistance has been considered an important parameter because of the weather in Alaska. At present, CRREL has little data on the freeze-thaw resistance of urea-formaldehyde based foams. In a study at Fort Greely, Alaska [35], urea-formaldehyde based foam was injected into 2 x 6 wood stud wall cavities which contained either 2 1/2 in (68 mm) foiled faced fiberglass or expanded aluminum foil insulation. The foam was applied from the outside of the buildings such that the existing insulations were pressed against the interior sides of the walls. The walls were filled with foam in August, 1975 and were opened for visual inspection of the foam insulation in April, 1976 after an extremely cold winter and numerous freeze-thaw cycles. No problems with the foam were detected. It was also observed that the exterior sheathing and wind-paper (asphaltic kraft paper having low permeability) were dry which was an indication that no significant amount of moisture had passed through the urea-formaldehyde based foam and collected on the vapor resistant outer wall elements [35].

A field inspection was carried out by CRREL to observe a urea-formaldehyde based foam in the walls of a chapel at Eielson Air Force Base near Fairbanks [69]. The foam was installed in late July of 1975 without addition of an interior vapor barrier. The following March the foam was observed in some of the wall sections. At that time there was frost present in the foam, but the foam appeared to have retained its structural integrity. It could not be determined whether the water observed in March resulted from the foam application or from condensation during the winter. The wall sections of the chapel were re-examined in August, 1976 at which time the foam was observed to be dry and in satisfactory condition.

Freeze-thaw cycling appears important enough to warrant additional research and testing. Foam applied in cold regions of the United States where condensation is likely to occur may be subjected to stress caused by freezing and thawing. Although no evidence was found which showed that freeze-thaw cycling is detrimental to the foams, evidence on this point is incomplete. Additional data are needed.

7.9 Mechanical Properties

Within the density range employed for cavity wall insulation, the mechanical strength of urea-formaldehyde based foams is low [2, 4, 6, 9, 12, 16]. In addition the foams are described as being friable and brittle [12, 16]. The mechanical properties have little relationship to the performance of the foams as cavity wall insulations, except that the foams must be strong enough to support their own weights in the cavity. The foams should not collapse or crumble. Based on the available information there appears to be no problem with regard to the foams' mechanical properties. The Agrément Board in England has examined cavity wall fills of up to 2 stories high [14]. They found no evidence that the foams at the properly specified densities would fail due to collapse under their own weight. The Dutch standard allows the filling of a continuous cavity up to 6 stories high [51].

7.10 Mold and Vermin Resistance

There is agreement within the literature that urea-formaldehyde based foams are mold resistant [3, 4, 8]. Nevertheless, both the Dutch and West German standards have specified a mold resistance requirement [51, 52]. It is conceivable that changes in formulation could result in a foam that is not mold resistant. No evidence was found in this survey that indicates mold growth has been a problem in the United States. Also, no evidence has been found to indicate that vermin attack is a problem. The Swedish State Planning Organization has reported that the foam does not constitute a feed for rats or insects [54].

7.11 Odor

There was concern that the application of urea-formaldehyde based foams in residential construction may, under certain conditions, lead to odors of formaldehyde. This aspect of performance was examined in detail and is reported in Section 8.

7.12 Photodegradation

Urea-formaldehyde resins are susceptible to photodegradation. It was observed that foam samples exposed to natural and fluorescent lighting in the NBS laboratories for a few months have shown yellowing and a tendency to crumble. Photodegradation presents no problem for foams in cavity walls because the foams are not exposed to light. For new constructions, where the foams may be applied to open stud spaces, the foams should be covered immediately after installation. Covering not only assures that the foams do not dry too rapidly but also assures that the foam are not exposed to light. At least two of the major producers of urea-formaldehyde based foam insulations recommend that freshly applied foam in open wall construction be covered immediately.

7.13 Rain Penetration

Rain penetration of masonry cavity walls filled with urea-formaldehyde based foams has occasionally been a problem in Europe [8, 14]. These walls are designed such that rain may penetrate the exterior wall of the cavity. In severe rains, free flowing water will run down the inside surface of the outer wall and drain away from the residence at the bottom of the cavity. Filling a cavity with foam insulation may, under certain circumstances, direct the water into the residence. Within the cavity, hydrostatic pressures are not generally great enough to force water through the dry foam [14]. The water can penetrate across the cavity by flowing through voids which may result from inadequate foaming or shrinkage cracks.

Measures to reduce rain penetration problems in Europe include water repellent treatment of the outer surface of the exterior wall, or facing with stucco or siding. In the United Kingdom the Agrément Board does not recommend the use of urea-formaldehyde based foams for cavity walls in areas of the country which receive severe rain exposure unless the masonry is protected with an outer facing [55].

In the United States, rain penetration due to cavity wall filling was not found to be a problem. No complaints of rain penetration due to foam filling were uncovered during this survey. The exterior walls of U.S. residences are generally designed to resist and shed rain water. One caution, based on the European experience, is noted. A foam filled masonry cavity wall may have an increased risk of rain penetration, especially if exposed to severe rains.

7.14 Reactivity of the Foam Ingredients

The foam ingredients should react chemically at a rate that is slow enough to allow complete filling of wall cavities and fast enough to allow an initial cure of the foam in the cavity without collapsing. The reactivity is a function of proper formulation and application. The West German standard has considered this parameter and specified that the foam ingredients must sufficiently react within 60 seconds to leave a smooth surface when a conical specimen is sliced with a spatula [52]. The revised Dutch standard, the proposed Canadian application standard and the British Agrément Board have made similar recommendations [51, 53, 55].

Sixty seconds is also the maximum reactivity time recommended by the majority of major U.S. manufacturers. One manufacturer recommended the maximum reactivity time to be 30 seconds. In a few typical foam applications observed by the authors, the foam reacted (set up) within 60 seconds.

7.15 Service Temperature Range and Decomposition Temperature

There is wide disagreement among various literature sources as to the maximum service temperature to which urea-formaldehyde based foams may be subjected. As can be seen in table 2, the maximum service temperature has been reported to be as low as 120°F (49°C) or as high as 320°F (160°C). In addition, the service temperature range has been quoted as being -20 to 120°F (-29 to 49°C) [9] or -300 to 210°F (-180 to 99°C) [7].

It has not been possible during this survey to document the reasons why such disagreement exists among the published values for the maximum service temperature. None of the publications cited in table 2 described the test method and conditions under which these values were measured. Possibly, the test conditions were different. The results of a heat stability test of the foam may be dependent upon the relative humidity during testing, and the water content in the foam, since it has been shown that the foam may degrade when subjected to high temperature and humidity (see Section 7.19).

The Dutch standard requires heat testing of the foam [51]. The foam must be at least 4 weeks old and conditioned at 77°F (25°C) and 50% rh for 2 weeks before testing. The Dutch requirement is that the foam should not show any change (with the exception of color) on heating to 158°F (70°C) and no decomposition on heating to 320°F (160°C).

Regarding the minimum service temperature, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) is conducting field experiments at Fort Greely, Alaska to evaluate urea-formaldehyde based foam insulation under conditions of intense, sustained cold temperatures [35]. Minimum temperatures at Fort Greely often approach -60°F (-51°C). The preliminary results indicate that the foam insulation has a potential for use in very cold regions.

The published values for the thermal decomposition temperature of urea-formaldehyde foam were found to be in general agreement. They have been given as 415°F (212°C) [11] or 428°F (220°C) [44]. The Swedish State Planning Organization has listed the decomposition temperature as 392°F (200°C) [54]. Decomposition temperature is not considered a performance parameter for normal use as cavity wall insulation. It may be used as an indication of the quality and the overall thermal stability of the foam.

7.16 Shrinkage

It is known that during the curing process urea-formaldehyde based foams undergo linear shrinkage in all three dimensions. However, there is disagreement in the literature as to the magnitude of the shrinkage and time period over which it occurs. The linear shrinkage during curing is most often quoted as being within the range of 1-3 percent [7, 11, 14, 15, 27, 28], but there are other reports stating that this shrinkage is higher. The French Centre Scientifique et Technique du Batiment (CSTB) has reported a shrinkage of 6 percent which occurred over one month at 68°F (20°C) and 65% rh [46]. The Swedish State Planning Organization has stated that the shrinkage may be as high as 8-10 percent and occurs over a period of a year [54]. The environmental conditions were not described.

The Dutch and West German standards both contain shrinkage requirements that foam specimens must meet for acceptance, but their respective requirements differ [51, 52]. Under the conditions of testing, the Dutch standard requires that the freshly prepared foam specimen not shrink more than 8 percent, while the West German standard requires not more than 4 percent. The Dutch standard specifies that the shrinkage be measured after the foam has dried, while the West German standard specifies that the shrinkage be measured after 28 days. It is not known how these requirements relate to the amount of shrinkage that occurs during the curing of the foam within a cavity wall.

Shrinkage of the foam during curing is an important performance parameter. As the shrinkage occurs, the foam either pulls away from the wall studs or splits and cracks. The resulting gaps and cracks are void spaces in which air may circulate and thus lower the insulating properties of the foamed wall (as discussed in Section 7.20). It is thus desirable that additional data be gathered to understand in detail the shrinkage process and the conditions, such as temperature, humidity and rate of drying of the foam, which influence the magnitude of the shrinkage. It is generally reported that the slower the rate of drying of the foam, the less is the shrinkage. However, there is even some disagreement with this point. It has been reported that the final shrinkage of the foam in the free state does not seem to be much affected by rate of drying [14].

Most of the shrinkage data reported in the literature has been based on laboratory experiments and not in-service evaluations. The amount of shrinkage and the time period over which it occurs in building constructions has not been fully documented. Limited data are available from the NBS retrofit study in which one urea-formaldehyde based foam had been installed in a wall of a test house [43]. A section of the wall insulated with the foam has been periodically inspected to document the amount of shrinkage. The average linear shrinkage has been determined across the width of the foam within the 14.5 in (368 mm) space between studs. The results of the inspections are given in table 7. It can be seen that after approximately 20 months, the foam had undergone an average linear shrinkage of 7.3 percent. A plot of the percent shrinkage versus time gives a straight line which indicates that the foam has not yet, even after 20 months, shown a tendency to stabilize dimensionally.

Table 7. Percent Linear Shrinkage of the Urea-Formaldehyde Based Foam in the National Bureau of Standards' Test House as a Function of Time [43]

Date of Measurement	Time, Months	Shrinkage, %
January 27, 1975	0	-
May 1, 1975	3.1	2.6
April 21, 1976	14.8	5.6
September 29, 1976	20.1	7.3

It is pointed out that the NBS data are preliminary. They should not be construed as conclusive evidence that urea-formaldehyde based foams undergo excessive shrinkage in all applications. The NBS data represent the results of a single test which may have been influenced by a number of factors such as the chemical compositon of the foam, the application and the climate. The shrinkage of 7.3 percent in the NBS test house is still lower than the 8-10 percent reported by the Swedish State Planning Organization [54]. However, their report that the shrinkage stops in about 1 year conflicts with the NBS results, since the foam in the NBS test was still apparently shrinking after 20 months.

The observation from the NBS test house that the shrinkage is still occurring after 20 months also contradicts statements that the foams undergo only a short-term shrinkage as they dry out. Although the NBS data are limited, they suggest the possibility of a long-term shrinkage, and raise some questions regarding the shrinkage problem. For example, is there more than one mechanism by which shrinkage can occur? If so, is it possible to differentiate between the mechanisms? What are the factors which influence the long-term shrinkage? Perhaps the most important question is, at what point does the shrinkage stop?

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) has limited data on the shrinkage of foam injected into walls of buildings at Fort Greely, Alaska [35]. The walls were insulated in August, 1975 and visually examined in April, 1976. The linear shrinkage of the foam was observed to be less than 2 percent over the 8 month period. This rate of shrinkage was much less than that observed at the NBS test house which showed a 2.6 percent shrinkage in a little more than 3 months [43]. The colder climate at Fort Greely may be partially responsible for the lower shrinkage of the foam observed there. These data suggest that the foam may undergo less shrinkage or shrink at a lower rate in cold climates than in hot humid climates.

The small amount of field data concerning shrinkage is far from conclusive. Additional data are needed. A comprehensive survey is recommended in order to evaluate the extent of shrinkage occurring in foams in buildings. The performance of the foam in areas of the United States which experience long periods of hot humid weather should be emphasized during the survey.

7.17 Specific Heat

A value of the specific heat of urea-formaldehyde based foams was not found in the literature.

7.18 Sound Absorption and Acoustic Properties

In cases where urea-formaldehyde based foams are applied in buildings as thermal insulation, sound absorption is not considered to be a performance parameter. However, since the foams have been applied both as thermal and acoustical insulations, information for the assessment of the foams as acoustical insulation is given in Section 9.

7.19 Temperature and Humidity

During the course of this survey, it was pointed out that urea-formaldehyde resins may be susceptible to hydrolysis. Hydrolysis is defined as the chemical reaction of the resin with water. For the purposes of this report, hydrolysis should be considered as the degradation of the urea-formaldehyde based foam by water. Because of the potential consequences of degrading the foams, this performance parameter was given much attention during the survey. In particular, attempts were made to ascertain whether or not the combination of high temperatures and high humidities will have a deleterious effect on the foams.

A review of the literature showed that the effect of high temperatures and high humidities on the foams was a nearly neglected topic. In one publication, it was reported that the foams do not hydrolyze [7], but no evidence was given supporting this conclusion. On the contrary, it was learned that the National Research Council of Canada was conducting tests on the effect of high temperature and humidity on foams [70]. The final results of these tests are not yet available. In general, the preliminary results have shown that foam specimens undergo shrinkage and weight loss when subjected to high temperatures and humidities. The magnitude of the shrinkage and weight loss at a constant humidity were, in general, dependent upon the temperature of the test as well as the composition of the foam.

In another test carried out in a commercial laboratory, cured foam specimens, 4 x 4 x 1 in (102 x 102 x 25 mm), were exposed for 10 days to 158°F (70°C) and 95 to 100% rh [29]. During the test period, it was observed that the specimens underwent a 9.6 percent weight loss and a linear shrinkage of approximately 30 percent. It was also reported that the specimens had warped severely, were very powdery and could not be handled.

Because of the implications of these test results [29, 70], and because other data concerning hydrolysis were lacking, it was decided to conduct a preliminary experiment at the National Bureau of Standards on the effect of high temperature and high humidity on foams. The description and results of this test will be presented in a separate publication [71]. A synopsis is given herein.

Foam insulation specimens were obtained from four major manufacturers or their representatives. After curing for at least a month in the laboratory, the specimens, approximately 4.7 x 3.9 x 3.5 in (120 x 100 x 90 mm), were exposed to 122°F (50°C) and 92% rh for a 7 week period. Figure 1 shows the specimens before their placement in the temperature-humidity chamber. Once a week, the specimens were removed from the chamber and their dimensions and weights were recorded.

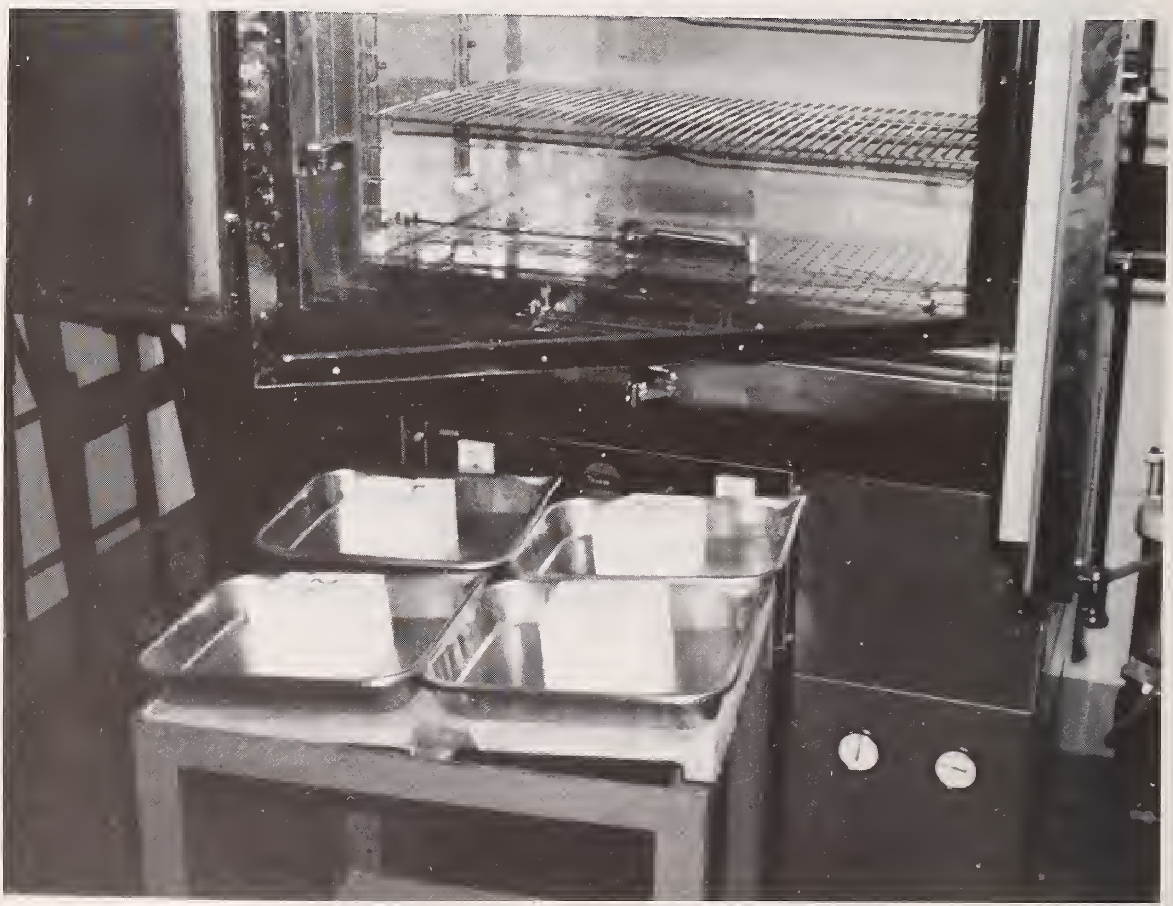

Figure 1. Foam Specimens before Exposure to a Combination of High Temperature and High Humidity.

The results showed that the foam specimens were susceptible to degradation under the test conditions. The specimens underwent shrinkage and weight loss, slightly discolored and lost mechanical strength. After the 7 week period of testing, 3 of the 4 specimens had disintegrated into small pieces. Figure 2 shows each of the exposed test specimens along side similar unexposed specimens. After the first two weeks of testing, the average linear shrinkage occurring in the chamber was 4 percent. The additional shrinkage during the remaining 5 weeks of the test was small. Obviously, shrinkage could no longer be determined after the specimens disintegrated. The average weight loss of the specimens after 7 weeks was approximately 8 percent.

In a similar test conducted in NBS laboratories comparable foam specimens were exposed to 104°F (40°C) and 92% rh [71]. The same 3 out of the 4 specimens disintegrated after 14 weeks as in the test carried out at 122°F (50°C).

The results from this experiment are preliminary. Nevertheless, they are considered significant. They have pointed out that the durability of the foams under certain environmental conditions may be questionable. Further research is needed to establish the extremes of temperature and humidity to which the foams may be exposed without a severe loss of performance properties. These NBS results suggest that foams should not be applied in areas subjected to high temperature and high humidity. Since high temperature and high humidity may be encountered over prolonged periods of time in attics and ceilings, it is recommended that foams not be applied in these areas until additional data are available.

7.20 Thermal Conductivity

The thermal conductivity value of urea-formaldehyde based foam insulations is a controversial subject. Thermal conductivity values cited in the literature range from 0.18 to 0.29 Btu in/h ft^2 °F (0.026 to 0.042 W/m·K), as is shown in table 2. The thermal conductivity of the foams is a function of test parameters such as the mean temperature of the materials, their density and moisture content. For many of the values cited in the literature, the test parameters are not given. Thus, it is difficult to compare the values given in the literature or to recommend a design value from these data. When recommending a design value, it is important that the properties of the test specimen used for thermal conductivity measurements be approximately equivalent to those of cavity wall or in-service insulations.

Figure 2. Foam Specimens after Exposure to 122°F (50°C) and 92% rh for 7 Weeks Control Specimens 12, 22, 32 and 42 were not Exposed to High Temperature and Humidity.

Measurement of the thermal conductivity of a urea-formaldehyde based foam was recently performed at the National Bureau of Standards [43]. The density of the foam was approximately equal to that of cavity wall insulation. In lieu of oven drying, the foam was permitted to reach moisture equilibrium with room air (similar to the case of cavity wall insulation) at 75°F (24°C) and 40% rh. The thermal conductivity measurement was performed according to ASTM C 177-71. The result and test parameters are given in table 8.

Table 8. National Bureau of Standards Thermal Conductivity Measurement of Urea-Formaldehyde Based Foam [43]

Test Result		Test Parameter			
Thermal Conductivity Btu in/h ft^2 °F (W/m·K)	R-Value h ft^2 °F/Btu in (m·K/W)	Moisture Content Before Test % (wt)	Moisture Content After Test % (wt)	Mean Temp. °F (°C)	Foam Density lb/ft^3 (kg/m^3)
0.246 (0.0354)	4.07 (28.2)	16.8	16.8	75.7 (24.3)	0.60 (9.6)

The thermal conductivity value of 0.246 Btu in/h ft^2 °F (0.0354 W/m·K) given in table 8 is within the range of values reported in the literature although it is higher than many, as shown in table 2. Because the foam in this NBS test was chosen to approximate that of urea-formaldehyde based foam in cavity walls, it is recommended that for design purposes the thermal conductivity value for the foams be taken as 0.24 Btu in/h ft^2 °F (0.035 W/m·K) at 75°F (24°C). Since only one foam was tested at NBS and comprehensive round robin tests by technical organizations such as ASTM and ASHRAE have not been conducted, a comprehensive test program may result in a value of thermal conductivity which will supersede the value recommended in this report.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) has reported on the thermal conductivity values of a urea-formaldehyde based foam measured at various temperatures using the Dynatech Rapid K testing apparatus [35]. These values are given in table 2. The CRREL thermal conductivity value of 0.26 Btu in/h ft^2 °F (0.037 W/m·K) at 71°F (22°C) is slightly higher than the NBS recommended design value of 0.24 Btu in/h ft^2 °F (0.035 W/m·K) at 75°F (24°C).

The Institution of Heating and Ventilating Engineers (IHVE) Guide has recently published thermal conductivity values for urea-formaldehyde based foam [72] as shown in table 9. The data from the Institution of Heating and Ventilating Engineers Guide shows that at densities slightly above the normal recommended application density of 0.7 lb/ft^3 (11 kg/m^3), the thermal conductivity of urea-formaldehyde based foam decreases. This decrease in thermal conductivity with an increase in density, for the density range near the normally recommended density, has also been shown in another report [39], from which data are also given in table 9. It is interesting to note that the data agree favorably with the thermal conductivity value determined at NBS.

The effective insulating properties of foamed walls may be lower than those calculated on the basis of the thermal conductivity of the foam as measured in the laboratory. Shrinkage may result in cracks in the foam, gaps between the wall studs and the foam, and gaps between the wall surfaces and the foam. Shrinkage thus creates void spaces where the thermal resistances are less than that of the foam. In addition, convection air currents within the voids created by shrinkage may contribute to reducing the overall insulating properties of the wall from the calculated values.

Recently, a laboratory test was conducted by a commercial laboratory on a full-scale wall to evaluate the effect of shrinkage of the foam on the insulating properties of the wall [73]. The wall specimen was 9 x 14 ft (2.7 x 3.7 m), constructed with 2 x 4 studs spaced 16 in (400 mm) on centers and insulated with a urea-formaldehyde based foam in accordance with the supplier's recommendations. The exterior of the wall consisted of redwood siding placed over wood-fiber sheathing. The interior was gypsum board. During testing, the wall specimen was exposed to approximately -21°F (-29°C) on the exterior and 74°F (23°C) on the interior.

The results of the study showed that the measured thermal transmittance (U-value) of the wall specimen was 0.077 Btu/h ft^2 °F (0.44 $W/m^2 \cdot K$) [73]. NBS calculated the thermal transmittance of the test wall described above, using the thermal resistance method as outlined in Appendix D. Using a thermal conductivity value of 0.24 (0.035) for the urea-formaldehyde based foam, the calculated value of thermal transmittance of the test wall was 0.062 Btu/h ft^2 °F (0.35 $W/m^2 \cdot K$). The experimental thermal transmittance was thus found to be 24 percent higher than that predicted from calculations. Although shrinkage of the foam increased the observed thermal transmittance of the insulated wall above the expected design value, the thermal transmittance of the insulated wall was observed to be 63 percent lower than that calculated for the uninsulated wall. The calculated thermal transmittance of the uninsulated wall was 0.21 Btu/h ft^2 °F (1.2 $W/m^2 \cdot K$).

Table 9. The Thermal Conductivity of Urea-Formaldehyde Based Foams as a Function of Density

Thermal Conductivity Btu in/h ft^2 °F (W/m·K)	Density lb/ft^3 (kg/m^3)	Mean Temperature °F (°C)	Reference
0.25 (0.036)	0.75 (12)	-	67
0.22 (0.032)	0.94 (15)	-	
0.22 (0.032)	1.9 (30)	-	
0.245 (0.0355)	0.48 (7.8)	72 (22)	34
0.235 (0.034)	0.64 (10)	72 (22)	
0.225 (0.0325)	0.86 (14)	72 (22)	
0.23 (0.033)	1.05 (17)	72 (22)	
0.225 (0.0325)	1.07 (17)	72 (22)	

The foam in the test wall was observed to shrink 3 percent across the stud space width, which was considered to be partially responsible for reducing the effective insulating properties of the wall [73]. Table 10 shows the reduction in the calculated thermal transmittance of the test wall as a function of the percent of the hypothetical shrinkage of the foam insulation. The calculations by which the values in table 10 were obtained are given in Appendix D. As can be seen from table 10, the increase in the thermal transmittance of the wall corresponding to a 3 percent shrinkage of the foam was calculated to be 6.5 percent, which is much less than the 22 percent increase observed experimentally. The calculation only considers heat flow paths of high thermal conductance created by shrinkage of the foam away from the studs. The calculation does not consider heat losses due to convection, nor any effect of moisture accumulation in the foam during testing.

The effect of shrinkage on the thermal insulating properties of a foamed wall has been discussed in the literature. The Swedish State Planning Organization reported that the effect of convection currents occurring in shrinkage cracks and moisture content in the material reduces the thermal-insulating capacity of the foam to about one-half of that of the dry uncracked foam [54]. They recommend that, for practical purposes, the "applicable thermal conductivity" of the foam in walls can be assumed to be about 0.48 Btu in/h ft^2 °F (0.069 W/m·K).

The Dutch standard does not specify the thermal conductivity of urea-formaldehyde based foams. Rather it requires a thermal resistance test of a wall specimen in which foam has been applied [51]. For the foam to conform to the Dutch standard, the effective thermal conductivity of the foam in the test wall should not be greater than 0.35 Btu in/h ft^2 °F (0.050 W/m·K).

It is difficult to correlate these literature data concerning relationships between shrinkage and the effective thermal conductivity of urea-formaldehyde based foams. The Swedish assumption that the effective thermal conductivity may be twice the value measured in the laboratory [54] is not substantiated with test data. Two other reports have suggested lower values of the effective thermal conductivity of the foams in walls [51, 73]. These latter reports are based on laboratory tests which may or may not have a relationship to in-service performance. In particular, the shrinkage of the foam in the test specimens at the time of testing may be less than that occurring in building constructions after a prolonged period of aging. Additional data are needed to correlate the effects of shrinkage on the insulating properties of foamed walls.

Table 10. Calculated Overall Thermal Transmittance Values for a Test Wall as a Function of the Percent of the Hypothetical Shrinkage of a Urea-Formaldehyde Based Foam

Linear Shrinkage in (mm)	Linear Shrinkage percent	Thermal Transmittance Btu/h ft^2 °F (W/m^2·K)	Thermal Transmittance percent increase
0	0	0.0618 (0.351)	0
0.44 (11)	3	0.0663 (0.376)	7.3
0.52 (13)	3.6	0.0672 (0.382)	8.7
0.89 (23)	7.1	0.0710 (0.403)	14.9
2.07 (53)	14.3	0.0833 (0.473)	34.8

7.21 Toxicity

The question has arisen as to the toxicity of the foams and the components from which the foams are produced. The foams are normally used in cavity walls; therefore, there is no direct contact with the building occupants. Danger to building occupants, if present, would result from inhalation of or contact with gases released by the foam. The results of two inhalation toxicity tests on proprietary foams were made available during the survey [66, 67]. Both of these test reports indicated that the foam in question was classified as non-toxic according to the Federal Hazardous Substances Act, Section 191 (f) (2)-1961.

Urea-formaldehyde based foams may release formaldehyde gas under certain conditions. Toxic effects of formaldehyde gas are discussed in Section 8.

Few data or guidelines are available which indicate whether or not a health hazard exists during foam production at the job site. The available evidence shows that there is no hazard when proper application procedures are followed. No complaints that the foam production has caused health problems were uncovered during this survey. One brief report was made available on this subject [74]. It was reported that, after reviewing the components used in preparing a proprietary foam, the foaming process should not pose a significant health hazard if reasonable precautions are observed. It was recommended in this report [74] that protective gloves or clothing be worn to eliminate or reduce to a minimum skin contact with the foam ingredients. The Canadian Government has recommended that the applicator must exercise care in the handling of foam ingredients and the resulting foam because they can cause severe eye and skin irritation [53]. It is noted that none of the major U.S. manufacturers recommends the use of respirators by workmen during foam application.

Possible safety hazards presented by the application of foams to buildings which store foodstuffs in the open have not been addressed in this report. As a precautionary measure, foam should not be applied in warehouses or similar buildings where foodstuffs may be stored in the open, unless it is determined prior to application that the foam application presents no safety hazard. Some manufacturers of the foams have mentioned that their products have been applied in warehouses where foodstuffs have been stored in the open. It is anticipated that these manufacturers have data concerning the health and safety aspects regarding this type of application.

7.22 Water Absorption

Water absorption is a significant performance factor since the thermal conductivity of the foams is dependent upon the amount of water in the foam. The Centre Scientifique et Technique du Batiment (CSTB) has reported on the thermal transmittance of a test wall as a function of time and moisture content of the foam [46]. They showed that a decrease in the moisture content of the foam was accompanied by a reduction in the thermal transmittance of the test wall.

Moisture may be absorbed either in the form of water vapor or liquid water. In the case of water vapor, values of the equilibrium moisture content have been given in the literature. NBS has reported a value of 16 percent by weight at 75°F (24°C) and 40% rh [43]. The Swedish State Planning Organization has reported 8 and 15 percent by weight at 35% and 85% rh, respectively [54], but no corresponding temperature was given. The CSTB has stated that the equilibrium moisture content is 0.2 percent by volume at 68°F (20°C) and 65% rh [46]. Two tenths of a percent (0.2%) by volume is approximately 18 percent by weight. The CSTB has indicated the relative humidity of the air has little influence on the equilibrium moisture content of the foam [46]. This observation supports an earlier report that a freshly applied wet foam will dry out at very high humidities [14].

The resistance of the foams to liquid water absorption is not clearly defined in the literature. The amount of water absorbed during immersion of the foams has been reported as being as low as 2 percent by volume or as high as 42 percent by volume. Reasons for this wide range are not understood, although variations between the types of cells, cell sizes and voids in the foams, as well as differences in test methods, may be responsible.

For cavity wall insulations, both the CSTB and the British Agrement Board have stated that water absorption of the foams through capillarity is slight [46, 55]. The resistance of the foams to water absorption through capillarity has been described in the literature [75]. However, under pressure the foams may absorb large quantities of water [54]. The Dutch and West German standards have requirements for low capillary moisture absorption of the foams [51, 52].

As previously mentioned, water absorption is important because of its adverse effect on the thermal conductivity of the foams. Little data are available which show this effect. The Swedish State Institute for Construction Research has published a graph of the results of a study performed in Denmark [59]. It is difficult to obtain precise values of the thermal conductivity as a function of the water content from this graph. The graph indicates that, as expected, the thermal conductivity increases with an increase in moisture content. Additional data on the effect of water absorption on thermal conductivity are needed from laboratory research.

7.23 Water Vapor Transmission (Permeability)

There is a wide range of values in the literature for the water vapor permeability of urea-formaldehyde based foams. As can be seen from table 2, values for the water vapor permeability are reported as low as 4.5 perm-in or as high as 100 perm-in (7 or 146 x 10^{-12} kg/Pa·s·m). The water vapor permeability is significant in so far as water vapor migrating through the foam may condense within it under certain temperature and relative humidity conditions and thus increase its thermal conductivity. It is anticipated that water condensation problems may be reduced through the use of a properly designed vapor barrier. For a cavity wall retrofitted with an insulation, the vapor barrier would most likely be a paint or coating applied to the surface of the interior wall. Guidelines for such vapor barriers are presently not available.

In the previously mentioned study conducted at Fort Greely, Alaska, by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), a section of a wall insulated with a urea-formaldehyde based foam was visually examined in the spring after an extremely cold winter [35]. It was observed that the exterior sheathing and wind-paper (asphaltic kraft paper of low permeability) were dry, which indicated that no significant amount of moisture had passed through the foam and collected on the low permeability outer wall elements. It is noted that before application of the foam these walls contained insulations having vapor barriers as previously described in Section 7.8. The foam was described as being tight against the inside of the sheathing, and shrinkage was less than 2 percent.

8. FORMALDEHYDE GAS

One of the questions that has been raised concerning the use of urea-formaldehyde based foam insulations is whether or not the foams liberate formaldehyde gas within the insulated structure. If formaldehyde gas is liberated, is its presence a health hazard to the occupants? These questions have been addressed in this review of the performance of urea-formaldehyde based foam insulations.

8.1 Health Hazard

Formaldehyde is a colorless gas which condenses to a liquid at -2°F (-19°C) and freezes to a solid at -180°F (-118°C) [76]. The gas is denser than air, and has a pungent and characteristic odor. The toxicity and health hazards of formaldehyde have been reviewed [77-79]. Formaldehyde toxicity is evidenced on inhalation, contact with the mucous membranes of the eyes, nose and throat and oral imbibition of solutions. The toxic effects of formaldehyde have been determined by studies involving workers who have been exposed to formaldehyde gas in their occupations. Allowable concentrations of exposure are defined according to the threshold limit value (TLV). The threshold limit value represents the concentration that would have no harmful effect on almost any worker on repeated exposure throughout a normal work day (8 hours) [78]. For exposures longer than 8 hours, the maximum concentration that may be tolerated by building occupants has not been defined.

The most recently recommended threshold limit value for formaldehyde gas is 2 parts per million (ppm) by volume in air [77]. The symptoms of exposure to formaldehyde gas have been described [78]. Exposure to small concentrations causes burning of the eyes, weeping, and irritation of the upper respiratory passages. Stronger concentrations produce coughing, constriction in the chest, and a sense of pressure in the head. Inhaling a large quantity of formaldehyde may cause sleeplessness, a feeling of weakness and palpitation of the heart. It has been reported that a threshold limit value of 5 ppm is low enough to prevent respiratory injury but not necessarily low enough to prevent subjective evidence of irritation [77]. With some individuals, irritation to the eyes, nose, and throat, as well as disturbed sleep, may be possible at limits below 5 ppm. It is for these reasons that the threshold limit value is recommended at 2 ppm.

Short-term exposure to 10-20 ppm produces immediate eye irritation and a sharp burning sensation of the nose and throat which may be associated with sneezing, difficulty in taking a deep breath, and coughing [79]. Recovery is reported to be prompt from these transient effects after elimination of exposure. The atmospheric concentration of formaldehyde which is immediately hazardous to human life is not known [79].

It is interesting to note that the least concentration of formaldehyde gas which can be detected by its odor has been reported as 0.8 ppm [78]. This is below the recommended threshold limit value of 2 ppm. Thus, formaldehyde gas may be present in the atmosphere in concentrations that are detectable by the sense of smell but which may not in normal circumstances cause irritation problems to a worker during an 8 hour day. Formaldehyde gas serves as its own warning agent and can be detected before it may cause irritation.

It may be speculated that the effects of exposure to 2 ppm for 8 hours a day may be less severe than the effects of exposure on a building occupant to the same or lower concentrations for longer periods of time (possibly up to 24 hours a day). Information regarding the health hazard to such exposure was not found. In this regard, the Dutch standard has specified the maximum allowable concentrations of formaldehyde gas which may be liberated in the rooms of a building insulated with urea-formaldehyde based foams [51]. Two weeks after foaming, the maximum allowable concentration of formaldehyde is specified as 0.5 ppm. After two months, the maximum allowable concentration is specified as 0.02 ppm.

8.2 Chemical Determination of Formaldehyde Concentration

Formaldehyde can be detected and determined quantitatively by a number of chemical methods [78]. The chromotropic acid (1,8-dihydroxynaphthalene-3,6-disulfonic acid) method used for determining formaldehyde at low concentrations in ambient air is reliable in the concentration range of about 0.01 to 200 ppm. In brief, the method consists of sampling the formaldehyde in a solution of chromotropic acid, and analyzing the resulting solution in a laboratory. Upon heating, the chromotropic acid-formaldehyde solution develops a violet color. The intensity of the violet color is proportional to the concentration of formaldehyde.

8.3 The Incidence of Formaldehyde Odor Problems

During the application of urea-formaldehyde based foam insulations, an odor of formaldehyde may occur because the foam contains formaldehyde. Under normal circumstances, any odor occurring during application should dissipate rapidly and not linger longer than a few days. One major manufacturer has stated that formaldehyde gas is emitted from the foam, in the part per million range, during the drying and curing process which he states will be over in two weeks. The severity of an odor problem depends upon the intensity of the odor and the time period over which it lasts.

It was not possible to document the number of formaldehyde odor problems which have occurred in the United States within residences insulated with urea-formaldehyde based foams. Based on the results of this survey, the incidence of formaldehyde odor problems in the United States appears to be minor. Three cases were noted, but the severity of the problem in two of the three cases was not determined. In the third case, the odor problem was so severe that the urea-formaldehyde based foam was removed from the walls and replaced with another insulation. This points out a disturbing aspect to the formaldehyde odor problem. Although the incidence of occurrence may be minor, a problem, if it does occur, may be major and in extreme cases, require an expensive solution such as removal and replacement of the foam.

In support of the findings regarding the minor incidence of formaldehyde odor problems in the United States, some documented figures were received from the Netherlands [80]. It was reported that in 60,000 Dutch dwellings insulated from the middle of 1974 to early 1977, 32 cases of formaldehyde odor problems were documented. The severity of the problems was not reported.

8.4 Causes and Solutions of Formaldehyde Odor

Formaldehyde odors are caused by the presence of free formaldehyde gas. There are two sources of the formaldehyde. First, formaldehyde is present in the urea-formaldehyde based resin and may be liberated upon foaming. Secondly, formaldehyde is liberated during hydrolysis of urea-formaldehyde based foams which may occur under conditions of high temperature and high humidity.

Factors which would increase the likelihood of liberating formaldehyde from either source will contribute to an odor problem. The major manufacturers of urea-formaldehyde based foam insulations have outlined a number of these factors which are in general related to improper manufacture or improper application of the resin. The relative significance of these factors is not known. The factors contributing to formaldehyde odor problems as described by the manufacturers are:

° an excessive amount of formaldehyde in the resin
° an excessive amount of catalyst in the foaming agent
° an improper ratio of resin to foaming agent
° excess foaming agent
° foaming at high humidities
° foaming with cold chemicals
° dry density of the foam exceeding manufacturers' specifications
° application against recommended practice; e.g. in an air plenum or ceilings
° improper use or lack of vapor barriers
° improper venting on some constructions.

To ensure formaldehyde odor problems will not occur, the foam producing materials must be properly manufactured and the foam must be properly applied. In particular, excess formaldehyde in the resin must be kept to a minimum, and the foam should not be applied in areas subjected to high temperature and high humidity.

If prolonged formaldehyde odor problems occur, there are a number of procedures which are recommended by manufacturers of urea-formaldehyde based foams for correcting the problems. These corrective procedures include:

- ventilation (open doors and windows for 20-30 minutes twice a day)
- modification of air conditioning filters to contain impregnated activated charcoal
- evaporate household ammonia in closed and overheated rooms, then ventilate
- inject ammonia gas into the foam through holes in the walls
- spray air filters or floors with a specified odor absorbent (available from the manufacturer)
- employ a "masking agent" (available from the manufacturer)
- apply vinyl wall paper or a non-permeable paint to interior walls.

9. ACOUSTIC PROPERTIES

A quantitative measure of the air-borne sound insulation of a structure is referred to as the sound transmission loss. The sound transmission loss is a measure of the reduction in transmission of randomly incident sound energy, in decibels (dB), through a partition.

The procedure for measuring the sound transmission loss in the laboratory is to place a test wall specimen in an aperture between two rooms that are acoustically insulated from each other. Only the wall under test transmits sound from the source room to the receiving room. The sound transmitted through the test wall gives rise to a random sound field in the receiving room. By measuring the sound level in the receiving room, it is possible to determine the sound transmission loss through the test wall.

The results of several sound transmission tests on wood stud partition walls performed according to ASTM E 90 are given in table 11. These tests were performed on conventional partition walls having nominal 2 x 4 wood studs spaced 16 and 24 in (106 and 610 mm) with either 1/2 or 5/8 in (13 or 16 mm) gypsum board on both sides of the wall. Values of sound transmission loss are provided for various frequencies for walls of this type containing either urea-formaldehyde based foam, glass-fiber batts or no insulation in the cavities.

Table 11. Sound Transmission Loss of Wood Stud Interior Partitions[1/]

Type of Insulation in a Partition Wall	Transmission Loss, dB						Citation	Reference
	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz		
Urea-formaldehyde based foam	19	29	37	42	41	45	T.R.[2/]	81
	22	32	37	45	45	47	T.R.	82
	21	29	40	45	44	43	T.R.	83
Glass-fiber batts	17	31	39	46	47	43	L.[3/]	84
No insulation	15	25	34	38	36	42	T.R.	81
	17	26	33	41	39	43	T.R.	82
	23	28	37	45	48	42	T.R.	83
	16	28	35	43	44	41	L.	84

1/ Tests conducted according to ASTM E 90 on conventional partition walls having wood studs with gypsum wallboard on each side.
2/ T.R. indicates that the quoted reference is a test report citation.
3/ L. indicates that the quoted reference is a literature citation.

The need to provide a single-number rating for comparing the sound transmission loss of partitions for general building design purposes has led to the development of the Sound Transmission Class, STC, which is described in ASTM E 413-73. The procedure for obtaining the STC rating is given in this ASTM standard. It involves fitting a contour, the STC contour, to measured sound transmission loss data. The rating is designed to correlate with subjective impressions of the sound insulation provided against the sounds of speech, radio, television, music and similar sources of noise in offices and dwellings. In general, a high STC rating corresponds to a high resistance to sound transmission.

Table 12 presents the STC ratings for the sound transmission loss data given in table 11. These data in table 12 show that installing urea-formaldehyde based foam or glass-fiber batts in wood stud partition walls as acoustical insulation did not appreciably affect the STC rating. From table 12 it can be seen that the difference in STC ratings ranged from 0 to 6 depending on which tests are compared. The relative ineffectiveness of the cavity insulation is due to the transmission of sound by vibration through the rigid coupling of both sides to the studs.

Table 12. Sound Transmission Class (STC) Ratings for Various Wood Stud Partition Walls

Type of Cavity Insulation	STC Rating[1/]
Urea-formaldehyde based foam	39
	41
	40
Glass-fiber batts	40
No insulation	35
	36
	40
	37

1/ The STC ratings correspond to the transmission loss data presented in table 11.

In a recent study [85], it was confirmed that the effectiveness of cavity insulation could be markedly improved by installing resilient channels between the studs and the gypsum wall boards. Tests conducted in that study showed in general that with the inner walls decoupled by the resilient channels, transmission took place largely through the air cavity rather than through the studs. This allowed the sound absorbing action of the cavity insulations to become more effective.

Sound transmission loss data and corresponding STC ratings for metal stud partition walls are given in tables 13 and 14, respectively. A comparison of the STC ratings presented in tables 12 and 14 shows that the metal stud walls were more resistant to sound transmission than the wood stud walls. The higher resistance of the metal stud walls is attributed to the metal studs being more resilient than the wood studs. In addition it can be seen from table 14 that the insulated metal stud walls had higher STC ratings than the uninsulated walls and the STC ratings for metal stud walls insulated with urea-formaldehyde based foam and glass-fiber batts were comparable.

In the previously mentioned study [85] it was shown that installing insulation in a conventional exterior frame wall, as is also true of an interior partition wall, was not effective in providing significant reduction in sound transmission. As in the case of the partition wall, the ineffectiveness was attributed to the transmission through the wood studs rather than the cavity.

Measured data on the sound transmission loss of exterior frame walls insulated with urea-formaldehyde based foams were not found in the literature. Although data are not available, it is believed that urea-formaldehyde based foams or other insulations will not provide significant reduction in the sound transmission of exterior walls when most of the transmission is taking place through the studs.

Table 13. Sound Transmission Loss of Metal Stud Interior Partitions[1/]

Type of Insulation in the Partition Wall	Transmission Loss, dB						Citation	Reference
	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz		
Urea-formaldehyde based foams	23	36	45	49	47	46	T.R.[2/]	86
	23	35	46	50	46	47	T.R.	87
	23	34	45	57	51	54	T.R.	88
	25	31	43	53	50	54	T.R.	89
	25	34	46	52	50	48	T.R.	90
Glass-fiber batts	23	35	44	53	45	43	L.[3/]	79
No insulation	15	30	40	47	39	40	T.R.	86
	21	32	38	46	39	40	T.R.	87
	20	31	40	48	42	45	L.	79

1/ Tests conducted according to ASTM E 90 on conventional walls having metal studs with gypsum wallboard or gypsum plaster on either side.
2/ T. R. indicates that the quoted reference is a test report citation.
3/ L. indicates that the quoted reference is a literature citation.

Table 14. Sound Transmission Class (STC) Ratings for Various Metal Stud Partition Walls

Type of Cavity Insulation	STC Rating 1/
Urea-formaldehyde based foam	44
	45
	46
	44
	43
Glass-fiber batts	43
No insulation	37
	39
	41

1/ The STC ratings correspond to the transmission loss data presented in table 13.

10. GENERAL APPLICATION GUIDELINES

The question of proper application of urea-formaldehyde based foam insulations was addressed during this survey. It was found that application guidelines existed both in the United States and in some foreign countries. The four major U.S. manufacturers have guidelines for applying their own materials. In addition, the Dutch standard for urea-formaldehyde based foams contains a section on proper application procedures [51], and a draft application standard has been written by the Canadian Government [53].

These documents were reviewed and form the basis for the general guidelines presented in this section. The authors believe that the major U.S. foam manufacturers have conscientiously attempted to assure that their products are properly applied. Application manuals have been written and programs for training applicators have been initiated. Adherence to the manufacturers' guidelines by applicators should reduce the risk of problems due to improper application to a minimum.

Each manufacturer's recommended set of application instructions differs slightly from those of the other manufacturers because of variations in foam formulation and differences in design of the gun for applying the foam. It is not feasible to recommend a detailed set of application guidelines that would be universally applicable to each of the urea-formaldehyde based foam systems which are currently available in the United States.

Therefore, this section presents a general set of guidelines to assist contractors, inspectors, and users in ascertaining that proper application procedures and certain safety precautions are being followed.

The general set of guidelines includes:

- Foam installation should only be performed by an applicator who has been trained or approved by the foam manufacturer. Installation by an inexperienced applicator may result in an unacceptable foam which may perform poorly.
- Foams should not be applied in ceilings or attics. (Reasons for this recommendation are noted in Section 11.)
- Foams should not be applied in exposed applications. U.S. model building codes require that all foam plastics used on the inside of buildings in walls and ceilings be protected by a thermal barrier of fire-resistive materials having a finish rating of not less than fifteen minutes. In addition exposed urea-formaldehyde based foams may be subject to photodegradation.
- Prior to the application of foams in warehouses or similar buildings where foodstuffs may be stored in the open, it should be determined if this type of application presents a safety hazard. Possible safety hazards presented by the application of foams to buildings which store foodstuffs in the open have not been addressed in this report.
- Foaming equipment should be kept clean and well-maintained. Manufacturers have cleaning and maintenance recommendations for their equipment.
- Dates after which the resins and foaming agents are not usable should be clearly labeled on the resin and foaming-agent containers. These dates (or shelf-lives), as recommended by the manufacturers, should never be exceeded. One U.S. manufacturer has stated that his resin whose shelf-life has not been exceeded should have a milk-like consistency and be white to transparent.
- The resins and foaming agents should be stored within the temperature range recommended by the manufacturer. Some U.S. manufacturers have recommended that 70°F (21°C) is the maximum storage temperature for their materials. The Canadian Government Specification Board has proposed a storage temperature range of 50 to 86°F (10 to 30°C). In general, as the storage temperature is increased, the shelf-life is shortened.

- The temperatures of the resins and foaming agents as they enter the foaming gun should normally be within the range of 59 to 86°F (15 to 30°C), unless otherwise specified by the foam manufacturer. One U.S. manufacturer recommenc that his materials enter the gun at temperatures not less than 70°F (21°C). The maximum temperature of 86°F (30°C) should never be exceeded. For cold weather applications, the resins and foaming agents should be kept in a heated area (normally the applicator's van) during foam production, and the supply-lines from the storage containers to the foaming gun may have to be insulated.

- The surface temperature of the cavity in which foams are to be applied should be within the range of 23 to 86°F (-5 to 30°C). It is recommended that these temperature limits should not be exceeded for a period of four days after application. This guideline concerning the temperature range of the surface of the cavity is adopted from the Canadian Government Specificatio Board's application guidelines [53] and all U.S. manufacturers do not agree with it. For example, one manufacturer recommends that his product be applied within cavities whose surface temperatures range from 0 to 90°F (-18 to 32°C).

- The resins and foaming agents should be pumped to the foaming gun at pressures recommended by the foam manufacturers.

- Power lines in excess of 200 volts within cavities in which foams are applied should be shut off until the foams have dried or until the cavities are sealed.

- Power lines in excess of 110 volts within cavities in which foams are applied should be shut off during application if foaming is performed with the applicator standing on wet ground or not electrically insulated from wet ground.

- The appearance of the foams should be checked immediately before application. The foams should be white in color and fluffy with a warty surface. When the foams are sliced, the cells should be uniform.

- The setting time of the foams should be determined before application and should be no less than 20 seconds and no longer than 60 seconds. The setting time determined as follows:

  A conical sample of foam, approximately 12 in (300 mm) in diameter at the bottom and 12 in (300 mm) in height, is formed by spraying. Immediately after spraying, the foam sample is sliced repeatedly with a spatula or trowel until it can no longer be sliced but shears off leaving a smooth surface on the foam sample. The time interval between spraying the foam sample and the initial shearing of the foam is the setting time.

- The wet density of the foams should be determined before application and should lie within the manufacturer's specified range for the wet density. The normal wet density of the foams is approximately 2.5 lb/ft^3 (40 kg/m^3). Wet density is measured by filling a cardboard box or plastic bag of known weight and volume and then weighing the filled box or bag.
- If the foams are inadvertently sprayed on aluminum building components such as door frames, window frames, or awnings, the foams should be immediately removed and the aluminum component should be rinsed thoroughly with water. In cases where it is anticipated that an aluminum component may be sprayed during application, the component should be protected before application begins.
- Foams which are sprayed on glass should be removed by rinsing with water.
- Water present in the foams at application should be permitted to escape from the wall as the foams dry in the cavity. In cases where the two wall surfaces may restrict the water vapor transmission, provisions such as vent plugs should be provided to allow the water in the wall to escape. The effectiveness of vent plugs has not been demonstrated.
- In applying the insulation in exterior walls of homes which are located in geographic locations having long cold winters, consideration should be given to applying a vapor barrier on the interior (warm side) surface of the wall. The absence of the vapor barrier on the interior of the insulated wall may cause condensation and the accumulation of excessive moisture within the wall. This may lead to problems such as blistering and peeling of paint, buckling of wood siding, or in extreme cases rotting of wood members within the wall. A vapor barrier may be created by applying a low permeability paint or vinyl wallpaper to the surface of the interior wall.
- In retrofitting the walls of residences with any type of insulation, if the need arises to verify the completeness of filling the wall cavities, one method which can be used is infrared thermography.

11. RECOMMENDATIONS

This study on urea-formaldehyde based foam insulations involved a comprehensive review of the literature which was complemented by private communications and preliminary test results. The intent of the study was to assess the performance of the foam insulations. Guidelines are presently not available in the United States for their evaluation and use. The results of the study have shown that available information to establish guidelines is in many cases lacking or contradictory. Therefore, based on this study the following recommendations are made:

- A voluntary national consensus standard be developed for urea-formaldehyde based foam insulations. At the present time there are no U.S. material, product or industry standards nor federal specifications available.

- The design value for the thermal conductivity of the foams should be taken as 0.24 Btu in/h ft^2 °F (0.035 W/m·K).

- The foams should not be applied in attics and ceilings. This recommendation is based on properties of the foams dealing with shrinkage, resistance to high temperature and high humidity, and odor. Excessive shrinkage may occur when the foams are applied to an open cavity and dried too rapidly. Preliminary laboratory data indicate degradation of the foams when exposed to high temperature and high humidity. If free formaldehyde gas is present, being denser than air, it may tend to settle in inhabited areas.

- Foams should not be applied in exposed applications. This recommendation is made to comply with fire resistance requirements of the U.S. model building codes and to avoid photodegradation of the foams.

- The description of foams as "noncombustible" is improper and should be disregarded. Additional information on the rate of heat release and on the performance of the foams in full scale room fire tests should be developed.

- Additional information should be developed through field surveys and laboratory research. Data are not available on long-term performance or durability of the foams in typical wall constructions in the United States. Information is needed from both field surveys and laboratory research on shrinkage, resistance to a combination of high temperature and high humidity, freeze-thaw resistance and the effect of the foams on other construction materials. Information is also needed from laboratory tests to determine the effects of shrinkage, resistance to high temperature and high humidity, and moisture content of the foam on the thermal transmittance of walls filled with urea-formaldehyde based foams.

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APPENDIX A

THE MAJOR U.S. MANUFACTURERS OF
UREA-FORMALDEHYDE BASED FOAM INSULATIONS

- Borden Chemical
  Division of Borden, Inc.
  50 West Broad Street
  Columbus, Ohio 43215

- Brekke Enterprises, Inc.
  1320 Tidehaven Road East
  Tacoma, Washington 98424

- C.P. Chemical Company, Inc.
  25 Home Street
  White Plains, New York 10606

- Rapperswill Corporation
  305 East 40th Street
  New York, New York 10016

APPENDIX B

BUILDING RESEARCH INSTITUTES
CONTACTED FOR INFORMATION ON
UREA-FORMALDEHYDE BASED FOAMS

Country	Institute
Canada	National Research Council Division of Building Research Ottawa, Ontario KlA OR6
France	Centre Scientifique et Technique du Batiment Establishment de Grenoble 24, Rue Joseph Fourier BP 55 38401 Saint Martin D'Heres-Isere
Netherlands	Bouwcentrum Ratiobouw Rotterdam-3 P.O. Box 299 700 Weena
United Kingdom	Building Research Establishment Building Research Station Garston, Watford WD2 7JR
	The Agrement Board Lord Alexander House Waterhouse Street Hemel Hempstead, Hertfordshire HP1 1DH
West Germany	Bundesanstalt fur Materialprufung 1000 Berlin 45 Unter den Eichen 87

APPENDIX C

ADDRESSES OF MODEL BUILDING CODE AND OTHER ORGANIZATIONS REFERENCED IN SECTION 6

BOCA Basic Building Code, 1975
Building Officials and Code Administrators International, Inc.
1313 East 60th Street
Chicago, Illinois 60637

Uniform Building Code, 1976
International Conference of Building Officials
5360 South Workman Mill Road
Whittier, California 90601

Standard Building Code, 1976
Southern Building Code Congress, International
3617 Eighth Avenue, South
Birmingham, Alabama 35222

The City of New York
Housing and Development Administration
Department of Buildings
100 Gold Street
New York, New York 10038

The Society of the Plastics Industry, Inc.
355 Lexington Avenue
New York, New York 10017

APPENDIX D

CALCULATIONS OF OVERALL THERMAL TRANSMITTANCE OF
A WOOD-FRAME CAVITY WALL DESCRIBED IN SECTION 7.20

1. Background

The purpose of this appendix is to calculate the effect of linear shrinkage of urea-formaldehyde based foam on the overall thermal transmittance of a conventional wood-frame cavity wall. When the installed foam shrinks, void spaces adjoining the studs are normally created which extend the height of the wall cavities. Void spaces are also created at the top and possibly bottom of the wall cavity. These void or air spaces create high conductance heat flow paths through a portion of the wall. The foam also normally shrinks in the thickness direction, creating thin air spaces between the foam and the inside and the outside wall surfaces. A continuous air space completely encompassing the foam may exist, and thereby make it possible for air exchange between the front and back sides of the foam to occur. This analysis includes only the effect of the creation of high-conductance heat flow paths adjacent to the studs. The effects of shrinkage at the top or bottom of the wall cavity and of air exchange between the front and backsides of the foam are not included.

2. Wall Construction Details and Heat-Transfer Properties

The wall construction details are given in the following:

Inside to Outside
1/2 in (13 mm) gypsum board
2 x 4 studs, 16 in (400 mm) on center
1/2 in (13 mm) wood-fiber sheathing
3/4 in (19 mm) redwood siding.

The thermal conductivity values used in the analysis are given as follows:

	Btu in/h ft^2 °F	W/m·K
Gypsum board	1.13	0.16
Wood-fiber sheathing	0.38	0.055
Redwood siding	0.84	0.12
Urea-formaldehyde based foam	0.24	0.035
Wood stud	0.82	0.12

The coefficient of heat transfer and the thermal conductance of the air space were taken to be the following values:

	Btu/h ft^2 °F	W/m^2·K
Inside surface heat-transfer coefficient	1.5	8.5
Outside surface heat-transfer coefficient	4.0	23
Air space	1.0	5.7

3. Calculation Procedure

The portions of the wall having studs, insulation, and air spaces sandwiched between other wall components were treated as separate parallel heat-flow paths. The heat transfer through these separate heat transfer paths was treated as one-dimensional; lateral heat transfer between adjacent elements was neglected. The thermal transmittance, U, through the separate heat-flow paths was calculated using the steady-state equation:

$$U = \frac{1}{1/h_i + \sum_{n=1}^{N} (L/k)_n + 1/h_o} \quad (1)$$

where h_i, h_o = overall heat-transfer coefficient at the inside surface and outside surfaces, respectively

$(L/k)_n$ = thermal resistance of the n-th layer.

The overall thermal transmittance for the wall is given by the relation:

$$U_{overall} = \frac{A_s}{A_t} \cdot U_s + \frac{A_a}{A_t} \cdot U_a + \frac{A_I}{A_t} \cdot U_I \quad (2)$$

where A denotes surface area. The subscripts s, t, a, I denote stud, total, air, and insulation property, respectively.

4. Results

Using the foregoing procedure the effect of linear shrinkage on the thermal transmittance of a wood-frame cavity wall was calculated. The percent increases in the overall thermal transmittance for various percents of linear shrinkage are given in table 10 (see Section 7.20).

These values, as calculated herein, show that the overall thermal transmittance of the described wood-frame cavity wall insulated with urea-formaldehyde based foam increases by approximately twice the percentage of linear shrinkage of the foam. The values given in table 10 are plotted in figure 3. As previously noted, the calculated values were based on shrinkage of the foam adjacent to the studs and the effects of shrinkage at the top and bottom of the wall cavity were not included.

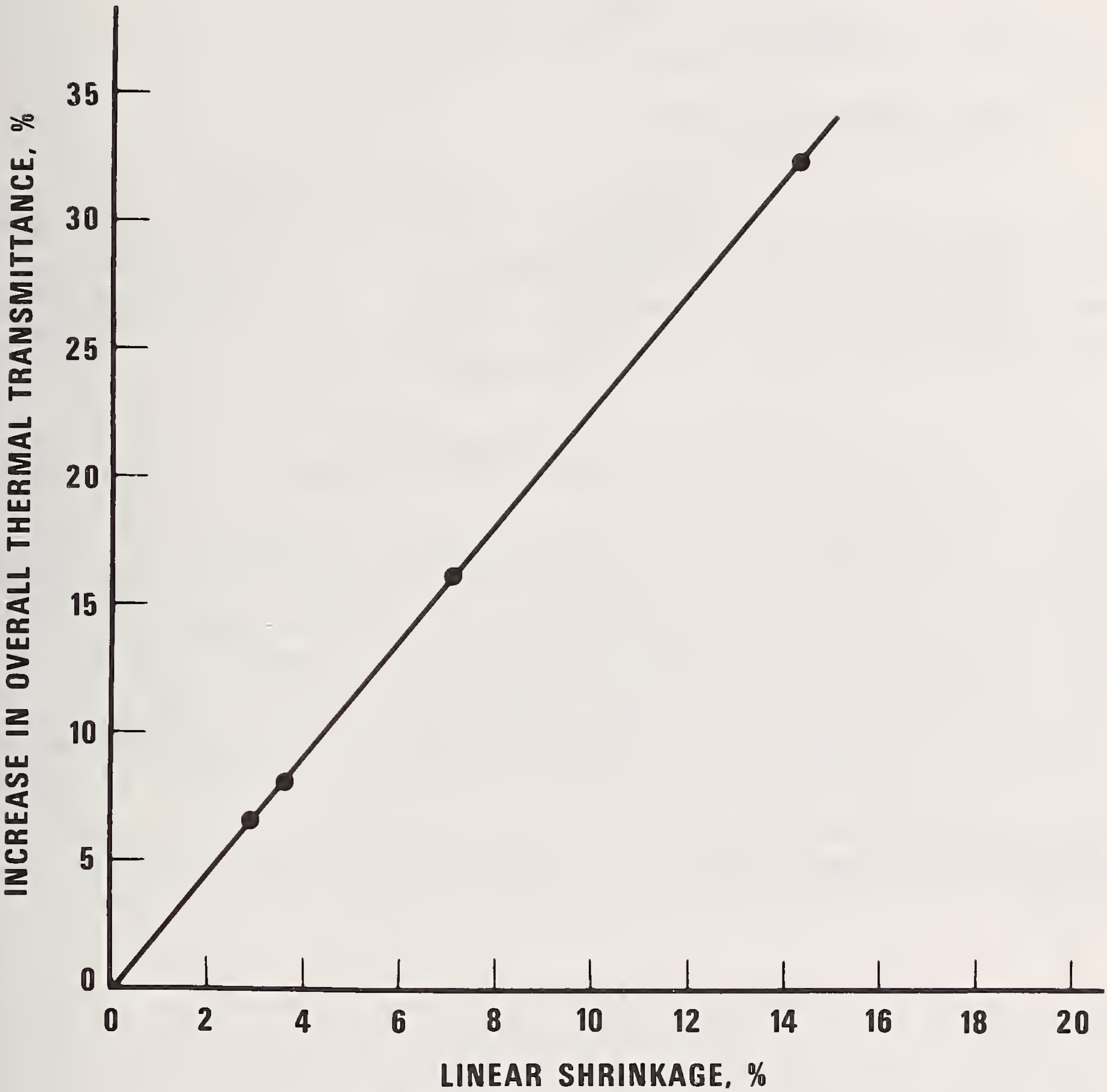

FIGURE 3. EFFECT OF LINEAR SHRINKAGE OF THE FOAM ON THE OVERALL THERMAL TRANSMITTANCE OF A WOOD-FRAME CAVITY WALL.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The properties and performance of urea-formaldehyde based foams pertinent to their use as insulation in buildings were assessed based essentially on existing information. Pertinent materials properties were identified and guidelines prepared for the suggeste values of these properties along with corresponding methods of test. For certain materials properties information was not found to enable suggested values of these properties. The factors affecting performance of urea-formaldehyde based foam insulati were also identified and discussed. Some performance factors could not be adequately evaluated because of insufficient or contradictory data in the literature. Methods of foam application were studied and suggested general application guidelines were prepare

The advantages and disadvantages of using urea-formaldehyde based foam insulations were discussed and problem areas identified. Recommendations were made pertaining to the use and assessment of urea-formaldehyde based foam insulations for residential construction.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Cellular plastics; foam insulation; insulation; materials properties; performance; urea-formaldehyde.

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