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An Assessment of Thermal Insulation Materials and Systems for Building Applications

June 1978

Prepared For
U.S. Department of Energy
Assistant Secretary for Conservation
and Solar Applications
Division of Buildings and
Community Systems
Washington, DC 20545

Under Contract No. EY-76-C-02-0016

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An Assessment of Thermal Insulation Materials and Systems for Building Applications

June 1978

Prepared by
Brookhaven National Laboratory
With the Assistance of Dynatech R/D Company

For

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Assistant Secretary for Conservation
and Solar Applications
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Community Systems
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EXECUTIVE SUMMARY

The increasing emphasis being placed upon energy conservation in general and insulation materials in particular has given rise to a proliferation of conflicting claims and confusion about the performance of energy saving devices. Accordingly, Brookhaven National Laboratory and the Energy Research and Development Administration (now Department of Energy) commissioned Dynatech R/D Company to undertake an assessment of thermal insulation materials and systems for building applications. The primary goal of the study was to provide a proper foundation for decision making by the federal government, industry, and consumer. This report may be used to identify areas where new test methods and standards are needed to establish new programs for improving thermal performance of buildings, and as a basis for setting new or improved standards after the recommended test programs have been completed.

Seven major generic types of insulation were identified, based upon the nature of the material used: mineral fiber (glass, rock, and slag), cellulose, cellular plastics, perlite, vermiculite, reflective surfaces, and insulating concrete. There are widely varying degrees of concentration of manufacturing capacity within these categories: for example, there are four manufacturers of fiber glass insulations and approximately 300 manufacturers of cellulose fiber insulation. Not all products are suited for all building applications, particularly if both new and retrofit applications are considered. The manufacturers, described above, generally sell insulation products to dealers/wholesalers, to large insulation contractors or to chain stores. The dealers/wholesalers sell to retail stores and to insulation contractors. The insulation contractors install insulation both in new homes for builders or in existing homes for the homeowners. The retail stores and chain stores sell to homeowners and to small contractors. Manufacturers give instructions and recommendations for installation procedures, but they do not control installation practices by the

installers. In most cases, plant manufacturing quality control is adequate, but problems have been experienced with some insulation materials processed on-site. Also, there is evidence that installation of insulation materials is not always well controlled. With the sensitivity to energy conservation, attention to installation details is improving.

The total size of the insulation market is estimated at between \$2,000 million and \$3,000 million with approximately one-half to two-thirds being for building envelope applications. Fiber glass is the predominant material. Rapid expansion of plant capacity is expected throughout the industry by 1980, e.g., 30-40% for mineral fiber products, about 200% for cellulose insulation, and about 900% for urea-based foam insulation. If expansion plans for each segment of the industry are realized, the relative market share of each material will change, with urea-based foams and cellulose insulation increasing their market shares at the expense of mineral fiber insulation. It has been suggested by others that this expansion will enable the industry to meet the increased demand resulting from programs designed to improve the thermal performance of buildings. The impact of this expansion on raw materials availability is uncertain at the present time.

Over 400 manufacturers of insulation materials were requested to provide information concerning the properties of their products. This information included thermal performance, fire performance, water vapor transmission, density and mechanical properties, where relevant to a material. An assessment of insulation materials was performed, using all available information, including responses received, manufacturers' literature, open literature, and knowledge of experts in the field. The information was often incomplete, presented in an indirect manner, or contained no reference to accepted test procedures. In some cases information from various manufacturers varied widely enough for a generic material as

to be suspect. In some cases, improved materials or processes are necessary. Comprehensive information was generally more readily available for insulation used in commercial/industrial applications than for residential use.

There are many factors which have been identified as having an effect upon thermal performance of insulations: compaction, thickness, humidity, temperature, and moisture/air barriers. The insulation in turn has an effect on the system in which it is placed due to its fire performance, corrosion, water absorption and similar properties. In general, insulation materials have been sufficiently characterized for properties of generic materials under static (steady-state) conditions, but additional work is necessary to evaluate these materials under dynamic (transient) conditions.

Insulation assemblies for roofs/ceiling, walls, and floors/foundations, typical to residential construction as well as those representative of commercial/industrial applications (as identified in Sweet's Catalogue) were reviewed. Data are available based upon static test conditions and calculation procedures are used to estimate performance for average conditions over time. These performance estimates do not take into consideration dynamic effects which may have significant impact on actual field performance. Additional investigation is necessary to determine the effects of dynamic conditions on assembly thermal performance under laboratory and actual field conditions.

The technology for static testing is sufficiently advanced to enable reliable measurement of R-values and other properties. To support this testing there is an urgent need for reference materials. There is also a need for improvement in the technology of dynamic testing which would enable reliable measurement over a wide range of conditions experienced in actual practice. Building codes are now incorporating energy conservation provisions, and the standards reflect the state-of-the-art of testing technology and insulation materials.

Properties of insulation materials are usually presented for the material isolated from the field environment. These data are then used in design calculations to predict the performance of insulation assemblies which are part of the building structure. Various methods employing different assumptions are used for design calculations. This could result in performance predictions which are different from actual performance. There is a lack of sufficient experimental verification of the predicted performance of these systems, both by simulated laboratory experiments and tests in actual field conditions. There is also a lack of sufficient test methods and instrumentation for field evaluation of performance.

It is clear from this assessment that significant gaps exist in our knowledge of properties and performance of insulation materials and systems. Recommendations have been made which should result in better use of thermal insulations for conservation purposes in both new and existing buildings. Some of the important recommendations are summarized as follows:

- Establish a cooperative effort among the various interested parties to obtain the information that is lacking and disseminate existing and new information to those groups which require it.
- Develop standard heat flow reference specimens to be used for calibration of testing equipment.
- Investigate the long-term effects of dynamic conditions (temperature, moisture, weathering, etc.) on the thermal performance and fire resistance of all insulation materials.
- Determine the quantitative relationship between R-value and temperature for all insulation materials.
- Establish quantitative small- and large-scale test methods for fire performance of insulation materials and systems.

- Develop a test method for toxicity of products of combustion from insulation materials.
- Develop a test method for corrosive effects of insulation materials.
- Develop equipment and test procedures for large-scale dynamic thermal performance tests.
- Develop a method for determining the effects of air movement through insulation materials.
- Determine the importance of vapor barriers.
- Develop equipment and procedures for field studies of thermal performance of insulation assemblies.

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Section 1

INTRODUCTION

Today, as energy shortages become more apparent and costs of heating and cooling continue to escalate, the use of energy conservation methods has become more economically attractive. One approach to conservation is the use of thermal insulation.

Insulation has frequently made headlines in the U.S. as its use in reducing energy consumption becomes more important. Much has been said about possible insulation shortages, price gouging, and windfall profits by insulation manufacturers, particularly in view of possible government programs which would lead to increased product demand. Items in the Wall Street Journal (1), Business Week (2), Energy Users Report (3), Newsweek (4), and Chemical Week (5) emphasize these points. A Washington Post article (6) discussed potential problems arising from poorly manufactured products. A Consumer Product Safety Commission hearing (2, 7) on August 22, 1977 considered safety aspects of insulation materials, particularly flammability of cellulosic insulation and possible carcinogenicity of mineral fiber insulation. Conflicting claims with regard to performance have led to confusion among the public and decision makers in government. It is obvious by the plethora of news items, advertisements, government hearings, etc. that insulation is becoming more important to the public. Consistent, factual information about some products has not been readily available to the public.

In light of current action and statements by both Congress and the Administration, it is apparent that the federal government is moving to upgrade the thermal performance of both new construction and older buildings. The massive programs being proposed can lead to severe problems if sufficient technical background is not developed. The potential investment by the federal government, whether in the form of subsidies, grants, tax incentives, or loan guarantees could be enormous. The potential direct economic impact

on the public is obvious. It is imperative that this investment be made wisely so that both short-term and long-term energy savings are maximized.

In order to provide a proper basis for decision making, the U.S. Energy Research and Development Administration (now Department of Energy) and Brookhaven National Laboratory contracted with Dynatech R/C Company to undertake a comprehensive assessment of insulation materials available to improve the performance of building envelope systems. The objectives of this program were the compilation and assessment of available data on building thermal insulation materials and systems and identification of areas where sufficient data have not been developed or made available. Manufacturers were surveyed to obtain information with regard to the thermal performance, flammability, toxicity, stability, and other physical characteristics of insulation materials and systems. Manufacturing and marketing information were also obtained. An assessment of the information obtained was undertaken. Applicable codes and testing methods were reviewed.

In order to meet the objectives of this program, Dynatech assembled a project team consisting of technical experts from throughout the insulation industry. Dynatech is an independent testing laboratory and manufacturer of thermal measurement instruments. The other project team members were chosen to provide input, analysis, and assessment from the three major segments of the insulation industry: mineral fibers (Johns-Manville Sales Corporation), cellular plastics (Dow Chemical Company), and cellulose (Rollin, Inc.).

This report is a result of the assessment study. A history of the insulation industry is presented in Section 2, followed by an indication of the market size. Available data of the various generic insulation materials were compiled and the assessed thermal property and other data for generic materials are presented in Section 3. The application of insulation materials in building envelopes is discussed in Section 4 for both residential and industrial/commercial structures. The state-of-the-art of thermal

and other property testing methods and building codes are presented in Sections 5 and 6, respectively. It is anticipated that this document will provide decision makers in government, regulators, manufacturers, installers, and consumers with a collective source of authoritative, state-of-the-art information on insulation materials and systems. Conclusions and recommendations, presented in Sections 7 and 8 respectively can be used as:

1. A basis for setting new or improved standards after recommended research and test programs have been completed;
2. A basis for identifying areas where new test standards and methods are needed;
3. A basis for establishing new program for improved thermal performance of buildings;
4. A basis for establishing priorities in insulation R&D.

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Section 2

DESCRIPTION OF THE INSULATION INDUSTRY

2.1 History

Techniques and materials for separating man from the heat and cold in his external environment are as old as civilization itself. Thatched roofs of tropical settlers and adobes developed by American Indians were early versions of insulations. They performed, to some degree, their intended functions - isolating man from the heat of the sun in summer and the cold of winter winds and snow.

Development of insulation materials paralleled that of buildings in which it was installed. It had, until quite recently, one purpose - that of man's comfort. Today, the use of insulation has become more an economic necessity, reducing the loss or gain of heat and the costs associated with that loss or gain.

In the 1800's, insulations used were natural materials - largely vegetable, principally wood and its derivatives. Early in the 20th Century, the beginning of what is today the insulation industry - the development and manufacture of materials specifically designed to retard the movement of heat - was started.

The first materials manufactured on a large scale were rock and slag wools. Natural rocks or industrial slags were melted in a furnace, fired with coke, and the molten material was spun into fibers and formed into felts or blankets. These were used in buildings of all types, and also for industrial processes but on a very limited basis where temperatures of an "extreme" nature existed. The use of these materials gradually increased during the first half of the 20th century and at the end of that period they were being used in most houses as well as industrial/commercial buildings, although still limited in terms of quantities and thicknesses used.

In 1928 there were about 8 plants manufacturing these products in the U.S. This number increased to 25 by 1939 and 80-90 in the 1950's, but has since declined to about 15-20 today.

Glass fibers were successfully developed on a commercial scale in the U.S. in the 1930's by Owens-Illinois, Corning Glass Company, and Owens-Corning Fiberglas Company (a company formed by the first two companies). Fiber glass insulations were developed during the 1940's and 1950's by melting inorganic materials - principally sand - and fiberizing the molten glass into blanket-type material. Owens-Corning Fiberglas was the only producer of fiber glass insulation in the U.S. until 1950. An anti-trust action filed in 1949 by the U.S. Department of Justice resulted in a settlement in which Owens-Corning Fiberglas agreed to and did license qualified companies to produce fibers. In addition, alternative processes have since been developed and are now being used to produce glass fiber.

In the mid-40's, the domestic perlite industry began commercial production. One major application of the crude perlite when processed and expanded was as thermal insulation. At the same time, some entrepreneurs in various parts of the United States began grinding waste paper into a fibrous state for use as an insulating material. This was the start of the cellulose insulation industry.

The commercial production of plastic foams began in the mid-1940's with extruded, foamed polystyrene, originally developed by Dow Chemical company. It was followed in the late fifties by the commercial production of urethane foams, polystyrene foams manufactured from beads, and urea formaldehyde foams. Phenolic foams, which have never been very significant commercially in the U.S., have been produced in Europe since the 1950's and in Canada since about 1972. The major emphasis in the first 10 or 15 years of its commercial life was its use in particularly severe insulating applications, such as in low-temperature space facilities, because of its moisture

resistance and its high stable thermal resistance. Over the last 10 or 15 years, however, the uses for plastic foams, particularly the polystyrenes and polyurethanes, have expanded rapidly into building insulation applications. Plastic foams are often considered to be new as building insulation materials because only in the last 5 years or so they have become widely known in the marketplace.

The 1960's saw rapid development of fiber glass as an insulating material, at the same time as homes and buildings were being better insulated, still largely for comfort purposes. As fiber glass use grew, rock wool (and slag wool) declined. The small rock wool plants, approximately 80 to 90 in number in the 1950's declined to about 15 to 20 today, their product being replaced by fiber glass.

Although patents for cellulosic fiber insulation were issued in the 1800's, the product did not find a firm foundation in the marketplace until late in the 1950's. The primary use of the material was for retrofitting attics, and to a lesser degree, insulation of existing wood-frame sidewalls.

The "Battle of the Fuels" in the late 50's, Electric Heating vs. Fossil Fuels, was a major impetus for the insulation industry. Accelerating air conditioning sales found electric utilities with surplus capacity in winter months. The long sought "balanced load" seemed to have its solution in the sale of electric heat. Aggressive marketing of electric power for heating began a trend to greater insulation usage. The relatively high cost of electric energy was balanced against other heating fuels by the use of full wall insulation, 6" to 8" thick attic insulation, and 2" to 4" thick underfloor insulation. The concept prospered and soon fossil type heating plants were being replaced or displaced with electric heating apparatus and insulation.

About 1970, certain private and government groups began to see energy shortages on the horizon. The insulation that had been used for comfort purposes in the past took on a new role - contributing to more efficient use of a scarce natural resource. Prices of energy started to rise, and the use of insulation became more economically attractive. New homes and buildings were better insulated at the time of construction, and in the mid-1970's, the refitting of existing buildings, constructed during times of inexpensive and available energy, began to demand larger and larger amounts of insulation materials.

Today, buildings of all types are being insulated thoroughly; codes and standards increasingly require it. As energy shortages become more apparent and costs for heating and cooling continue to rise, interest in use of insulation for economic purposes continues to grow. In summary, the increased use of insulation is being stimulated by concern for resource conservation, new energy-use provisions of building codes, and simple economics of fuel savings.

2.2 Types of Insulation Materials

In this section a description of the more important insulation materials with a general overview of manufacturing processes for these materials is presented. Principal applications for each of these materials are shown in Tables 2.1 and 2.2.

2.2.1 Rock or Slag Wool

Rock and slag wool are terms that are used commonly to denote glassy fibrous substances made by melting and fiberizing slags obtained from smelting metal ores including iron ores ("slag wool"), or by melting and fiberizing naturally occurring rock ("rock wool"). (Mineral wool is a generic terms which includes fiber glass and rock and slag wool.)

Table 2.1

PRINCIPAL BUILDING APPLICATIONS

LOCATIONS	FIBER GLASS	ROCK WOOL	CELLULOSE	CELLULAR PLASTICS	PERLITE	VERMICULITE	REFLECTIVE SURFACES	INSULATING CONCRETE
<u>INDUSTRIAL</u>								
New Construction								
Roof/Ceiling	X			X	X			X
Walls	X	X		X	X	X		
Floors/Foundation				X				
Retrofit								
Roof/Ceiling	X			X	X			X
Walls	X			X				
Floors/Foundation								
<u>COMMERCIAL</u>								
New Construction								
Roof/Ceiling	X	X	X	X	X			X
Walls	X	X		X	X	X		
Floors/Foundation	X	X		X				
Retrofit								
Roof/Ceiling	X	X	X	X	X			X
Walls	X		X	X				
Floors/Foundation								
<u>RESIDENTIAL</u>								
New Construction								
Roof/Ceiling	X	X	X	X				
Walls	X	X		X			X	
Floors/Foundation	X	X		X			X	
Retrofit								
Roof/Ceiling	X	X	X	X		X		
Walls	X	X	X	X				
Floors/Foundation	X	X		X			X	

Table 2.2

MARKET SEGMENTS AND PRODUCT USAGE

Location or Building Section	Products Used	
	New Buildings	Retrofit
<u>Residential Buildings (Wood framed)</u>		
Ceilings	Fiber Glass Batt Fiber Glass Loose Fill Rock Wool Batt Rock Wool Loose Fill Cellulose Loose Fill	Fiber Glass Batt Fiber Glass Loose Fill Rock Wool Batt Rock Wool Loose Fill Cellulose Loose Fill Vermiculite
Sidewalls	Fiber Glass Batt Rock Wool Batt Cellular Plastic Sheathings Wood Fiber Sheathings Reflective Surfaces	Fiber Glass Loose Fill Rock Wool Loose Fill Cellulose Loose Fill Cellular Plastics
Floors	Fiber Glass Batt Rock Wool Batt Reflective Surfaces	Fiber Glass Batt Rock Wool Batt Reflective Surfaces
<u>Commercial/Industrial Buildings</u>		
Roof/Ceiling	Cellular Plastics Perlite Board Fiber Glass Boards Insulating Concrete Cellulose (Spray-On)	Cellular Plastics Perlite Board Fiber Glass Boards Insulating Concrete Cellulose (Spray-On)
Walls	Cellular Plastics Fiber Glass Batt Perlite Vermiculite	Cellular Plastics Fiber Glass Batt Cellulose Loose-Fill
Floors (Wood Framed)	Fiber Glass Batt Rock Wool Batt	Fiber Glass Batt Rock Wool Batt
Floors (Masonry)	Cellular Plastics	

In the early manufacture, raw materials, either slag or rock, were melted in a cupola furnace and the molten stream of material was fiberized by passing it in front of a high-pressure steam jet. As the process evolved, more sophisticated designs of the steam jet were made in an effort to obtain more effective fiberization of the molten slag. The molten stream of slag tends to be broken up into many small droplets by the steam jets, and as these droplets are swept out at high velocity in front of the jet, fibers are formed by the streaming of "tails" from the heads of the droplets. Not all of the material is converted into fibers by the process, and some non-fiberized droplets, referred to as "shot", remain in the product. This unfiberized slag does not contribute to the thermal performance of the product.

Until the early 1940's, almost all rock and slag wool in the U.S. was made with one version or another of the steam jet process. Around the 1940's, however, at least two other processes were developed and commercialized for rock and slag wool production. The Powell process used a group of rotors operating at relatively high centrifugal speeds to collect and distribute the molten stream of slag in a thin film on the surface of the rotors, and then to fiberize the slag by throwing it off the rotors with centrifugal force.

A second fiberization method which came into use at about this time was the Downey process which combined a spinning concave rotor with steam attenuation. The molten stream was distributed in a thin pool over the surface of the dish-shaped rotor, and flowed up and over the edge of the dish where it was caught up in a high-velocity steam or air stream surrounding the dish and fiberized.

Although both the Powell and Downey processes had advantages over the steam jet method, they still produced a product with a relatively high "shot" content.

Current problems in rock and slag wool manufacture include coke availability and, more importantly, blending of available slags to get the desired fiber properties.

A typical manufacturing process flow scheme for rock or slag wool insulation is presented in Figure 2.1.

Rock and slag wool products, batt materials and loose-fill for blown or poured application, are principally used for residential construction and retrofitting.

2.2.2 Fiber Glass

Fiber glass, in many ways, is similar to rock or slag wool, with refinements due to process evolution and improvements. Fiber glass consists of an inorganic, mineral base and is made into glass wool by several different processes. A process flow chart for the manufacture of fiber glass insulation is shown in Figure 2.2. The glass raw materials are combined and melted in a furnace, and then led out through a forehearth to the fiberization devices. Binder is applied to the fiber as it flows through a collection chamber. Phenolic resin is a binder commonly used by the industry. The fiber with resin is collected on a moving belt and passed through an oven in order to "cure" or "set" the resin, and the finished product is taken off the end of the line and packaged.

One type of fiberizing device used with this process uses a rapidly spinning rotor in which the molten glass stream is flowed into the bowl of the rotor, where it is distributed to the sidewall of the spinning rotor. The sidewall contains many small holes, and as the glass flows through these holes it is attenuated by high-velocity jets around the outside periphery of the rotor.

Figure 2.1 Manufacturing Process for Rock or Slag Wool Insulation

Figure 2.2 Manufacturing Process for Fiber Glass Insulation

Another process for making glass "wool" does not utilize the rotor concept, but uses a high-pressure, high velocity gas jet to fiberize rather coarse primary filaments of glass. In this flame-attenuation process the primary filaments are fed in front of the high-velocity burners, a binder is applied to the attenuated fiber, and it is collected and cured by passing through an oven.

Fiber glass insulation is used in residential and commercial/ industrial building envelopes for both new construction and retrofit applications. It is sold as batt, loose fill, and boards, with the usage as indicated in Table 2.2.

2.2.3 Cellulose

Cellulose insulation is made by converting used newsprint, other paper feedstock, or virgin wood to fiber form with incorporation of various chemicals (typically used are borax, boric acid, and aluminum sulphate at a loading of approximately 20% by weight) to provide flame retardancy. This type of insulation is available as loose fill or spray-on with principal applications indicated in Tables 2.1 and 2.2.

2.2.3.1 Dry Process

The original manufacturing technique for cellulose insulation is a dry process, which is commonly in use today. It consists of feeding the cellulosic material, in most cases newsprint, into one or more mills to shred and pulverize the material into a fibrous, reasonably homogeneous bulk material.

Typical single mill processes operate with up to 150 H.P. motors. The single mill may function with swinging or fixed hammers or work as a cutter/shredder which forces the final product out through a

mill screen with approximately one-quarter inch openings. Paper stock is usually hand fed to allow for sorting of undesirable foreign materials. A dry chemical is usually augur fed directly into the inlet of the mill where it is blended forcefully onto the fibers. The "finished" product is then air conveyed to a bagging machine for packaging.

This type of operation, which is being utilized by between 75 and 100 plants, is not a capital intensive investment. The end product performs as a thermal insulation, but may not meet other criteria set forth by federal and local regulatory bodies, e.g., flammability, corrosiveness, due to the lack of balanced feed rates for paper and chemicals. Other factors influencing product quality are discussed elsewhere. Production capacity for this type of operation can be as high as 3.5 to 4.0 tons per hour, but is usually around 1.5 to 2.0 tons per hour on a day-in day-out operation.

Multi-mill processes are designed with many variations to cope with increased output, physical layout, material handling, and quality control problems. They generally follow the basic layout shown in Figure 2.3. Paper stock is introduced to the first mill via one or more conveyors. The first mill is usually referred to as a hogger/shredder or cutter. It may perform its task of breaking the paper into approximately three inch to four inch size pieces, sometimes smaller, through the use of fixed or swinging hammers or rotary type cutters.

In some designs shredded paper is passed from the first mill into a holding bin. In others it is immediately fed to a second stage hammer mill where it is reduced into "confetti" size particles and then fed to a holding bin.

In either process the holding bin is used to achieve a uniform feed rate to the next or last mill in the process. The dry chemical, either a single element or component mix, is usually introduced simultaneously with the ground paper at the second or final mill. This is the most

Figure 2.3
Flow Diagram for Multi-Mill Process

critical stage of the manufacturing process. It is at this point where the human element of physical supervision must be combined with mechanical/electrical controls to maintain a consistent quality in the product.

Introduction of chemicals into the systems may be by pneumatic means (vacuum or forced draft), gravity feed, or augur feed. In many processes the chemicals are pre-blended, proportioned, and then ground in a mill to the consistency of fine sugar or flour. This finely ground material is dispersed more readily and easily blended into the cellulose fiber materials. The final stage of the process is the bagging operation. The finished product is conveyed into one or more large storage bins which feeds one or more baggers.

2.2.3.2 Wet Process

The dry process is the more widely used in the industry, but two other methods are available for manufacture of cellulose fiber insulation and can be classified as wet processes. One process involves introduction of an aqueous fire retardant solution sprayed, misted, or sprinkled onto the paper stock material at some point in the process. This is usually done after the paper stock leaves the first mill and prior to entering the finish mill. The method relies on the evaporative ability of the air stream and the short duration heat build-up in the final milling process to remove excess moisture. The amount of chemical, and its evaporative characteristics in response to the process in which it is used, are critical to the properties of the end product. Too little or too much chemical may result in an unmanageable or unuseable end product.

The details outlined in the manufacture of dry material are essentially unchanged except for introduction of liquid dispensing equipment to replace bins, augurs, chemical mills, etc., used for bulk handling of dry chemicals.

The other wet process incorporates conventional paper making process equipment. It reduces paper stock to a slurry via a pulping process, dewateres it via compression, squeezing up to 50 to 60 percent of the water from the pulp, and then fluffing and drying the material prior to bagging it as a finished product. There are many potential variations in this process. There are a wider range of opportunities to introduce chemical treatment, dye or other modifications to the process.

There are distinct advantages to either wet process system, but little technical information is available for the evaluation of these processes. Little work has been done in this field due to production economics and as a result, it is being used by very few plants. It is relatively simple and inexpensive to get into the business of manufacturing some form of cellulose fiber insulation by the dry process. The return on investment typically is seldom less than 10% net after taxes. Some operations claim to yield 22% net after taxes. Thus, there is little incentive to invest in untried, yet to be proven wet processes.

Wet processes offer a potentially improved product with better chemical dispersion, fire retardant characteristics, corrosiveness control, and improved resistance to leaching. The wet process may allow for more flexible manufacturing procedures and chemical treatments which are not possible with the dry process. The disadvantage of needing a drying operation with the associated energy requirements should be balanced against the benefits of the process.

2.2.3.3 Spray-On Cellulosic Fiber Insulation

Application of cellulosic fiber insulation to a given substrate, by means of a bonding agent, has been known for many years. The earliest patent, awarded in the early 1900's, demonstrates a technique for spraying

cellulosic fiber and recommends several types of adhesive formulas. Over a period of years, this has evolved into a small segment of the insulation industry with relatively sophisticated application equipment.

Cellulosic fiber material for spray-on application is processed in a manner similar to that outlined for dry process material. It will usually have more chemical, generally boric acid, added to it to improve its flame retardant values. Since the product is usually left as an exposed finish, the extra flame retardancy is extremely critical to its in-place performance. Generally, a polyvinyl acetate or an acrylic adhesive is used to bind the material to itself and the substrate. In some techniques, adhesive is mixed with water and sprayed onto the product in fine mist as it is pneumatically conveyed through a special application nozzle. This mist wets the fibers, adds adhesive, and produces the resultant spray-on finish. Another technique has a dry resin added to the product which is activated by a water spray at the nozzle just prior to its installation.

2.2.3.4 Cellulose Fiber Insulation Flame Retardants

The earliest registered chemical treatment for a flame retardant applied to cellulosic fiber material incorporates the use of boric acid. Since that time many combinations, including or excluding boric acid, have been experimented with in an effort to provide flame retardant properties in cellulosic fiber insulation. These chemicals have been used individually and in combined formulations in an effort to provide minimum cost and acceptable performance as a fire retardant. Some of the common formulations used contain combinations of the following chemicals: boric acid, borax, aluminum sulfate, lime, ammonium sulfate, ammonium phosphate, mono- and diammonium phosphate, aluminum hydrate, aluminum trihydrate, and zinc chloride. Many combinations have been tried but none have been found totally effective. One combination may produce high resistance to flame spread but permit severe afterglow. Changing the balance of chemicals

alters the results, sometimes reversing them. Increasing a component found successful at one concentration may cause failure at another concentration.

2.2.4 Cellular Plastics

There are several different plastics which have use as insulation materials when produced as foams. Both foamed-in-place and board stock foams exist. Due to the significant difference in chemical composition, it is best to discuss separately each cellular plastic insulation.

2.2.4.1 Polystyrene Foam

Polystyrene, a thermoplastic material, is produced by polymerization of styrene, $C_6H_5 \cdot CH:CH_2$, in the presence of a catalyst. Two methods are widely used for producing polystyrene foam, namely, extruded and expanded.

The extruded form is manufactured by flowing a hot mixture of polystyrene, solvent, and pressurized gas (blowing agent) through a slit into the atmosphere. Due to the reduction in pressure, the gas expands, resulting in a foam with a fine, closed-cell structure. The blowing agent is usually a fluorocarbon.

The expanded (or molded) form is made by placing polystyrene beads (containing a blowing agent) into a mold and exposing them to heat. The vapor pressure of the blowing agent causes expansion of the beads, resulting in a predominantly closed-cell foam. The blowing agent is usually pentane.

Polystyrene foam is primarily used in commercial/industrial buildings as an insulation in ceilings/roofs, walls, and floors/foundations. Use in residential structures includes perimeter slab insulation, foundation insulation, exterior sheathing, and siding backerboard. It has also

been used in cathedral type roof/ceiling construction. Application in residential construction is increasing due to more favorable economics as energy costs continue to increase.

2.2.4.2 Polyurethane and Polyisocyanurate Foams

Polyurethanes are plastics which are the reaction product of isocyanates and alcohols. Polyisocyanurates are made from isocyanates in the presence of a catalyst, resulting in the formation of a more thermally stable isocyanurate ring structure.

Originally, polyurethane foams were formed during the chemical reaction by release of carbon dioxide. However, halocarbons are now used as blowing agents, resulting in an essentially 100% closed-cell foam. Either rigid or flexible foam can be produced, depending on the functionality of isocyanates and alcohols and the molecular weight. For thermal insulations, the rigid foam is used.

Polyurethane and polyisocyanurate foams are produced by several different processes. Continuous slab stock is made by mixing the necessary components and continuously metering the mixture onto a moving conveyor. The mixture forms a continuous foam which can be cut to lengths dependent on ultimate use. Laminates can be made by a similar process, dispensing the mixture between sheets.

Foamed-in-place polyurethanes and isocyanurates are prepared by mixing or metering the components and dispensing them either manually or automatically. Specially designed units are available for spray-on applications.

Rigid polyurethane and polyisocyanurate foams are used primarily for commercial/industrial buildings as roof insulation, floor and foundation insulation, cavity wall insulation, and interior and exterior spray-on wall insulation. Both board stock and foam-in-place forms are available. There is increasing use of these foams in residential construction, principally as sheathing.

2.2.4.3 Urea-Formaldehyde and Urea-Based Foam

The major application of urea-formaldehyde and urea-based foam as a thermal insulation is for retrofitting residential wall cavities. It is also used, but to a lesser extent, as an insulation in commercial/industrial buildings for both new construction and retrofit and in residential new construction.

Urea-formaldehyde foam is generated at the site of application by the combination of an aqueous solution of a urea-formaldehyde based resin, an aqueous solution foaming agent which includes a surfactant and acid catalyst (or hardening agent), and air. In the mixing or foaming gun compressed air is mixed with the foaming agent to produce small bubbles which are expanded and coated with the urea-formaldehyde resin. The foam is delivered at about 75 percent water by weight and immediately begins to cure. The foam typically cures sufficiently to be self-supporting in less than 1 minute while full chemical curing requires several weeks. The rate of water dry-out from the foam depends on the type of structure in which the foam is applied. The foam produced in this manner consists of an approximately 60% closed-cell structure.

Urea-based foam insulation has been considered a generic material. However, it is known that differences exist in the composition and properties of the foams available in the United States. The specific formulations used by the industry are proprietary and include chemical components for the purpose of improving foam properties. Also, different types of apparatus are used to produce the foam.

2.2.5 Perlite and Perlite Mineral Board

Perlite is a naturally occurring, siliceous, volcanic glass containing between two and five percent water by weight. Perlite ore is

composed primarily of aluminum silicate. Crushed ore particles are expanded to between 4 and 20 times their original volume by rapid heating to a temperature of 1000°C, which vaporizes the occluded water and forms vapor cells in the heat-softened glass.

Perlite is used primarily in industrial/commercial buildings as a roof insulation board material. The next largest use is in lightweight insulating concrete where expanded perlite is mixed with Portland cement. A wide range of density is available. Perlite insulating concrete, both preformed and cast-in-place, is used primarily for roof decks, floor slabs, and wall systems. Low density expanded perlite is used as a loose fill insulation.

2.2.6 Vermiculite

Vermiculite is a mica-like hydrated laminar mineral consisting of aluminum-iron-magnesium silicates with both free and bound water. When the mineral is subjected to high temperatures it expands due to formation of steam which is driven off, thereby causing the laminae to separate. A wide range of density is available, depending upon the amount of expansion.

The principal thermal insulation applications for vermiculite are for residential attic loose fill and as an aggregate in lightweight insulating concrete for roof decks.

2.2.7 Insulating Concrete

Insulating concrete, made with perlite or vermiculite aggregate, has already been mentioned. Insulating concrete can also be made by foaming a Portland cement mixture. When a foaming agent, such as aluminum dust, is added, a chemical reaction occurs evolving a gas, which produces a closed-cell porous material. A wide range of densities is possible, density being a function of the amount of gas evolved. The concrete normally will set in about 3 days to sufficient strength to permit roofing.

Insulating concrete is primarily used for roof systems and decks. Higher density concretes can also be used for wall insulation, where the increased strength is balanced against poorer insulating properties for the higher density material.

2.2.8 Reflective Surfaces

Aluminum foil, the major reflective surface insulation, is different from other insulating materials by the manner in which it retards transfer of heat, namely by reflection of incident infra-red radiation. This reduces radiant heat transfer.

Aluminum foil facings are used in conjunction with mineral fiber and rigid board plastic foam insulations and will add to thermal performance where a dead air space is adjacent to the foil.

Multilayer aluminum foil is used to insulate residential building walls and floors.

2.2.9 Insulation Board

Board insulation is used in commercial/industrial buildings as part of the roof/ceiling system. For flat roofs, insulation board is placed on the roof deck and the built-up roofing is applied directly to the board.

There are several different types of insulation board, including perlite board, foamed plastic board, fiber glass board, laminated board, consisting of perlite or glass and foamed plastic, wood fiber board, and sandwich panels. Applications of these products are discussed in Section 4.

2.3 Manufacturing Facilities

Information concerning the location and number of insulation manufacturing plants has been developed.

Figure 2.4 shows the population (1970 Census) by state in the United States. The locations of insulation manufacturing facilities are given in Figures 2.5, 2.6, and 2.7, for mineral wool (including fiber glass and rock and slag wools), cellulose and plastic foam, respectively. After location of these plants was determined, an analysis was made to ascertain what market influences exist, if any, which led to these manufacturing locations. Several trends have been noted as a result of this analysis. In general, insulation materials are high bulk products which tend to have relatively high transportation costs. Hence, markets are a primary determinant of plant location. Raw materials, which tend to be relatively dense, have a lesser influence on plant locations. Some processes require larger plant sizes to be economical; hence, these plants are fewer in number.

Manufacturers of rock and slag wool are influenced primarily by proximity to raw material supply as well as their access to the largest markets. The same holds true to some extent for manufacturers of fiber glass products.

The plastic foam insulation manufacturers appear to locate closer to their market with less dependence on raw material supplies. Generally, for the large manufacturing plants more research goes into selecting the best location for plant site with all the normal trade factors considered prior to making a final decision on location.

The cellulosic fiber manufacturers apparently locate close to their market, although there is some dependence on paper supplies. There is no dependence on the local availability of flame retardant chemicals, such as borax and boric acid. These chemicals are routinely shipped from their West Coast source to East Coast consumers. The basic requirements for locating a cellulose fiber insulation plant appear to be dependent on the interest of individual investors as well as availability of a receptive market.

Figure 2.4
UNITED STATES POPULATION BY STATE
 1970 CENSUS

Figure 2.5

MINERAL WOOL PLANTS

Figure 2.6

MANUFACTURERS OF CELLULOSIC FIBER PRODUCTS

Figure 2.7

PLASTIC FOAM MANUFACTURERS

Cellulose fiber manufacturers at one time shipped their products distances of up to 600 miles via truck, but now find it economically unfeasible to do so and seldom ship more than 100-150 miles from a plant. Other manufacturers of insulation materials, especially with products of a denser nature, may still find it economical to ship distances of 500-600 miles. These shipments may be by railcar or truck as appropriate to the specific situation.

2.4 Insulation Market

The size of the building envelope insulation market is extremely difficult to assess. Different products report by different category definitions, and numbers which are reported could include equipment, pipe, and duct insulations and products for acoustical purposes in addition to building envelope insulation.

In order to obtain an estimate of market sizes, several different sources of data were used. A questionnaire (Appendix A), "Survey of the Building Insulation Industry", was sent to insulation manufacturers (about 400) in order to obtain the necessary information. The response to this survey was limited, Section 2.4.8, due to the proprietary nature of information requested. A second source was a recent survey made by the Office of Business Research and Analysis (OBRA), U.S. Department of Commerce. The OBRA study report, "U.S. Residential Insulation Industry", issued in August, 1977, contained up-to-date market information for the insulation industry. Other recent reports were also used as data sources. These include an ICF, Inc. report, entitled "Supply Response to Residential Insulation Retrofit Demand", submitted to the Federal Energy Administration, June 17, 1977, and a report by the Council on Wage and Price Stability, Executive Office of the President, June 14, 1977.

The overall size of the insulation market has been reported to be between \$2,000 million and \$3,000 million with approximately one-half to two-thirds being for building envelope insulation applications. The market size for each of the various types of insulation materials is discussed below.

2.4.1 Rock or Slag Wool

The number of rock and slag wool manufacturers has been indicated to be ten in the OBRA report (8), whereas the ICF report (9) indicates there are only eight manufacturers. Information supplied by the National Mineral Wool Insulation Association indicates the number of such manufacturers presented in the OBRA report is correct (10).

The rock or slag wool industry capacity for structural insulation as of January 1, 1977 was reported to be 917 MM sq. ft. of R-11 equivalent (batts and blankets) and 491 MM sq. ft. of R-19 equivalent (loose-fill) (8). These numbers were obtained from the manufacturers, who also projected industry capacity as of January 1, 1980 to be 30% greater for batts and blankets and 75% greater for loose-fill (8). The numbers in the OBRA report include some building envelope insulation for industrial use. Residential building applications account for about 90% of this total.

This predicted rise in the industry capacity differs from the trend of approximately a 2-3% annual increase since 1960. The sharp upturn predicted by producers is probably due to an expected increase in insulation demand as a result of increasing energy costs.

2.4.2 Fiber Glass

Fiber glass is produced by four manufacturers, Owens-Corning Fiberglas Corp., Johns-Manville Corp., Certain Teed Corp., and Gebr. Knaut Westdeutsche Gipswerke. The OBRA report (8) indicates the present (as of January 1, 1977) production capabilities for building envelope insulation

to be 8 billion sq. ft. of R-11 equivalent (batts and blankets) and 1/2 billion sq. ft. of R-19 equivalent loose-fill. The predicted expansion as of January 1, 1980 is 35% for the R-11 equivalent and 53% for R-19. The OBRA report values, converted to a weight basis, give a capacity of about 1.56 billion lbs. This compares with total fiber glass structural insulation shipments of 1.38 billion lbs. as reported in the 1976 Department of Commerce, Bureau of Census, "Current Industrial Reports." The Council on Wage and Price Stability Report (11) indicates an estimated capacity of 2.3-2.5 billion lbs.

The growth rate for the fiber glass insulation market has averaged about 12% annually since 1961, which is about the same as the growth rate forecast by the manufacturers in the OBRA report. Over the last five years, manufacturers have doubled their capacity in anticipation of increased demand (1). Other indications are that the industry expects to expand capacity by about 40% by 1980 (2), a continuation of present growth trends.

2.4.3 Cellulose Fiber Insulation

The size of the cellulose fiber insulation industry is extremely difficult to assess because there are many small manufacturers and the number of these facilities is changing every week. An estimated 70-100 producers began operations this year (2). The OBRA report (8) estimates approximately 250 manufacturers as of June, 1977 and the ICF report (9) indicates between 200-300 producers. It was estimated in this study that there were about 400 plants at the end of 1977. The production capacity was reported as 1.7 billion pounds (8). (This was obtained from information provided by 120 companies, but there was no indication as to the percentage of the industry these represent.) Data presented in the ICF report (9), 0.6 billion lbs/yr., are significantly lower than the OBRA value. This study indicated production rate for over 300 manufacturers to be about 10% less than the OBRA report value.

The three-fold expansion indicated in the OBRA report is in agreement with the growth rate over the last few years, but is greater than the two-fold increase indicated in the ICF report. However, certain industry factors should be mentioned which could affect the future rate of production, specifically raw material supplies, including newsprint and chemicals for flame retardants.

There have been recent reports of a boric acid shortage (5), boric acid being the major component of flame retardant chemicals for cellulose fiber insulation. Presently, boric acid is used in a ratio of approximately 3 lbs. boric acid per 40 lbs. of newsprint so that the current annual demand of boric acid for cellulose insulation is about 105 million lbs., and with expected increase in cellulose output, the boric acid demand could increase to over 100 million lbs. by 1980. The current boric acid capacity is about 400 million lbs./yr., with U.S. Borax and Chemical accounting for about 65% of this amount. U.S. Borax plans a 30% expansion, expected to be completed by 1980. Other increases in availability could result from imports, particularly from Turkey, Russia, and South America.

Even with the increase in boric acid supply, there still could be future problems with availability due to the much higher rate of increase in demand predicted for cellulose insulation. Developments of new flame retardant formulations requiring less boric acid could alleviate potential supply problems. Several chemical companies, including U.S. Borax and Chemical (5, 13) are now in the process of investigating different formulations requiring less boric acid.

The ICF report indicates that, except for spot shortages, waste paper for cellulose insulation is available. However, as indicated above, an increasing demand for this raw material supply is expected which could result in higher costs. This could have a "chilling effect" on new entries into the market, and result in less than predicted future capacity. This, in fact, could account for some of the difference between the OBRA and ICF forecasted relative increases in production capacity.

2.4.4 Cellular Plastics

The consumption of plastic foams for building insulation has been growing at a rate between 10-15% annually. This consists primarily of polyurethane, polyisocyanurate, polystyrene, and urea-formaldehyde foams. The growth rate of the plastic foam has been estimated to be 11% annually through 1985 (13, 14, 15). This growth rate thus extrapolates from 400 million lbs. in 1974 to a production of about 700 million lbs. for 1977.

2.4.4.1 Polyurethane and Polyisocyanurate Foams

The OBRA report gives the polyurethane and polyisocyanurate foam production capacity as 528 million board feet for foam board and 447 million cubic feet for foam-in-place applications (8). However, this latter amount differs drastically from other sources of information. The difference is most probably due to the use of wrong units in the OBRA report, i.e., cubic feet rather than board feet. (This could not be confirmed by conversation with Department of Commerce, Office of Business Research and Analysis.) An article in Rubber & Plastics News, May 17, 1976 (16), indicates on-site application capacity for 1976 to be 375 million board feet and foam board capacity of 407 million board feet. Plastics World, August, 1975 (17) indicates 291 million board feet for in-place and 520 million board feet for board stock. On a weight basis, the 1976 output was about 200 million lbs. The same total production (in lbs. and board feet) was given in Chemical Marketing Reporter, May 10, 1976 (18).

The indicated growth rate for polyurethane foam is about 10-15% annually, so that extrapolation to 1977 gives a capacity which is equivalent to that in the OBRA report (when considering the indicated error). Polyurethane/polyisocyanurate foams are primarily used for commercial/industrial applications. Wider use for residential construction is expected in the future, particularly for wall insulation to obtain a resistance of R-19 (19), which could be the standard minimum insulation R-value established in the future.

There are approximately 35 manufacturers of polyurethane and polyisocyanurate foams, about 10 of which produce boardstock.

2.4.4.2 Polystyrene Foams

Polystyrene production capacity was approximately one billion board feet in 1977 (8) with a 32% expansion anticipated by 1980. This is in agreement with information presented in the Foamed Plastics Directory (20), namely 75 million lbs. in 1976 with expansion to about 98 million by 1980. The only producer of extruded polystyrene foam board is Dow Chemical Company. There are approximately 100 producers of expanded bead polystyrene foam.

2.4.4.3 Urea-Formaldehyde Foam

There are four major producers of the chemicals for urea-formaldehyde foam, namely, Borden Chemical, Brekke Enterprises, C.P. Chemical Company, and Rapperswill Corporation (21). The indicated present capacity in the OBRA report (8) is 158 million lbs. with Rapperswill having about 80% of the U.S. market (3).

The forecast capacity increase by 1980 is to 1549 million lbs., about a 10-fold increase. Presently, U-F foam is used primarily for residential retrofit applications. It is estimated that demand for this application will be met by 1983 (8). This could result in a lesser expansion than predicted due to the unwillingness of manufacturers to invest in such a short term market.

2.4.5 Perlite

Expanded perlite is produced by over 30 companies in the United States. The production for loose-fill thermal insulation has increased from 14 million lbs. in 1964 to 24 million lbs. in 1968, and 32 million lbs. in 1973 (22), an historic growth rate of 9% annually. The

1977 production capacity for loose-fill perlite presented in the OBRA report (8) is 66 million cu. ft. which, assuming a density of 6 lbs./cu. ft., is approximately 400 million lbs. per year. It appears that firms may have reported total capacity for expanded perlite without regard to end use, since this is a ten-fold increase over historic growth trends for loose-fill perlite insulation.

The primary use of perlite is in aggregates, such as perlite concrete, plaster, and insulating board. The consumption of perlite for these applications, much greater than for loose-fill, was about 500 million lbs. in 1964 and 600 million lbs. in 1973, with a forecast of 1.5 billion lbs. by the year 2000 (22, 23).

2.4.6 Vermiculite

The production capacity of vermiculite for loose-fill thermal insulation was 116 million cu. ft. in 1977 (8), which is approximately 500 million lbs. This is about a 9% annual increase over the 225 million lbs. consumption in 1968 (24). The 119 million cu. ft. forecast for 1980 in the OBRA report (8) is an indication that vermiculite use is not expected to increase significantly.

2.4.7 Reflective Surfaces

The production capacity for 1977 for reflective surfaces, mainly aluminum foil, is given in the OBRA report as 854 million sq. ft with minimal expansion expected by 1980.

2.4.8 Analysis of Marketing Survey

There were 63 responses to the questionnaire "Survey of the Building Insulation Industry," (Appendix A). The majority of replies came from manufacturers of cellulose insulation and polystyrene board. For these two segments of the industry, there appears to have been sufficient response to draw some conclusions.

2.4.8.1 Cellulose

Twenty-seven replies were received from cellulose insulation manufacturers. With a few exceptions, the major application reported was retrofit of residential buildings. Only 7 firms reported that 50 percent or more of their product is used for new construction. The largest market for cellulose is insulation of residential housing.

Most firms sell through dealers and applicators, a lesser number use distributors. All firms claimed quality control of the manufactured product while a few reported control down through the applicator.

Those that reported production capacity anticipated a 2 to 5 fold increase by 1982.

A wide range of product price, from \$.015 to \$0.10 per board foot was reported by manufacturers in the survey. The arithmetical average of responses was 4.2¢ per board foot.

2.4.8.2 Polystyrene Board

Ten replies were received from manufacturers. The major application for the products of the firms reported (with one exception) is in new construction. Six firms indicated the major market for their products is in residential buildings, and four firms sell primarily to the commercial/industrial market.

A primary product distribution is through applicators while a few firms sell through distributors or dealers. Only one firm reported quality control of the product beyond the manufacturing plant.

Those that reported production capacity intend to increase to 1.5 to 2 fold by 1978. Product price reported was 6.5¢ to 26¢ per board foot.

2.4.8.3 Other Insulation Materials

Replies from producers of other insulation materials were, in most cases, of insufficient representation of the industry to allow one to draw valid conclusions. They are summarized below.

The reply from the major producer of foam glass indicated their products were used primarily in new commercial applications. Reported price is 28¢ per board foot.

Four foam chemical suppliers replied. The information they reported was not pertinent to the study.

One manufacturer of reflective insulation reported on four products. They are used primarily in new construction for industrial and commercial applications. The price of these products is 3 to 5¢ per square foot.

Several replies were received from cellulose board, foam boards, and combination boards manufacturers. These replies do not represent a good cross-section of the industry.

One reply was received from a honeycomb manufacturer.

Three replies were received from spray-in-place urethane and isocyanurate foams suppliers. One indicates the major application to be industrial new construction. Two indicate retrofit as a major market.

One reply was received from a producer of perlite and vermiculite. One reply came from a urethane bun supplier.

Three replies were received from the mineral fiber insulation industry. They indicated that new construction is the major application for their products, and residential housing represented the major market segment.

2.5 Trade Associations

The thermal insulation industry contains a number of manufacturer and trade associations. The majority of these are manufacturers organizations each representing the interests of one particular generic material. Two associations do represent the building and contractors industry. In each case, an organization was formed and has grown as the specific material or application has developed. Thus, some are well established while others are in the early stages of development. The materials and the organizations representing them are as follows.

2.5.1 Mineral Fiber

Mineral fiber producers are represented by The National Mineral Wool Insulation Association which is primarily oriented towards the use of mineral fiber in building insulation applications.

2.5.2 Cellulose

Currently there are no less than four organizations representing the material and a possible fifth body is in the process of being formed. The present associations are as follows:

- (i) The National Cellulose Insulation Manufacturers Association which is the oldest established cellulose manufacturer organization;
- (ii) Society of International Cellulose Manufacturers Association;
- (iii) Manufacturers Association of Cellulose Insulation International;
- (iv) Society of American Cellulose Insulation Manufacturers.

Currently discussions are underway between officers of each organization to explore ways of combining these smaller separate bodies into one.

2.5.3 Perlite

This material, both when used separately and in other products, is represented by the Perlite Institute.

2.5.4 Vermiculite

The Vermiculite Association represents this material in its various insulation applications.

2.5.5 Cellular Plastics

At the present time the Society of the Plastics Industry, a very large organization, represents all aspects of the manufacture and utilization of plastics. Within the SPI there are a number of divisions, committees, and other bodies, including a Urethane Division, an Expanded Polystyrene Division, a Plastics in Construction Council, a Fire Safety Division and a Polystyrene Safety Group, all of which have interests in cellular plastics as a thermal insulation. Some integration of these interests is currently being carried out within the Society.

In August, 1977, the National Urea-Formaldehyde Manufacturers Association was formed to represent the urea-based products.

The only group which has members from some of the different thermal insulation groups included above is the Thermal Insulation Manufacturers Association. However, the interests of this body are oriented mainly towards industrial and commercial applications of thermal insulation materials.

Two other associations are:

- (1) The National Insulation Contractors Association which covers both building and industrial applications of thermal insulation materials and systems;

- (ii) The National Association of Home Builders which has specific interests in the area of thermal insulation within its total very broad scope.

Section 3

ASSESSMENT OF THERMAL INSULATION MATERIALS

3.1 Introduction

In undertaking an assessment of the properties of the current insulation materials it is first necessary to define the parameters for which properties information is required. Following this it is then necessary to try to obtain the information on which an objective study can be made.

In the majority of cases manufacturers of the products do provide data sheets containing some basic information on the properties. In general, information is reported on thermal performance, fire performance, water vapor transmission, density and mechanical properties where relevant to a material. However, comprehensive information is not available for all products.

An examination of this information shows it often provides limited data, with other properties inferred by reference to a specification. There is no uniform method utilized by manufacturers to present material property data. For a few generic materials, values of one or more properties, particularly thermal performance, can differ very significantly as will be shown later.

The thermal performance of a material (or system) is usually quantified in terms of thermal resistance (R-value) which describes the ability of that particular material (or system) to restrict the flow of heat. Thermal resistance is defined as a property of a particular material or material assembly measured by the ratio of the differences between the average temperature of two surfaces to the steady-state heat flux in common through them and is currently expressed in units of $\text{hrft}^2\text{F/Btu}$.

Most of the information has been generated by the manufacturers as part of their research, development, and quality assurance programs. Much of this information is obviously proprietary and therefore not available in published literature.

One source of "design values" is the ASHRAE Book of Fundamentals (Chapters 18 and 20 in editions up to 1972 and Chapters 20, 22, and 25 in the 1977 Edition). Design values have been agreed upon within the relevant TC 4.4 Thermal Insulation and Vapor Barrier Subcommittee and based upon three independent sources of information submitted to the committee. The majority of the information is for thermal performance with some additional data on water vapor transmission characteristics.

More recently there has been an independent study on cellulose fiber material (24a) but it did not cover all of the relevant properties. The results of a recent and comprehensive study on urea-formaldehyde have just been published (21). For polyurethanes and polystyrenes in particular, some papers containing information concerning mechanical properties, thermal performance, effects of aging on thermal properties together with other related properties have been published (24b).

In considering the properties of thermal insulating materials which are important to overall satisfactory performance in buildings, a number of parameters are important. Of these, the thermal performance predominates since the application is for thermal insulation. Resistance to fire and the production of toxic gases during combustion are factors, as are water vapor permeability and absorption. However, while accurate laboratory-performed tests can provide information on all of these properties the results may not adequately represent the performance of the materials in use or after installation for a period of time. Little public data are available on the effects which parameters such as aging, temperature cycling, effects of moisture, etc., may have on the overall performance of these materials.

An attempt was made to establish whether additional information did exist and to obtain it for the assessment. A questionnaire, "Survey of Building Insulation Material Properties" (see Appendix B), was prepared requesting information (if available) relating to a wide range of factors. It was believed that some of these may be important in the overall life cycle function of the material within the envelope for different regions of the USA. These questionnaires were sent to manufacturers of all products being considered. While trying to obtain confirmatory information for some of the basic properties which were already available, the questionnaire requested information on other factors, such as air permeability, aging and degradation effects.

The overall assessment of the properties, details of which are presented later in this section, was based therefore upon information obtained from these four major sources:

- (i) Manufacturers' literature;
- (ii) Open literature;
- (iii) Results of questionnaires;
- (iv) Knowledge of experts in the insulation field who were members of the project team.

However, in all cases the information for a particular generic material or product was reviewed in relation to some of the major factors which can influence the properties, particularly thermal performance. In this way the individual properties subsequently reported are consistent with basic physical principles and thus can be accepted as a reliable guide for present use. Some of these basic considerations are now outlined prior to the review of the individual materials.

3.2 Thermal Properties

This area is the one where a large number of factors have to be considered in relation to the overall applicability and validity of information available.

The energy crisis has resulted in a need to reassess energy conservation practices. The approach to energy conservation, proposed by the insulation manufacturers long before the energy crisis, was to invest in insulation to reduce equipment and operating costs. Insulation manufacturers have recommended the practice of economic thickness, particularly in industrial applications (25). It is the intent here to bring to the attention of the reader a number of basic concepts related to the use of insulation and the general practice of energy conservation which, in the end, will result in optimizing the return from the insulation investment. Today, there is extensive knowledge of the principles of heat flow and the performance of insulation, but little quantitative information is available on the possible detrimental effects introduced by various construction practices.

Before proceeding with this aspect of the discussion, the basic heat transmission mechanisms in an insulation need to be outlined in order to appreciate how the insulation retards the flow of heat.

3.2.1 Mechanisms of Heat Transfer

Radiation is the primary mode of heat transfer between to surfaces at different temperatures. Conduction and convection are important only as they interfere with the primary mode, radiation. The objective of the insulation in relation to these modes is as follows:

- (i) Minimize Radiation Transfer;
- (ii) Minimize Convective Transfer;
- (iii) Introduce a Minimum of Solid Conduction;
- (iv) Minimize Gas Conduction.

To obstruct the radiative transfer, as many radiation absorbers as possible are placed between the temperature boundaries without significantly increasing the solid conduction. Most building insulations consist of many small voids, containing air, separated by a small fraction of solid material. The solid contributes only minimally to conduction while the small voids inhibit convective transfer. For materials containing air, which has a thermal conductivity of approximately 0.18 Btu in/hft²F at 75F, the maximum R-value per inch must be below 5.6 hft²F/Btu. However, some plastic foams, which are closed cell, contain a fluorocarbon gas which has a much lower thermal conductivity than air and therefore can yield a higher R-value per inch.

3.2.2 Heat Transfer Through Thermal Insulations

To examine the mechanisms of heat transfer within the insulation, the present familiar term "thermal conductivity" or "k", will be used. This is the simplified expression describing the combined conductive effects within a very complex system.

The term itself ("k") and its definition, referring to an intrinsic property of a homogeneous material, is subject to theoretical questioning when referring to insulations and this point will be discussed in a later section. However, in many instances when using insulation, it is still a practical way to define the characteristics of an insulation.

The apparent thermal conductivity resulting from the parallel mechanisms of heat transfer may be defined as

$$"k_{app}" = k_g + k_{cv} + k_s + k_{rc} + k_{rt} + k_i \quad (1)$$

where: k_g = "k" of air or other gas $\times (1 - f)$ for
0.01 < f < 0.25; where f is the volume
fraction of the solid portion of the
system

k_{cv} = "k" of convection under specific conditions

k_s = "k" of solid particle to particle conduction

k_{rc} = "k" of radiation conduction (inter-particle radiation)

k_{rt} = "k" of radiation transmission (influenced by bounding
surfaces)

k_i = "k" attributable to interaction with gas

" k_g ": The thermal conductivity of air or other gas in low density materials is nearly a constant since the major portion of the structure consists of the gas (for example, 99 percent air volume in 1.6 lb/ft³ mineral fiber and not less than 75 percent for most insulations).

" k_s ": The thermal conductivity of the solid is related to the number of discontinuities in the network (contact between the fibers or other solid particles). It should be kept to a very small portion. It is also related to the gradient along the fiber or structural component, which is influenced by the orientation of the individual fiber. Thus, many insulations are anisotropic in thermal conduction properties.

" k_{cv} ": The natural convective transfer appears only when the cells are large enough to allow natural convective air turbulence. These cells usually must be several millimetres across for the phenomenon to become significant. For example, at room temperature, in a 0.50 lb/ft³ density mineral fiber insulation

with a uniform 4 micrometre (micron) fiber diameter distribution, the average pore size is approximately 1 millimetre. However, because of non-uniformity of the fiber distribution, a small amount of convection will occur in slightly higher densities (0.60 lb/ft^3 approximately with 4.5 micrometre fiber).

" k_r ": Radiation is a significant portion of the total heat transfer at room temperature in insulations having densities lower than 2 lb/ft^3 . At higher densities and elevated temperatures, it is also significant. This is the portion which influences the shape of the " k_{app} " versus density, " k_{app} " versus temperature, and " k_{app} " versus thickness curves of any insulation.

The radiation contribution can be divided into two major parts. (1) " k_{rt} ", the radiation transmission is the portion of the overall radiant heat transfer not absorbed, but rather reflected and scattered by the fibrous structure. (2) " k_{rc} ", the fiber-to-fiber re-radiation, or radiation conductivity, which is dependent upon the absorptance and emittance of the fiber and the temperature difference between fibers.

" k_i ": The interaction between the air and the solid components of the system. The air conduction acts as a short circuiting process since it contacts all radiation absorbing surfaces.

In order to appreciate the relative level of these terms and how they contribute to a given thermal conductivity value the thermal conductivity of a typical glass fiber insulation is taken as an example

(26, 27). Figure 3.1 shows these mechanisms under very specific conditions and Table 3.1 shows how each of these mechanisms is modified by the presence of glass fiber insulation or modification of the boundaries (27). The mechanics of heat transfer illustrated in this example can help explain the mechanisms as they operate in other insulating materials used as building insulations.

An insulation material will perform as designed if all factors remain as initially assumed for the design. Actual performance could be affected by such factors as packaging, handling, installation, and the environment.

3.2.3 Insulations Used As Building Insulations

Figure 3.2 shows the k vs. density relationship of several materials commonly used as building insulations. The basic mechanisms of heat flow can explain the relationships of these varied materials. However, there are differences, discussed later, between materials and these differences can be of significance in selecting the materials for an application.

3.2.4 Factors Affecting Insulation Performance

The complexity of the mechanics of heat losses or gains through building envelopes is such that no single solution will estimate accurately the individual values or average savings which may be realized on different installations under varying conditions. The thermal performance of an insulation material is one factor in the prediction of energy savings. It is intended to be used as input for calculations to design and estimate the thermal performance of a building envelope. The design methods should also recognize where individual application factors may produce significant deviations from the average design estimates.

FIGURE 3.1
THERMAL CONDUCTIVITY COMPONENTS VERSUS DENSITY FOR
A TYPICAL GLASS FIBER INSULATION⁽²⁷⁾

[100F (38C) Hot Face, 50F (10C) Cold Face,
1.0 in. (25.4mm) thickness, black boundaries]

Table 3.1

EFFECT OF GLASS FIBER INSULATION ON MECHANISMS OF HEAT TRANSFER⁽²⁷⁾

CONDITIONS OF TEST: UPWARD HEAT FLOW — HOT FACE 100F, COLD FACE 50F

BOUNDARY EMITTANCE

SOURCE OF HEAT FLOW	BLACK SURFACE $\epsilon = 0.95$		GOLD SURFACE $\epsilon = 0.08$	
	NO INSULATION	0.66 PCF GLASS FIBER	NO INSULATION	0.66 PCF GLASS FIBER
RADIATION	1.054*	0.077	0.046	0.030
CONDUCTION				
AIR	0.178	0.177	0.178	0.177
SOLID	0	0.016	0	0.016
CONVECTION	0.435	0	0.435	0
INTERACTION		0.014		0.047
TOTAL "K _{app} "	1.667	0.284	0.659	0.270

*Numbers in table expressed in BTU-in/ft²hF.

FIGURE 3.2

APPARENT THERMAL CONDUCTIVITY VERSUS DENSITY OF
VARIOUS THERMAL INSULATIONS USED AS BUILDING INSULATIONS

Factors which appear important in determining how well insulation will perform in place are:

- (i) The actual R-value of the insulation as found in the market place.
- (ii) The actual thickness as installed.
- (iii) The quality of installation (open spaces, holes, vapor barrier, or better yet, air barrier to eliminate infiltration, etc.
- (iv) Changes resulting from time, vibration, moisture, air movement, etc.

A limited study, by the Minnesota Energy Agency for the Department of Energy, of some of these effects with different insulation materials in existing residential buildings is in progress and the results should be available by mid-1978.

Technology does not exist to measure adequately the in-place thermal performance of thermal insulation in a building system. A number of field measurement devices have been proposed, but none has been proven to give quantifiable results. There is a need to provide technology which will enable the user to ascertain that insulation being purchased or having been installed really provides the published performance values. It appears that in a number of cases the anticipated thermal resistance and related energy conservation are not being achieved.

Individual effects which can alter thermal performance are discussed further as follows:

3.2.4.1 Compaction Effects

(i) Loose-Fill or Blown Insulation

With all loose-fill or blown insulations it is possible to apply the insulation lighter than the recommended coverage directions given on bag labels, thereby achieving a greater coverage. With time, the product, so applied, tends to densify by settling with a consequent reduction in thickness resulting in an overall loss in thermal resistance. However, when installed in accordance with manufacturers recommended coverage directions settling should still result in a product which meets design specifications.

This factor is illustrated by calculations presented in Tables 3.2 and 3.3 for typical blown cellulose fiber and fiber glass respectively. It should be noted that for the glass fiber product the loss of thickness has a negative impact on resistance but this is somewhat offset by an improved k_{app} . Loss of thickness for cellulose insulation has a negative impact on both resistance and " k_{app} ".

(ii) Blanket, Rolls and Batts, Preformed Insulation

Blanket type insulations must have proper recovery of thickness after packaging in order to perform as specified. Insulations of this type, by nature, are bulky and in this form they are normally packaged with a compression of 6 or 7 to 1. The resiliency of the bonded fibers should allow the product to recover at least to the design thickness to ensure that the claimed thermal resistance will be met.

An experimental study is currently being undertaken by Dynatech, on behalf of the U.S. Department of Energy, to investigate the validity of the various parameters, including thickness recovery, which affect thermal performance of all currently available R11 and R19 mineral fiber batt products. The results of the study are expected in mid-1978.

TABLE 3.2

CELLULOSE INSULATION
CALCULATED EFFECT OF COMPACTION ON INSTALLED R

COMPACTION percent	THICKNESS inch	DENSITY lb/ft ³	"K _{app} " BTU-in/hft ² F	INSTALLED R	% REDUCTION in R
0	5.5	2.5	0.274	20.1	
10	5.0	2.75	0.277	18.1	10
20	4.5	3.06	0.280	16.1	20

TABLE 3.3

LOOSE FILL FIBER GLASS INSULATION
CALCULATED EFFECT OF COMPACTION ON INSTALLED R

COMPACTION percent	THICKNESS inch	DENSITY lb/ft ³	"K _{app} " BTU-in/hft ² F	INSTALLED R	% REDUCTION in R
0	6.0	0.82	0.300	20.0	
10	5.4	0.91	0.290	18.6	7
20	4.8	1.03	0.277	17.3	13

3.2.4.2 Moisture

The need of vapor barriers to stop or minimize the flow of moisture into the insulating components was demonstrated in the early days of insulation usage in cavity walls. The problem was recognized when insulation installed in cavity walls resulted in paint blistering on the outside surface of the building. The higher level of moisture inside the dwelling caused a migration to the outside where the moisture content was lower. The solution to the problem involves the use of a good vapor barrier on the inside surface and/or making sure that the permeance to moisture of the outside surface is greater than that of the inside surface. Under these conditions there are relatively few cases where moisture would accumulate to great enough levels in the insulation to destroy its overall effectiveness.

The requirement that a vapor barrier be applied to the insulation is an attempt to provide a good moisture seal on the inside surface; unfortunately, the vapor barrier is perforated by electrical outlets and other service connections in the wall. The most ideal seal is obtained by using a plastic film under the interior of the gypsum or wall finishing material.

In most instances, moisture vapor movement under these conditions will cause very little detrimental effect on open cell insulation performance unless there is real accumulation (as a result of water leaks) of water high enough to saturate the insulation. There may be more serious damage to the building components which will hold and absorb this water.

Suggestions have been made that moisture vapor may have some very damaging effects on the performance of some insulations, particularly fibrous materials, where it is supposed that the fiber will tend to hold water, slump and form a dense mass with poorer insulating properties. While no controlled laboratory or field test results are available to prove or

disprove this suggestion, thousands of homes which have been insulated with fibrous insulation do not appear to show any detrimental effects of this nature.

Recent studies at the National Bureau of Standards (30) have indicated that the air movement within the insulated wall may be the most important factor affecting the moisture transport into the wall. At the conclusion of this report Drs. Kusuda and Ellis state:

"It was shown that the fibrous glass test panel accumulated moisture when air leakage through the vapor barrier occurred, and further, that this accumulation became significant only when holes were punched in the vapor barrier both in the top and bottom of the wall. It was also shown that the accumulation occurred only at the top of the panel. These facts lead to the conclusion that convection flow of moist air is of major importance in the condensation of water vapor. A separate small specimen experiment also demonstrated that the wet insulation can be dried out by applying a slight pressure in the cold chamber.

"Although these experimental investigations successfully demonstrated the applicability of Takashi's air-moisture transfer theory, accurate prediction of vapor condensation and drying requires more precise knowledge of the air flow characteristics, vapor diffusion coefficient, and temperature and vapor pressure distribution across the structure. The Takashi theory should be extended for the composite wall system for its realistic application. Extended evaluation of critical air flow velocity for various parameter combinations for the outgoing air flow system is also needed. Similar experimental studies, as performed on the tube-type specimen are being planned at present for materials of different air permeabilities."

3.2.4.3 Air Infiltration

Air infiltration, including wind effects, has an influence on heating and cooling loads in a building (31). Results indicated that air infiltration in winter can result in an average 33.4 percent of the heat loss from townhouses while with wind velocities of over 20 mph the heat loss can be as high as 60 percent.

The effect of air infiltration into a building is multiple. First, the air itself has to be heated and secondly, in some instances, it may partially negate the benefit of insulation in walls by introducing a cold air flow on the side of the insulation which is normally warm. This air infiltration can be minimized by a properly applied vapor/air barrier on the inside and/or a tight outer sealed sheathing.

Effective caulking of windows and doors provide the major benefit. Perforations into and between stud spaces of walls which allow for installation of service fixtures should be well sealed. However, there are some insulation-related factors which can help.

Filling a cavity with thermal insulation will present some resistance to air movement and will tend to reduce the effects of air infiltration. Additional benefits can also be gained by using plastic foam sheathing materials to improve the sealing of the exterior. In this case the overall conservation benefits measured in actual installations utilizing plastic foam are greater than those indicated by commonly used calculation techniques which do not correct for air infiltration. However, more experimental measurements are required to quantify fully these effects.

Air infiltration can, therefore, be seen as a significant factor which, through lack of adequate data, demands serious and immediate attention. More information is needed for the development of improved construction techniques. This will require improving the technology of measurement of thermal performance of systems under actual conditions.

3.2.5 Factors Affecting Measurement and Design

3.2.5.1 Effect of Thickness

Recent advances in thermal insulation technology, both as a result of improvements in the measurement techniques and greater understanding of the principles of heat flow in insulating materials, have prompted conceptual changes in the evaluation techniques relating to the effectiveness of insulation materials. These changes have an impact on the presentation of the technical data for materials and systems at the greater thicknesses now in use. The historically accepted concept of a thermal conductivity value for insulation, which by definition is an intrinsic property obtained with materials having only conductive modes of heat transfer governing the process, is not applicable to low density insulations.

The change in concept is based on the fact that radiation is a significant mode of heat transfer in low density insulations. While radiation between parallel surfaces is independent of distance, the measurement of k_{app} of materials where the radiation mode of heat transfer is significant requires the introduction of an additional variable, thickness (48,49), since radiation absorption by the material is thickness dependent. This phenomenon, called the "thickness effect", is observed in materials of low density at ambient temperatures and in materials of higher density at elevated temperatures (26,27). The effect is shown schematically in Figure 3.3. The shape and extent of the curve for a given insulation depends upon the radiation permeance of the material which is influenced by its density.

Low density building insulations are commonly applied at thicknesses of from 1 to 12 inches. Traditionally, measurements have been undertaken on 1-inch to 1.5-inch thick samples, and guarded hot plate equipment and heat flow meter equipment were developed for measurements at such thicknesses. The test methods used and the results obtained were

SCHEMATIC DIAGRAM OF THE EFFECT OF THICKNESS

Figure 3.3

in accordance with the technology and equipment available up to the early 1970's. However, the recent increase in knowledge of heat transport phenomena in low density thermal insulations brought about a change in the philosophy of measurements in 1973 (47). Since that time, the test method specifications have been changed to reflect the new philosophy. These changes are now incorporated in ASTM Standard Test Methods ASTM C.177-76 and C.518-76.

Large-scale guarded hot plate equipment and heat flow meter equipment have been developed and have been used to evaluate materials at the greater thicknesses during recent years. Because the concept is relatively new, limited experience has been acquired to substantiate the accuracy of the measurements made with these larger instruments. Reference and calibration materials are necessary to verify the performance of guarded hot plate equipment or to calibrate heat flow meter equipment. The only material available from the National Bureau of Standards to the industry as a reference material is a 1-inch thick high density (8 lb/ft^3) fiber glass. Reference materials, including low density insulations, are needed at thicknesses greater than 1-inch, as described in Section 5. The National Bureau of Standards has historically provided reference materials.

The insulation industry, in cooperation with its trade associations, independent testing laboratories, instrument manufacturers, and standards organizations, is contributing to the recognition and acceptance of full-thickness testing. The governing ASTM Standard Test Methods (STM) ASTM C.177-76 (STM for Steady-state Thermal Transmission Properties by Means of the Guarded Hot Plate Method) in its paragraph 1.6.2 and ASTM C.518-76 (STM for Steady-state Thermal Transmission Properties by Means of the Heat Flow Meter Method) in its paragraph 1.7.2 impose the requirement for "full-thickness" testing, up to a thickness for which the thermal resistivity (reciprocal of thermal conductivity) of the material does not change by more than 2% with further increases in thickness. These Standard Test Methods are made specific to insulating materials by their incorporation by reference in the following ASTM Standard Recommended Practices and Standard Specifications:

- ASTM C578-69 - Specification for Preformed, Block-Type Cellular Polystyrene Thermal Insulation.
- ASTM C591-69 - Specification for Rigid Preformed Cellular Urethane Thermal Insulations. (This is in course of revision.)
- ASTM C687-71 - Recommended Practice for Determination of the Thermal Resistance of Low Density Fibrous Loose-Fill Type Building Insulation.
- ASTM C726-72 - Specification for Mineral Fiber Roof Insulation Board.
- ASTM C739-77 - Specification for Cellulose Fiber (Wood-Base) Loose Fill Thermal Insulation.
- ASTM C764-73 - Specification for Mineral Fiber Loose Fill Thermal Insulation.
- ASTM Cxxx - Specification for Membrane-Faced Rigid Cellular Polyurethane or Polyisocyanurate Roof Insulation Boards. (In course of ballot.)
- ASTM Cxxx - Specification for Urea-Based and Urea-Formaldehyde Cavity Fill Insulation. (In course of ballot.)

ASTM C665-70, Specification for Mineral Fiber Blanket Thermal Insulation for Wood-Frame and Light Construction Buildings and ASTM C653-70, Recommended Practice for Determination of the Thermal Resistance of Low-Density Mineral Fiber Blanket-Type Building Insulation incorporate by reference both ASTM C177 and C518, but also provide for an alternative test method for thicker blanket products which allows extrapolation from measurements made on samples of partial thickness sliced from the blanket.

It appears that there is general recognition of the effect of thickness on the measurement of thermal transmission properties of

building insulations. It is apparent from Figure 3.3 that the requirement for "full-thickness" testing will not impose testing at the same thickness for all insulating materials; that is, low density insulations will require testing at greater sample thicknesses than will high density insulations, to meet the criterion that the thermal resistivity not change by more than 2% with further increases in thickness. There remains a controversy within the industry as to whether these methods, practices, and specifications for "full-thickness" testing can be implemented in absence of availability of reference materials of lower density and substantially greater sample thickness than are presently available from NBS. The National Mineral Wool Insulation Association has provided a viewpoint, as follows:

"Mineral Fiber Insulation Industry Position on
Implementation of ASTM C.177-76 and C.518.76"

"Major firms in the mineral fiber insulation industry have been leaders in the advances in thermal insulation technology which led to the concept of testing at full thickness as currently specified in ASTM C.177-76 and C.518-76. These studies in principles of heat flow in insulating materials have led to the rather radical change in concept. This change in concept is an outgrowth of the production of insulations which are lower in density and consequently less homogeneous. The heat flow characteristics of low density insulations are affected by sample thickness. These mineral fiber insulation industry firms supported the revised ASTM specifications as a step forward in technology.

"The National Mineral Wool Insulation Association, as representative of the mineral fiber insulation industry, offers an essential and complementary comment for consideration in conjunction with this report.

Of great concern has been the lack of calibration standards which can be used to verify the performance of a guarded hot plate or to calibrate the more commonly available heat flow meters, the latter being a secondary dependent method. The recognized agency which should provide this calibration/referencing authority is the National Bureau of Standards. Their current equipment capability is based on the thermal conductivity concept. Their measurement capability is currently limited to a 1-inch thickness. NBS has recently taken steps to acquire the necessary equipment to provide measurement of thermal resistance of insulations at greater than 1-inch thickness. The establishment of NBS capability to make measurements at full thickness and to provide calibration and reference standards for use by other laboratories is an essential step before ASTM C.177-76 and C.518-76 can be implemented.

"The National Mineral Wool Insulation Association fully supports the NBS program to provide calibration capability for full thickness testing, it supports the round robin tests being implemented by ASTM, and it supports the implementation of ASTM C.177-76 and C.518-76 when NBS calibration capability is established. It supports the technical validity of the two ASTM specifications. The National Mineral Wool Insulation Association does not concur with implementation of these specifications until NBS calibration samples are available and ASTM round robin testing has been completed."

3.2.5.2 Mean Temperature Effects

Because equipment limitations and the practical case of attaining mean temperatures of 75F, thermal performance of insulations for building applications has been reported only at the above mean temperature. While selection of this temperature has practical advantages, it is not representative of temperatures encountered during winter or summer use. For example, under application conditions in winter, the outside temperature

may be -10 to +10F with the inside at 70F, resulting in a mean temperature of 30 to 40F. Alternatively, for summer conditions, particularly in Southern climates, mean temperatures of 90 to 110F can be experienced. For the lower temperatures the apparent k will be lower than that at 75F while for the higher temperatures the opposite will be true.

Table 3.4 contains information on several typical building insulation materials to illustrate this point. Since many temperature conditions are actually encountered and a number of buildings are designed for specific uses involving temperature conditions other than 75F, it is suggested that in the future information on thermal performance contain values covering the range of temperatures expected to occur. This could be derived from one measured temperature point combined with an accepted experimentally determined k vs. temperature slope for a generic material or type.

3.3 Other Properties

3.3.1 Fire Performance

In considering the information available to describe the fire performance of insulations it should be pointed out that the current small- and large-scale tests do not provide truly quantitative information. Results for spread of flame and intensity of smoke are given in terms of numerical ratings and are descriptive in nature. Furthermore the various small- and large-scale tests do not necessarily provide results which correlate. Finally the major test methods now in use involve conditions and orientations of the insulation which are not those normally found for insulations as installed. It is also necessary to state that in buildings the insulation materials are normally placed between inner and outer sheathings or in systems which are highly resistant to fire. The actual information presented, therefore, should not be taken as representative of the materials in actual practice for all conditions.

Table 3.4

THERMAL RESISTANCE VALUES FOR DIFFERENT TEMPERATURE APPLICATIONS ⁽⁶⁴⁾

<u>Mean Temperature</u>		<u>Apparent Thermal Conductivity, Btu-in/hrft² F</u>					<u>Thermal Resistance, hrft² F/Btu per 1" Thickness</u>				
<u>Condition</u>	<u>F</u>	<u>Fiberglass</u> ¹	<u>Cellulose</u> ²	<u>Molded Polystyrene</u> ³	<u>Extruded Polystyrene</u> ⁴	<u>Urea Formaldehyde</u> ⁵	<u>Fiberglass</u>	<u>Cellulose</u>	<u>Molded Polystyrene</u>	<u>Extruded Polystyrene</u>	<u>Urea Formaldehyde</u>
Winter	40	0.28	0.26	0.225	.185	0.22	3.57	3.85	4.44	5.41	4.54
Design	75	0.316	0.27	0.25	.200	0.24	3.16	3.70	4.0	5.00	4.17
Summer	110	0.355	0.28	0.275	.215	0.26	2.81	3.57	3.65	4.65	3.85

1. Conforming to an R11 product at 75F.
2. Loose-fill at 2.5 lb/ft³ (average results from Reference 28).
3. Molded polystyrene at 1.0 lb/ft (averaged results).
4. Extruded polystyrene at 2 lb/ft³.
5. At 0.7 lb/ft³.

The manufacturers of insulations for dwellings do not, in general, give fire data in sales brochures. They do, however, indicate compliance to pertinent Federal or other specifications which contain requirements for allowable maximum ASTM E-84 Surface Burning and Smoke Developed Values. These are pertinent values useful for comparing materials. It can be argued that as long as insulations are no less fire safe than the wood frame, they do not add further hazard to the structure when installed. However, there may be increased safety to be obtained by requiring that an insulation material complies with one or more of the following available or proposed tests.

1. Tests for spot ignition to demonstrate that the material will not ignite or smolder under local heating conditions such as discarded cigarettes, overloaded wiring, heat sources such as recessed light fixtures, etc.

2. Compliance to ASTM E-136 for proof of non-combustibility might permit relaxation of current requirements that such insulations do not contact sources of heat such as chimneys. This would require that wood framing also in contact with the chimney not be heated to smoldering by the increased temperature caused by insulation.

3. Use of suggested test methods, such as the NBS Flooring Radiant Panel, or the Canadian Upside-Down E-84 Tunnel Test, to show that exposed attic insulation will not spread flame on the upper surface. These would replace current reliance on the present E-84 test which is useful for measuring surface burning on lower exposed surfaces or on vertical surfaces.

Plastic foam manufacturers have made increased use of the ICBO 8 x 12' full room fire test for evaluating the burning characteristics of plastic foams. ASTM has issued E-603-77 (a recommended practice for room fire experiments) which is intended to evaluate the burning characteristics of materials in a similar manner.

The data on insulations used for commercial and industrial applications is generally more specific. The information usually includes compliance to requirements for exterior fire exposure such as the ASTM E-108 Roofing tests, interior fire exposure such as the UL Roof Deck Construction tests or the Factory Mutual Calorimeter, or the concepts of limited combustibility such as the National Fire Protection Association (NFPA) No. 259 or the ASTM E-136 Combustibility Test.

At the present time information on toxicity of combustion gases is published only for some plastic foams. This is understandable as no accepted method of assessment is yet available. It is presumed that some data are available under a number of test conditions, but since there is no consensus as to test methods or limits, there is reluctance to provide the available data except in answer to specific requests.

It should be remembered that absolute non-combustibility of all insulations is an utopian concept not to be achieved without sacrificing many materials of good insulating quality. Moreover, a system approach to use of materials of low combustibility can afford adequate safety.

3.3.2 Corrosion

Very little information is supplied for corrosion properties. This is due in the main to there being a lack of suitable corrosion tests. However, the full impact of possible effects of the environmental conditions developing a corrosive atmosphere due to components of the insulations has not been realized until recently. In addition, in recent years many newer materials are used in building constructions and the corrosive effects of these materials have not been studied to any extent.

3.3.3 Moisture Absorption

In the case of moisture absorption, results are often available for one set of environmental conditions. However, some insulation materials undergo cyclic changes with environmental temperature and humidity conditions and information is required on these factors. In certain conditions, capillarity action within an insulation material in a cavity could be envisioned but no test method to study this behavior is available. Some information on the effect of moisture on the thermal performance of certain plastic foams has been given. However, equivalent data for other insulating materials is not readily available.

3.3.4 Summary

Information, where it is available, for properties other than thermal performance is sparse, but is probably adequate for most use conditions. Certain property values for materials under actual use conditions are available for very limited or specific conditions only. The development of additional information with regard to these other properties would provide a better basis for selection of materials. More adequate test methods are required for these other properties if deemed significant for the conditions of use.

3.4 Validity of Data

In general, it can be said that data for materials used for industrial or commercial applications is more specific and complete than that for insulations used in residential construction. This appears to be the result of the more technically oriented purchaser and the more severe use requirements of insulations used in commercial or industrial applications.

The purchaser of insulations used for residential construction has been in general the builder who is satisfied in fulfilling the basic

requirements established by FHA and other agencies. This rather non-technical concern is sometimes reflected in the less than thorough attention to details of the installation of the insulation, sometimes to the point of disregarding the recommendations of the manufacturer. To ensure that design performance is achieved in applications, means should be provided at the user level to inspect and enforce the proper installation of the insulation. Inspectors will have to be made aware of factors which govern insulation performance and proper installation procedures necessary to obtain design effectiveness. There has been, in fact, no power of enforcement in this segment of the market until recently when some building codes have included energy conservation sections. Also, some builders have shown concern with the effectiveness of the insulation, particularly for solar heated homes.

The information reported was found generally to be consistent with accepted limits for the generic classifications. There were only two classifications where there were significant variations in the claims. Both of these relate to relatively recent technologies, or at least to materials which have only recently taken an important position in the insulation market; these are the cellulosic and some of the cellular plastic materials. With additional experience and study, the thermal performance of these newer materials as well as the older types of materials will be better understood.

3.4.1. Mineral Fiber Blowing/Pouring Wool

The thermal resistance, R, values cited in the reported data infer apparent thermal conductivity values which can be met with the product if the density or coverage requirements stipulated by the manufacturer are met. Much depends on application procedures, as with all loose fill insulation. Generally, the most critical criterion will be the coverage, which

implies a certain density and thickness requirement; if these requirements are met, the product will perform within the limits of the generic classification of the product.

3.4.2. Cellulosic Blown Insulation

Since the survey provided inconclusive data from the many manufacturers, two additional sources of information were used (28, 24a). In the first study (28), a large number of materials were measured, covering a wide range of products and temperature. Spray applied materials were also included. Measurements were, in general, carried out on samples 12" square and a maximum of 1.5" thickness. In the second report (24a), there was a comparison of data claimed by manufacturers with measurements made at one laboratory. No details of the methods or sample sizes were given for the manufacturer's data. However, the measurements made independently were performed on samples close to the thickness of application. A third report containing data is the Building Materials Directory published by Underwriters Laboratories (29).

A comparison of this information is shown in Figure 3.4. This shows the wide divergence of the results from very low claims by the manufacturers to much higher values measured at thicknesses of use. Some of the scatter can be explained partially by the test methods used, and partially by the material itself. The size and type of cellulosic material forming the insulation may play a part. As discussed earlier, the extremely low values cannot be substantiated since they approach the "k" of still air. The independent laboratory tests performed on the same material showed a total variation of 55 to 63 percent from a "mean" value. The current ASHRAE Book of Fundamentals, Chapter 22, contains design values which propose R per unit thickness value of the order of $3.6 \text{ hrft}^2\text{F/Btu}$ at 2.5 lb/ft^3 blown density. It should be pointed out that while this value may be reasonable for material blown in attic applications, a lower R per unit thickness value should be used for wall applications where the density is normally well above 3 lb/ft^3 .

FIGURE 3.4

APPARENT THERMAL CONDUCTIVITY
OF
CELLULOSIC INSULATION

3.4.3 Mineral Fiber Batts and Blankets

The thermal performance of all mineral fiber products used in building applications are reported solely in terms of a thermal resistance, R value, coupled with a corresponding nominal thickness. The R values are based upon measurements of k_{app} under the NAHB Certification Program and assume that R is directly proportional to thickness and the material fully recovers in thickness.

When mineral fiber materials are used for industrial and commercial applications they are usually higher density products and as stated earlier and shown in Figure 3.5 the thermal performance data are more specific.

The k_{app} range for all products is 0.27 to 0.34 Btu in/hr ft²F and as shown in Figure 3.2 such values can be obtained for the various products at different densities. Since fiberglass produced by different processes and rock and slag wool will have different characteristics for k_{app} versus density, density specifications for the products are inappropriate.

3.4.4. Urea Based Foams

A significant range of thermal conductivities have been reported. The values of equivalent thermal resistance per unit thickness range from 5.5 to 3.5 hrft²F/Btu. Comparisons between the values are difficult since little or no documentation specifying the test conditions were provided and in some cases the density was not given. However, for many years recommended values published for European products (32) and widely accepted there indicated that a typical value of R of 4.2 hrft²F/Btu per inch of thickness was the same for densities in the 0.7 to 0.8 lb/ft³ range as used in the U.S.A. This value has been substantiated by tests undertaken at NBS

and at NRC in Canada. Values much in excess of these numbers are clearly incorrect from the earlier basic discussions of general behavior. The European information indicates clearly the increase of thermal resistance per unit thickness with increase in density to approximately 1.8 lb/ft^3 . The general behavior is thus similar to other cellular plastic materials.

A documented concern about urea-based foams is the shrinkage which takes place as the product cures. While shrinkage does not affect the thermal conductivity of the foam itself, it does detrimentally affect the thermal performance of the final installation.

3.4.5 Wood Fiber/Mineral Insulation Boards

The survey data on roof insulation boards both for wood fiber and mineral board products conform to the generic values of these products. These materials have been in use for many years, and meet the engineering requirements of the trade.

3.4.6 Polyurethane/Isocyanurate Foam Insulation Boards

For some plastic foam roof insulation boards made with urethane foam, a controversy on applicable "k" exists. There has been a narrowing of the range from 0.11-0.16 to 0.13-0.16 $\text{Btu-in/hrft}^2\text{F}$. The ASHRAE Book of Fundamentals proposes a design R-value per inch of $6 \text{ hrft}^2\text{F/Btu}$ for urethane board products. The claims for using values at the lower end of this range are based on materials as manufactured or on claims of sealing surfaces-against gas flow in or out of the foam. The long term effects of gas movement are not fully quantified. However, it is known that the thermal performance is reduced when fluorocarbons are replaced by air. Since these materials are now used extensively in industrial/commercial applications, there will be in time some accepted long term applicable value for polyurethane foam boards protected with impervious or low permeance skins. There

also will be an applicable value for products which are not protected by impermeable skins. The urethane foam problem does not affect the data relating to composite foam mineral board panels where the reported R values reflect the discrepancy in acceptable "k" of the urethane component of the panels.

3.4.7 Extruded Polystyrene Foam Board

Extruded polystyrene foam board has a reasonably consistent k-value of 0.20 Btu-in/hrft²F for the commercial densities of this product. The k-values reported for extruded polystyrene foam are 5-year aged design values.

3.4.8 Molded Polystyrene Foam Board

Molded polystyrene foam board thermal performance does not deteriorate with age. It does, however, vary with density. The claimed k-value for one lb/ft³ density foam varies from 0.23 to 0.26 Btu-in/hrft²F. The claimed k-value for two lb/ft³ density ranges from 0.20 to 0.23. Additional quantification of actual performance is needed.

3.5 Material Properties

Material properties for the various insulation materials are presented and discussed in this section. Tables 3.5-3.12 present values of the material properties for each generic classification of materials, based upon the assessment of available data.

3.5.1 Fiber Glass

Fiber glass insulation is made of thin glass fibers felted in batts or nodules. It falls into two major classifications as a result of different manufacturing processes. Process A: The fibers are produced by

Table 3.5
FIBERGLASS

Material Property	Value	Test Method
Density	0.6-1.0 lb/ft ³	
Thermal Conductivity (k factor)	varies with density	
Thermal Resistance (R value) per 1" of thickness*at 75F	3.16 hft ² F/Btu (batt) 2.2 hft ² F/Btu (loose-fill)	ASTM C518, C653
Water Vapor Permeability	>100 perm-in	
Water Absorption	<1% by weight	ASTM C553-70
Capillarity	none	
Fire Resistance	non-combustible	ASTM E136
Flame Spread	15-20	} ASTM E84
Fuel Contributed	5-15	
Smoke Developed	0-20	
Toxicity	Some toxic fumes could develop due to combustion of binder.	
Effect of Age		
a) Dimensional Stability	none (batt) settling (loose-fill)	
b) Thermal Performance	none	
c) Fire Resistance	none	
Degradation Due To		
Temperature	none below 180°F	
Cycling	none	
Animal	none	
Moisture	none	
Fungal/Bacterial	does not promote growth	
Weathering	none	
Corrosiveness	non-corrosive	Federal HH-I-558D
Odor	none	ASTM C553 - Sec. 16

*Derived from R19 and R11 products for 6 and 3.5" thickness respectively.

melting glass marbles into primary fibers which are attenuated into relatively long fibers. Process B: This process, known as the rotary process, produces fibers by flowing molten glass into a spinning perforated disc, thus projecting glass fibers. This process produces shorter fibers. For both processes, the fibers are sprayed with a binder and collected into wool-like mats that have a high air content, forming a low-density material (typically less than 1 lb/ft³) with good thermal resistance. Fiber glass is cut into batts or blankets of various thicknesses and lengths which have a derived R-value of about 3.2 per inch thickness. An important factor in thermal performance of a batt or blanket product is that it should recover to its design thickness.

Glass fiber loose fill insulations (for blowing and pouring) are usually produced by hammer milling glass fiber blanket material, thereby retaining the bonded fiber quality which insures good loft and thus a high R per pound ratio. A typical R-value for this form is 2.2 per inch thickness at 75F.

Both loose fill and batt or blanket forms of fiber glass insulation are permeable to water vapor to the extent of over 100 perm-inch. Water absorption is typically no more than 1% by weight, by ASTM C553-70, and no capillarity is apparent in these materials.

Fiberglass itself is an inorganic, non-combustible material, but flammable, organic binders are used in the production of batts and blowing wool. ASTM E-84 yields an approximate rating for the material with binder of flame spread: 15-20; fuel contributed: 5-15; smoke developed: 0-20. Facings on fiberglass building insulation usually consist of an asphalt coated kraft or foil-kraft paper laminate which is a flammable surface. The facing must not be exposed to open flames or temperatures exceeding 180°F. Any burning of facings or organic binders used could produce thermal degradation products which are toxic.

Fiber glass batt insulation does not appear to settle or shrink with age, but loose fill may settle. Other properties of the material, such as thermal performance and resistance to fire, are reportedly unaffected by age and temperature cycling at normal installed temperatures. Fiberglass does not promote bacterial or fungal growth, and provides no sustenance to vermin. Insulation products made from fiberglass are non-corrosive (Federal Spec. HH-I-558D) and have no objectionable odor (ASTM C553-Sec. 16).

3.5.2 Rock and Slag Wool

The overwhelming majority of this product manufactured in the U.S.A. is made from steel, copper, or lead slag as opposed to natural rocks as raw material which is used extensively in Europe. The slag is melted using coke as a fuel, then spun into fibers by pouring the molten material onto rotating discs. The fibers are attenuated with steam, and rapidly cooled to room temperature. In rock or slag wool insulation the fibers do not have the resiliency of glass. After packaging, the product may fail to recover to the design thickness, thus resulting in lower than design R values. The fibers are sprayed with a phenolic resin, which serves as a binder, compressed, and cured by passing through an oven. The resulting "slabs" are cut to desired sizes to make batts. Another additive is mineral oil which serves to seal the surface against dust production and give water-repellancy.

Rock wool batts and blowing wool are produced with densities in the range of 1.5 to 2.5 lb/ft³, and reported unit thermal resistances (R values) of 3.2 to 3.7 hrft²F/Btu-in. at 75F (k factor 0.31 to 0.27 Btu-in/hrft²F) for batts, and 2.9 at 75F (k factor 0.34) for blowing wool. Water vapor permeability is reported (survey) to be >100 perm-in, and water absorption up to 2% by weight. Rock wool exhibits little or no capillary actions.

Table 3.6
ROCK AND SLAG WOOL

Material Property	Value	Test Method
Density	1.5-2.5 lbs/ft ³	
Thermal Conductivity (k factor) at 75F	0.31-0.27 Btu-in/ft ² hr°F (batts) 0.34 Btu-in/ft ² hr°F (loose fill)	ASTM C177
Thermal Resistance (R value) per 1" of thickness at 75F	3.2-3.7 hft ² /Btu (batts) 2.9 hft ² /Btu (loose fill)	ASTM C177
Water Vapor Permeability	> 100 perm-in	
Water Absorption	2% by weight	
Capillarity	none	
Fire Resistance	non-combustible	ASTM E136
Flame Spread	15	ASTM E84
Fuel Contributed	0	
Smoke Developed	0	
Toxicity	none	
Effect of Age		
a) Dimensional Stability	none (batt) settling (loose-fill)	
b) Thermal Performance	none	
c) Fire Resistance	none	
Degradation Due To		
Temperature	none	
Cycling	none	
Animal	none	
Moisture	transient	
Fungal/Bacterial	does not support growth	
Weathering	none	
Corrosiveness	none	
Odor	none	

Made from rock or slag, and melting above 1200C, the base material of batts or blowing wool is non-combustible, but binders added to the wool may be flammable. Flame spread is reported (survey) to be less than 25 (by ASTM-84). Asphalt coated or foil-laminated kraft paper may be used as a vapor retardant facing on batts, and should be considered flammable. Rock wool may be used as a high temperature insulation with a temperature limit of about 1000C. Because the insulation is non-combustible, no toxic gases are generated. Burning of facings or organic binders could produce toxic thermal degradation products.

Properties such as dimensional stability, thermal performance, and fire resistance are reportedly unaffected by age, temperature cycling, or weathering. Thermal conductivity is affected by moisture content, but the change is transient and the material returns to its original properties upon drying. Rock wool does not support the growth of fungus, bacteria, or vermin, exudes no odor and is non-corrosive. The thermal properties of the material are affected by "shot" content, pieces of slag that spun off as particles rather than fibers. Higher apparent thermal conductivity with density increase is due to high shot content, and this content is usually reported for individual products.

3.5.3 Cellulose

As described earlier, cellulose insulation is manufactured from waste paper, primarily used newsprint or virgin wood fiber, by shredding and milling to produce a fluffy, low density material. Chemicals are then added to provide resistance to fire, water absorption, and fungal growth.

Typical applied cellulose insulation density is in the range of 2.2 to 3.0 lb/ft³ when pneumatically blown or poured in place in attics and somewhat higher in wall cavities. Accepted thermal resistance values

Table 3.7
CELLULOSE

Material Property	Value	Test Method
Density	2.2-3.0 lb/ft ³	
Thermal Conductivity (k factor) at 75F	0.27 to 0.31 Btu-in/ft ² hr°F	ASTM C177, C518
Thermal Resistance (R value) per 1" of thickness at 75F	3.7 to 3.2 hft ² F/Btu	
Water Vapor Permeability	high	
Water Absorption	5 - 20% by weight	ASTM C739
Capillarity	not known	
Fire Resistance	Combustible	E-136
Flame Spread	15-40	} ASTM E84
Fuel Contributed	0-40	
Smoke Developed	0-45	
Toxicity	develops CO when burned	
Effect of Age		
a) Dimensional Stability	settles 0-20%	
b) Thermal Performance	not known	
c) Fire Resistance	inconsistent information	
Degradation Due To		
Temperature	none	
Cycling	not known	
Animal	not known	
Moisture	not severe	
Fungal/Bacterial	may support growth	
Weathering	not known	
Corrosiveness	may corrode steel, aluminum, copper	ASTM C739
Odor	none	ASTM C739

are in the range of 3.7 to 3.2 ft²hrF/Btu per inch for this density range. Compaction due to vibration and settling under its own weight results in a decrease in R value in two ways: loss in thickness, and an increase in "k_{app}" due to the increase in density.

According to ASTM C739-73, weight gain from water absorption should not exceed 15 percent. Properly treated cellulosic materials do not exceed this specification, but poor quality control and improper selection of flame retardant chemical may result in greater water absorption. Some information on permeability of the material to water vapor has been reported (24a).

Large amounts (up to 25 percent by weight) of chemicals, primarily boric acid, aluminum sulfate, ammonium sulfate, and calcium sulfate, are added to provide flame retardancy. Separation of these additives from the insulation material has been reported (24a) although there are no standard specifications (ASTM, Federal, or NCIMA) or requirements for non-separation of fire retardant additives. Values for flame spread, fuel contributed, and smoke developed according to ASTM E84 varied from product to product but generally fall within the specifications for Class I materials. These chemicals may cause corrosion on metals such as steel, aluminum, and copper (24a).

Cellulose insulation is a material in which fungal and bacterial growth may be a problem. Bacteria and fungus that degrade cellulose as a thermal insulation material are present everywhere. Chemicals are usually added which inhibit the development of these problems. Cellulose has no odor, and its properties are unaffected by cycling, with the possible exception of moisture cycling.

3.5.4. Expanded Polystyrene Foam

Polystyrene foam insulation is manufactured in two forms, extruded, and molded expanded bead, as discussed in Section 2.2.4.1.

Foam produced by the extrusion process has a more consistent density, uniform appearance, and greater compressive and tensile strength than that produced by the molding process. Extruded density is usually in the range of 2.0 lb/ft^3 . The reported (from the manufacturer survey) "k" factor is $0.12 \text{ Btu-in/hrft}^2\text{F}$ as manufactured but as the air diffuses in, the "k" factor rises to $0.20 \text{ Btu-in/hrft}^2\text{F}$. This value with an equivalent R per 1" thickness of $5 \text{ hrft}^2\text{F/Btu}$ is normally accepted for this material in use.

Extruded polystyrene shows a permeability to water vapor of 0.6 perm-in when tested by ASTM-C355-64 and a volumetric water absorbance of 0.7% (21.8% by weight) by ASTM-C2842-69. There is no apparent capillary action by polystyrene.

Molded polystyrene is made to have densities in the range of 0.8 to 1.8 lb/ft^3 . Variations of about 10% from the average density can be found in a piece of molded polystyrene due to the molding process. Thermal conductivity of this material is directly proportional to density, and is usually in the range of 0.23 to $0.26 \text{ Btu-in/hrft}^2\text{F}$. This value does not change with age. The R-value for molded polystyrene is lower than the R-value for extruded polystyrene since the former has air in the cells while the latter has a mixture of air and fluorocarbon. Water vapor permeability for the molded material is reported (survey response) to be 1.2 to 3.0 perm-in by ASTM-C355, and water absorption less than 2% by weight by ASTM-C272.

The advantage of polystyrene boardstock used as frame sheathing in building construction is in providing insulation over the whole building frame, thus minimizing the effect of the more conductive structural members. An even more important benefit of this use is the reduction of air infiltration into a building; this foam sheathing provides a better air seal than conventional sheathing. Plastic foam sheathing materials are non-structural with low nail holding ability.

Table 3.8
EXPANDED POLYSTYRENE FOAM

Material Property	Value	Test Method
Density	0.8 to 2.0 lb/ft ³	
Thermal Conductivity (k factor)	0.20 Btu-in/ft ² hr°F (extruded) 0.23-0.26 Btu-in/ft ² hr°F (molded)	ASTM C177, C518
Thermal Resistance (R value) per 1" of thickness at 75F	5 hft ² F/Btu (extruded) 3.85 to 4.35 hft ² F/Btu (molded)	
Water Vapor Permeability	0.6 perm-in extruded 1.2 to 3.0 perm-in molded	ASTM D2842-69 ASTM C355
Water Absorption	<0.7% by volume extruded <0.02% by volume extruded <4% by volume molded <2% by volume molded	ASTM D2842-69 ASTM C272 ASTM D2842-69 ASTM C272
Capillarity	none	
Fire Resistance	combustible	ASTM E136
Flame Spread	5-25	ASTM E84
Fuel Contributed	5-80	
Smoke Developed	10-400	
Toxicity	develops carbon monoxide when burned	
Effect of Age		
a) Dimensional Stability	none	
b) Thermal Performance	k increases to 0.20 after 5 years extruded none molded	
c) Fire Resistance	none	
Degradation Due To		
Temperature	above 165°F	
Cycling	none	
Animal	none	
Moisture	none	
Fungal/Bacterial	does not support	
Weathering	direct exposure to UV light degrades polystyrene	
Corrosiveness	none	
Odor	none	

Other properties of polystyrene insulation are independent of the manufacturing process. Polystyrene is combustible, and in use must be covered with a flame resistant covering such as gypsum board. It must also be protected from direct exposure to ultraviolet light, which causes dusting and yellowing. Insulating properties, however, are not affected by short-term exposure to UV light. The maximum service temperature of polystyrene is 165°F; exposure to higher temperatures will cause the plastic to soften. There is no effect (survey responses) of cycling or weathering on the insulation in the service temperature range. Polystyrene does not promote the growth of fungus or bacteria, and contains nothing of food value for animals. This insulation has no odor, and is non-corrosive.

3.5.5 Polyurethane and Polyisocyanurate Foams

Polyurethane and polyisocyanurate foams are fluorocarbon-blown materials available in both precast boardstock and spray-in-place forms. These foams have a thermal conductivity (k factor) of 0.11 to 0.15 Btu-in/ft²hrF at 75F when new, and a density of 2.0 lb/ft³. Closed cell content of these rigid foams is approximately 90%; cells are filled with fluorocarbon blowing agent. The fluorocarbon vapor in the cells has a significantly lower thermal conductivity than air, which explains the low "k" factor of the material.

There is some question about the validity of published "aged" values of thermal conductivity for urethane or isocyanurate foam. These range from 0.13 to 0.16 Btu in/hr·ft²°F. It is known that "as manufactured" foam will have values of 0.11 to 0.12 Btu-in/hr·ft²F, but that the thermal conductivity will increase as the foam ages and air replaces the fluorocarbon gas in the cells. This process is reduced or eliminated when a relatively air tight facing is used on the foam. The ASTM Standard Specification for Rigid Preformed Cellular Urethane Thermal Insulation, C-591-69, shows values of 0.16 to 0.17 for material aged over 300 days with an initial value of 0.11 to 0.12 Btu-in/hr·ft²F.

The advantage of polyurethane or polyisocyanurate board stock used as frame sheathing in building construction is in providing insulation over the whole building frame, thus minimizing the effect of the more conductive structural members. A major manufacturer of polyisocyanurate foam sheathing specifies vent strips to allow escape of water vapor which has penetrated the inner face vapor barrier. This may lessen the benefits of reduced air infiltration.

Because of the high closed cell content, water absorption and permeability are very low; permeability is typically 2 to 3 perm-in.

Polyurethane and polyisocyanurate foams are flammable and must be covered with a fire retardant material when used for thermal insulation in most applications. Certain polyisocyanurate foams have been approved for exposed use in certain industrial/commercial buildings. Typical burning characteristics for polyurethane are a flame spread of 30-50, fuel contributed value of 10-25, and smoke developed of 155 to over 500. For polyisocyanurate, the flame spread is less than 25, fuel contributed is less than 5, and smoke developed is 55-200.

Polyurethane and polyisocyanurate foams show dimensional change upon curing and aging. The degree of expansion or shrinkage is related to conditions of temperature and humidity and the duration of exposure to extreme conditions. For polyurethane, results of ASTM-D-2126 Procedure F (160F and 100% RH) indicate a change in volume of up to 12% after 14 days. For polyisocyanurate, results with this same test indicate a 3% change in volume after 14 days.

Most compositions of these foams begin to decompose above 250F.

Polyurethane and polyisocyanurate foams are resistance to fungal and bacterial growth.

Table 3.9
POLYURETHANE/POLYISOCYANURATE FOAMS

Material Property	Value	Test Method
Density	2.0 lb/ft ³	
Closed Cell Content	90%	ASTM C591-69
Thermal Conductivity (k factor)	0.16-0.17 Btu-in/ft ² hr°F (aged & unfaced or spray applied) 0.13-0.14 Btu-in/ft ² hr°F (impermeable skin faced)	ASTM C177, C518
Thermal Resistance (R value) per 1" of thickness at 75F	6.2-5.8 hft ² F/Btu (aged unfaced or spray applied) 7.7-7.1 hft ² F/Btu (impermeable skin faced)	
Water Vapor Permeability	2 to 3 perm-in	
Water Absorption	Negligible	
Capillarity	none	
Fire Resistance	combustible	ASTM E136
Flame Spread	{ 30-50 polyurethane 25 polyisocyanurate	} ASTM E84
Fuel Contributed	{ 10-25 polyurethane 5 polyisocyanurate	
Smoke Developed	{ 155-500 polyurethane 55-200 polyisocyanurate	
Toxicity	produces CO when burned	
Effect of Age		
a) Dimensional Stability	0-12% change	ASTM D-2126
b) Thermal Performance	0.11 new 0.17 aged 300 days	
c) Fire Resistance	none	
Degradation Due To		
Temperature	above 250°F	
Cycling	not known	
Animal	none	
Moisture	limited information available	
Fungal/Bacterial	does not promote growth	
Weathering	none	
Corrosiveness	none	
Odor	none	

3.5.6 Urea Based Foams

This insulation is used primarily for retrofit applications and is normally manufactured on site and applied directly. An aqueous solution of a urea formaldehyde based resin is combined with an aqueous solution foaming agent which includes an acid catalyst or hardening agent and compressed air.

Recently the National Bureau of Standards has studied the insulating properties performance of this material (21) and the information presented herein consists largely of the major results suggested in their report.

It is concluded that the physical properties which are agreed upon in the available literature include density, mechanical strength and water absorption. However, a significant range of thermal conductivities have been reported. From basic considerations of general behavior, European experiences, and measurements both at NBS and NRC in Canada, an R value of $4.2 \text{ hrft}^2\text{°F/Btu}$ is recommended as a reliable value at the density of use, $0.7 \text{ to } 0.8 \text{ lb/ft}^3$.

For the remaining properties of interest, the NBS reports that there are sufficient data available from which the performance of the material may be adequately evaluated, and, further, that some of the data in the literature are contradictory. In particular, concern was expressed with regard to the present understanding of dimensional stability of urea-formaldehyde based foams and its resistance to high temperature and high humidity. The NBS conducted preliminary tests which indicated that the material performance with respect to shrinkage and resistance to high temperature and humidity may be suspect. Until time based studies reveal the in-service performance of this material, the question of durability will remain unanswered. It should be pointed out that European practice,

Table 3.10

UREA-FORMALDEHYDE AND UREA-BASED FOAMS

Material Property	Value*	Test Method
Density	Wet - Approximately 2.5 lb/ft ³ Dry - 0.6 to 0.9 lb/ft ³	Weigh a foam-filled plastic bag of known volume.
Closed Cell Content	0.7% - 80%	
Thermal Conductivity (k factor)	0.24 Btu-in/hrft ² F	ASTM C177-76 Mean temperature 75F
Thermal Resistance (R value) per 1" of thickness at 75F	4.2 hft ² F/Btu	
Water Vapor Permeability	4.5 to 100 perm-in @ 50% rh 73F	ASTM-C355
Water Absorption	32% by weight (0.35% volume) 95%rh 18% by weight (0.27% volume) 60%rh 68F 180-3800% by weight (2-42% volume) immersion	
Capillarity	slight	
Fire Resistance	combustible	ASTM E-136
Flame Spread	0-25	ASTM E84
Fuel Contributed	0-30	
Smoke Developed	0-10	
Toxicity	No more toxic than fumes from burning wood.	
Effect of Age		
a) Dimensional Stability	1 to 4% shrinkage in 28 days due to curing. 4.6 to 10% shrinkage @ 100F 100% rh for 1 week 30 to 45% shrinkage @ 158F 90 to 100% rh - 10 days	ASTM D2126 proc C ASTM D2126-66
b) Thermal Performance	No change	
c) Fire Resistance		
Degradation Due To		
Temperature	Decomposes at 415F	
Cycling	No damage after 25 freeze-thaw cycles.	
Animal	Not a feed for vermin.	
Moisture	Not established	
Fungal/Bacterial	Does not support growth.	ASTM G21-70 (1975)
Weathering		
Corrosiveness		
Odor	May exude formaldehyde until cured	

*taken from Reference 21.

now also being applied in Canada, is to derate the overall calculated or measured thermal performance of systems containing urea based foams up to 40 percent in order to allow for shrinkage associated factors. The recent HUD specifications recommend derating to 72% of claimed R-value for design purposes (38). Further study is required on the various parameters which can affect the thermal performance of systems containing this insulation.

3.5.7 Perlite

Expanded perlite can be produced with densities in the range of 2 to 11 lb/ft³. This material has a pellet-like form which contains countless tiny glass-sealed air cells that account for its thermal insulation properties. Non-flammable silicone treatment increases its resistance to water penetration and perlite is claimed to be water repellant and impervious to moisture. Being inorganic, perlite is rot, vermin, and termite resistant, and is non-combustible. It softens at temperatures between 890C and 1100C, and melts between 1280C and 1350C.

The thermal conductivity of loose-fill perlite varies with density. This density dependence is illustrated in Figure 3.6.

Expanded perlite is also mixed with Portland Cement to form a light weight insulating concrete. Density is varied by controlling the perlite/cement ratio, and a range of 20 to 40 lb/ft³ is typical. Perlite concrete, which may be precast in a number of shapes or cast-in-place, possesses sufficient mechanical strength to be load-bearing at high densities. It has a k-factor of 0.51 to 2.00 Btu-in/hrft²F, k increasing with increasing density.

3.5.8 Vermiculite

Vermiculite is exfoliated to many times its original value when heated rapidly to high temperatures (700-1000C) by steam which forms and

Figure 3.6
THERMAL CONDUCTIVITY OF PERLITE (37b)

Table 3.11
PERLITE

Material Property	Value		Test Method
	<u>Loose-Fill</u>	<u>Perlite Concrete</u>	
Density	2-11 lb/ft ³	20-40 lb/ft ³	
K _{app} at 75F	0.27-0.40	0.50-0.93	ASTM C-177
	Btu-in/ft ² hr°F	Btu-in/ft ² hr°F	
Thermal Resistance (R value) per 1" thickness at 75F	3.7-2.5	2.0-1.08	
	hft ² F/Btu	hft ² F/Btu	
Water Vapor Permeability	high	high	
Water Absorption	low		
Capillarity			
Fire Resistance	non-combustible	non-combustible	ASTM E136
Flame Spread	0	0	} ASTM E84
Fuel Contributed	0	0	
Smoke Developed	0	0	
Toxicity	not toxic	not toxic	
Effect of Age			
a) Dimensional Stability	none	none	
b) Thermal Performance	none	none	
c) Fire Resistance	none	none	
Degradation Due To			
Temperature	none under 1200°F	none under 500°F	
Cycling	none	none	
Animal	none	none	
Moisture	none	none	
Fungal/Bacterial	does not promote growth	does not promote growth	
Weathering	none	none	
Corrosiveness	none	none	
Odor	none	none	

forces the laminae apart. By controlling the degree of exfoliation, a density range of, typically, 4 to 10 lb/ft³ can be produced in the expanded material. The lower density material has an average particle size of 6.5 mm and is commonly used as loose-fill insulation and concrete aggregate. Higher density material is used as plaster aggregates and for high temperature applications, as particle sizes are smaller (1.5 to 4.5 mm), air voids between particles are smaller and convection is minimized. The thermal conductivity of exfoliated vermiculite is typically 0.33 to 0.41 Btu-in/hrft²F at ambient temperatures, which translates to R values of 3.0 to 2.4 per inch.

Vermiculite is also mixed with Portland Cement and sometimes sand to produce vermiculite concrete. Densities of this material usually range from 20 to 60 lb/ft³, with higher densities resulting in higher thermal conductivities which range from 0.59 to 0.96 Btu-in/hrft²F (R of 1.7 to 1.0 per inch).

Vermiculite is treated to ensure water repellancy. It is non-combustible and melts at 1315C. Being an inorganic material, it is resistant to rot, vermin, and termites, and is not affected by age, temperature, or humidity. Vermiculite is chemically inert, therefore, non-corrosive, and exudes no odors.

3.5.9 Insulating Concrete

The density of insulating concrete is proportional to the degree of foaming. The range is 12 to 88 lb/ft³. As is the case with perlite and vermiculite concretes, thermal resistance decreases sharply and compressive strength increases, with increasing density. For example, a material which is strong enough for compressive loading purposes may have a density of 40 lb/ft³ and a thermal conductivity of 1.17 Btu-in/hrft²F (R = 0.85 per inch) while a material with density of 25 lb/ft³ cannot be used for load-bearing purposes but has a thermal conductivity of about 0.83 Btu-in/hrft²F (R = 1.2 per inch). The thermal conductivity of insulating concrete increases with increasing moisture content (32a, 32b).

Table 3.12
VERMICULITE

Material Property	Value		Test Method
	<u>Loose-Fill</u>	<u>Vermiculite Concrete</u>	
Density	4 to 10 lb/ft ³	20 to 60 lb/ft ³	
K _{app} at 75F	0.33-0.41 Btu-in/ft ² hF	0.59-0.96 Btu-in/ft ² hF	ASTM C177
Thermal Resistance (R value) per 1" of thickness at 75F	3.0-2.4 hrft ² F/Btu	1.7-1.0 hrft ² F/Btu	
Water Vapor Permeability	high	high	
Water Absorption	none	none	
Capillarity	none	none	
Fire Resistance	non-combustible	non-combustible	ASTM E136
Flame Spread	0	0	} ASTM E84
Fuel Contributed	0	0	
Smoke Developed	0	0	
Toxicity	none	none	
Effect of Age			
a) Dimensional Stability	none	none	
b) Thermal Performance	none	none	
c) Fire Resistance	none	none	
Degradation Due To			
Temperature	none below 1000F	none below 1000F	
Cycling	none	none	
Animal	none	none	
Moisture	none	none	
Fungal/Bacterial	does not promote growth	does not promote growth	
Weathering	none	none	
Corrosiveness	none	none	
Odor	none	none	

Table 3.13
INSULATING CONCRETE

Material Property	Value	Test Method
Density	12 to 88 lb/ft ³	
Thermal Conductivity (k factor) at 75F	1.17 Btu-in/ft ² hr°F (40 lb/ft ³) 0.83 Btu-in/ft ² hr°F (25 lb/ft ³)	ASTM C177
Thermal Resistance (R value) per 1" of thickness at 75F	0.85 hft ² F/Btu (40 lb/ft ³) 1.2 hft ² F/Btu (25 lb/ft ³)	
Water Vapor Permeability	varies with density	
Water Absorption		
Capillarity	none	
Fire Resistance	non-combustible	ASTM E-136
Flame Spread	0	} ASTM E-84
Fuel Contributed	0	
Smoke Developed	0	
Toxicity	none	
Effect of Age		
a) Dimensional Stability	none	
b) Thermal Performance	none	
c) Fire Resistance	none	
Degradation Due To		
Temperature	none below 1000C	
Cycling	none	
Animal	none	
Moisture	none	
Fungal/Bacterial	does not support growth	
Weathering	below 30 lb/ft ³ must be protected from frost	
Corrosiveness	none	
Odor	none	

Insulating concrete is highly resistant to moisture penetration; however, materials with a density of less than 30 lb/ft³ may be damaged by frost and must be protected when used in exterior applications. The material is non-combustible and can be exposed to temperatures as high as 1000C without damage. Because of its inorganic nature, it does not support the growth of fungus or vermin. Shrinkage is less than .05% between the fully water-saturated and completely dry stages. Precast, autoclave-cured material is very stable and has no tendency to deteriorate with age.

3.5.10 Reflective Surfaces

Reflective materials act as insulations by reflecting incident radiant heat energy, rather than by reducing conduction as conventional bulk insulations do. In a vertical cavity, a wall, for example, about 60% of heat transfer is due to radiation, while in loft and underfloor spaces, radiation contributes about 50% and 70% to heat transfer respectively. Aluminum foil, the most common reflective insulation material, is effective in reducing such losses by 90% when applied to one side or both of a cavity. However, aluminum foil has relatively little effect on conduction or convection heat losses. Thus, aluminum foil would be of greatest benefit in applications where convective and conductive heat losses are relatively small (such as underfloor spaces).

The reflective insulations consist of a varying number of reflective air filled cells. The thermal resistance of the system is governed by the number of cells and the direction of heat flow. As a system, it performs very effectively in reducing the radiative heat transfer. It does require, however, a reflective air space, a condition which is not always adequately met. The foil itself is non-combustible and an excellent vapor barrier. Aluminum foil insulation has a low mass and heat capacity, so that buildings employing it will heat rapidly, and it takes up minimal

space in a wall. Foil is not affected by age or temperature and will not support the growth of fungus, bacteria, or vermin, but the surfaces may be affected by water vapor. If dulling of the reflective surface by oxidation or dusting takes place, the effectiveness will be reduced.

3.5.11 Other Materials

In concluding this section on materials, reference is made to other materials which are only in the experimental or developmental stage for consideration as thermal insulations in buildings. These include:

1. Foamed gypsum whereby the base product is combined with glass fiber and a fluid blowing agent. This material has the advantage of very good fire resistance properties and the promise of good thermal performance at low densities.
2. Foamed asbestos, an European product, has similar attributes to foamed gypsum. However, it does have possible health hazards.
3. Polyvinyl-chloride foams are closed cell cellular plastics having a similar range of densities as the present polystyrene and polyurethanes. In general their performance characteristics will be somewhat similar to present materials.

3.6 Certification and Inspection Programs

Mineral fiber batt and blanket insulation products may carry a third party certification label under the National Association of Home Builders Research Foundation certification program. Under this program, inspectors from NAHB-RF select samples from each producing plant, measure dimensions after the insulation is removed from the compressed package, and test for thermal performance in their own research laboratory as described in Section 5. Use of labels attesting to NAHB-RF certification

are contributed by NAHB-RF and are permitted only on individual items produced at specific plants where NAHB-RF tests show continuing compliance.

Manufacturers of other building insulation materials, including mineral fiber loose fill, are now considering similar certification and inspection programs for their respective products.

Section 4

INSULATION ASSEMBLIES

In use, building insulation must be installed in or on the building envelope and the heat loss or gain through the envelope becomes much more complex than for insulation alone. The structural members are usually more conductive than the envelope itself and the system must limit or account for that greater heat flow. The structural members are typically wood, steel, or masonry and the envelope insulation may be located between the framing members or on the interior or exterior of those members. Placement of insulation outside the frame reduces the effect of short circuits of heat flow through the structural members.

Table 4.1 presents a simplified classification of insulation as used in elements of the building envelope. Residential and industrial/commercial categories are separated because of major differences in building construction. Wood frame construction is only a small portion of the industrial/commercial segment, whereas it constitutes the major form of residential construction, Table 4.2. Many of the applications listed in Table 4.1 are not widely used. However, it is important to describe some of these lesser used applications because they offer solutions to some of the more difficult to insulate types of construction, and they are often applicable to retrofit as well as new construction. Also, these applications could become more widely used as increasing energy costs make them more economically attractive.

Table 4.3 shows the relative importance of various building categories. The values are calculated from the Dodge Construction Potentials as reported in December, 1976. The importance of the residential building area is apparent. Almost two-thirds of major new construction, additions, and alterations were in residential buildings. In fact, single family units

TABLE 4.1

INSULATION ASSEMBLIES

COMPOSITE ASSEMBLY	INSULATION USED	
	RESIDENTIAL	INDUSTRIAL/COMMERCIAL
<u>ROOF/CEILING</u>		
Roof Truss/Joists	Mineral Fiber Batt or Loose Fill,	Fiber Batt, Loose Fill
Overdeck	Cellulose Loose Fill	Foam Board, Mineral or Wood Fiber Insulation Board, Insulating Concrete
	Foam Board, Wood Fiber Board	Foam Board
Over Roof Membrane	Foam Board	Foam Board
Underdeck	Mineral Fiber Batt, Wood Fiber Board	Mineral Fiber Batt, Spray-In-Place Foam and Wood Fiber Insulation Board
Cathedral Ceiling	Mineral Fiber Batt, Foam or Wood Fiber Board	
<u>WALLS</u>		
Cavity Wall	Mineral Fiber Batt or Loose Fill, Foam,	Mineral Fiber Batt, Foam, Cellulose
	Cellulose Loose Fill	
Insulated Frame-Sheathing	Foam Board, Wood Fiber Board	Foam Board, Fiber Batt
Interior Wall Substrates	Foam Board	Foam Board, Fiber Batt
Stucco Base		Foam Board
Panels		Panels with Foam, Wood Fiber, or Mineral Board, Mineral Fiber Batts Encased in Metal or Mineral Faces
<u>FLOOR</u>		
Masonry Slab Substrate	Foam Board	Foam Board
or Perimeter Insulation		
Wood Framed Floor	Mineral Fiber Batt	Mineral Fiber Batt
<u>FOUNDATION/WALL</u>		
Exterior Application	Foam Board	Foam Board
Interior Wall Substrate	Foam Board, Mineral Fiber Batt	Foam Board, Mineral Fiber Batt

NOTE also that Mineral Loose Fill Insulations such as Perlite and Vermiculite or Foam Pellets are used to Fill Voids in Concrete Blocks

Table 4.2

1973 TYPICAL BUILDER PRACTICES IN SINGLE FAMILY HOMES*
(Percent of Housing Units)

	Region				US Total
	North East	North Central	South	West	
Roof Structures					
Roof Trusses	59.2	69.5	72.1	72.3	70.0
Rafters	37.6	28.1	24.7	20.2	25.8
Other & No Answer	3.2	2.4	3.2	7.4	4.1
TOTAL	100.0	100.0	100.0	99.9	99.9
Exterior Wall Structures					
2 x 4 Studs	95.1	97.1	80.3	90.1	89.8
Solid Masonry	.5	.1	12.9	7.0	6.4
Other & No Answer	4.3	2.8	6.8	2.9	3.8
TOTAL	99.9	100.0	100.0	100.0	100.0
Floor Framing					
Wood Joist/Beam	89.9	88.6	45.6	59.9	61.2
Other & No Answer	10.0	2.4	4.5	8.2	5.6
Not Applicable (Concrete)	.0	9.0	49.9	31.9	33.3
TOTAL	99.9	100.0	100.0	100.0	100.1
Foundation Construction					
Concrete Block	28.8	45.0	33.8	2.4	28.7
Poured Concrete	67.8	51.5	60.7	95.6	67.3
Other & No Answer	3.4	3.5	5.5	2.0	4.0
TOTAL	100.0	100.0	100.0	100.0	100.0
Foundation Type					
Full/Partial Basement	51.8	71.4	20.4	24.7	36.8
Crawl Space	3.0	7.0	16.5	25.4	15.0
Slab-on-grade	43.3	18.0	60.0	42.4	44.3
Other & No Answer	1.9	3.5	3.1	7.4	4.0
TOTAL	100.0	99.9	100.0	99.9	100.1

*National Association of Home Builders Survey
Title "Survey of Single Family Home Characteristics" (33)

Table 4.3

DODGE CONSTRUCTION POTENTIALS⁽³⁴⁾
(December, 1976)

	<u>% Total Sq.ft.</u>
RESIDENTIAL BUILDINGS	
Single Family	52.1
Multi Family	<u>12.3</u>
Total Housekeeping Residential	64.4
Total Nonhousekeeping Residential	<u>1.2</u>
 TOTAL RESIDENTIAL BUILDINGS	 65.6
 INDUSTRIAL/COMMERCIAL BUILDINGS	
Total Commercial Buildings	16.0
Total Manufacturing Buildings	5.4
Total Educational & Science Buildings	4.3
Total Hosp. & Other Health Treat. Buildings	2.6
Total Amusement, Social & Recreat. Buildings	1.7
Total Public Buildings	1.4
Total Religious Buildings	1.1
Total Miscellaneous Nonresidential Buildings	<u>1.9</u>
 TOTAL INDUSTRIAL/COMMERCIAL BUILDINGS	 <u>34.4</u>
 TOTAL BUILDINGS	 100.0

alone accounted for over half of major construction and remodeling square footage in the United States. One and two family units are usually similar in construction. These two categories accounted for 53.5% of the total. The remaining 46.5% of major new construction, additions, and alteration projects utilize a wide variety of methods of construction, yet there are many similarities in basic construction methods. The basic methods will be described in the Industrial/Commercial insulation assemblies section, Section 4.2.

4.1 Residential Insulation Assemblies

Residential construction is standardized to a great extent and therefore provides a consistent basis for analysis and evaluation. Table 4.3 shows the primary construction practices for the major structural portions of single family homes which will be insulated.

4.1.1 Heat Losses in Residential Buildings

In considering energy conservation within buildings, residential structures are a major area primarily because of the number of structures involved (Table 4.3). This is especially true when the subject of retrofitting of the estimated 25 million under-insulated dwellings (defined as less than the HUD Minimum Property Standards of R-11 walls and R-19 ceilings) which were deemed likely candidates for re-insulation (8).

The principal heat losses in residential buildings are through the ceiling, the walls, the floors, the windows and doors, and through infiltration. Table 4.4 shows the level of some of these losses in an uninsulated house and a well insulated house.

The problems of heat gain during the summer air conditioning periods as shown in Table 4.5 are similar. The relationships remain about the same.

Table 4.4
HEAT LOSS DISTRIBUTION FOR A TYPICAL RESIDENCE (35)
(Thousand BTU)

	HEATING			
	UNINSULATED		WELL-INSULATED	
	PEAK HOUR*	DAY	PEAK HOUR*	DAY
Ceiling	18.4 (42%)	338.8 (43%)	2.8 (12%)	53.9 (14%)
Wall	7.0 (16%)	177 (22%)	2.8 (12%)	68.6 (17%)
Glass				
Conduction & Convection Radiation	9.3 (22%)	130 (16%)	9.3 (40%)	130.0 (33%)
Infiltration	8.4 (20%)	144.7 (19%)	8.4 (36%)	144.7 (36%)
Total Load	43.1	790.5	23.3	397.2

*Peak Hour is the hour of the day which corresponds to the highest thermal load

Table 4.5
HEAT LOSS DISTRIBUTION FOR A TYPICAL RESIDENCE (35)
(Thousand BTU)

	COOLING			
	UNINSULATED		WELL-INSULATED	
	PEAK HOUR*	DAY	PEAK HOUR*	DAY
Ceiling	5.5 (18%)	84.0 (22%)	1.6 (7%)	22.9 (8%)
Wall	2.9 (10%)	44.0 (12%)	1.1 (5%)	14.9 (6%)
Glass				
Conduction & Convection	2.1 (7%)	29.2 (8%)	2.1 (9%)	29.2 (10%)
Radiation	14.9 (49%)	117.6 (31%)	14.9 (60%)	117.6 (41%)
Infiltration	5.0 (61%)	101.3 (27%)	5.0 (19%)	101.2 (35%)
Total Load	30.4	376.1	24.7	286.0

*Peak Hour is the hour of the day which corresponds to the highest thermal load.

4.1.1.1 Ceilings

Attic or ceiling insulation results in a significant reduction in heat loss. This very significant improvement is due to the fact that an uninsulated ceiling has practically no resistance to heat flow, (less than an R of 3 when the two air film resistances and the plaster are considered). In an uninsulated house, the heat loss through the ceiling amounts to more than 40 percent of the total heat loss. This problem is the first to be corrected, and is often simple to correct.

4.1.1.2 Walls

A wall consists of a number of resistive surfaces and materials which produce a moderate thermal resistance (approximately R-5). Thus, the addition of insulation into uninsulated walls does not produce the dramatic improvement obtained with the addition of insulation in uninsulated ceilings. The insulation of the walls of older houses is more difficult; it can be achieved by blowing or otherwise injecting insulation into the cavities. Significant savings can be achieved by insulating basement walls.

4.1.1.3 Floors/Foundations

The insulation of floors, which are not listed in Tables 4.4 and 4.5, is subject to much debate. Definitely, floors over ventilated unheated crawl spaces should be insulated. Past practice has been to heat the crawl space partially with the heat losses from the heating air ducts and other basement heat sources. Frequently, floors over unheated basements have been uninsulated since it was felt that the rising heat from the furnace would minimize the heat loss from the living area.

In Table 4.6 taken from the Arkansas Study (36), it can be seen that insulating the floors can result in significant savings of energy.

Table 4.6

THE ARKANSAS STORY* - HEAT LOSS COMPARISON CHART¹

	<u>Energy Conservation Construction</u>	<u>FHA Minimum Property Standards**</u>
Floor	3,179 Btu	8,722 Btu
Walls	4,411	6,757
Ceiling	2,041	4,320
Windows & Doors	3,050	13,131
Infiltration	<u>3,007</u>	<u>7,548</u>
SubTotal	15,688 Btu	40,478 Btu
Duct Loss 3 Percent	471 15%	6,072
TOTAL BTU HEAT LOSS	16,159 Btu	46,550 Btu

Total Heat Loss Reduction = 65 Percent

¹From Arkansas Power & Light Load Calculation Forms
at 70° Temperature Difference Heating and 25° Temperature
Difference Cooling

*Joint Project by Arkansas Power & Light Company and
others to demonstrate method for Energy Conservation
Report by Owens-Corning Fiberglas

(Reference 36)

**Approximately 1974

Perimeter insulation of foundation walls is an alternative to floor insulation primarily for unvented crawl spaces. For slab-on-grade construction, the perimeter edge of the slab should be insulated in most geographical areas. The furnace should be supplied with outside air by ducts to reduce air demand from the inside, thus decreasing air infiltration.

4.1.1.4 Windows and Doors

While strictly not insulation materials, the overall effect of windows-doors are included in this analysis. They present an entirely different problem. Because they break the continuity of the walls, they produce many peripheral heat loss areas, some of which are not corrected by doubling the glass panes. In general, heat loss calculations do not consider the solar collecting capabilities of the windows. Selecting location and protection of the windows should result in a significant improvement in efficiency. Protective draperies can be used effectively in controlling the heat losses or gains from the windows. The use of storm windows has the advantage of reducing air infiltration in addition to the double pane benefit.

Table 4.6 also illustrates the total benefits in conserved energy which could be obtained by modifying existing standard construction techniques to take full advantage of the use of thermal insulation. Ceilings had 12 inches of fiber glass insulation, wall cavity insulation was increased from 3-1/2 to 5-1/2 inches in thickness, floors were insulated with 6 inches of insulation and 1-1/2 inch of rigid urethane foam perimeter insulation was installed around concrete slabs. Window and door area was reduced from 166 square feet to 106 square feet, while caulking was used extensively to reduce infiltration. The comparison of heat losses from the house with these above conditions with that of a comparable one insulated to FHA Minimum Property Standards shows that overall savings due to added insulation are truly significant.

While this example applies to new construction, it does illustrate problem areas of existing buildings and the significance of their solution by the correct use of insulation in the various sectors.

4.1.1.5 Heat Loss Calculations

Consideration should be given to the effect of added amounts of insulation. Using recommended ASHRAE methods, the overall coefficient of heat transmission (U) was calculated for typical 2 x 4 stud (16 in. on center) walls with various amounts of insulation. These calculations use the recommended 20% framing correction and a 75°F mean design temperature. The results are shown in Table 4.7. Adding an R-7 insulation to the cavity of an uninsulated wall produces a 56% reduction in conductive heat loss. The addition of R-13 insulation to the cavity of an uninsulated wall produces a 66% reduction in the conductive heat loss. This is 24% better than the use of R-7 cavity insulation. Similarly, when both plastic foam sheathing and R-13 insulation are added to an uninsulated wall there is a 74% reduction in calculated conductive heat loss, which is a 24% improvement over a wall with R-13 cavity insulation. This illustrates that, percentage wise, initial installation of insulation provides the most significant reduction in conductive heat flow. Additional amounts of insulation yield progressively less reductions in heat loss. This is true of all insulations and all insulated areas (roof/ceilings, walls, floors/foundations). However, the value of added insulation should be judged by the quantity and dollar value of energy saved and the pay-back on the insulation investment. Additional amounts of insulation can be economically justifiable when energy costs and the severity of the climate are taken into account via a proper economic analysis. The "Thermal Performance Guidelines" recommended by the National Association of Home Builders (NAHB), "Retrofitting Existing Housing for Energy Conservation: An Economic Analysis" by the National Bureau of Standards and the FEA, "Optimum Insulation Thickness in Wood-Framed Homes" by the U.S. Department of Agriculture, and "In the Bank...or Up the Chimney"

Table 4.7

THE EFFECT OF INCREASING INSULATION IN AN OPAQUE WALL
(in terms of thermal resistance and heat transmission)

	No Cavity Insulation		R-7 Cavity Insulation		R-13 Cavity Insulation		R-13 Cavity Insulation Plus Plastic Foam Sheathing	
	Through Framing	Through Cavity	Through Framing	Through Cavity	Through Framing	Through Cavity	Through Framing	Through Cavity
Outside air film*	.17	.17	.17	.17	.17	.17	.17	.17
Siding (Average)	.40	.40	.40	.40	.40	.40	.40	.40
1/2" Wood fiber sheathing	1.32	1.32	1.32	1.32	1.32	1.32	--	--
1" Extruded polystyrene sheathing	--	--	--	--	--	--	5.0	5.0
2" x 4" Stud	4.35	--	4.35	--	4.35	--	4.35	--
Air space	--	.94	--	.81	--	--	--	--
Mineral fiber insulation	--	--	--	7.00	--	13.00	--	13.00
1/2" Gypsum board	.45	.45	.45	.45	.45	.45	.45	.45
Inside air film	.68	.68	.68	.68	.68	.68	.68	.68
Total Resistance (R) at section	7.37	3.96	7.37	10.83	7.37	16.02	11.05	19.7
"U" (BTU/hr.ft. ² °F) at section	.1357	.2525	.1357	.0923	.1357	.0624	.0905	.0508
Framing correction	x 20%	x 80%	x 20%	x 80%	x 20%	x 80%	x 20%	x 80%
	.0271	.2020	.0271	.0738	.0271	.0499	.0181	.0406
"U" of wall	.2291		.1009		.0770		.0587	
"U" improvement(over no cavity insulation)	--		.1282		.1521		.1704	
% improvement (incremental)	--		56%		24%		24%	
% improvement (total)	--		56%		66%		74%	

*Resistances expressed as hr ft²F/BTU at 75°F mean temperature.

by the Department of Housing and Urban Development are examples of approaches which consider the economic justification of added insulation to establish a base for its recommendations.

4.1.2 Residential Roof/Ceiling Assemblies

Table 4.8 describes in more detail the predominant roof/ceiling assemblies for residential construction. The predominant roof structures are the roof truss and the rafter type of construction.

4.1.2.1 Roof Truss/Rafter Cavity Applications

The rafter has traditionally been 2 x 6 inch or 2 x 8 inch joists spaced 16-inch on center. The materials used for roof/ceiling applications of this construction are the traditional inexpensive loose fill and batt mineral fiber, cellulose fiber, and vermiculite insulations since there are seldom any thickness restrictions. These systems are used in new construction and retrofit applications.

There are three methods of installing blanket insulation in ceilings:

1. Laying faced insulation in from above when the ceiling finish material is in place (Figure 4.1a).
2. Stapling from below (Figure 4.1b).
3. Installing unfaced pressure-fit blankets with a separate vapor barrier (Figure 4.1c) wedged between ceiling joists.

Table 4.8

ROOF/CEILING ASSEMBLIES*

	Region				US Total
	North East	North Central	South	West	
Roofing Material					
Shingles/Shakes	99.3	95.8	93.0	88.0	93.2
Built-up	.0	.5	.8	4.7	1.4
Other & No Answer	.7	3.7	6.3	7.2	5.4
TOTAL	100.0	100.0	100.1	99.9	100.0
Roof Structures					
Roof Trusses	59.2	69.5	72.1	72.3	70.0
Rafters	37.6	28.1	24.7	20.2	25.8
Other & No Answer	3.2	2.4	3.2	7.4	4.1
TOTAL	100.0	100.0	100.0	99.9	99.9
Ceiling Surface					
Gypsum board (1/2" or more)	80.9	88.9	82.2	82.4	83.4
Other & No Answer	19.1	11.1	17.9	17.7	16.5
TOTAL	100.0	100.0	100.1	100.1	99.9

(33)

*National Association of Home Builders Survey
 Title "Survey of Single Family Home Characteristics"

Figure 4.1a

Figure 4.1b

Figure 4.1c

Reprinted from "Insulation Manual" published by NAHB, Research Foundation, Inc. (37)

Loose fill fiber insulation can be installed as shown in Figure 4.2.

Figure 4.2

TYPICAL LOOSE FILL RAFTER APPLICATION

There are, however, several less predominant roof/ceiling assemblies. These include cathedral ceilings, rafters spaced 24-inch on center, overdeck applications, and insulated roof membranes.

4.1.2.2 Cathedral Ceiling Substrate Application

Rigid insulation boards are useful in cathedral ceilings because of limited space in which to position mineral fiber or loose fill insulation. One effective method of improving the insulation of the cathedral ceiling is to use cellular plastic foams. This application has essentially three variations.

It can be used to cover an exposed deck while leaving the beams exposed for aesthetics as shown in Figure 4.3. This is applicable to both new construction and to retrofit.

Figure 4.3

Construction Detail

A second variation, an application for new construction where there are no exposed beams, is shown in Figure 4.4. Increased thermal performance, which cannot be met by the traditional materials in the rafter cavity, can be attained by application of an appropriate thickness of plastic foam. For instance, if R-25 insulation is desired in a cathedral ceiling constructed of 2" x 6" rafters and filled with R-19 mineral wool batts, 1" of plastic foam can be used to bring the total R value (insulation alone) to R-24. The insulating values of the inside and outside air films, the 1/2" plywood deck and the interior 1/2" gypsum board will bring the total R value to R-25, even when considering the thermal shorts created by the rafter.

Figure 4.4

CONSTRUCTION DETAIL

A third variation is a retrofit application and is very much like the second variation. Here the cellular plastic foam is applied directly to the existing cathedral ceiling and a layer of 1/2" drywall is then applied and finished.

4.1.2.3 Overdeck Applications

When an owner or builder wishes to have a cathedral ceiling with exposed deck and beam for aesthetic reasons he can utilize an over-deck application such as that shown in Figure 4.5. The desired thermal performance dictates the required thickness of any given type of rigid cellular plastic foam boards. This application is particularly suitable to new construction, but is also viable as a retrofit application if the need and decision to reshingle has been established. The Asphalt Roofing Manufacturers Association recommends that plywood be installed over the foam board before roofing application.

Figure 4.5

CONSTRUCTION DETAIL

4.1.2.4 Insulated Roof Membrane

Insulated roof membrane assemblies are applicable to built-up roofs. Table 4.8 shows that the usage of built-up roofs in residential construction is very small, only 1.4% in 1973. This system is used more extensively for Industrial/Commercial buildings and therefore will be discussed in Section 4.2.1.

4.1.2.5 24-Inch On Center Rafter

The use of wood rafters 24-inches on center is desirable from the viewpoint of reducing overall heat loss through the roof. This spacing permits more efficient use of insulation by reducing the framing which short circuits heat flow.

4.1.3 Residential Wall Assemblies

Table 4.9 describes the predominant wall components used in residential construction. The primary structure consists of 2" x 4" stud framing on 16" centers with a gypsum board interior finish, fiberboard sheathing, and a variety of exterior finish materials.

4.1.3.1 Insulated Frame-Cavity Assemblies

The most popular and economic stud cavity insulations for use with 2 x 4" framing on 16" centers are 3-1/2" R-11 and 3-1/2" R-13 mineral fiber batts. When used in a conventional wall, as shown in Figure 4.6a, 4.6b, and 4.7, and allowing for 20% framing as estimated by ASHRAE, the R-11 batts provide a U_o range of 0.076 to 0.084 BTU/hr.ft².F and the R-13 batts provide a range of 0.070 to 0.077. The range is dictated by the exterior finish. This translates to overall calculated opaque wall resistance of about R-12 to R-14. In order to improve the opaque wall thermal resistance, the conventional wall must be changed. There are essentially

Table 4.9

WALL COMPONENTS*

	Region				US Total
	North East	North Central	South	West	
Interior Wall Surface					
Gypsum board (1/2" or more)	80.9	88.9	82.9	82.4	83.4
Other & No Answer	<u>19.1</u>	<u>11.1</u>	<u>17.9</u>	<u>17.7</u>	<u>16.5</u>
TOTAL	100.0	100.0	100.1	100.1	99.9
Exterior Wall Structures					
2 x 4 Studs	95.1	97.1	80.3	90.1	89.8
Solid Masonry	.5	.1	12.9	7.0	6.4
Other & No Answer	<u>4.3</u>	<u>2.8</u>	<u>6.8</u>	<u>2.9</u>	<u>3.8</u>
TOTAL	99.9	100.0	100.0	100.0	100.0
Exterior Wall Sheathing					
1/2" fiberboard (all grades)	49.9	81.8	57.4	31.9	56.3
None	6.4	4.4	2.1	35.8	10.5
1/2" & 3/8" Plywood	33.9	6.7	1.3	16.2	9.7
1/2" Gypsum board	4.5	3.6	15.6	3.6	9.1
Other & No Answer	<u>5.3</u>	<u>5.4</u>	<u>23.5</u>	<u>12.5</u>	<u>14.3</u>
TOTAL	100.0	99.9	99.9	100.0	99.9
Principle Exterior Wall Finish Materials					
Brick Veneer	10.3	20.8	51.1	13.1	31.4
Aluminum	38.0	34.7	10.3	.0	16.6
Wood Siding	2.9	5.7	10.3	9.5	8.4
Stucco	.0	.0	.7	33.3	7.9
Hardboard	.9	15.0	1.3	12.5	6.8
Plywood	8.8	2.5	1.7	17.1	6.4
Concrete	.0	.0	6.1	2.3	3.2
Other & No Answer	<u>39.0</u>	<u>21.5</u>	<u>18.4</u>	<u>12.3</u>	<u>19.4</u>
TOTAL	99.9	100.2	99.9	100.1	100.1

(33)

*National Association of Home Builders Survey
 Title "Survey of Single Family Home Characteristics"

Fig. 4.6a

Fig. 4.6b

To install batts or blankets in a stud cavity, push them against the exterior sheathing. Insulation with a vapor barrier may be stapled to the sides of the studs (Fig. 4.6a) or to the faces of the studs (Fig. 4.6b). Use enough staples to hold the vapor barrier flanges snugly against the wood. Batt ends should be cut to fit tightly against the plates without stapling or the vapor barrier may be pulled to the plates and stapled.

Reprinted from "How To Insulate Homes" by National Mineral Wool Insulation Association, Inc.

polyethylene
vapor barrier

Fig. 4.7

Pressure-fit blankets without a vapor barrier are wedged into place. The inside face of wall studs is covered with a 2-mil-thick polyethylene vapor barrier (Fig. 4.7), stapled to top and bottom plates. Foil-backed gypsumboard may be used as a vapor barrier instead of polyethylene.

Reprinted from "Insulation Manual" published by NAHB, Research Foundation, Inc. (37)

three alternatives, one of which is accomplished by changing to 2 x 6" stud wall constructions and two of which can be accomplished with cellular plastic foam with the conventional 2 x 4" stud wall construction.

For retrofit applications, other insulation materials are used; blown-in mineral fiber, cellulose fiber and urea-formaldehyde and urea-based foams. These systems lend themselves to wall retrofit applications where there is no insulation in the cavity. The R-value for the insulation material between the frame is approximately R-11 for blown-in mineral fiber, R-12 for cellulose, R-15 for urea-based foams (3-1/2"), and R-19 for polyurethane/polyisocyanurate, but it should be noted that this last mentioned insulation is rarely used for this application in residential construction. The conductive thermal performance for urea-formaldehyde foam-in-place insulation is presented in Table 4.10. Similar calculations are presented in Section 4.1.3.2 for R-11 and R-13 insulations. The use of foam-in-place urea-based foam requires careful application. There is an appreciable amount of water released during curing. Shrinkage and humidity-aging are two important factors which affect long term performance. (NBS Technical Note 946 (21) and HUD UM 74 (38) present a detailed discussion of these effects). Urethane spray-on-foams have high thermal resistance, but are expensive and require complicated application.

The toxicities of most of these foams examined here have been tested by the manufacturers. During the curing stage, the spray-on-urea formaldehyde foam does release some unpleasant odor. When foam is installed properly, the odor disappears within a few days. The products of combustion were also examined for polyurethane foam and urea formaldehyde foam. Studies by manufacturers indicate that the toxicity of products of combustion is not worse than those released by burning the same weight of red oak.

Table 4.10

INSULATED FRAME - CAVITY ASSEMBLIES

(Conductive Thermal Performance)*

(Foam-in-Place Urea Formaldehyde Between Studs - 3-1/2")

	1/2" Hard Board	3/8" Plywood	1/2" Aluminum	1/2" Beveled, 4" Brick Veneer 8" Lapped	Plus 3/4" - 1"	1/2" Stucco
<u>Sheathing</u>	<u>Siding</u>	<u>Siding</u>	<u>Siding</u>	<u>Wood Siding</u>	<u>Air Space Siding</u>	<u>Siding</u>
1/2" Regular						
Density Wood	R-14.4	R-14.14	R-14.32	R-14.57	R-15.43	R-13.8
Fiber Board	U-.0694	U-.0707	U-.0698	U-.0686	U-.0648	U-.0724
1/2" Intermediate						
Density Wood	R-14.29	R-14.05	R-14.21	R-14.46	R-15.3	R-13.65
Fiber Board	U-.07	U-.0712	U-.0703	U-.0691	U-.0653	U-.0738
1/2" Exterior	R-13.55	R-13.3	R-13.49	R-13.73	R-14.6	R-12.9
Grade Plywood	U-.0738	U-.0752	U-.0741	U-.0728	U-.0684	U-.0775

* These values do not take into account the effects of any shrinkage of urea-formaldehyde foam on thermal performance. See References 21 and 38 which indicate that a 6% foam shrinkage results in a 28% decrease in R-value for the wall assembly. R- and U-values calculated for 75F mean temperature.

4.1.3.2 Insulated Frame Foam Sheathing Assemblies

An insulated frame-sheathing assembly, Figure 4.8, consists of an interior finish, a stud cavity with or without insulation in the cavity, exterior insulating sheathing, and exterior siding.

This type of assembly was not widely used for residential applications, as is indicated in Table 4.9 for 1973 data. However, as the cost of energy increases, the use of insulated sheathing assemblies has become more economically attractive and therefore more widely accepted. This has already been observed over the last few years by a growth from a negligible amount in 1975 to about 10% of the sheathing market in 1977.

Figure 4.8

Construction Detail

The over-all conductive thermal performance of the opaque wall using an insulated sheathing assembly is calculated utilizing recommended ASHRAE methods. Representative R-values (at 75°F) for the various wall components are given in Table 4.11 and calculated thermal resistances are presented in Tables 4.12 and 4.13 for the indicated combinations of wall components. For these calculations, the interior finish was assumed to be

Table 4.11
R-VALUE OF WALL COMPONENTS

		R-Value * Through Framing	R-Value * Between Framing
Inside Air		0.68	0.68
1/2" Drywall		0.45	0.45
2 x 4 Wood Studs		4.35	0
Mineral Fiber	R-11 Batts	0	11.0
with Vapor Barrier	R-13 Batts	0	13.0
Foam-In-Place	Urea-Formaldehyde (3 1/2")	0	15.2
Loose Fill	Cellulose Fiber Insulation, 3.5 pcf	0	12.0
Spray-On	Polyurethane (3")	0	18.78
Sheathing	1/2" Reg. Density Fiber board	1.32	1.32
	1/2" Inter. Density Fiber board	1.22	1.22
	1/2" Ext. Grade Plywood	0.62	0.62
	1" Extruded, Expanded Polystyrene Foam	5.0	5.0
	1" Molded, Expanded Polystyrene Foam 1# Density	3.85	3.85
	1" Molded, Expanded Polystyrene Foam 1.5# Density	4.17	4.17
	3/4" Polyurethane-Isocyanurate Foam with Impermeable Facings	5.4	5.4
	3/4" Polyurethane-Isocyanurate Foam with Permeable Facing or without Facing	4.7	4.7
Sidings	1/2" Hardboard	0.67	0.67
	3/8" Plywood	0.47	0.47
	1/2" Aluminum	0.61	0.61
	1/2" Beveled, 8" Lapped Wood Sidings	0.81	0.81
	4" Brick Veneer plus 3/4" or 1" Air Space	0.44 + 1.1	0.44 + 1.1
	1/2" Stucco Facing	0.15	0.15
Outside Air		0.17	0.17

*R expressed as $h \text{ ft}^2 \text{ F/Btu}$ at 75F
mean temperature.

Table 4.12

INSULATED FRAME - SHEATHING ASSEMBLIES
(Conductive Thermal Performance)*
R-11 Mineral Fiber Batts with Vapor Barrier

<u>Sheathing</u>	<u>1/2" Hard Board Siding</u>	<u>3/8" Plywood Siding</u>	<u>1/2" Aluminum Siding</u>	<u>1/2" Beveled, 8" Lapped Wood Siding</u>	<u>4" Brick Veneer Plus 3/4" - 1" Air Space Siding</u>	<u>1/2" Stucco Siding</u>
1/2" Regular Density Wood Fiber Board	R-12.18 U-.0821	R-11.95 U-.0837	R-12.11 U-.0826	R-12.33 U-.0811	R-13.1 U-.0763	R-11.6 U-.0862
1/2" Intermediate Density Wood Fiber Board	R-12.06 U-.0826	R-11.84 U-.0884	R-12.0 U-.083	R-12.22 U-.0819	R-13.0 U-.0769	R-11.5 U-.087
1/2" Exterior Grade Plywood	R-11.4 U-.0877	R-11.18 U-.0894	R-11.34 U-.0882	R-11.56 U-.0865	R-12.36 U-.0809	R-10.82 U-.0924
1" Extruded Polystyrene Foam	R-16.1 U-.0622	R-15.9 U-.0630	R-16.0 U-.0624	R-16.2 U-.0616	R-17.0 U-.0589	R-15.5 U-.0644
1" Expanded Polystyrene Foam	R-14.9 U-.0672	R-14.7 U-.0682	R-14.8 U-.0675	R-15.0 U-.0666	R-15.8 U-.0633	R-14.3 U-.0698
1# PCF						
1" Expanded Polystyrene Foam	R-15.21 U-.0657	R-15.0 U-.0667	R-15.15 U-.0660	R-15.36 U-.0651	R-16.12 U-.0620	R-14.66 U-.0682
1.5# PCF						
3/4" Urethane- Isocyanurate Impermeable Facing	R-16.5 U-.0606	R-16.3 U-.0614	R-16.43 U-.0608	R-16.65 U-.0600	R-17.39 U-.0575	R-15.96 U-.0627
3/4" Urethane- Isocyanurate Permeable Facing	R-15.77 U-.0634	R-15.55 U-.0643	R-15.7 U-.0637	R-15.91 U-.0628	R-16.67 U-.0599	R-15.22 U-.0657

*At 75F Mean Temperature.

Table 4.13

INSULATED FRAME - SHEATHING ASSEMBLIES
(Conductive Thermal Performance)*
R-13 Mineral Fiber Batts with Vapor Barrier

<u>Sheathing</u>	<u>1/2" Hard Board Siding</u>	<u>3/8" Plywood Siding</u>	<u>1/2" Aluminum Siding</u>	<u>1/2" Beveled, 8" Lapped Wood Siding</u>	<u>4" Brick Veneer Plus 3/4" - 1" Air Space Siding</u>	<u>1/2" Stucco Siding</u>
1/2" Regular Density Wood Fiber Board	R-13.28 U-.0753	R-13.05 U-.0766	R-13.2 U-.0757	R-13.44 U-.0744	R-14.26 U-.0701	R-12.69 U-.0788
1/2" Intermediate Density Wood Fiber Board	R-13.17 U-.0759	R-12.94 U-.0773	R-13.1 U-.0763	R-13.33 U-.075	R-14.15 U-.0706	R-12.57 U-.0796
1/2" Exterior Grade Plywood	R-12.13 U-.0824	R-12.25 U-.0816	R-12.40 U-.0805	R-12.64 U-.0791	R-13.48 U-.0742	R-11.87 U-.0842
1" Extruded Polystyrene Foam	R-17.3 U-.0577	R-17.1 U-.0585	R-17.3 U-.0579	R-17.5 U-.0572	R-18.3 U-.0548	R-16.8 U-.0596
1" Expanded Polystyrene Foam 1# PCF	R-16.1 U-.0622	R-15.9 U-.0630	R-16.0 U-.0624	R-16.2 U-.0616	R-17.0 U-.0587	R-15.5 U-.0644
1" Expanded Polystyrene Foam 1.5# PCF	R-16.43 U-.0608	R-16.31 U-.0613	R-16.39 U-.0610	R-16.58 U-.0603	R-17.0 U-.0587	R-15.86 U-.0630
3/4" Urethane Isocyanurate Impermeable Facing	R-17.75 U-.0563	R-17.62 U-.0567	R-17.69 U-.0565	R-17.81 U-.0560	R-18.67 U-.0536	R-17.18 U-.0582
3/4" Urethane- Isocyanurate Permeable Facing	R-17.0 U-.0588	R-16.79 U-.0595	R-16.94 U-.059	R-17.15 U-.0583	R-17.93 U-.0558	R-16.56 U-.0603

*At 75F Mean Temperature.

1/2" gypsum drywall board and wood studs were assumed to be 2 x 4" - the most popular dimension. Also, a 20% framing factor, as estimated by ASHRAE for studs on 16" centers, was used. The cavity insulation was assumed to be R-11 and R-13 for the calculations in Tables 4.12 and 4.13 respectively. A total of 96 combinations were examined and the results for conventionally sheathed walls indicate a calculated opaque wall thermal resistance of R-10.8 to R-13.1 with an R-11 cavity insulation and R-11.9 to R-14.3 with an R-13 cavity insulation. Use of insulated sheathing improves the opaque wall resistance to a range of R-14.3 to R-17.4 with R-11 cavity insulation and R-15.5 to R-18.3 for R-13 cavity insulation. The ranges are due to the type of exterior finish and the type of sheathing material used.

The component R values used for these cases were for 75°F mean temperature. This allows for comparison of various assemblies. ASHRAE Handbook of Fundamentals gives data on the effect of mean temperature on R values of insulations. Most of the data are given for industrial insulations, but these values could be used to estimate effect of mean temperature on R values of building insulations if data for building insulations are not available. The R value of an insulation increases as temperature decreases. In winter conditions where the mean temperature is usually less than 75°F mean, the insulation performs better than predicted from an R at 75°F mean. Conversely, in warm weather or summer conditions, the performance of the insulation is less than predicted from 75°F mean data.

The availability of data over a temperature range of 25°F to 105°F would make it possible for a designer to utilize data which more closely corresponds to the anticipated conditions of use. Accurate estimates can be made using approximate mean temperatures, but for extremely accurate calculations an iterative process is necessary. Such design

calculations can give a more accurate projection of heating and cooling loads of a building and aid in sizing of heating and cooling equipment. In such calculations, other factors such as air infiltration should be considered, as they could be significant.

The calculated performance as presented in Tables 4.12 and 4.13 considers only the heat loss through conduction. Some sheathing materials have special tongue and groove edge treatment so that the wall composite is most likely tighter than the conventional wall. Air infiltration reduction has been observed in both occupied and unoccupied homes using these sheathings. Further, additions of insulation at the sheathing location may improve the thermal performance of the system by reducing the ΔT across the cavity which in turn reduces any remaining convection currents in the cavity. Not all plastic foam sheathings provide benefits of reduced air infiltration. Some manufacturers recommend use of vent strips, or have vents molded into the board to reduce possible condensation problems.

Application procedures may be slightly different for the various wall assemblies. For instance, the plastic foam sheathing requires 1 x 4" let-in bracing or metal cross or angle bracing at the corners (Figure 4.8). The manufacturer of impermeable faced isocyanurate foam sheathing specifies vent strips on the top or bottom plates (in colder climates), and 6 mil polyethylene film vapor barrier. The manufacturer of extruded, expanded polystyrene foam sheathing and the manufacturers of conventional sheathings specify warm side vapor barriers in accordance with the National Mineral Wool Insulation Association recommendations, e.g., polyethylene film or asphalt laminated paper facing. For some molded, expanded polystyrene foam sheathing systems, no vapor barrier is specified on the warm side. Because plastic foams are not nail base materials, the nails used for the sidings need to be long enough to penetrate studs 3/4", and adjustments may be necessary in the application techniques for the exterior siding.

The installation methods are fairly straight forward. The glass fiber insulation comes with either asphalt laminated paper/foil facing or non-faced, friction fit batts. The former can be stapled on either the side or the face of the studs, and the latter needs a polyethylene film to act as a vapor barrier. The plastic foam sheathings are stapled or nailed to the studs with roofing nails, then the sidings are nailed to the studs.

The fire protection rating of wall composites with various plastic foam sheathings are similar. The critical element in the wall component is the 1/2" gypsum drywall which is commonly used in residential construction. Most plastic foam sheathing manufacturers specify 1/2" gypsum drywall or equivalent as the recommended fire barrier, e.g., a 15 minute finish rating by ASTM E-119 test. It is also required by the three model codes. The products of combustion of the plastic foam types examined here have been tested extensively.

The insulated frame-sheathing composite insulating assemblies discussed to this point are only applicable to new construction. A variation of this assembly is, however, applicable to retrofit construction. Figure 4.9 shows this application as described by the manufacturer of extruded polystyrene foam. Their analysis of conductive thermal performance is shown in Table 4.14. As can be seen in this table, there can be a significant improvement in thermal performance. This assembly is most economical only when a decision has already been made by the homeowner to replace existing siding.

Some advantages and disadvantages of plastic foam sheathing boards are presented below.

Advantages

1. Simple application - the application is not unlike that of conventional sheathing products.

Table 4.14

COMPARISON OF WALL SYSTEM "R" VALUES
BEFORE & AFTER RETROFIT
WITH EXTRUDED POLYSTYRENE FOAM

Components of wall	wall with no cavity insulation		wall with 1 1/2" cavity insulation		wall with 2 1/2" cavity insulation	
	through framing	between framing	through framing	between framing	through framing	between framing
Outside air film	0.17	0.17	0.17	0.17	0.17	0.17
Siding (average)*	0.40	0.40	0.40	0.40	0.40	0.40
Building paper	0.06	0.06	0.06	0.06	0.06	0.06
3/4" wood sheathing	0.98	0.98	0.98	0.98	0.98	0.98
3 1/2" wood frame	4.35	--	4.35	--	4.35	--
3 1/2" air space	--	0.97	--	--	--	--
1 1/2" fiberglass batt	--	--	--	4.00	--	--
2" air space	--	--	--	0.94	--	--
2 1/2" fiberglass batt	--	--	--	--	--	7.00
1" air space	--	--	--	--	--	0.92
3/4" wood lath & plaster	0.41	0.41	0.41	0.41	0.41	0.41
Inside air film	0.68	0.68	0.68	0.68	0.68	0.68
"R" value of old sect.	7.05	3.67	7.05	7.64	7.05	10.62
"U" value of old sect.	0.1418	0.2725	0.1418	0.1309	0.1418	0.0942
Framing correction	x. 20%	x 80%	x 20%	x 80%	x 20%	x 80%
	0.0284 +	0.2180	0.0284 +	0.1047	0.0284 +	0.0754
Average "U" of old wall	0.2464		0.1331		0.1038	
Average "R" of old wall	4.058		7.513		9.634	
RETROFIT SECTION						
3/4" Extruded Polystyrene foam	3.75	3.75	3.75	3.75	3.75	3.75
Aluminum siding (hollow back)	0.61	0.61	0.61	0.61	0.61	0.61
"R" value of Retrofit section	11.41	8.03	11.41	12.00	11.41	14.98
"U" value of Retrofit section	0.0876	0.1245	0.0876	0.0833	0.0876	0.0668
Framing correction	x 20%	x 80%	x 20%	x 80%	x 20%	x 80%
	0.0175 +	0.0996	0.0175 +	0.0666	0.0175 +	0.0534
Average "U" of Retrofit Section	0.1171		0.0841		0.0709	
Average "R" of Retrofit Section	8.54		11.88		14.10	
"U" value improvement (%)	0.1293 (52.5%)		0.0490 (36.8%)		0.0329 (31.7%)	

*Thermal resistance for siding of 0.40 is the average thermal resistance of wood (R=0.85), asbestos (R=0.21), and asphalt roll siding (R=0.15).

**75F Mean Temperature.

2. Lightweight and easy to handle - foam board sheathing products are lighter in weight than conventional sheathing products. Lifting, placing, and nailing in place is easily accomplished.
3. Reduction of air infiltration - Most applications of rigid plastic foam sheathing products result in a reduction of air infiltration. All foam products with joints on the studs will reduce air infiltration. Those products which have an edge joining system such as tongue and groove or ship lap need not be joined on studs to reduce air infiltration. Those products recommending vent strips do not provide the full benefit of air infiltration reduction.
4. High insulation value - The thermal resistance of foam sheathing products range from 3.85 per inch to 7.30 per inch depending on the type of product used.
5. Provides an uninterrupted envelope of insulation - The sheathing application also insulates the framing members of the structure, thereby reducing the thermal shorts created by those members.
6. Common construction is not altered significantly in order to increase thermal performance - typical 2 x 4 stud (16 in. on center) walls are the most common wall construction and its thermal performance is improved with little or no alteration of the framing (see Disadvantage 2).
7. Partial offset of cost - Being a sheathing material, the investment of plastic foam sheathing is at least partially offset by the cost of the conventional sheathing that is replaced.

Disadvantages

1. Some breakage problems - Some foam sheathing products tend to break more easily than conventional sheathing products and must be handled with appropriate care. The higher density, thicker, or faced products tend to exhibit less breakage problems.
2. Non-structural sheathing - Foam sheathing products are non-structural and like other non-structural sheathings cannot be used as a nail base and are required to be augmented with acceptable corner bracing.
3. Some finishing construction alterations are necessary - for those products thicker than 5/8 inch it is usually necessary to utilize longer nails and extended window and door jambs.
4. Interior finish restrictions - being combustible it is required by code that the interior be covered with at least 1/2" thickness of gypsum board.

Figure 4.9

4.1.3.3 Interior Wall Substrate Assemblies

Rigid plastic foam boards can also be applied on the interior of the frame wall behind the gypsum drywall. There would be no difference in the calculated thermal resistance (R-value) as compared with exterior applications. However, there are some disadvantages associated with interior applications. The framing members of the wall are closer to outside temperatures; sheathing is still needed; under transient temperature cycles the insulation is less effective on the warm side of the wall composite; the living space is reduced under the same exterior dimension. The advantage is that certain foams on the warm side can serve as a vapor barrier.

Rigid plastic foam boards can be economically applied to the interior walls of residential masonry construction. The predominant application of this assembly is in industrial/commercial buildings. This is discussed in detail in Section 4.2.2. The application for residential construction is identical.

4.1.3.4 Masonry Wall Construction

Solid masonry wall construction constitutes a small fraction of residential wall construction, with primary usage being for commercial/industrial buildings. Hence, a detailed analysis of these types of assemblies will be found in Section 4.2.2.

4.1.4 Residential Floor/Foundation Assemblies

Table 4.15 describes the predominant types of floors and foundations found in residential buildings. The primary foundation construction is masonry. The primary type of foundation is slab-on-grade, followed closely by full/partial basement. Floors other than slab-on-grade are framed primarily via wood joist/beam, 2 x 8" spaced 16" on center.

Table 4.15

FLOOR/FOUNDATION COMPONENTS*

	Region				US Total
	North East	North Central	South	West	
Foundation Construction					
Concrete Block	28.8	45.0	33.8	2.4	28.7
Poured Concrete	67.8	51.5	60.7	95.6	67.3
Other & No Answer	3.4	3.5	5.5	2.0	4.0
TOTAL	100.0	100.0	100.0	100.0	100.0
Floor Framing					
Wood Joist/Beam	89.9	88.6	45.6	59.9	61.2
Other & No Answer	10.0	2.4	4.5	8.2	5.6
Not Applicable (Concrete)	.0	9.0	49.9	31.9	33.3
TOTAL	99.9	100.0	100.0	100.0	100.1
Foundation Type					
Full/Partial Basement	51.8	71.4	20.4	24.7	36.8
Crawl Space	3.0	7.0	16.5	25.4	15.0
Slab-on-grade	43.3	18.0	60.0	42.4	44.3
Other & No Answer	1.9	3.5	3.1	7.4	4.0
TOTAL	100.0	99.9	100.0	99.9	100.1

*National Association of Home Builders Survey
 Title "Survey of Single Family Home Characteristics" (33)

Floor/foundation perimeter insulation applications utilizing plastic foams have been used for many years on industrial/commercial buildings and are discussed in Section 4.2.3. However, some residential applications are slightly different. Applications shown in Figure 4.10 are for rigid plastic foams. Some foams should have a moisture barrier, since they are more susceptible to moisture pickup and, consequently, are also subject to deterioration from freeze-thaw cycling. The advantages of this type of assembly are ease of application, continuity of the exterior building insulation envelope, and retention of the interior mass to dampen the interior temperature cycling. The primary disadvantage is that the section between the siding and the grade must be covered to prevent UV deterioration, damage, and exposure to possible sources of ignition.

Floors over crawl spaces may be insulated with mineral fiber batts either by insulating the foundation walls if the crawl space is unvented, or if the crawl space is vented and unheated by placing insulation between the floor joists. The former method, as described below, is usually more economical. The vapor barrier (polyethylene film) covering the crawl space ground is placed against the wall (Figure 4.11a), and then the insulation is installed. One edge of insulation is placed on top of the foundation wall with the remainder of the insulation draped over and against the inside of the wall. The main disadvantage of this application is that the sill is not fully insulated.

Floors over vented crawl spaces (Figure 4.11b) can be insulated by installing insulation between the joists. The insulation should be pushed tightly against the subflooring above and is held in place with stiff wire fasteners or flexible wire laced under the joists. In all cases, the vapor barrier side of the insulation should face the floor above--that is, be adjacent to the warm side in winter. Polyethylene may be used as a vapor barrier to cover the ground. If it is desired to protect the insulation from the weather, such as may be the case in open

Figure 4.10

Slab-on-grade

Rigid cellular
plastic foam

Basement

crawl spaces, nail standard, interior grade softwood plywood, nail-base insulation board, or similar covering to the bottom of floor joists.

Figure 4.11a

Figure 4.11b

Reprinted from "How to Insulate Homes" published by National Mineral Wool Insulation Association, Inc. (37a).

In some cases, blanket insulation is located between furring strips on the interior wall (usually unit masonry and/or poured concrete) when finished rooms are located in the basement.

Loose fills, such as perlite, vermiculite, or plastic foam beads, may be installed in the cavities of unit masonry to increase thermal resistance.

4.1.5 Prefabricated Wood Framed Structures

Three manufacturers of prefabricated wood framed dwellings responded to a telephone questionnaire on their products. They represent at least 25 plants located east of the Mississippi and serving that area. For walls, most supplied R-11 or R-13 mineral fiber batts, although one manufacturer offered an alternate of 6-inch stud walls with R-19 batts. Ceilings were offered with R-22 to R-40 batts or R-30 and R-38 blown cellulose insulation. Floors over unheated crawl spaces were offered with R-11 to R-19 batts. Two of the manufacturers did not have available figures on installed cost per square foot, but the third, representing more than half of the plants, offered installed cost figures approximately the same as quoted for site built structures. All calculated over-all heat loss for the building. All offered energy savings packages featuring increased insulation, storm or multiple glazed windows, and thermal doors. The return on investment for the energy savings packages was calculated to be 3 to 5 years for 2 by 4-inch stud walls and 12 years for the 2 by 6-inch stud walls. One emphasized air infiltration control in the energy package with sealing of joints, electrical boxes, etc.

4.1.6 Residential Insulation Installed Costs

A survey of 35 thermal insulation installation contractors throughout the country elicited 28 replies covering most areas of the lower 48 states. These contractors install insulation, mainly in wood frame, newly constructed dwellings, as specified by the general contractors or owners. A summary of this survey is indicated below.

Only batt or blanket insulation was reported to be used in wall cavities, with a thermal resistance (R) of R-11, the most common. Some contractors reported that up to 10 percent of their installations involved 6-inch stud walls with R-19 batts installed. Others reported use of R-11

or R-13 batts with plastic foam sheathing used in place of plywood or wood fiberboard sheathing. These both provide a total wall resistance of up to R-21 or a U as low as 0.05. There are debit factors. Six inch studs are less available and more expensive than 4" studs and the use of 6-inch studs decreases the enclosed areas by 2-inches for each wall, where equal outside dimensions are assumed. For a 47 by 33-foot single story house, the decrease in living area is 27 square feet in approximately 1,240 square feet. Plastic foam sheathing does not provide racking strength to the walls so the added expense of wall bracing must be included.

Ceilings are most often insulated with blown or blanket type insulation with cellulose, fiberglass, or rock wool as the common types. Cellulose is, of course, only installed by blowing. A thermal resistance of R-19 was most common with some contractors reporting installations up to R-30. Demand for resistance over R-30 was found small.

Floors over unheated spaces are commonly insulated with batts, usually supported by wire laced over the bottom face of the joists. A thermal resistance of R-19 was again the most common.

Floor slabs were commonly insulated with 24-inch widths of 3/4-inch or thicker plastic foam placed around the perimeter. In some instances, blanket or foam insulation is placed on the interior face of basement walls, but the above are most commonly installed by other contractors.

A rough rule of thumb for 1977 installed cost of batt insulations is a base price for kraft paper faced batts of 1 to 3 cents per square foot above the R value, i.e., an R-11 batt will cost between 12¢ to 14¢ per square foot. This corresponds to about \$0.01/square foot/R. Foil faced batts command a premium of about 1 cent per square foot, while unfaced batts with a 2 or 4 mil polyethylene vapor barrier installed separately require a

premium of about 2 to 4 cents per square foot. Ceiling installation of batts by an experienced contractor costs about the same as wall installation as the workers commonly operate on stilts for 8-foot ceilings. Higher ceilings cost more with the price increasing with height and the staging required. Floors over crawl spaces may cost the same with cost increasing with more difficult working conditions.

Blown insulation is priced in a similar manner. There is a need for installation of air deflectors near the eaves to prevent blockage of ventilation for moisture control and care in not placing insulation near sources of heat.

Insulation can provide the greatest reduction in heat loss when located in attics. Installation of mineral fiber batts or loose fill insulation for this application is less expensive than for walls. Therefore, the attic should be one of the first places to examine for upgrading thermal performance.

Floors in need of retrofitting are more expensive. This is, again, due to obstructions where the crawl space has been used for storage, limited working space, and generally difficult working conditions. Again, the premium varies with conditions.

Refitting walls is considerably more difficult. In the cases where the interior wall surface is to be replaced, the problem is simple as batts may be installed as for new construction. Otherwise, insulation must be blown into each stud space by removal or cutting a hole in the exterior or interior facing and repairing the hole. Obstructions such as fire stops, plumbing, electrical assemblies, or ducts require careful attention to obtain full insulation value. Mineral wool or cellulose blowing insulation, or urea based foam-in-place insulation may be installed. Cost will be higher and efficiency questionable due to internal obstructions.

Improvement may also be obtained by exterior installation of foamed plastic sheathing or foam or other panels installed on the interior. Both foam board methods usually require additional trim at window or door openings due to the increased thickness.

4.1.7 General

As a summary, the most commonly used residential insulations, where they may be used for new construction and retrofit applications, and some advantages and disadvantages of each are presented in Table 4.16.

4.2 Industrial/Commercial Insulation Assemblies

There are many building assemblies used in industrial/commercial building construction. This discussion is limited to the typical assemblies shown in Sweets Catalog(39). In Table 4.17 is presented a tabulation of the most commonly used commercial/industrial insulations, where applied, and advantages and disadvantages.

4.2.1 Roof/Ceiling Insulation Assemblies

Insulation of roofs is the most efficient insulation operation in commercial/industrial buildings. The roof deck is usually flat and may be constructed of cast masonry, preformed masonry planks, steel planks or panels, or wood. In practically all instances, the insulation is located above the roof structure, while a large majority will have the insulation covered by the built-up roof. This is the conventional overdeck assembly, Figure 4.12. Other techniques for roof insulation assemblies include insulation roof membrane assemblies, underdeck assemblies, and structural panel assemblies. The structural panel assemblies described in Section 4.2.2.5 for wall systems are also applicable to roof/ceiling assemblies. Ceiling

Table 4.16

MAJOR INSULATION USAGE IN RESIDENTIAL CONSTRUCTION

	Mineral Wool		Cellulose	Wood	Plastic	Urea Formaldehyde
	Batts	Loose	Loose	Fiberboard	Foam Board	Foam-In-Place
<u>ROOF/CEILING</u>						
In-Frame Cavities	N-R	N-R	N-R	---	---	---
Above Roof Sheathing	---	---	---	N	N-R	---
Cathedral Ceilings	N-R	---	---	N-R	N-R	---
<u>WALLS</u>						
In-Frame Cavities	N	R	R	---	---	R
Sheathing	---	---	---	N	N-R	---
<u>FLOORS</u>						
Wood Joisted	N-R	---	---	---	---	---
Concrete Slab	---	---	---	---	N	---
<u>BASEMENT WALL</u>						
Exterior	---	---	---	---	N	---
Interior	N-R	---	---	---	N-R	---
<u>APPROXIMATE COST</u> (\$/sq ft/R)						
	0.01	0.01	0.01	0.04-0.05	0.02-0.05	UF 0.04-0.06
<u>ADVANTAGES</u>						
	Low Cost Non- Combustible Without Facings		Low Cost Availability	May provide racking support and nail holding properties as sheathing	High R/inch; may act as infiltration seal; low water absorption	High R/inch; may act as infiltration seal
<u>DISADVANTAGES</u>						
	Facings may be combustible		Combustible;	Combustible	Combustible; Non-structural	Combustible; Foam may shrink in place which reduces the effectiveness of the insulation and may permit air infiltration.

N - Used in New Construction
R - Used in Retrofitting

Table 4.17

MAJOR INSULATION USAGE IN COMMERCIAL/INDUSTRIAL STRUCTURES

	Mineral Wool Batts	Wood Fiber Board	Mineral Board	Plastic Foam Board Foam-In-Place		Combined Mineral & Foam Boards	Insulating Concrete Lightweight Air Entrained Aggregate	
<u>ROOF/CEILING</u>								
Above Roof Deck	---	N-R	N-R	N-R	N-R	N	N-R	N-R
Below Roof Deck	N-R	---	---	---	R	---	---	---
<u>WALLS</u>								
In Cavities	N-R	---	---	N	N-R	---	---	---
Sheathing or Siding	---	---	N-R	N-R	---	---	---	---
<u>FLOORS</u>								
Concrete Slab	---	---	---	N	---	---	N-R	N-R
Wood or Steel Joists	N-R	---	---	N-R	N-R	---	N-R	N-R
<u>THERMAL RESISTANCE</u> (per inch thickness)	2.9-4.6	2.8	2.8	5.0-7.7		4.5-7.3	0.3-1.8 Depending on Density	
<u>APPROXIMATE COST</u> (\$ per R per sq ft)	0.01	0.04-0.05	0.05-0.06	0.03- 0.05	---	0.04-0.05	---	---
<u>ADVANTAGES</u>	Low Cost, Non-Combustible	Availability	Limited Combustibility	High R/inch		Mineral Board acts as a fire barrier to protect foam	Non-Combustible	
<u>DISADVANTAGES</u>	Facings may be combustible	Combustible	Less thermal efficiency than foam or combined boards	Must be protected from fire exposure as is combustible		Greater thickness/R than foam alone. Foam is combustible	Greater thickness/R than other products	

N - Used in New Construction

R - Used in Refitting

Figure 4.12

CONVENTIONAL OVERDECK ASSEMBLY

- (1) Supports
- (2) Deck
- (3) Adhesive
- (4) Vapor Barrier
- (5) Adhesive
- (6) Insulation
- (7) Roof Covering

truss/rafter cavity assemblies and ceiling substrate assemblies are rarely used for industrial/commercial applications. A description of these last two designs is presented in Section 4.1.2 describing roof/ceiling assemblies for residential buildings.

4.2.1.1 Conventional Overdeck Assembly

The conventional overdeck assembly depicted in Figure 4.12 uses insulation between the roof deck and roof covering. The insulation is usually provided in board form, ranging from 2 x 4 foot to 4 x 8 foot panels. Materials in use include wood fiberboard, perlite board, fiberglass board, polystyrene, urethane, or isocyanurate foam boards, or composite foam and mineral boards. The purpose of the combined mineral and foam boards, where the mineral board is installed next to the roof deck, is to provide a fire barrier to prevent flame penetration of the roof from interior or exterior fires and spread of fire below the roof due to combustibles penetrating the roof and adding fuel to an interior fire. Limitation of fuel contribution was developed following the 1953 large, undivided Livonia automobile plant fire where roofing asphalt penetrated steel roof plant and caused extensive spread of interior fire. Combustible roof insulation was found adequate with limited quantities of approved adhesives to reduce spread of flame. Roof insulation of limited combustibility can attain hourly fire resistance ratings (3/4 hour and greater).

More recently, some foam plastic has qualified for use directly over steel or other decks without use of the low combustibility protective layer. It still appears necessary to use protective barriers such as perlite or gypsum board to attain hourly fire resistance ratings. Attaining Class A, B, or C ratings for exterior fire exposure depends on the exterior surfacing material.

Other insulation materials include insulating concrete and plastic foams of urethane or isocyanurate. The cementitious materials include perlite concrete, vermiculite concrete, and air entrained concrete. They are available in densities as low as 25 pcf. Densities below 100 pcf are not recommended as load bearing decks, but may be used as insulating fill layers above structural decks. The thermal conductivity increases with density. Poured gypsum concrete is available with wood chip or perlite aggregate. The former has an advertised R of 0.67 per inch, while the latter has an R of 0.87 per inch. The product with wood chip aggregate may not attain a classification of non-combustible. Values of thermal conductivity similar to the above may be attained with lightweight aggregate concrete. Aggregates include perlite, shale, vermiculite, etc.

Roof insulation, with few penetrations to serve as heat flow short circuits, makes a textbook case for calculation of total thermal resistance or thermal transmission. The manufacturer must provide adequate information on the product sold and it is then a matter of using values compiled by ASHRAE for resistance of the built-up roof, the roof deck, and the inside and outside air film resistances. All manufacturers provide data on thermal conductance, as required by several Federal Specifications, or thermal resistance. Some provide thermal conductivity data. Several manufacturers provide examples of heat transmission calculations or "U" values for various configurations of metal, gypsum, concrete, or wood decks for winter and summer conditions as well as energy conservation calculations based on various locations and energy costs. Most of those calculations are based on values obtained at 75°F mean temperature. A more precise practice would be to provide data at mean temperatures consistent with winter or summer conditions. For 70°F inside conditions, a winter mean temperature of 40°F and a summer mean temperature of 90°F are suggested. This is equivalent to outdoor temperatures of 10°F for winter and 110°F for summer. These appear adequate.

4.2.1.2 Insulated Roof Membrane Assemblies

This assembly differs from the conventional overdeck assembly in the relative location of the insulation. For the conventional system, the insulation is between the deck and membrane, whereas this assembly places the insulation above both the deck and membrane as shown in Figure 4.13. Extruded polystyrene foam is suited for this application because of its high moisture resistance.

Figure 4.13

Construction Detail

The design concept of the insulated roof membrane assembly is essentially the same for all roof decks. Complete instructions and design sheets are supplied by the manufacturer. Basically, the design concept is to put the built-up roof membrane directly on the wood deck, apply boards of extruded polystyrene to the asphalt top coat, and finally, cover the insulation with a specified layer of stone. The advantages include improved membrane life, ease of application, and ease of adding additional insulation later, if desired.

The insulated roof membrane assembly may be used for reroofing. If the old roof must be totally removed because of deterioration, the insulated roof membrane assembly can be placed on the new membrane just as in new construction. Where the roof membrane remains essentially intact, some patching and one or two new plys will be sufficient. An asphalt top coat, the desired thickness of insulation and the specified stone cover complete the retrofit assembly. The most important precaution is to make sure that the old roof assembly can accommodate the load of stone.

4.2.1.3 Underdeck Assemblies

In underdeck assemblies, the insulation is applied below the roof deck. Mineral fiber batts or board insulation are often used in the frame cavity, being held up by wiring or interior finishing. Mineral fiber blankets are often draped over metal roof purlins prior to application of the metal roof panels on many prefabricated metal buildings. Spray-on-foam or cellulose insulation could be used, but this would require sufficient interior finishing to meet fire resistance standards.

4.2.1.4 Prefabricated Metal Buildings

Many metal buildings are produced with corrugated or shaped metal facings as the roof surface. These must be insulated below that metal facing. Fiber glass blankets are the major insulation material used for this application. Plastic foam boards are also used in conjunction with fiber glass blankets. The foam boards are laid across the metal purlins or trusses and the metal roof surface is then placed over the foam boards and attached. This method of assembly reduces the thermal shorts caused by the metal structural members. The fire rating of these materials must be considered in any design.

4.2.2 Industrial/Commercial Wall Assemblies

The basic methods of wall construction in Industrial/Commercial buildings are as follows:

- Steel Frame - Welded/riveted load bearing beam construction. Typically uses sandwich panel/curtain wall insulation and insulated frame cavity assemblies. Applicable to high rise and low rise building.
- Reinforced Concrete - Poured and reinforced concrete. May use sandwich panel, cavity wall, interior wall substrate, or stucco base insulating assemblies. Mostly used for low rise buildings.
- Load Bearing - Concrete block and/or brick construction. May use sandwich panel, cavity wall, interior wall or stucco base insulating assemblies. Mostly used for low rise buildings.
- Prefabricated - Prefabricated metal buildings typically use sandwich panel/curtain wall, insulated frame-sheathing and insulated blanket frame-cavity assemblies. Mostly used for low rise buildings.
- Combinations - Combinations of the basic walls listed above are common.
The insulating assemblies match those listed above.

Accurate market share information on these wall assemblies is not available for public use. It is available on a purchased confidential basis from McGraw-Hill. However, some information is available from trade associations. For instance, the Metal Building Manufacturers Association indicates that 20% to 25% of the low rise market (floor square footage) is prefabricated metal building. Data on the other categories is less known.

The major assemblies reported in manufacturers' literature and Sweets' catalog are:

- (1) Cavity Wall Assemblies.
- (2) Interior Wall Substrate.
- (3) Insulated Frame Construction.
- (4) Stucco Base Assemblies.
- (5) Sandwich Panel/Curtain Wall Assemblies.

4.2.2.1 Cavity Wall Assemblies

Cavity wall assemblies basically consist of attaching rigid board insulation to the outside of the structural masonry wall before adding the exterior veneer brick. Illustrations of typical systems are shown in Figure 4.14. The size of the cavity between the masonry wall and the brick veneer is limited by standard construction practices. Therefore, it is usually advantageous to use insulation materials with a high R-value per unit thickness in order to obtain reasonable thermal performance. Rigid polystyrene and polyurethane foam board stock are the major insulations used in this application.

The insulation boards are normally installed with the long dimension horizontal and they are attached to the load-bearing masonry wall with some type of mastic adhesive. Brick ties are provided to tie the exterior face brick to the load-bearing masonry wall. Normally a 1/2-inch to 3/4-inch air space is provided between the insulation board and the outer wythe of brick to provide finger space for placement of brick and to provide a drainage passage for wind-driven rain which may penetrate the face brick. Weep holes are provided at the bottom of the wall to drain this excess moisture. Vapor barriers may or may not be recommended in this system depending on the sensitivity of the insulation to moisture and the inherent water vapor transmission properties of the material itself.

1. Outside Air
2. Face Brick
3. Air Space

4. Insulation
5. Concrete Block
6. Inside Air

Figure 4.14

Cavity wall assemblies. Pourable insulation fill may be provided in the cavities in addition to or instead of the board insulation.

Another variation on cavity wall construction is the use of loose fill materials such as loose-expanded polystyrene beads, reprocessed foam granules, perlite, or vermiculite as a pourable masonry fill insulation. This material is poured within the cavities of masonry wall construction. Normal precautions for wind-driven moisture must be followed. Perlite loose fill treated with silicone for moisture resistance is accepted and available.

Both the board and loose-fill applications find their widest use in new construction. The systems are not limited to exterior veneers using stackable wythes of brick but also could be used with granite, slate or masonry veneer panels as exterior cladding. However, the applicability for retrofit is limited. It is not likely the loose-fill system would be used as refit at all, while the board system would only be economical if an exterior "face-lift" were included as part of the project plans. If energy conservation were the only motive for building modification, the cost of the exterior finish would cause the project to have excessively long payback periods (i.e., greater than 15 years).

The thermal performance of cavity wall assemblies is directly dependent on the type and thickness of insulation used. There is an inherent advantage in the use of insulation on the outside of the masonry wall insofar as the main mass of the structure is insulated against the extremes of the annual and daily temperature cycle. The amplitude of temperature changes "seen" by the structural masonry wall is dampened by the insulation and, therefore, remains closer to the conditioned space temperature. Theoretically, this will allow the HVAC equipment to operate more efficiently without having to compensate for wide temperature changes. However, a meaningful analysis of this benefit is outside the scope of desk-type calculation and requires the use of a sophisticated computer program.

The cavity wall assemblies in common use today make use of polystyrene or polyurethane board insulation approximately 1-inch thick, and this type of wall will have U-values between 0.10 and 0.15 as compared with a non-insulated wall U-value of approximately 0.30.

Because of the masonry components in the cavity wall system, the walls have inherently high resistance to fire. Building codes prescribe the allowable flame spread and smoke values for the insulating materials used in these types of walls. Fire-stopping is required in the cavity of each floor level of the building. Because of the encapsulation of the insulation between the two masonry surfaces, the safety threat to occupants in the event of a fire is remote. There are no requirements or standards with respect to toxicity and odor for these cavity wall assemblies nor is there need for any.

The significant advantage of the cavity wall systems is the inherently high fire safety associated with these systems. The disadvantage is the limited ability to upgrade thermal resistance after construction through retrofitting.

4.2.2.2 Interior Wall Substrate Assemblies

Interior wall substrate assemblies involve attaching a layer of rigid plastic foam, mineral fiber, or other insulation to the interior surface of the load-bearing masonry wall and then adding an interior finish material, typically 1/2-inch thick gypsum board. Illustrations of typical constructions using rigid plastic foam board are shown in Figure 4.15.

When rigid plastic foam board insulation is used in this assembly, wood furring strips may be provided for attachment of the gypsum board interior finish. When furring strips are not used, mastic-type adhesives are used to bond the gypsum board to the insulation. Normally wood-nailer

Interior Wall Substrate Assemblies

- 1. Inside Air
- 2. Interior Finish
- 3. Rigid Plastic Foam

- 4. Masonry Block
- 5. Outside Air

Figure 4.15

strips are provided at the top and bottom of the wall to provide some mechanical attachment for the gypsum board. Also, wood-nailer strips are provided at locations where heavy wall fixtures such as cabinets are to be hung. Electrical runs must either be surface mounted or provide for shallow receptacle boxes (1.5").

When fiber glass blankets are used it is necessary to attach wood furring strips or to build an interior stud wall assembly on which to attach the interior finish material. Fiber glass blankets do not provide any support for the interior finish and require greater thicknesses to provide insulation values equivalent to the plastic foam systems.

The gypsum drywall systems are normally used in new construction; however, they do have retrofit applicability. A masonry substrate is not required for the insulating layer; it could be applied over any sound existing wall surface. This assembly could be one of the least expensive retrofit systems, particularly if some remodeling is included in the building retrofit plans. Minor trim modifications would be required around window and door openings and around electrical outlets. Normally these details would be no great burden in a modification of this sort.

As in the cavity wall assembly, the thermal performance will be dependent on the type and thickness of insulation used. No air infiltration benefits are expected and heat loss is calculated by straight conduction methods. Since the insulation is applied to the conditioned space side of the wall, no benefit from the thermal mass of the building can be claimed. Again, it should be pointed out the thermal-mass benefit has not been quantified to the point where it is accounted for in standard heat loss calculations.

Typically 1 to 2 inches of plastic foam insulation is used in this application, which results in over-all thermal transmittance values (U) of from 0.08 to 0.15 BTU/hft²F compared to non-insulated walls which have a transmittance of from 0.30 to 0.40. Systems utilizing fiber glass blankets will have U-values of approximately 0.20 at comparable thicknesses.

The resistance to fire of this particular system is dependent on the type of insulation used and in some cases on the thickness of the interior finish provided. All model building codes allow the use of plastic foams, provided the plastic foam is fully protected from the interior of the building by a thermal barrier of 1/2-inch gypsum wall board having a finish rating of not less than 15 minutes by ASTM E119 test or other approved materials having an equivalent finish rating. Greater endurance ratings can be obtained by using thicker layers of Type X Gypsum Board. The manufacturer's literature for all plastic foam insulation makes note of the 15-minute building code requirement. Standard nailing gypsum board is required to meet this 15-minute requirement.

As with other applications, there are no requirements or data with respect to toxicity or odor.

The advantages of this wall system with foam board insulation include: (1) ease of applicability for retrofit, (2) low labor intensity if furring strips are excluded, (3) a completely insulated wall without thermal shorts, and (4) a structurally-sound wall since the interior finish is completely supported by the insulating layer. The principal disadvantage is the loss of the "thermal mass" effect.

4.2.2.3 Insulated Frame Construction

Practically all residential construction and a large portion of industrial/commercial construction is the insulated frame assembly with mineral fiber insulation commonly used in the frame cavity. This is discussed for residential construction in Section 4.1.3.

One popular system for improving the thermal efficiency of industrial/commercial walls is to use plastic foam insulation as exterior sheathing in combination with mineral fiber insulation in the cavity as illustrated in Figure 4.16. In this system the insulating capacity of the wall is economically maximized by using the lower cost per unit volume

Insulated Frame Construction

Figure 4.16

material (i.e., mineral fiber) in the available cavity space, and using the highest R per unit thickness material (i.e., plastic foam) in the area where space is limited. Not only does the plastic foam sheathing add to the thermal resistance across the cavity, but it insulates the thermal short circuits caused by the framing members. The efficiency of the mineral fiber insulation is improved because the reduced ΔT across the cavity results in reduction of any remaining convection currents. In addition, air infiltration to the interior is reduced.

An alternate assembly is to spray-in-place a rigid polyurethane type foam insulation in the cavity. This foaming-in-place technique takes place from the inside of the structure after the exterior sheathing or siding is in place. Advantages of this type of system are the complete sealing of all openings with foam and a very high R-value per unit thickness. However, a vapor barrier and a thermal fire barrier with at least a 15-minute finish rating needs to be added to the interior surface.

Another approach is to insert preformed blocks of plastic foam insulation in the cavity. This type of application is not in common usage and would only be justified economically where the absolute minimum U-value is required for a fixed wall thickness.

With respect to installation methods, the plastic foam sheathing system is applied in the same manner as any other type of sheathing material. The plastic foam is not a structural sheathing. Therefore, bracing of some form is required between the framing members at the corners of the building to meet rack loading requirements (ASTM E-72 Tests). Also, the plastic foam cannot act as a nail base so exterior siding materials must be attached to the framing members.

Installing spray-in-place polyurethane requires specialized equipment and trained operators which are provided by the insulation supplier. Proper safety precautions with respect to personnel exposure to component chemicals are important and must be followed to eliminate hazards.

The preformed block insulation for cavity fill requires no specialized installation techniques other than careful precutting of the block to assure an accurate fit in the cavity.

All of the above methods can be used for new construction. Only the plastic foam sheathing system has real application for retrofit. Several board manufacturers have developed systems in which the plastic foam sheets are attached to the exterior of the wall over the old finish material and a new finish is added to cover the foam. This system is particularly applicable to wood-frame-type construction. Metal framing would present a fastening problem unless the existing siding can act as a nail base or mechanical fasteners or adhesives are used.

The thermal performance of insulated frame construction will be dependent on the type and thickness of insulation used. The plastic foam sheathing assembly will tend to deliver the best cost-performance index when the system includes mineral fiber insulation in the cavity. No manufacturer lists actual performance data for non-residential buildings using any of the three systems discussed. This should come as no surprise, however, since it is impossible to select a "typical" non-residential building. All plastic foam manufacturers do list overall U-values for various wall systems when their product is used and the range normally is 0.05 to 0.08. These values take no credit for energy savings via reduced air infiltration and this savings can be substantial (>10%) depending on the type of foam used and the type of construction.

All building codes will require an interior finish material with a 15-minute fire resistance rating if plastic foam is used as part of the wall construction. All plastic foam manufacturers point out this requirement in their literature and will normally include ASTM E-84 Test data for flame spread and smoke developed for their product.

4.2.2.4 Stucco Base Assemblies

Stucco base wall assemblies could be included as merely another exterior cladding assembly for either frame wall or masonry wall construction. However, several plastic foam manufacturers list the stucco type of construction as a separate category in their literature and point out unique benefits of this system. Two manufacturers have developed a modified thin veneer stucco finish for use over molded polystyrene foam. Other manufacturers of rigid plastic foam issue detailed specifications for conventional 3 coat stucco finishes.

In the latter case, the installation practice is identical to normal stucco application with the exception that the rigid foam boards replace the back-up paper on frame construction or in masonry construction the boards are attached to the wall prior to installing the reinforcing mesh.

The two thin veneer systems differ substantially from conventional stucco. In both case, a fiberglass loose-weave fabric forms the reinforcement and only two coats of a specially-formulated cementitious coating are applied. This results in a surface coating of approximately 1/8-inch thick as opposed to the conventional stucco thickness of 1 inch. Although the main thrust in the promotion of this system is in new construction, the two thin veneer systems are suitable for retrofit applications when an exterior face lift is desired, particularly in block wall construction where the original wall was non-insulated and has no exterior finish except paint.

The thermal performance of any assembly is dependent on the thickness of the foam layer. When applied to an 8-inch concrete block wall the thin veneer systems have U-values ranging from 0.09 for 2-inch thick foam to 0.13 for 1-inch thick foam. The non-insulated concrete block wall would have a U-value of 0.29.

Masonry wall assemblies are highly fire resistive and the inclusion of plastic foam insulation as part of a stucco finish system does not significantly change the fire performance. With frame wall constructions, all manufacturers point out the need for interior thermal barriers in the design. When the systems are properly designed, the fact that they incorporate plastic foam does not increase the fire hazard over commonly accepted alternate systems.

The prime advantage of a stucco base system is the ease with which it can be incorporated into retrofitting masonry block walls. Masonry block walls cannot accommodate some of the other popular retrofit insulation types such as urea-formaldehyde foam or blown cellulose, and therefore, this type of system could fill a significant need in the non-residential building category. One limitation which still exists with the proprietary thin stucco veneer systems is the longevity of the surface coat. Because of the dissimilarity in coefficients of thermal expansion between the cementitious surface coat and the cellular plastic, questions arise concerning cracking and delamination from thermal cycling during the life of a building. The thicker stucco coatings, because of their reinforcement, larger thickness and history of performance, are not as suspect of this type of failure.

4.2.2.5 Sandwich Panel/Curtain Wall Assemblies

Sandwich panels are a building component in which rigid plastic foam may be foamed-in-place between two rigid facings, or foam or other board stock may be adhesively bonded to two facings to form a monolithic panel. This type of panel offers both high insulating value and structural strength. Since these panels are commonly prefabricated in a factory, labor savings are realized at the construction site due to faster assembly. Commonly, corrugated steel and aluminum (0.32-inch thick) are used as facings, but plywood, gypsum board, or polymer-modified concrete may also be used. Thickness of the panels normally ranges from 1 to 2 inches, although panels up to 6-inches thick may be used in low temperature space applications.

Sandwich panels fit a variety of construction applications. Full height panels may be placed over single-story steel-frame construction to form the complete walls or roof. They may also be used as curtain walls or spandrel panels in multi-story steel frame buildings. In retrofit applications, they may be used to replace windows or portions of windows. They can be attached as an overlay for masonry walls. Occasionally, panels may be used as the walls of single-story buildings without additional framing, in which case the panel forms the bearing wall. For retrofit applications over an existing wall, a single-faced panel (liner panel) is commonly used. Commonly, rigid board insulation is used if the panels are to be adhesively laminated and polyurethane type foams are used for the foam-in-place type panel. Manufacturers of these panels promote both new construction and retrofit applications about equally.

The thermal performance of the systems are dependent on thickness and material composition. A typical 1-inch panel with 26 gage steel facings will have a U-value of 0.23 with a molded bead polystyrene foam core, a U-value of 0.20 with an extruded polystyrene foam core, a U-value of 0.16 with a urethane core, and a U-value of 0.33 with a fiber glass core. Systems of this sort do have the advantage of insulating the thermal short circuits caused by the steel framing members.

When one surface of a foam panel forms the interior surface of the building, all building codes require that either a 15-minute thermal barrier be provided or when sprinklers are provided the facing material be at least 28-gage steel or 32-mil aluminum. Some insurance companies will require testing and approval by Factory Mutual Corporation large wall-corner test. Several manufacturers' panels carry this approval or listing. None of the approvals carry requirements with respect to toxicity and odor other than FDA approval of the facing material used on the interior of food processing rooms. Significant advantages of the panel systems are:

- (1) High thermal resistance per unit thickness.
- (2) High strength to weight ratio for wall systems.
- (3) Thermal properties not degraded by exposure to moisture.
- (4) Lower labor intensity during construction.
- (5) Insulation of thermal short circuits through framing members.

Limitations associated with this type of construction system are:

- (1) Poor acoustics from low mass systems.
- (2) Limited flexibility in architectural design.
- (3) Difficulty in incorporating electrical and water lines in the wall.
- (4) Limited fire resistance characteristics.

Other faced panel systems use mineral fiber insulation in the voids with or without insulation boards placed at some inside location. In many cases, the metal faces penetrate the assembly for strength. Such penetrations can form a thermal short circuit, but insertion of plastic "thermal breaks" can minimize such short circuits.

Fire resistive faced panel systems are available. These commonly incorporate mineral panel insertions or additions, such as gypsum board, and are available in 3/4 to 4 hour time temperature ratings.

4.2.3 Foundation/Floor Insulation Assemblies

In foundation insulation applications, also known as perimeter applications, rigid plastic foams are widely used. In this application, the insulation is in constant contact with the earth and is subjected to back fill pressure, active ground chemicals which may be under pressure, and active biological mechanisms. Due to water resistance and closed-cell structure, some rigid plastic foams can withstand this exposure and continue to maintain insulating effectiveness for the building life.

Sketches of typical construction details are shown in Figure 4.17. When the floor slabs carry heat ducts or resistance heating cables, the insulation may be continuous beneath the floor slab. In most cases, however, the insulation is applied to the vertical face of the foundation wall. All types of plastic foams are used in this application including the spray-in-place systems. Some manufacturers of molded polystyrene and urethane board stock recommend vapor barriers be applied to the side of the insulation in contact with the earth.

For the vertical wall portions of a foundation, the insulation is installed by adhering the board to the masonry block with a mastic or asphaltic adhesive and then backfilling. For floor slabs, the boards are placed on the prepared earth grade and the concrete is poured upon the insulation. This assembly is primarily used for new construction, but there are instances where rigid foam may be added to the outside of foundation walls on the area of the wall exposed above grade line. In this case, some type of barrier coating must cover the foam to prevent degradation from ultraviolet light. Below grade application of insulation around the perimeter edge would require some excavation which may be practical in some instances and impossible in others.

The foundation wall of a building can be a sizeable heat loss area. The new ASHRAE 90-75 standard includes requirements as to maximum U-values for floor slabs depending on the climate. ASHRAE also indicates that the insulation should continue down the vertical foundation wall for a minimum of 2 feet. In the residential building area, the FHA Minimum Property Standards have set requirements for perimeter heat loss from slab-type floors. To meet these standards, anywhere from 3/4-inch to 2-inch thick rigid plastic foam is used depending on the winter design temperatures.

Floor/Foundation Assemblies

Figure 4.17

Few manufacturers present claims with respect to the percentage of heat loss saved by this application, but all show the U-values of various combinations which can be used to calculate heat loss.

Resistance to fire is not a consideration in this application due to the nature of the installation. When the plastic foam is used on the interior surface of the foundation wall in a crawl space, all manufacturers recommend using the same thermal barrier requirements as used elsewhere in the building.

The advantages of this type of insulation assembly are many. Not only do they retard heat loss from a highly conductive part of the building envelope, but their inclusion limits condensation formation on floors and improves the human comfort factor in a building. The only limitation of the system is the difficulty presented for retrofit in many instances.

4.2.4 Survey of Commercial/Industrial Assemblies

A survey of 30 architects located in all sections of the country was made to determine their requirements and use of thermal insulation in nine geographic areas of the United States (as indicated in Figure 2.9). The cross-section of contacts made were as follows: Pacific-4, Mountain-3, West South Central-4, West North Central-2, East North Central-5, East South Central-2, South Atlantic-2, Middle Atlantic-6, New England-2.

All contacts were registered architects and all turned out a considerable volume of work and could easily be classified as among the better architects of the area they represented. In all instances, the architects contacted seemed to have an excellent grasp of the energy situation, were very willing to discuss the subject, but as far as cost of installation or energy savings dollars were concerned, they either did not

know or were not willing to discuss this subject. We found that 75 percent of the architects interviewed were concerned with the complete envelope, and in several cases took into consideration insulation of the floor slab as well.

In addition to the envelope, other facets of this survey were:

1. Type of structure (steel frame, concrete, or wood).
2. High rise or low rise.
3. Building type and/or use (school, factory, nursing home, etc.).
4. New construction or retrofit.
5. Type of insulation (board, spray, fill, etc.).
6. Wall construction.
7. Design criteria for insulation (ASHRAE 90-75, local codes, or manufacturers recommendations).
8. Design criteria for fire protection (Factory Mutual, Underwriters', burning and toxicity of foams).

The following information was obtained as a result of the survey:

1. Type of structure - Steel 90 percent, Wood 5 percent, Concrete 40 percent. The overlap indicates some firms built both steel and concrete structures or a combination of both.
2. Low rise structures comprised 75 percent of the total, while the remaining 25 percent were high rise.
3. Commercial buildings such as shopping centers, schools, churches, and office buildings comprise 75 percent of building types. Residential, such as apartments, barracks, nursing homes, were 10 percent and the remaining 15 percent were industrial type such as small manufacturing plants.

4. New construction amounted to 80 percent of the work done by these architects. The 20 percent of retrofitting was primarily due to re-roofing. In almost every instance, additional insulation was added when a new roof was installed. It was noted that little or no tear-off of old roofs was done, as protection of the building interior was critical, and any tear-off could expose this area to water damage. In some instances of retrofitting, the need for added insulation was critical and insulation in the form of batts or rolls was installed over a suspended ceiling. Occasionally, a cellulosic spray was used to increase thermal value.
5. For roof/ceiling construction, the type of insulation primarily used was in rigid board form. This was installed mostly over steel roof decks-75 percent, wood-15 percent, and concrete decks, either plain or insulating-10 percent. The board types consisted of perlite, mineral fiber, polystyrene, urethane, foam glass, and combination perlite and urethane. Spray urethane was a very minor factor, but other reports indicate increasing use in thermal refitting. Insulating, leveling fills such as asphalt and perlite, perlite concrete, vermiculite concrete, or insulating concrete made up 20 percent of insulation types.
6. Those concerned with the complete building envelope, about 75 percent, employed masonry systems for sidewalls. The most popular construction was block walls with an insulated air space between exterior wall and interior finish. The insulation usually was a rigid foam, either urethane or polystyrene. Some designs called for batt type insulation between furring studs to which was fastened the interior finish. One architect reported he used hollow block walls into which was poured vermiculite pellets.

7. All architects were familiar with ASHRAE 90-75, but felt the standards were too restrictive. In some instances, the architect set his own standard or the customer for whom they designed dictated what over-all "U" value was to be achieved. If local codes had adopted "U" values, such as Title 24 in California, then the architects were required to meet these codes. If not, then a typical design criteria was a "U" of 0.08 for walls and 0.10 for ceilings. Most architects accepted manufacturers' published values for insulation, however, some had tests conducted to insure the thermal properties as published were correct.
8. As steel decks were used by 75 percent of those surveyed, Factory Mutual approved constructions played a major role in determining what design parameters were set. Factory Mutual seemed to be much more of a force than Underwriters'. If the constructions were Factory Mutual approved for fire from the underside, there was little or no particular concern for the roof covering having to meet any specific Underwriters' Laboratories classification. It was apparent, however, that designs were developed for roofing systems rated at no less than Class B for the type building under discussion. Combustion and toxicity of foam insulations did not seem to be a major concern since foams were encased in a roofing system or in a wall cavity.

It is interesting to note that the architects considered ASHRAE 90-75 standards too restrictive, but they did consider heat loss or gain through the entire building envelope. Upgrading of designs would occur if required by Building Codes or by owners desiring to reduce energy costs.

4.3 The Use of Water Vapor Barriers with Building Insulation

The normal heating and cooling of the interior spaces of buildings results in a significant potential for the undesirable transmission and accumulation of moisture within building envelope systems. Water vapor barriers are materials which are used in buildings to provide a resistance to the transmission of water vapor in the building envelope under specified conditions.

Moisture transfer in building envelope systems is caused by differences between the indoor and outdoor absolute humidity. The rate of moisture transmission through building envelopes is proportional to the overall permeability of the envelope structure. Water vapor passing through a building envelope structure will condense in the structure at any point where the local temperature is below that of the local dew point temperature. The presence of condensed water in insulation will markedly affect its thermal resistance and the presence of condensed water for extended periods of time can result in the physical degradation of many common building materials.

Insulation in heated buildings reduces the heat loss from the building and lowers the temperature of the outer element of the building structure. This increases the likelihood of condensation if no measures are taken to prevent the movement of water vapor from the interior of the building. Similarly, buildings with air conditioning may experience condensation in the inner elements of the building structure due to the propagation of moisture from the environment into the building envelope.

The increased use of insulation in buildings, along with other measures such as improved weather-stripping have significantly reduced air infiltration-exfiltration rates and, thus, have increased the importance of an effective vapor barrier. Reducing the rate of air replacement and thus

reducing the rate of water vapor removal from the building results in increased humidities in the conditioned spaces.

Types of vapor barriers utilized with building insulation systems may be classified as structural, membrane, or coatings. Structural water vapor barriers would include rigid insulations which are relatively impervious to water. Membrane barriers include metal foils, laminated foil and treated papers, coated felts and papers, and plastic films or sheets. These membrane barriers are flexible and are supplied in roll form or as an integral part of an insulation. Coating barriers are found in a variety of semi-fluid or fluid forms and may be asphaltic, resinous, or polymeric in composition.

The American Society of Heating, Ventilation, and Air Conditioning Engineers, in recognition of the distressing results its omission may bring, has tentatively recommended that the walls of every well-constructed modern dwelling include a vapor barrier when the construction includes any material which would be damaged by moisture or its freezing. In applying a vapor barrier to a wall, ASHRAE recommends certain fundamental principles should be followed. They are that the vapor barrier should be placed as near to the warm surface of the wall as practicable and that it should be continuous with no direct openings through the barrier. Field data which indicate that a vapor barrier with only a small break can result in excessive moisture levels substantiate this recommendation.

Mineral fiber insulation materials are normally installed in new wooden frame buildings in a batt form with an integral vapor barrier. The types of barriers used include compositions of kraft paper, aluminum, and asphalt. The ASHRAE Handbook of Fundamentals notes that batt or blanket insulation with an integral vapor barrier is reasonably adequate in ceilings if installed by fastening the batt to the joists by nailing flanges which are provided.

However, it is further noted that in the general installation of this type of insulation - vapor barrier system the edges should be lapped over framing members and stapling to the sides of framing should be avoided. If stapling to the sides of the framing is unavoidable, a separate vapor barrier, such as polyethylene plastic sheeting, is recommended for best results.

Applications of loose-fill mineral fiber or cellulose insulation in either new construction or existing building ceilings requires the installation of a vapor barrier. Polyethylene sheeting is commonly used for this purpose.

Plastic foam sheathing applied to the exterior of framed buildings in conjunction with a cavity fill insulation requires a good vapor barrier on the interior wall since the foam sheathing would tend to prevent normal drying out of the wall during favorable weather conditions. Experience with systems composed of plastic foam sheathing, mineral fiber batts and polyethylene, kraft-asphalt, or foil vapor barrier indicates moisture control is adequate.

Retrofit of walls with insulation poses a problem with respect to constructing an adequate moisture barrier. Studies by the Forest Service of the U.S. Department of Agriculture (40,41) has concluded that the addition of insulation to walls of an older house with no vapor barrier subject to the climate of Madison, Wisconsin, may not cause moisture problems. However, it is noted that this is a marginal situation and will vary with tightness of the house and the habits of the occupants. Further, their study concludes that where no visible problems occur, moisture decreases the thermal efficiency of the insulation and the use of mechanical humidification presents special problems. The wall moisture data acquired by the Forest Service nevertheless does demonstrate the effectiveness of aluminum paint applied over the plaster even where mechanical humidification is used.

4.4 Dynamic Insulation

Standard methods of thermal insulation are based on the principle of preventing the movement of air in a confined space. A new method of building insulation, which has been developed with the support of the National Swedish Board for Technical Development depends on moving rather than stationary air (42). The new system of dynamic insulation depends on the use of a controlled slow flow of air inward through the wall insulation opposite to the outward flow of heat. The incoming air absorbs the escaping heat and returns it to the interior. Originators of this concept claim that in houses with dynamic insulation it is possible to regulate the outward flow of heat so that the effective R-value of the walls is very large.

The proper function of this system requires a large enough air flow rate through the insulation to minimize conduction to the outside. However, since the air drawn into the building will necessarily be exhausted in some manner, there is the need to minimize this air flow to minimize heat withdrawn from the building. It is claimed that at an air flow of 6 ft/hr, the apparent thermal conductance of the wall diminishes to near zero and results in an air change rate in a typical residence of approximately half the volume per hour. Achieving the proper air flow into the building requires an unconventionally tight house of special construction. Any air drawn into the house at any point other than through the insulation will result in degraded over-all thermal performance of the structure. During the summer months the same dynamic heat recovery principle applies. Heat flow into the building could be reduced by reversing the direction of air flow. Additionally, solar gain on the outside wall of the structure during the winter would possibly benefit the over-all heat balance on the building when utilizing this system.

The Swedish originators are continuing development of this concept.

Section 5

THERMAL INSULATION TESTING: PRESENT STATUS AND FUTURE REQUIREMENTS

In the seventies, particularly since 1973 when the oil embargo truly emphasized the world energy crisis, the increased use of thermal insulation has become one of the major immediate solutions to the problem. With this increased use has come a realization that thermal insulation needs to be used both correctly and economically. The architect and designer require sufficient design information on a product or system in order to balance initial cost against operating cost while the consumer needs to be assured that the design is economically viable and the structure is safe to inhabit.

It is apparent that an individual insulation material or system should be examined in field application rather than isolated from actual application. While the static properties of an individual product may be evaluated quite adequately, the relevant "in-use" properties in a particular geographical or climatic location may be different and have not been evaluated. It is thus important for those working in the thermal insulation field to ensure that adequate test methods are or become available in a reasonable time period to aid in improving the thermal performance of buildings.

In discussing the current status of testing methods and practices promulgated or proposed for thermal insulation materials and systems, the major source of standards and specifications is the American Society for Testing and Materials Committee C16 on Thermal and Cryogenic Insulation Materials. The present scope of this Committee is given below⁺ to indicate the depth of interest which this body now has and the impact that it can have on the needs of the thermal insulation field. The complete set of available C16 documents together with relevant ones developed by other Committees, especially Committee E5 on Fire Tests of Materials and Construction, relating both to building and industrial applications and requirements

is published annually by ASTM (43). There are a limited number of test methods in use which have been developed by other organizations: for example, the National Fire Protection Association, Factory Mutual Insurance, and Underwriters Laboratories for particular fire testing requirements. However, such tests and others, usually relating to particular industries, are far outnumbered by the ASTM documents and naturally more limited.

In addition to the test specifications, there are a large number of materials specifications dealing solely with description and performance characteristics of various classes or types of insulations. These contain direct reference to many test methods as the means of evaluating the properties necessary to characterize and qualify the suitability and acceptability of the said material or system. In many cases maximum or minimum values or ranges of performance characteristics are noted in these specifications for the qualifying procedure.

In all cases these ASTM documents are accepted American National Standards. They are, in general, cited wholly or in relevant parts within all major Federal, State and Building Code Standards for thermal insulations. Furthermore, with Committee C16 in a leading role, International Standards Organization Committee C163 on Thermal Insulation was formed in 1975. At the Plenary Meeting in Stockholm in 1976, test methods, particularly those for thermal performance, were given the top priority rating for action. Several of the current ASTM Standards have been proposed as a basis for such internationally accepted specifications.

+The scope of the Committee shall be the promotion of knowledge, stimulation of research and the standardization of test methods including criteria for the technical qualification of laboratories performing these tests, specifications, practices and definitions relating to thermal and cryogenic insulation materials, products, systems and services including their application and use (except those used in the insulating refractory field), and to any protective coating and covering material or system associated therewith to preserve the thermal and cryogenic insulating performance. These activities will be coordinated with those of other relevant committees of ASTM and other national and international organizations having similar interests.

The present discussion of test methods will be centered upon this comprehensive series of ASTM tests which have been developed by C16 during the thirty-nine years of its existence. As in any other ASTM Committee dealing with materials or products, the Committee consists of a number of separate subcommittees devoted to individual materials types (classified as the 20 series) and to test methods (classified as the 30 series) for determining their properties, supplemented with the appropriate administrative subcommittees. At present there are no documents for systems and little work is currently in progress in this area other than for specific packaged systems, for example, insulated ducts. Some test method specifications are applicable to systems. A number of others are in the course of development, in cooperation with other ASTM Committees devoted to buildings, and these will be discussed later.

One important factor to be noted in the development of C16 is that it was started by the manufacturing industry itself and much of the input including technical expertise has been provided directly by members of the different manufacturing organizations. The Committee has increased in strength with additions to its membership drawn from outside the manufacturers, but the manufacturers still play a very important role in the continued development of the Committee. Thus in its history of development the emphasis in the activities has been directed to insulation materials and specific individual needs. It is only recently that there has been a recognition of the importance of a material being considered as a system itself and of the role of insulation material within a larger system.

All standards and specifications are developed as "Consensus" documents by a fixed democratic process encompassing the efforts and views of the "manufacturer", the "user", and the "general interest" members. Once a standard is produced it is reviewed regularly, at least once every five years, and revised as the current technology and knowledge dictates.

A criticism of this process is that the gestation period of a standard is often too long, and as the needs become more urgent, this statement becomes more valid. However, it is probably still the most viable procedure for producing a thoroughly researched and developed, and consequently acceptable, standard.

A further criticism is that the process produces a "lowest common denominator" document. This may apply in a variety of cases where a materials standard is prepared and the document must apply to all products within a specific class or type. However, there is no real justification for this form of criticism related to test methods since they are developed normally to be relevant to all materials. There is no doubt that the development procedure needs to be accelerated but the basic process must be maintained to ensure that the quality of a newly-developed specification does not suffer. The results of the cross-fertilization of the inputs of the three groups is the process whereby one ensures that a standard is both a useful and useable document. The involvement of workers in relevant individual materials and general areas ensures that an appropriate balance is obtained, especially for test specifications.

The materials and test methods specifications within Cl6 have grown historically from an original view of an insulation having intrinsic features and properties. More recently the understanding of insulation behavior has increased while new materials or needs have arisen or been foreseen. As the complexity and scope of the subject has grown, the test specifications have developed in a similar manner albeit at a slower pace. There is a basic problem in that old ideas tend to die hard. It is incumbent upon those workers involved in the measurement of insulation performance to assist others in the interpretation of the method and provide an understanding of the implications of the procedures.

A number of adequate test methods exist for developing the different thermal, dimensional, mechanical and physical performance characteristics of materials under laboratory conditions. The immediate requirement is an extension of this knowledge for properties evaluated under real life conditions and for complete systems, i.e., materials and systems used in combination with each other and within the containing structure. The interrelationship between the effects of different parameters on individual materials and overall system performance needs to be investigated.

It is unrealistic to suggest that a total or full-scale evaluation of every system has to be undertaken. However there is a need to develop methods and test criteria for materials and systems evaluation which not only provide basic data, but also provide information such that realistic analyses of systems can be developed and verified. Thus it should be possible ultimately to reduce the total amount of measurements and experimental work required for most complete systems currently being used or developed while relating the actual performance to information obtained from reliable tests on individual components or smaller systems. However within the whole subject there is a need for coordination of the many facets of the work involved. In this way maximum benefits can be obtained and better test specifications developed somewhat faster than at present.

The testing required to provide an adequate increase in knowledge to cover the development of a new test method or a significant technical revision or upgrading of an existing one is a lengthy and expensive process. It has usually been beyond the means of any organization outside the major manufacturers or major user and government bodies. Until recently little or no public funding was available for any direct research in the field since the subject, despite its direct relevance, remained unexciting when compared, say, to space technology or development of new sources of energy.

We are now at the stage where significant unfilled testing needs in these newer areas can be identified and where a considerable amount of effort needs to be expended in a relatively short time period (5 to 10 years) in order to provide test methods to be made available for actual field conditions.

Another major factor which has to be addressed in the context of materials testing is the development of a set of general testing procedures relevant to all materials and systems plus the establishment of reliable guideline values to be included for material qualifications within the insulation materials standards. These will have to be supplemented with limited special methods applicable to one material or type, for example, a loose-fill insulation, and practices, for example, the requirement of test information over a very specific temperature range or condition particular to one material or system. All too often one discovers that materials or systems are being compared with each other based upon results of different test methods used to evaluate the same or similar properties of the material or system. It is very important that materials and systems standards contain the correct and relevant test methods specifications. Furthermore, it is necessary that all properties and performance characteristics are given for specific materials in their mode of general use or specific application. The material developer and producer must work in true cooperation with the measurer in order to attain the goal of a set of correct general and specific test methods and criteria.

A further problem which also has to be addressed is the adequacy of organizations available to undertake the volume of testing and evaluation required in the future and the reliability of the results they obtain. Currently there is widespread dissatisfaction being expressed within the insulation field on both of these factors. It should be understood that there is no real mechanism for the enforcement of ASTM Specifications. Unfortunately, in this field, as in any other, the existence of a wholly acceptable

and widely used ASTM test procedure does not necessarily ensure guaranteed quality of results.

As the needs for reliable insulation performance characteristics increase this uncertainty factor becomes increasingly more critical. It has been shown in the preceding assessment sections that for certain materials and systems there have been widely diverging claims for particular properties, particularly thermal performance. For example, in some case the claimed thermal performance values are without physical basis. Within the membership of C16, and in the insulation field in general, considerable disquiet has been expressed on this matter and even the validity of the test specifications has been questioned.

In general, the test method is not at fault. The very fact that some organizations report unsubstantiated performance figures is disquieting. It implies a complete lack of appreciation of the fundamental performance of an insulation, not only by the person undertaking the evaluation, but just as importantly, by the manufacturer as well. In addition, it is possible that poor equipment or apparatus has been designed despite the guidelines supplied in a specification or that the test technique is not appropriate for the material or system in question. Thus, we must ensure that as we develop new test methods they can be understood and used correctly such that results obtained by any organization may be viewed as being reliable.

These factors imply the need for establishment of accreditation procedures for testing organizations complimented with a program of education as noted previously. Such accreditation could be imposed directly on the industry by government action or a voluntary scheme could be established by joint action of industry and government. Members of C16 Committee in conjunction with the Trade Associations, realizing the importance of this subject, made representations to the Department of Commerce in mid-1976 and requested that a voluntary accreditation procedure be established based on evidence which they supplied.

A summary of the factors and test procedures involved, together with a short history of the action which has been taken is given in Appendix C. This is a copy of an excerpt of the Federal Register Volume 42, Number 47, 10 March 1977, entitled National Voluntary Laboratory Accreditation Program (NVLAP). The need for such a program for thermal insulation is clearly defined and accepted, and the necessary formal establishment procedures are now under way. Within ASTM C16 it is realized that the establishment of such a program for insulation requires testing criteria and personnel evaluation and provision of adequate reference materials together with reliable performance characteristics for both, whatever the property under examination.

With the preliminary finding of a need the Department of Commerce has been engaged upon both setting up the machinery to form a Steering Committee, and collecting a staff to run the program. A further announcement in the Federal Register was made in October, 1977 (44) establishing the final need and the establishment of a Criteria Committee to serve as the advisory body.

Within the organization of the program a number of requirements relating to test methods and criteria become more urgent. One of the major factors here is the making available of both so-called "performance" samples and reference materials. Such materials are required for most of the tests covered in the NVLAP program. However, the needs in the thermal performance area are particularly urgent.

Performance samples can be described as individual stable, reproducible specimens having defined property values. The accepted individual values are kept on record within NVLAP but, in general, are unknown to the organization being accredited or checked. Reference samples are of a higher grade material, such that the variation within samples or lots of a material is very small. In general a sample from a stock of such a material will have a well-known, accepted behavior.

The former are required by the inspectors of the accrediting force both to undertake the preliminary accreditation and then to regularly check the accredited organizations. The latter are necessary to improve the performance of those involved in the measurements area and that of their equipment. In some cases it can be visualized that the same material or system can serve both functions. However, in the immediate future, performance samples are the first priority for NVLAP but in the general field of thermal insulations the reference material need is just as critical. Additional discussion relating to the particular case of thermal performance reference materials will be amplified in a later section.

5.1 Thermal Performance

In this group there are three major measurement specifications:

- (i) C177 - Steady State Thermal Transmission Properties by the Guarded Hot Plate Method (Latest Revision 1976).
- (ii) C518 - Steady-State Thermal Transmission Properties by the Heat Flow Meter Method (Latest Revision 1976).
- (iii) C236 - Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot Box (Currently being (Revised)).

These are supplemented with two recommended practices:

- (i) C653 - Determination of Thermal Resistance of Low Density Mineral Fiber Blanket Type Building Insulation
- (ii) C687 - Determination of Thermal Resistance of Low Density Fibrous Loose-Fill Type Building Insulation.

In evaluating thermal performance C177 is the oldest (1945) and until recently probably the most widely referenced and used specification worldwide. It is a direct steady-state method based upon absolute

measurement of longitudinal heat flow through two similar specimens constituting a test sample. Stringent guarding is required around the system to eliminate or reduce extraneous heat losses. Samples of any thickness can be evaluated, provided suitably sized hot plates are available.

The method requires great care in the design and operation of the apparatus, skill and understanding of heat flow principles involved on the part of the operator, and the availability of adequate time in order for thermal equilibrium to be established. With these principles established it can be very accurate and precise ($\pm 2\%$ or better) as indicated by two Round Robin programs (45,46). However, in each case large divergences were apparent with some hot plates.

The C518 heat flow meter specification is some 20 years old and has only become truly accepted and widely used comparatively recently. In principle it is somewhat similar to the guarded hot plate method but the longitudinal heat flow is determined in terms of a heat flow meter device which is an integral part of the apparatus. The whole system is calibrated using a sample or samples of known thermal conductance. In this respect it is absolutely dependent upon the guarded hot plate method providing accurate results on the calibration materials, and upon stability and reproducibility of such materials and of the heat flow meter itself. With a suitably sized apparatus large thicknesses can be evaluated.

Providing an adequate range of calibration materials of varying known thermal conductances are made available, accuracies of $\pm 5\%$ and better with a reproducibility of $\pm 2\%$ or better can easily be attained for the whole range of insulations used within the building envelope. While requiring careful design and construction, the method is much simpler than the hot plate method. It requires less operator expertise and considerably less time than a C177 test on a comparable material of the same dimensions and for the same conditions. It is ideal for comparative studies and quality

control applications since a minimum of operating variables are involved once the temperature conditions have been set and the apparatus calibrated.

The C236 method is a steady-state absolute method for evaluating both the surface-to-surface thermal conductance and air-to-air heat transmission coefficient of a thermal insulation system, i.e., a very thick material sample, a combination of materials into a given system, or a complex building wall, ceiling, or roof component for heat flow in a given horizontal or vertical direction.

In this case the sample separates two temperature-controlled chambers, one hot, containing a "metering" section which has to be representative of the system being evaluated. Here the measured power is generated within a metering box situated in a guarded temperature-controlled environment at the same temperature as that within the metering box. The other chamber is the cold side where both temperature and wind velocity can be controlled to simulate external conditions.

This method, at present, is probably the one utilizing the most realistic measurement conditions for any sample of a material or system. It is a steady-state method and has the same limitations and requirements as the guarded hot plate. It is possible to attain accuracies of $\pm 2\%$ or better on a known material sample or simple system. However, it is very time consuming to set up and run and thus very expensive to undertake any large volume of testing or evaluation. Furthermore, since systems may be evaluated the operator requires additional skills and knowledge above that required for apparatus and tests which can be applied only to materials and composites.

The C653 and C687 Recommended Practices were developed specifically for the evaluation of certain products only. Furthermore, the C653 practice was developed as a compromise measurement plus mathematical analysis technique. It provided a basis for undertaking quality-control measurements on a product where it was realized that there was a need but at the

time no available equipment of sufficient size to undertake the required total measurements. As additional knowledge of the product has been gained, testing specifications reviewed, and larger sizes of equipment made available for evaluation purposes, C653 is now conceptually invalid. In addition, C687 has been made redundant by the revising and upgrading of C518 as a totally general specification.

Until 1976 both C177 and C518 methods implied that the property being evaluated was the thermal conductivity. The C16.30 Thermal Measurements Subcommittee issued a Position Paper at its 1973 Thermal Insulation Symposium (47) drawing attention to the fact that a thermal insulation material, particularly a majority of those used as building insulations, does not have such a defined physical property. This is due to the fact that the major heat transmission mechanisms are gas conduction, radiation, and convection under certain conditions. The solid conduction mechanism is a very small part of the total, and the combined conduction process is practically constant for low densities (see Figure 3.1).

Furthermore, the measured values for a material or system can be different for different thicknesses (48) (see Figure 3.5), for different temperature gradients at the same mean temperature (49), and for different emittances of the boundary surfaces (27). All of these points have been amplified in various papers presented at the most recent C16.30 Symposium (50) held 19-20 September 1977, the Proceedings of which are to be published by ASTM in 1978. Only for very specialized conditions and for high density products can an insulation material be shown to have a measured property which is closer to the physical definition of thermal conductivity.

The C177 and C518 specifications were revised by C16.30 during the 1974-76 period to reflect this change to the correct philosophy of measurement. The present versions of the Specifications make note of

these factors and indicate the necessity of requiring measurements to be made either on a material or system in its actual thickness and form under required temperature and environmental conditions, or else at such thicknesses or conditions where the measured property can be shown to be independent of changes in any of the previously mentioned parameters. It is no longer sufficient to evaluate the thermal conductance of materials at limited thicknesses, e.g., 25 mm (1") and assume a direct linear relationship for thermal resistance based upon the value derived from that at the measured thickness.*

It has to be pointed out, that until recently, there has been little development work in the area of large guarded hot plates or large reliable fully integrating heat flow meters of the sizes required to evaluate samples of up to 12" in thickness. In addition, considerable input to the C177 and C518 revisions was made by industry members based on their experiences with the larger sized equipment which they had developed. Furthermore, there had been little or no need to use thermal insulations in such large thicknesses as those currently being recommended for buildings, particularly in northern climates. Thus for such evaluation in the past, the guarded hot box could be used for the necessary limited requirements.

More recently, however, recommended thicknesses of insulation for attics have been increasing so that values of R38 (equivalent to 12 in of rock wool or glass fiber, 10 in of cellulose or 6 in of polyurethane) are now suggested. In order to maintain good quality control of such products it is necessary to be able to undertake routine evaluation of such materials more rapidly than by the C236 methods. In consequence large guarded hot plates and more recently large heat flow meter equipments have been developed such that the materials can be evaluated in their full thicknesses.

*See Section 3.5.2.1 for a more detailed discussion of the effect of thickness and differing statements regarding the implementation of these specifications.

The above developments are only a partial solution. In general, the measurements carried out still apply, even in the guarded hot box test, to the performance under controlled laboratory conditions, with fully dried or otherwise conditioned samples. While the results obtained under such conditions are useful for grading or comparing materials these laboratory measurement conditions are never experienced in practice. It is essential to develop the performance characteristics of materials and systems for real life conditions, i.e., materials or systems containing moisture, systems evaluated under conditions of air infiltration and migration, water vapor movement, wind impingement and actual construction practices.

The influence of some or all of these factors has been recognized by C16.30 and developments have taken place in the following areas.

- (i) In anticipation of the evaluation of large insulations systems and building components containing insulations, work is in progress to develop a calibrated hot box (47, 50) test method. This is a slightly different approach to the basic C236 method in that the overall system is similar, but more basic in design, but does not use a separate metering box. The power developed on the hot side is measured and the minimal amount flowing through the massively insulated surrounding walls is also measured and subtracted from the total measured power. The heat losses in the system can also be determined using standard known thermal conductance panels as test samples evaluated under the same conditions. This latter process is used to calibrate the hot box.

Once this method is in use and the test method procedures established it has the advantage, unlike the guarded hot box system, that it can be used for evaluating overall thermal performance

of systems under the influence, separately or in combination, of the effects of moisture and moisture vapor and air movement. This method also had the further advantage that measurements can be made under transient or dynamic conditions simulating the diurnal, in-use conditions normally experienced. However, additional mathematical analysis is required in order to establish the correct test criteria needed to make adequate use of the results of both steady-state and transient measurements.

To include the transient effects in the analysis and measurement it is mandatory that heat capacities of materials and systems are determined accurately. Currently the only available specific heat specification is C351 which provides an average value between approximately 90 and 25C based on a drop calorimetric technique. However this one value at an average temperature, which is often above that experienced in buildings, while being reasonably accurate, easily obtained and useful for comparative and approximation purposes, will not be sufficient in the future. A new method is required based possibly on the adiabatic calorimeter (52), to cover the same range as for thermal conductance.

- (ii) The possibility exists of developing a transient test method for measuring the thermal conductance of insulations. This is based on the line source method (50). If it is found to be applicable to insulation materials it offers a relatively rapid and viable method to examine the effects of moisture or the properties of an insulation material since the time of measurement is reduced to the order of 5 to 10 minutes. Concurrent with this examination, another group within ASTM is involved in work oriented towards developing a specific technique associated with the C518 method to evaluate the thermal performance of moist or wet materials.

With the information gained in utilizing these newer methods or techniques the basis of further "use conditions" specifications can be developed. However careful analysis of the systems and the development of guideline knowledge of the individual effects of various parameters are required in order to establish reliable test criteria. In this connection, Committee C16.30 is cooperating with Committee E6 on Performance of Building Components and Systems to establish a suitable test method for overall performance of systems. Components include windows and doors in addition to the basic insulated wall, ceiling or roof, and requirements include air and moisture flow.

The thermal performance of an insulation can be affected markedly by poor application and other construction defects within a system. For example the effects of leaving gaps around the edges of installed batts, not filling cavities to the full extent, allowing dust or finger prints to reduce the performance characteristics of reflective foil systems are all well-known. Good performance as measured in the laboratory does not give assurance of good performance when installed.

Such criteria are adequate grounds for considering the development of field test methods. At the present time a great deal of work is required in a number of laboratories, particularly on systems by both guarded and calibrated hot box methods in the steady-state and transient, in order to produce suitable test criteria for reliable field evaluation measurements. However the number and quality of such facilities is very limited and as noted earlier they are very expensive to develop and run. The solution to a problem of this magnitude and nature can only be brought about by the influx of research and development funds.

A word of caution is also necessary within the context of field tests. A number of suggestions have recently been made regarding the use of a system consisting of small heat flow meters, a heat source

and means of temperature measurements on hot and cold surfaces to undertake field evaluation of thermal resistance. Some commercial packaged instruments based on the suggestion are being marketed. In the simplistic analysis associated with the use of any heat meter technique in the field no account is made of the effects of the diurnal variation, nor is any consideration made concerning the inhomogeneity of walls and roof systems. While the devices may work perfectly under laboratory conditions when determining the resistance of a piece of insulation only very large errors can result when they are used on insulation systems even under steady-state conditions.

Another suggestion for field measurements is the use of the infra-red scanning camera (Thermography) (53,54). Work has been carried out in Sweden combining the use of this technique with hot box measurements in the laboratory on building systems containing built-in faults typical of problems in Scandinavia. As a result it has been possible to build a "library" of pictures of such faults together with information on their quantitative effects. It should be emphasized that these measurements were still for steady-state conditions. However, by taking an infra-red scan of a building and comparing the resultant picture with those in the "library" it is possible to obtain a better performance value.

Without the availability of a similar "library" for U.S. construction practices and climatic conditions, thermography remains only a qualitative tool for field evaluation. However, the technique is a valuable one. Its use should be developed and utilized further in conjunction with steady and transient state hot box methods on known systems in the laboratory in order to establish its ultimate viability in the quantitative mode.

To conclude this section on thermal properties some further details concerning the important subject of performance and reference materials are presented. Since the use of thermal insulation is primarily

for its thermal resistive properties and since this is one area where there is uncertainty it is an area where concentrated effort has been expended by C16.30 in the past two years or so.

The Subcommittee first called attention to the need for reference materials in 1971 when a Task Force was established, and its preliminary findings were reported in 1973 (47). Despite the need very little experimental work has been carried out since then and few samples or materials are available to fulfill the needs. Without dwelling on the reason for lack of reference materials one can only reiterate the urgency of the problem and call for action to back up the effort initiated by the Task Force.

5.2 Physical Properties

In the over-all definitions of physical properties we include determination of density, dimensions, and the measurement of relevant mechanical strengths such as compressive, tensile, flexural, rupture, parting and adhesive strengths where relevant to appropriate materials and particular applications which may or may not apply in buildings.

These test methods have been developed usually for a specific need for a particular material or application. They are based in general upon accepted, simple techniques using existing commercial pieces of equipment. The techniques may be suitable for some materials but in general they do not apply specifically for all insulation materials and systems. It is in this general area that one can perceive the possibility of obtaining lowest common denominator tests.

5.2.1 Standardization of Measurements

In the C16.30 Position Paper given at the 1977 Symposium (50) the history of needs for reference materials is presented and a number of candidates suggested for examination. Priorities have been established,

the major one being the requirements for building materials and systems. It has been recognized that we require both reference materials and reference samples covering different ranges of apparent thermal conductivity and of different thermal conductances. A coordinated program of action has been suggested with C16.30 acting in an advisory role. In calling for action the obvious role of the National Bureau of Standards Office of Standard Reference Materials and NVLAP have been outlined. However, it is stressed that many other organizations have interests and needs in the vital area and that action within NBS or one body alone is not sufficient to solve this pressing problem.

At the conclusion of the Position Paper a short outline of one proposed course of action is given and since the priorities refer to building applications, this short statement is included in Appendix D together with the suggested list of materials (Table D.1). Currently, the NVLAP organization is preparing a course of action for establishing a first set of performance materials. This involves using organizations which have the equipment capacity to carry out the required measurements on the samples involved in order to provide the first series of performance samples. Some attempts will be made to try to coordinate the two activities so that both ends may be served since the same or very similar methods are involved.

In 1971 when the original need was recognized, C16.30 carried out an international survey of equipment which was available for evaluating the thermal performance of insulations. The collected results of this survey were reported in 1976 (55). Later, in 1976, a further survey was conducted concerning equipment in the USA and Canada. The results have not been analyzed and published so far and the survey is being upgraded because of the NVLAP needs. However, preliminary indications are that there are few organizations having the full capability of evaluating building insulations and systems in all necessary forms.

There are probably 30 to 40 organizations having some measurements capabilities. Of these there are on the order of 25 who possess guarded or calibrated hot boxes of various sizes, less than 10 who have guarded hot plates which can evaluate samples 3" thick or more and less than 5 who have heat flow meters to evaluate thicknesses up to 8 to 9". Overall there appears to be only five organizations which have at least one item in each of the above categories. Unfortunately, at the present time the National Bureau of Standards does not have sufficient large-scale heat meter and guarded hot plate equipment to be in a position to serve the overall needs of the insulation industry.

The proposed plan of action outlined in Appendix D will assist the 30 to 40 organizations mentioned above in meeting the overall objectives of the NVLAP. However, to meet the specific needs of the building insulation industry and NVLAP, other measurements programs and Round-Robins are either underway or proposed. The National Mineral Wool Insulation Association in cooperation with C16.30 has one series of low density (0.6 to 2 lb/ft³) fiber glass samples at 1" thickness plus one full thickness (3.5") fiber glass blanket being evaluated by those organizations having the available equipment.

The Association is currently planning a further Round-Robin to evaluate the effect of thickness in low density fiber glass. As described earlier, the thickness effect is a function first of density where relevant to building insulation requirements. Other parameters including mean temperature and temperature difference have to be considered for industrial insulation applications but are not included in the proposed measurements program.

It is planned to manufacture a number of 36" square and 1" thick samples of one type of fiber glass in three densities, 0.5, 0.75, and 1 lb/ft³. These samples will be stacked in a preset order up to 8" in

thickness and each organization having equipment to measure up to 4" or 8" will evaluate each series at increasing increments of 1" up to the maximum, all under the same temperature difference conditions. It is anticipated that this Round Robin will be carried out and the results analyzed within a year. It is to be hoped that the exercise will provide both performance and reference materials.

As far as we are aware, there is no similar major activity organized or planned concerning some of the other properties of thermal insulating materials or systems. It is realized that thermal performance is the prime need since this is the reason for using a thermal insulation in the first place. However, in the future similar requirements will be necessary in the area of fire resistance and other associated fire properties and in studies on corrosion and other chemical properties.

5.2.2 Physical and Mechanical Performance

The use of simple techniques involving, for example, measurements of mass, length and time are admirable. However, by their very simplicity these methods require a critical expertise and understanding both of the product and the problem by the operator. Because the methods are simple it does not follow that the tests are easily carried out in order to obtain the necessary degree of precision.

The inhomogeneity of the products present further problems. This can be solved, to some extent, by undertaking a number of tests on numbers of samples and carrying out statistical analyses of the results.

Further work is required to improve the existing methods and the analysis of results and to extend them for use on combinations of materials and systems. A specific example here is that reflective insulation systems have not been considered. They are utilized extensively in

the Southwest and West regions of the USA and their thermal properties can be evaluated as described earlier. However, information on their physical characteristics related to how the systems can be handled or affected in the intermediate processes between manufacture and installation is lacking.

A need which has not, in general, been addressed as far as these tests are concerned is the development of more complex test methods and the establishment of criteria to examine real life effects on the various properties. It is well known for example that the mechanical and thermal performance characteristics of materials are markedly degraded by development of cracks within a material while the effects of moisture vapor have been mentioned already.

It is often suggested that accelerated aging test criteria can be developed for materials in order for some of the above factors to be studied. It is not possible for all materials to be so evaluated. One only has to consider the chemical reaction rates which may take place in cellular plastics for example to realize the changes due to accelerated or increased temperature and cycling alone are not necessarily typical of the changes which may take place if normal temperature conditions and changes such as occur naturally are the test criteria.

There is a distinct need to study the effects of temperature cycling, aging, exposure to different moisture vapor levels, and to different weathering conditions and orientations on the dimensional, physical, and mechanical properties of materials and systems. In certain cases this may involve the subjection of whole systems to given temperature and environmental conditions in order for the full effects on one material or individual component system to be studied. In this case as for thermal performance, testing requirements will increase in size, complexity, time and, hence, cost.

5.3 Chemical and Related Properties

In this case we are concerned with a number of factors relating, in general, to the effects of materials and systems with each other, with the environment, with human beings and with animals. The very fact that insulation is installed in environments occupied by people and/or animals or in some cases where vegetables or animal food is stored makes it necessary for adequate test methods to be promulgated to ensure that the insulation materials or systems are not harmful to these environments.

Until recently very little attention has been paid to this question, but with the increased interest in protection of the environment more attention is being given to these factors. A Safety and Health Subcommittee has been established within C16 to examine the subject and make recommendations on some of the needs.

In applications within the building envelope, especially when considering climatic and diurnal changes, corrosion is a very important property. The use of a particular product in a selected environment may preclude the use of other materials of construction within the building envelope due to the activated corrosiveness of the chemicals within the product when exposed to moisture or to elevated temperatures for example. Interacting corrosive effects between building components and the environment must be considered.

Three corrosion tests are currently available in ASTM for insulation: C464 Corrosion Effects of Thermal Insulating Cements on Base Metals; C692 Stress Corrosion Effects of Wicking Type Thermal Insulation on Stainless Steel; C739 Cellulosic Fiber (Wood-Base) Loose-Fill Thermal Insulation - a special corrosion test is included in this materials specification. Federal Specifications HH-I-521F, Mineral Fiber Blankets; HH-I-558B, Industrial-Type Mineral Fiber; and HH-I-1030A, Mineral Fiber Loose-Fill are also available.

Neither C464 nor C692 are oriented towards corrosion in the building materials application while C739 is specifically oriented towards one product. A further point concerning this specification is that the test method is detailed specifically within a materials standard - an illogicality in itself.

This field, therefore, appears immediately deficient and there is very important need for a comprehensive general test method for building insulation products. Parameters to be considered include:

- (i) Corrosive effects of the insulation with other insulations, woods, metals, and plastics with which it may be in contact;
- (ii) Insulation type and form;
- (iii) Effects of temperature and moisture separately and a combination;
- (iv) Effects of cycling of environmental conditions;
- (v) Long-term stability.

Some of the features of the current methods may be applicable for the general test method but the full implications of the numbers of common materials and combinations involved have to be realized, and the quantity of testing will be very large indeed. However, in this particular case the testing needs are not large in scale. Some aspects of the tests may obviously have to be long-term in nature unless some acceptable accelerated testing techniques can be shown to be valid.

The recent Consumer Products Safety Commission hearing (56) on the health and fire hazards of different thermal insulation products has also served to emphasize the possible lack of test methods and establishment of acceptable criteria in this field. Chemicals mixed with particular products as binders or to enhance fire retardance characteristics or to repel insects or vermin may prove to be toxic or to have a deleterious effect on some of the other materials in the overall systems when exposed

to moisture vapor, water, temperature variations, etc. General test methods are required for the generation of and effects of odor, permanance of chemicals within the product in a changing environment, the ability to support harmful fungal growth (since certain fungal growth may not be harmful) the stability of the chemicals and the product in a normal environment. Their findings, which are due early in 1978, may necessitate prompt action in this area and much more work may have to be carried out to fulfill their requirements.

Within the insulation industry and the manufacturers of chemicals associated with some of the products there is proprietary information concerning these effects. A number of appropriate chemical tests are available and some effort should be made to coordinate the information and available expertise into a set of test criteria.

A great deal of attention has been paid to the matter of the effects of moisture vapor on the performance characteristics of thermal insulation in buildings. Little has been said about vapor barriers. As in the case of thermal performance, vapor barriers have been considered as individual materials. Adequate test methods are currently available to evaluate the water vapor transmission characteristics of the available forms of vapor barriers. However, as mentioned in earlier sections air permeability can be a considerable factor in the overall performance of an insulation system. As for the case of thermal performance systems, test methods are required which evaluate the water vapor and air permeability characteristics under simulated environmental conditions.

5.4 Fire and Related Properties

One need only review the annual statistics (57) concerning loss of life, injury, loss of property, loss of business, etc., due to

fires in buildings to realize the importance of the subject. Admittedly, few of the fires can be attributed to insulation produced under controlled production supervised by independent agencies and installed in accordance with current Building Code requirements. There is still an obvious need for additional test methods to provide information on the various fire related properties of materials and systems in order to give the designer, architect, and code officials the means to provide more fire-resistant structures.

The following is a list of the present fire related test methods which are being used to evaluate thermal insulations and systems:

- E84 - Surface Burning Characteristics of Building Materials (latest revision 1977).
- E108 - Fire Tests of Roof Coverings (latest revision 1975).
- E119 - Fire Tests of Building Construction and Materials (latest revision 1976).
- E136 - Noncombustibility of Elementary Materials (latest revision 1973).
- E162 - Surface Flammability of Materials Using a Radiant Heat Energy Source (latest revision 1976).
- E286 - Surface Flammability of Building Materials Using an 8 Ft. (2.44 m) Tunnel Furnace (latest revision 1975).

In examining the subject of fire testing in terms of the use of these test methods, it is somewhat surprising to discover that there are no completely adequate or truly meaningful test methods available to provide the necessary quantitative scientific information. This has been generally recognized and research is being actively pursued to alleviate the problem.

Most of the small-scale tests on materials provide information of spread of flame in terms of distance and time, production of smoke, etc., usually under one orientation of sample and for one set of conditions. There is often only very limited control of some of the actual parameters such as temperature, type and placement of the flame, environmental conditions, heat flux conditions, etc. The large-scale tests may be for one orientation of sample only, in many cases this orientation being one which is never experienced in actual applications of insulation materials or systems. In most cases results are not presented in quantitative terms.

It must be realized that no two fires are exactly the same and thus it is unlikely that truly definitive test methods can be developed. There is, however, a considerable amount of knowledge which can be gained by devising more scientific tests relating to the chemistry, thermodynamics, and kinetics of fires of materials and systems than are currently available or planned. As in the case of some of the thermal performance tests, large-scale, costly, time-consuming facilities and equipment are required for these tests. This means that they must be developed with a view to providing more meaningful quantitative results rather than the present qualitative or descriptive performance.

Toxicity is another important factor in the subject of fire-related properties. A recent account of fire-related fatalities (58) indicate that carbon monoxide was the prime cause of death in 60% of the victims. Animal tests under laboratory conditions have also stressed that CO is the prime toxic gas in fires. The particular use of organic materials as insulations increases the probability of generation of this gas in addition to others which may also be lethal in themselves. Analyses and animal testing of the gases involved in the various fire tests should also be included in the test methods where possible.

There is a school of thought which argues that since, in general, thermal insulation materials as typically used in buildings are very rarely directly exposed to flames or sources of fire, their fire and toxicity characteristics are not significant. While these arguments may be valid they do not justify treating the subject in a cursory manner. There is increased development and use of special structural and decorative thermal insulation systems which may not necessarily be protected by internal or external fire-resistant coverings. Test methods must still be developed to provide quantitative information on materials and systems so that building design can be made safer.

In ASTM, individual materials committees, for example, D7 on Wood, D13 on Textiles, and D20 on Plastics, have in the past developed small-scale test methods for their particular materials. It should be pointed out that these tests were developed originally for laboratory studies in order to obtain a rough classification of respective materials. They were not intended to be definitive fire-rating tests for materials but some have been misapplied for that purpose. Committee E5 on Fire Tests of Materials in Construction has the responsibility for writing test specifications relating to materials and systems in the building envelope. More recently Committee E39 on Fire Hazard Standards was formed but due to obvious overlapping of interests between them, E5 and E39 have now been amalgamated into a new Committee.

Other fire test methods developed by organizations including Underwriters Laboratories, National Fire Protection Association, Factory Mutual, National Bureau of Standards and Canadian organizations are also being used in the industry. As discussed later, there is the possibility that some of these tests will form the basis of new ASTM Specifications.

The C16 Thermal Insulation Committee has, in general, relied upon the use of the various tests produced by the other materials Committees where appropriate, together with the applicable E5 documents. In some

cases, particularly with inorganic materials, such as asbestos and gypsum-based products, the materials themselves are highly resistant to fire and no test method requirements were foreseen for the materials alone. However, for cellular plastics, for example, reliance was placed on small-scale tests developed by Committee D20. Unfortunately, due to

- (i) the use of non-scientific terms or classifications such as "non-burning" to describe experimental results,
- (ii) ascribing a numerical rating value, ratio, classification or index to results falling within a certain range for spread of fire and/or smoke production,

these small-scale tests fell into disrepute. As a result, some have been deleted from the ASTM Book of Standards while others have been drastically revised.

At the present time, all remaining ASTM Standards relating to fire characteristics contain the following caveat:

This Standard should be used solely to measure and describe the properties of materials, products or systems in response to heat and flame under controlled laboratory conditions and should not be considered or used for the description, appraisal, or regulation of the fire hazard of materials, products or systems under actual fire conditions.

It is difficult, therefore, to understand how any of these test methods for materials or systems can be used alone by designers or code officials for design or specification purposes. There is a need for quantitative tests.

The over-all unsatisfactory state of affairs is appreciated fully and there is currently a great deal of experimental work being carried out on materials and systems using both the available and proposed test methods for materials and systems. New methods of test are being developed, particularly for materials, with both small- and medium-scale tests involved. One of the major issues here is the ability to correlate results of the different scale tests. These material test methods are being supplemented with work on the large-scale tests mentioned earlier.

Critical studies of existing and proposed tests have been made in order to illustrate the magnitude of the problem. A recent report from the National Bureau of Standards (59) describes a full investigation of the 1970 version of E84 - Surface Burning Characteristics of Building Materials. This test method is the one primarily used at present within the construction industry. Some of the deficiencies of this document have been corrected in recent versions up to 1976 and it is currently undergoing further revision in light of more recent information and testing. However, there are still a number of very major drawbacks in the test method which make it somewhat unsuitable for providing truly meaningful information on the fire behavior of insulation materials and systems.

While these are described fully in the NBS report, together with the range of uncertainties in the actual test parameters, it is considered worthwhile to mention several of the major problems affecting E84.

- (1) The tunnel test was developed originally to study wood products as installed on a ceiling. The orientation of sample mounting remains unchanged and all samples irrespective of their actual use condition are ceiling mounted. It is highly unlikely that fire characteristics from this test will be the same for horizontal floor mounting.

- (ii) Flame spread and smoke development are still reported in numerical terms as a classification rather than actual results. Various Round-Robins have been carried out on selected wood, thermal insulations, carpets and plastics. As an example, in one carried out in 1973 (60) the differences between eleven participating laboratories ranged from 18 to 43% for the flame spread values and 22 to 117% for smoke developed. These results do not provide much confidence in the test method.
- (iii) Loose-fill materials cannot really be examined by the method with its current mounting procedure. The use of a supporting screen is recommended but this retards flame spread. Some organizations specify the use of a correction factor when testing such materials, others do not.

These are sufficient reasons to indicate the extent of the problem.

Within E39 a Task Force was established for assessing research needs in the area. An abbreviated version of their assessment of fire hazards and research needs has been published very recently (61). Three of their more major conclusions are presented since they are very relevant to the current discussion and indicate the large amount of work that is required. They are:

- (i) Methods are needed for quantifying the fire performance of and potential contributions to the hazard of products and systems under conditions of temperature, imposed radiation, etc., as experienced in real fires. Emphasis should be placed on methods for determining the likelihood of ignition and release of heat, smoke and gases for various fire situations.
- (ii) Small-scale tests and individual product test methods for scaling data from these tests to predict full-scale fire performance are also required.

- (iii) More knowledge is required of the chemical and physical mechanisms controlling ignition and subsequent fire growth to provide background useful for establishing product fire test procedures.

The Task Force was also of the opinion that the technology is currently available to allow initiation or revision of ASTM Standards in the area of fire endurance, ignition, smoke opacity and toxic product production. However, at the present time it is believed that the current technology is insufficient to allow standards development in the area of fire spread and growth rates, heat release, radiant output, and toxicity of combustion products, and susceptibility to external radiation.

There is an existing test method, E-136 - Noncombustibility of Elementary Materials, which is used for building products including insulations to indicate whether they do or do not aid combustion or add appreciable heat to a fire. It is a relatively simple furnace test involving measurements of temperature, weight loss and the appearance of flame. The test criteria are very rigid and conservative. For example, cinder block is classed as combustible by this test method. However, the method does not provide sufficient quantitative information for it to be used other than in a comparison mode.

Work in progress was mentioned earlier and some specific examples of the activities relevant to test methods for insulation materials and systems are given.

- (i) Both small-scale (4' x 4'), medium-scale (8' x 12'), and large-scale (up to 25' x 50') corner or fire exposure tests have been developed and are currently being studied and the results correlated. One specific advantage of the corner test is that it is a more severe test for walls or ceilings due to the increase in heat exposure from reradiation of heat from the corners. However, it is not suitable for materials which may burn on the upper surface.

Currently the Model Code bodies have specified the use of the 8' x 12' corner test in addition to other tests while ASTM has issued E603-77 - A Recommended Practice for Room Fire Experiments.

- (ii) The so-called upside-down tunnel tests where the test material is mounted on the tunnel floor and the gas flames directed downwards, in direct contrast to E84, is currently being studied, particularly in Canada. In the USA, the National Bureau of Standards has developed a Radiant Panel Test (62) for floor coverings whereby the critical radiant flux is measured when the test materials ignite and spread fire. These methods appear to have potential for loose-fill insulating materials where the flame spreads on the upper surface.
- (iii) In the area of combustibility NFPA No. 259 Standard Method of Test for Potential Heat of Building Materials issued in 1976 has been suggested as an appropriate test. This method does give a measure of defining limited combustibility of materials in quantified units. It is now referenced by the National Building Code with the definition of Limited Combustible Material as one having an upper limit of 3500 Btu/lb.

The Factory Mutual Construction Materials Calorimeter is another method providing quantitative results. This evaluates the heat release of assemblies, primarily roofs. Correlation of results by the test with those from larger scale tests has been good and the current Building Codes have accepted its use as proof of acceptable performance.

- (iv) In the field of small-scale comparative tests a revision of the current ASTM D2859-76 Standard Test Method for Flammability of Finished Textile Floor Covering Materials has been proposed by the National Bureau of Standards for testing loose-fill insulations. The original test method using a methenamine tablet placed on a test sample is not considered adequate for insulations. A proposed test for loose-fill insulations utilizes a lighted cigarette inserted vertically through the thickness of a test sample contained in a steel enclosure and noting the extent of ignition and combustion.

A useful comparative small-scale test is ASTM D2863-76, a version of the limiting oxygen index test. In this test, the percentage of oxygen in an oxygen-nitrogen mixture is gradually increased until the test material flames upon impingement of a pilot flame.

- (v) Since the arbitrary vision obscuration smoke test method currently used within E84 is too variable to be of real use, work is continuing on the use of optical density as the measurement factor. NFPA Method No. 258 - Smoke Generated by Solid Materials, issued in 1976, utilizes the optical density principle and it appears that the results are very reproducible.
- (vi) In the matter of toxicity a draft Recommended Practice for Biological Evaluation of the Toxic Effects of Smoke has been prepared within E5 and may soon be in the balloting process.

While much work is therefore in progress, more is obviously required. It needs to be complemented with

- (i) analyses of situations in past fires and the resultant damage,
- (ii) attempts at mathematical modelling of fires.

However, for this latter requirement, in particular, much more quantitative information is required on all materials of construction in addition to the materials used in furnishings. In the past, test methods have been oriented towards the more qualitative mode and in consequence the designer has not had the necessary information available.

In considering future developments of test methods in this field, the major criterion should be the production of reliable, meaningful, quantitative information. The test methods should be devised in such a way that the experimental results can be presented clearly in physical or chemical quantities and not obscured by incorporation into a ratio, index or numerical or descriptive classification. A recent report (24) was made to Committees E5/E39 outlining the present needs of the design engineer or architect for the above quantitative information. For insulations the major properties and variables which affect the results together with the proposed units of measurements are summarized in Table 5.1.

Table 5.1

SUMMARIZED MAJOR COMBUSTION PROPERTIES FOR WHICH ASTM TEST METHODS ARE REQUIRED

<u>Property</u>	<u>Units of Measurement</u>	<u>Principal Variables to be Considered</u>
Auto Ignition	Temperature	Ambient Temperature, Heat Flux, Gas Environment
Combustion Rate	Mass/Time	Ambient Temperature, Heat Flux, Gas Environment
Flame Temperature	Temperature	Gas Environment and Supply, Location
Flame Point	Temperature	Gas Environment and Supply, Ambient Temperature
Flash Point	Temperature	Gas Environment and Supply, Ambient Temperature
Flame Spread	Distance	Ambient Temperature, Heat Flux Location, Air Movement
Heat Release	Quantity of Heat, Mass	Temperature, Gas Environment
Heat Rate Release	Quantity of Heat, Mass, Time	Temperature, Gas Environment, Position
Oxygen Depletion Rate	Volume, Mass	Availability of Gas
Self Heating	Temperature (change)	Heat Flux, Thermal Properties
Self Ignition Temperature	Temperature	Heat Flux, Air Flow, Emittance
Optical Smoke Density	Opacity, Distance	Solid Type, Movement
Smoke Emission	Volume, Mass	Temperature, Area, Rate of Combustion
Smoke Emission Rate	Volume, Mass, Time	Temperature, Area, Rate of Combustion, Position, Gas Emission
Smoke Toxicity	Mass or Volume	Temperature, Gas Environment, Supply of Oxygen

Section 6

RESTRICTIONS & INFLUENCE OF STANDARDS & BUILDING CODES ON BUILDING ENVELOPE SYSTEMS

6.1 Historical Perspective

Building Codes have served traditionally to protect the safety and health of building occupants and the community. They have existed in cities for nearly four thousand years with the earliest known example being in the Code of Hammurabi in about 1750 BC. The earliest codes were specification codes which defined what materials and methods of construction were acceptable and that type of code has existed to the present time. A performance code defines the desired end result, but does not specify the means of achieving that result. The performance code permits use of new materials and designs as they become available and are found acceptable. Such provisions are essential for an expanding technology and must be included to enable use of improved materials and methods.

The Building Codes apply to new structures and traditionally have not governed structures erected prior to enactment of the codes. Only when existing structures are extensively renovated have they been required to conform to current building codes.

Fire codes have existed for the purpose of controlling community or occupant safety or limitation of property damage. They must be complied with upon construction and also during the life of the structure.

Insurance companies have exerted a strong influence on building design, but have traditionally been concerned with reduction of property damage and consequent lower damage claims. The control of structures by insurance companies has been by means of the premium rate structure with higher premiums required for buildings which loss experience indicates may be subject to greater damage due to fire.

Other controls have existed through limitation of the availability or cost of mortgage money for structures which do not meet minimum requirements. A prime example of this type of control is the Minimum Property Standards of the Federal Housing Administration. Properties meeting those requirements have been eligible for lower interest rates.

Historically, the control of energy efficiency of structures has not been part of the restrictions of Building Codes; rather the responsibility of codes has been safety. It is a recent concept due to the limitations of energy. For energy use control to become an integral and enforceable part of the building codes, a consensus must be developed among the interested parties in the industry concerning what limitations are desirable, acceptable, cost effective, and energy effective.

6.2 American Society of Heating, Refrigeration, and Air Conditioning Engineers Standard 90-75.

The publication of the ASHRAE Standard 90-75 (64) has provided the basis for energy conservation requirements in many Building Codes. The Model Codes developed by the various building code organizations in the United States have based their requirements upon that document.

Standard 90-75 has received criticism and is currently being revised. Many comments relative to the issue that the minimum requirements for building envelopes are not sufficiently restrictive or are overly restrictive have been advanced. A practical problem with performance standards in general is the inability to monitor or assure compliance, particularly when the number and variations of buildings is as large as in the case of residential or commercial/industrial construction. The value of the Standard is that it exists; that is, it specifies minimum design requirements more restrictive than those that previously existed, that it permits design options by trade-offs, and that it has led to incorporation of energy conservation requirements in Building Codes

and other related specifications. Now that the framework of this standard exists, it is much easier to change or upgrade the requirements within that framework. A proper place to work for upgrading is within the American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

ASHRAE Standard 90-75 is a comprehensive component performance document that includes all forms of energy consumed within a building. It relates to heating, ventilation, air-conditioning, lighting, service water heating, and electrical power distribution. With respect to building envelopes, it is based on calculations of steady-state conditions with empirical adjustment for air leakage, solar factor as influenced by latitude, and shading coefficient of the fenestration. For cooling only, the mass of wall construction is considered. However, the actual influence of these factors needs to be demonstrated by further laboratory tests or instrumentation of existing structures. The average thermal transmittance of the gross wall area for different building types as required by ASHRAE Standard 90-75 is given in Figures 6.1 through 6.6.

ASHRAE has recently added a Section 12 to Standard 90-75. This section deals with selection of energy sources and conservation of depletable or non-renewable energy sources.

In addition to ASHRAE 90-75, which applies only to new buildings, ASHRAE is issuing draft standards for comment on energy conservation in existing structures. The proposed standards are listed below:

- 100.1P - Energy Conservation in Existing Buildings
Low Rise Residentials (This includes mobile homes).
- 100.2P - Energy Conservation in Existing Buildings
High Rise Residentials.

Figure 6.1

U_o WALLS—TYPE "A" BUILDINGS

TYPE A BUILDINGS SHALL INCLUDE:

A 1 DETACHED ONE AND TWO FAMILY DWELLINGS

A 2 ALL OTHER RESIDENTIAL BUILDINGS, THREE
STORIES OR LESS, INCLUDING BUT NOT LIMITED
TO:

MULTI-FAMILY DWELLINGS
HOTELS AND MOTELS

ANNUAL CELSIUS HEATING DEGREE DAYS (18 C BASE)
(IN THOUSANDS)

Figure 6.2

R VALUES—SLAB ON GRADE

ANNUAL CEI SIUS HEATING DEGREE DAYS (18 C BASE)
(IN THOUSANDS)

ANNUAL FAHRENHEIT HEATING DEGREE DAYS (65 F BASE)
(IN THOUSANDS)

Figure 6.3

U_o WALLS—HEATING—TYPE—"B" BUILDING

FOR ALL BUILDINGS NOT COVERED BY PARA. 4.3

ANNUAL CELSIUS HEATING DEGREE DAYS (18 C BASE)
(IN THOUSANDS)

1 2 3 4 5 6

1 2 3 4 5 6 7 8 9 10 11 12
ANNUAL FAHRENHEIT HEATING DEGREE DAYS (65 F BASE)
(IN THOUSANDS)

Figure 6.4

U_o —ROOFS AND CEILINGS

TYPE "B" BUILDINGS

FOR ALL BUILDINGS NOT COVERED BY PARA. 4.3

ANNUAL CELSIUS HEATING DEGREE DAYS (18 C BASE)
(IN THOUSANDS)

Figure 6.5

U_o VALUES—FLOORS OVER UNHEATED SPACES

ANNUAL CELSIUS HEATING DEGREE DAYS (18 C BASE)
(IN THOUSANDS)

Figure 6.6

OVERALL THERMAL TRANSFER VALUE WALLS COOLING TYPE "B" BUILDING

FOR ALL BUILDINGS NOT COVERED BY PARA. 4.3

100.3P - Energy Conservation in Existing Buildings
Commercial.

100.4P - Energy Conservation in Existing Buildings
Industrial.

100.5P - Energy Conservation in Existing Buildings
Institutional.

100.6P - Energy Conservation in Existing Buildings
Public Assemblies.

Standard 100.6P was released for review in September 1977 and no comments are yet available. The 100.1P requirements are less restrictive than 90-75, while the others are comparable. Standards 100.2P and 100.3P are also issued for comment by the American National Standards Institute.

The last closing date for comments on the above drafts was October 31, 1977. If major revisions are not required, issuance of the above may be anticipated during 1978. If these standards have the impact of 90-75, inclusion in Building Codes or other regulatory documents may then be anticipated; but enforcement of regulations for existing buildings will require additional legislation or regulation.

6.3 The Model Codes

Due in part to the efforts of the National Conference of States on Building Codes and Standards (NCSBCS), the three Model Codes (Basic Building Code, Standard Building Code, and Uniform Building Code) now contain provisions on energy conservation. NCSBCS has been very active in the energy conservation area and has in preparation a draft Model Code for Energy Conservation. A resolution has been adopted by NCSBCS for States to adopt that code.

The Uniform Building Code is administered by the International Conference of Building Officials in Whittier, California. The Uniform Building Code, 1977 Supplement, has added Appendix Chapter 53 on Energy Conservation for all new buildings that are heated or cooled. This is a chapter that rather faithfully copies ASHRAE Standard 90-75 for new construction and includes provisions for exterior envelopes, heating, and piping, lighting and electrical distribution systems. This Appendix Chapter must be adopted separately by governmental enforcement bodies, but inclusion as a Chapter will lead to the later inclusion into the body of the code.

The Basic Building Code is administered by the Building Officials and Code Administrators International, Inc. in Chicago, Illinois. They have issued in 1977 the first edition of "The BOCA Basic Energy Conservation Code" which compiles energy conservation requirements published in the Basic Building, Mechanical, and Plumbing Codes as amended in the 1976 Supplements to the 1975 codes. These govern "all buildings and structures hereafter erected that provide facilities or shelter for human occupancy". That code copies the intent of Standard 90-75 with minor changes such as use of tables in place of graphs. It permits a " U_o " (combined thermal transmittance value for the gross area of roof ceilings) of $0.06 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$ for 8000 degree days or more, while Standard 90-75 and the Uniform Code require a maximum of $0.05 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$. It does not include provision for the Solar Factor, which corrects for the latitude of the site as provided by Standard 90-75, nor the shading coefficient under cooling criteria for walls. Neither is provision made for the effect of mass. As an amendment, it must be adopted separately.

The 1977 Revision to the 1976 Edition of the Standard Building Code published by the Southern Building Code Congress International, Inc. in Birmingham, Alabama completely revises Appendix "J" on Thermal

Performance. The 1976 version covered only Business, Schools, Institutional, and Assembly Buildings, while the 1977 version covers all buildings.

The Code states applicable provisions of ASHRAE Standard 90-75 shall be complied with to meet the requirements of the Appendix. This Appendix must, however, be specifically adopted by governing bodies in addition to the Chapters of the Code in order to be enforceable.

The provisions of Appendix "J" in general follow Standard 90-75, including the Figures, but with some important omissions and changes. Not present is the formula for Overall Thermal Transfer Value (OTTV) for mechanically cooled structures. It is stated that the Portland Cement Association 1976 publication "Simplified Thermal Design of Building Envelopes for Use with ASHRAE Standard 90-75" is an acceptable calculation procedure for determining thermal capacitance effects of insulation.

The National Building Code 1976 published by the American Insurance Association in New York City has nothing on energy conservation. Work is underway to include provisions of Standard 90-75 as a supplement or in the next revision.

The "One and Two Family Dwelling Code" published jointly by BOCA, AIA, ICBO, and SNCC in 1975 has nothing on energy conservation. Neither does the 1976 supplement, and a 1977 supplement is not yet available.

The building trade journal "House and Home" in the January 1977 issue reported on the existence of State Building Codes as shown in Table 6.1.

Upon adoption of the 1977 Basic, Standard, and Uniform Code supplements, the listed States, and possibly others, should have active energy conservation code requirements. Effective January 1, 1978, the State of New Jersey adopted the BOCA Basic Energy Conservation Code/1977.

Table 6.1

STATEWIDE MANDATORY BUILDING CODES

<u>State</u>	<u>Code Type</u>
Alaska	Uniform
Connecticut	BOCA
Idaho	Uniform
Indiana	Uniform
Massachusetts	BOCA
Michigan (except Detroit)	BOCA
Minnesota	Uniform
Montana	Uniform
New Jersey	BOCA
New Mexico	Uniform
North Carolina	State Written
Ohio	State Written
Oregon	Uniform
Rhode Island	BOCA
Virginia	BOCA
Washington	Uniform
Wisconsin	State Written

STATEWIDE VOLUNTARY BUILDING CODES

<u>State</u>	<u>Code Type</u>
Georgia	Standard
Maryland	BOCA
New York	State Written

6.4 Property Standards

The Minimum Property Standards of the Federal Housing Administration have great influence on construction. In the July 1974 Revision

No. 1 to Minimum Property Standards for One and Two Family Dwellings, Section 607-3 on Building Insulation sets maximum "U" values for building elements. These values do not include adjustments for structural framing nor sash frame or glass door frames.

The Flat Roof Deck maximum requirements are higher (or less restrictive) than ASHRAE Standard 90-75. For example, 4500 degree days or less sets a maximum "U" of $0.14 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$, while Standard 90-75 sets 0.09. Degree days of 8001 or more require 0.09 versus 0.06. Residential building walls require a maximum of 0.08 for all areas, while Standard 90-75 requires 0.16 for " U_o " on the gross area including windows and sash for degree days above 10,000. No limit on area of glazing exists although above 4500 degree days a maximum "U" of 0.65 is required (thermal windows). As an example, a 30 by 20-foot single story dwelling with 9-foot walls, 12 percent thermal glazing, and two doors calculates to a " U_o " (average thermal transmittance of gross area) of 0.16 or the same value as required by Standard 90-75.

The Federal Register dated June 17, 1977 published a revision to the HUD Minimum Property Standards for One and Two Family Dwellings effective May 1, 1977. That revision permits "optional use of Standard 90-75 where the results are equivalent to those obtained by using Minimum Property Standards". The published table of maximum "U" values is expanded and made more restrictive, but not quite as restrictive as Standard 90-75. The maximum "U" for thermal windows is increased to 0.69 from 0.65 to permit use of single strength glass. The maximum glass area is limited to 15 percent except where winter heat gain can be demonstrated to exceed the 25 hour heat loss. It should be noted that the Model Codes have, in 1977, reduced the minimum requirement for windows to 10 percent.

The Farmers Home Administration of the Department of Agriculture published thermal performance standards for Rural Housing loan funds for new construction and resold structures in the Federal Register, January 23, 1978 to be effective March 15, 1978. For new dwellings, the maximum "U" values not corrected for framing are more stringent than the cited HUD standards published June 17, 1977. For resale dwellings the same standards apply, but a note allows deviations for walls if attainment of the standard is not economical. No mention is made of trade-offs to attain overall efficiency.

Title 24 issued by the Department of Housing and Urban Development was printed as Part 280 "Mobile Home Construction and Safety Standards" in the Federal Register on December 18, 1975, to be effective June 15, 1976. In SubPart F, Thermal Protection, the requirements for Heat Loss/Heat Gain are specified. The country is divided into three winter design temperature zones. Zone 1, going from west to east includes California, Arizona, New Mexico, Oklahoma, Arkansas, Tennessee, and North Carolina. Zone 2 includes the rest of the contiguous 48 states, while Alaska is in Zone 3. The other outlying possessions are included in Zone 1.

The standard states that the transmission heat loss coefficients shall not exceed the following values:

<u>Zone</u>	<u>Maximum BTU/hr·ft²·°F</u>
1	0.157
2	0.126
3	0.104

Zones 2 and 3 require storm windows or insulating glass. Infiltration Heat Loss is limited to 0.7 BTU/hr. for each foot of perimeter of the pressure envelope. Transmission Heat Gains shall be similar.

Calculations must be in accord with the 1972 ASHRAE Handbook of Fundamentals. Comfort Heating and Cooling Certificates must be affixed to certify the design zones for which qualified.

These requirements are somewhat less restrictive than ASHRAE Standard 90-75 and essentially parallel to National Fire Protection Association (NFPA) Standard 501B, 1977.

6.5 Codes and Regulations Outside the USA

Some mention should be made of the activities in the Codes and Regulations Area in countries outside the USA. With the question of the energy crisis becoming increasingly important internationally and with the involvement of the USA in the new ISO 163 Thermal Insulation Committee, it is possible that future codes in the USA, where appropriate, may reflect the philosophy and/or substance of those in other countries. Clearly thermal performance is a prime subject for such consideration.

Since the early seventies considerable activity has taken place, in many European countries in particular, to produce national standards or codes. There has been a trend away from documents covering only the thermal characterization of opaque walls towards those containing more general and functional requirements attempting to cover some of the other important parameters which affect energy consumption for buildings. In a majority of cases these have been concerned only with the more important heating mode or winter condition. Attempts are now being made, particularly within the European Economic Community, to try to bring more conformity and concord between the various national documents (65).

France has been a leader in this area with the implementation on July 1, 1975 of Decree No. 74306 dated April 10, 1974. The United Kingdom implemented Building Regulation 1974, Part F - "Thermal Insulation" on January 31, 1975 while Belgium with Standard NBNB62-001 and West Germany

with an addendum to DIN 4108 were also quick to follow suit. Italy and Denmark drafted new national standards while The Netherlands revised NEN1068. The other Scandanavian countries, particularly Sweden, undertook drastic upgrading of their national documents in this field in 1975-76.

In general the codes are based upon some kind of coefficient or transmission index which limits the maximum quantity of energy which may be lost per unit volume of dwelling per hour per degree of temperature difference between the outside and inside.

If one takes the French document as an example:

The overall heat losses (by transmission and infiltration or ventilation) for seven classes of dwellings are limited by the stipulation of a maximum value for a coefficient G for three climatic zones. G is defined as:

$$G \text{ (W/m}^3\text{K)} = \frac{\text{losses of a dwelling per unit temperature difference}}{\text{Volume of dwelling}}$$

$$\text{and } G = G_{\text{tr}} + G_{\text{vent}}$$

A single value of $G_{\text{vent}} = 0.34 \text{ W/m}^3\text{K}$ is being used where the number of air renewals is unknown. This value corresponds to a constant renewal of air equal to once the total volume of the dwelling. Using this value, G_{tr} can be derived.

However, the French document is governed further by the application of Regles Th issued in 1975 which provides means of calculating heat losses in structures. In addition it introduces compulsory use of various multiplication factors to modify measured thermal properties of materials or component systems or the calculated values based on measurements on laboratory samples of individual materials. These factors reduce the

measured performance to take account of such parameters as effects of moisture vapor and water, air infiltration, etc. This is a very different philosophy to that which is in current use in the USA.

It should be pointed out that the use of these factors is becoming more prevalent. In West Germany for example the test methods for materials and systems themselves contain requirements which are most conservative to adjust the actual measured values for application purposes. This is a trend which should not become general practice.

Certainly it is correct to anticipate actual conditions of application when calculating thermal performance or applying laboratory test results. However, more definitive information than is available at present is required concerning the real effects of the various parameters on the insulation performances in order to make these correction factors applicable. In any case this is not a subject which is relevant to test methods but to methods of calculation of thermal performance. In this context, at the recent ISO 163 Subcommittee 1 on Test Methods in West Berlin the USA delegation, with some of the other delegations, were successful in persuading the whole group that the inclusion of these factors was in fact under the jurisdiction of Subcommittee 2 on Calculation Methods.

Overall, these activities outside the USA must in the future have a bearing on the thoughts, considerations, and actions of such organizations as ASHRAE, ASTM and, hence, on the Federal, State and Official Code Organizations. However, the philosophy described should not be adopted without further information being made available to justify any coefficients or indexes used.

6.6 Building Code Impacts Other Than Thermal Performance

In addition to specification of permissible heat loss or gain from buildings, the Building Codes influence the use and manner of installation of insulations. While many insulations have desirable properties

from a thermal performance aspect some have possible drawbacks due to other considerations. As an example, some cellular plastics have a high thermal resistance per unit thickness and serve as an air barrier to reduce heat loss due to infiltration. However, among the less desirable properties of some foams are fire spread characteristics, emission of large quantities of smoke during combustion, possible emission of toxic fumes during combustion, and deterioration of properties with time.

To protect building occupants from the hazards associated with the above fire properties, codes have set maximum surface flame spread and smoke developed requirements for foams as well as other products. They also require that foams not be installed with exposure to habitable spaces. Appropriate fire barriers such as 1/2 inch gypsum board must be installed between habitable spaces and foams. Such thermal protection delays the time of involvement of plastic foams in an interior fire and gains additional time for evacuation of the structure during a fire.

The toxicity of smoke and fumes emitted from building structures during fires is a matter of increasing concern. All organic materials emit smoke and various gases during combustion. Carbon monoxide is a component of all fire gases and is recognized as one of the major causes of fatalities. Exposure of building inhabitants and fire fighters to products of combustion could result in long-term harmful effects and even death. Those active in the study of fires and in building codes have done a great deal of investigation into toxicity of materials during fire, but the subject is very complex and no satisfactory means of measurement has yet been devised. In response to the need for regulation, all of the Model Codes had requirements that emitted gases must be no more toxic than those emitted by wood burned under similar conditions. This requirement has not been possible to enforce due to lack of an acceptable, statistically significant method of test, and therefore has been removed.

The Committee of the American Society for Testing and Materials which is responsible for Fire Tests of Materials and Constructions has studied the problem for several years and is now about to vote on a Recommended Practice for Biological Evaluation of the Toxic Effects of Smoke. They also will draft a test method aimed at identifying unusually toxic materials. Upon acceptance of such test methods, it is probable that Building Codes will include restrictions on materials, including insulations, based on accepted test standards.

6.7 Conclusions

Codes and specifications appear at this time to reflect adequately the state-of-the-art and consensus standards with regard to thermal insulation. As knowledge of materials, testing and systems increases, it is important that the codes keep abreast of developments and update those sections dealing with thermal insulations.

An existing deficiency in 1977 is that the Model Codes have only appendixes that refer to energy conservation. This is inherent in the method of operation of the code bodies. It is, therefore, of major importance that governmental bodies adopt these appendixes as part of their local codes so the provisions for energy conservation for new buildings will have the force of law.

It is suggested that the National Conference of States on Building Codes and Standards continue their efforts to induce states, municipalities, and federal agencies to adopt energy conservation code provisions.

Upon adoption, the problem will be code enforcement. Building officials and inspectors may not be sufficiently familiar with insulation theory and practice for enforcement as thermal performance of insulations

has not been a part of building codes. The model code agencies have traditionally conducted courses for building officials and inspectors on code interpretations.

A start is being made on such education in the energy conservation field. An Energy Conservation Summer Institute was conducted at Salt Lake City, Utah during August, 1977. Programs for building inspectors, plan reviewers, and building officials were included. This program was sponsored by the Model Code organizations under contract with ERDA. In the Building Officials and Code Administrators International (Administrators of the Basic Code) "Bulletin" dated September 5, 1977, the announcement was made of a three-day program on energy conservation to be presented at the BOCA meeting in January, 1978.

If the ASHRAE recommendations for refitting of existing buildings (drafts 100.2P through 100.6P) are accepted, a problem of enforcement will arise. Changes in building codes have not, for the major part, been retroactive. To adopt and enforce such provisions on refitting will require a change in philosophy and possible legal tests of constitutionality. This is a procedural matter that must be examined carefully to determine legality and public acceptance. If found acceptable it may be decided that enforcement should be by means other than building codes.

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Section 7

CONCLUSIONS

The present and near-future demand for building envelope insulation materials has created potential shortages, both in availability of certain insulation products and of certain raw materials used in the production of insulation. The industry has projected significant expansion by 1980. It has been suggested that this expansion will enable the industry to meet the increased demand resulting from programs designed to improve thermal performance of buildings (8). The impact of this expansion on raw materials availability is uncertain at the present time.

The bulk of information on properties and performance of insulation materials has been provided by the insulation manufacturers. This information has been developed and provided to meet user demand, e.g., more data have been requested and are available for commercial/industrial applications than for residential use. With the recent need for energy conservation, our knowledge of the thermal performance of all insulating materials systems has grown, and it is apparent that this knowledge must continue to grow. There are gaps in our knowledge for all insulating materials and systems. There is insufficient information on installed performance for most insulation materials, and in some cases there is a wide range of thermal performance claims for like materials.

Some erroneous and unsubstantiated claims have been made by those outside the industry concerning the performance and behavior of individual products and generic materials currently in the market place. Unfortunately, much documented information is proprietary and not in the public sector to assist in providing complete answers or to resolve some of the discrepancies.

This report is a compilation of available information dealing with factors which influence performance. As a result of this compilation and assessment, better informed decisions can be made regarding the use of the various materials or products concerned. In order to optimize effectively the use of thermal insulation in buildings, most of those involved in building design, construction, installation and operation, as well as legislators and enforcement officials, need more knowledge concerning insulation and its use.

In general, the thermal properties and performance information presented in this report were obtained under "static" test conditions. There is very limited information which describes the dynamic thermal performance and other effects in real life conditions of the actual installation.

Most information is presented for the insulation material as it would normally appear after removal from the manufacturer's package and made ready for installation or as otherwise indicated by the manufacturers' specifications. The major manufacturers do not have direct control over the distribution or installation of their products, although they do influence the system. They make very specific installation recommendations and some offer training courses. Some of the smaller manufacturers, particularly those making cellulose insulation, are integrated from manufacturing through installation. In most cases, plant manufacturing quality control is adequate, but problems have been experienced with some insulation materials processed on-site. Also, the installation of all insulation materials has not been well controlled. With the sensitivity to energy conservation, attention to installation details in the market place is improving.

Properties of insulation materials are usually presented for the material by itself, separated from its system. These data are then used in design calculations to predict the performance of envelope systems

which are part of the building structure. There are, however, differences in assumptions and methods used for design calculations. This could result in performance predictions which are different from actual performance. There is a lack of experimental verification of the predicted performance of these systems, both by simulated laboratory experiments and tests in actual field conditions. There is also a lack of test methods and instrumentation for field evaluation of performance.

The technology of "static" testing is advancing to meet current demands for the measurement of R-values over a wider range of insulation thickness and temperature. To support this testing, there is an urgent need for a variety of reference materials. These materials must represent a range of thermal conductance and a range of material thickness. The technology for dynamic testing is still in its infancy since there has been little demand for the data obtained by such testing.

This study has shown a lack of dynamic evaluation and field testing. However, it has also demonstrated that there is a broad spectrum of materials and systems currently available and presently in use. These form a good base for current and future energy conservation methods.

Codes and specifications appear to reflect adequately the state-of-the-art with regard to methods of testing and insulation materials. A present deficiency is that reference to energy conservation is not mandatory in all codes.

The field of thermal insulation has advanced rapidly over the years from the original concepts. It is no longer adequate to consider an insulation by itself. When considering thermal performance of a building envelope, both the insulation material and building system must be considered. The subject is very complex and thus requires comprehensive efforts to provide the information needed in order to use thermal insulation to its fullest advantage. The manufacturing segment of the industry must

continue to lead in the development of improved materials, manufacturing processes, test procedures and installation procedures. However, with recent emphasis on energy conservation, government now has a growing involvement in the use of thermal insulations. A coordinated, concentrated and cooperative effort by all interested parties is necessary in order to continue the progress that has already been made.

Section 8

RECOMMENDATIONS

It is clear from this assessment that despite all of the valid information that is now available on the properties and performance of thermal insulation materials for building applications, there are a number of significant gaps in our knowledge. In order for the nation to make the best use of thermal insulation for conservation purposes in both new and existing buildings, it is necessary that a concerted effort be made to fill some of these knowledge gaps. This is a multi-faceted problem of such magnitude that it will require considerable effort to develop acceptable solutions.

Two general recommendations which address the subject are:

1. There is an immediate need for a cooperative effort among manufacturers, associations, building contractors, installers, code organizations, standards making bodies, universities, federal, state, and local governments, and consumer groups. This effort should include:
 - (i) Collection and dissemination of information on thermal performance of buildings and the variables affecting performance;
 - (ii) Education of relevant groups to a higher level of knowledge about thermal performance and the factors affecting performance;
 - (iii) Integration and coordination of existing technical research studies on economics, supply and raw material factors, and performance evaluation of both general and specific areas relevant to building insulation materials and systems;
 - (iv) Initiation of research and development studies on performance of insulation systems.

2. Improve the coordination and cooperation among government departments and agencies having technical, economic, and regulatory interests in building insulations. These include the Departments of Energy, Commerce, Defense, Housing and Urban Development, Health Education and Welfare, the Federal Trade Commission, and the Consumer Product Safety Commission.

Specific recommendations which require immediate attention are:

3. The National Bureau of Standards should establish a capability to provide testing laboratories and insulation manufacturers standard heat flow reference specimens of sizes adequate for existing or proposed apparatus and in thicknesses to cover the range installed in structures.
4. Establish educational programs in thermal insulation practices for building insulation contractors and installers and building code, state and local officials. Encourage educational institutions to establish courses in thermal insulation technology in the current scientific and engineering curricula.
5. Encourage the National Conference of States on Building Codes and Standards to continue their efforts to induce states, municipalities, and federal agencies to adopt energy conservation code provisions based on performance criteria.
6. Timely studies are required specific to individual materials to identify realistic performance goals. Some of these studies are more appropriately undertaken by manufacturers or trade associations, others by the Department of Energy or other government agencies.
 - (1) Investigate changes with time of thermal performance and fire resistance of all insulation materials. In particular and where appropriate, the long-term effects of extreme temperatures, temperature cycling, shrinkage, settling, moisture, and weathering should be studied.

- (ii) Initiate efforts designed to improve both dry and wet cellulose fiber insulation manufacturing processes and quality control procedures.
- (iii) Initiate efforts to find other acceptable base materials and alternate chemicals to produce cellulose fiber insulation equal or superior to that currently available.
- (iv) Initiate immediately efforts to evaluate independently the effects of shrinkage and environmental conditions (temperature, humidity) on the thermal performance of urea-based foam products. These studies may indicate a need for improved urea-based foam products.
- (v) Initiate studies to determine a quantitative relationship between R-value and temperature for all insulation materials where such information does not exist or is not available. The R-values used for building design could then be based on the appropriate design temperatures experienced within the USA. This would allow more accurate conductive heat flow calculations for the variety of climatic conditions encountered. It would provide a better calculation base for cooling and heating conditions. It would also enable the designer to consider the effects of location or placement of the insulation within the structure.
- (vi) Establish standardized quantitative small- and large-scale test methods for fire performance of insulation materials and systems. Further developments in test methods for evaluating full-scale fire performance of building wall systems are necessary. Methods exist to test individual wall and roof/ceiling components, but this does not satisfy the need for understanding complete system performance. An extension of the Factory Mutual calorimeter test now used for roof assemblies might be desirable. Any test method should obtain information on smoke generation in addition to evaluation of the fire hazard.

(vii) A realistic test method for toxicity of products of combustion from all insulation materials should be developed.

(viii) A realistic test method for determining the corrosive effects of building insulation materials should be developed.

7. A number of significant long-term, large-scale systems studies should be initiated immediately in order to evaluate more accurately the over-all dynamic and transient effects of thermal insulations in buildings. These are intended to augment and not replace current programs in this area, such as the ASHRAE sponsored research programs on transient response. Among the most prominent are:

(i) The development of the equipment and establishment of the necessary analytical and experimental criteria for undertaking large-scale dynamic thermal performance tests. This must be supported by large-scale steady-state testing.

(ii) The establishment of a test method for determining the effects of air movement through insulation materials.

(iii) The evaluation of the effects of different size, shape and orientation of air gaps, cracks, and voids on system performance.

(iv) The establishment of effects of the mass of the building envelope on heat loss or gain under cyclic conditions.

(v) The determination of the importance of vapor barriers and ventilation under various climatic conditions. Important aspects that need to be considered are effects of condensation and ice formation on insulation, framing members, exterior siding, exterior paint, etc. Information is needed on the detrimental effects of penetrations of moisture barriers. Comparisons are needed of the

use of vapor barriers integral with insulation and the use of plastic films separate from insulation. Information is needed to show whether possible problems related to moisture condensation are influenced by increased thermal resistance. Such a study would define conditions where vapor barriers are deficient or improperly installed or where they should be required.

- (vi) The clarification of the actual in-service moisture flow conditions which take place in a wall with high thermal efficiency. Steady-state laboratory simulations of moisture flow have limited correlation with dynamic real world conditions.

8. A long-range goal is the establishment of criteria and suitable methodology and instrumentation for the quantitative determination of field performance of building envelopes. Areas of research and development to support this goal should include:

- (i) Development of analytical and experimental relationships between steady-state, transient, and dynamic effects in simulated laboratory scale tests.
- (ii) Development of quantitative relationships between thermography and laboratory tests for insulation systems.
- (iii) Evaluation of thermography, heat flow meter equipment, and transportable hot box equipment in field studies.
- (iv) Development of field equipment and test methods which are simple to operate and which can provide reliable performance data.

9. Ensure that analytical techniques for determining thermal performance of buildings and cost effectiveness or other measures of effectiveness of insulation are upgraded to reflect advances in the state-of-the-art of insulation technology.

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APPENDIX A

Questionnaire - "Survey of the Building Insulation Industry"

SURVEY OF THE BUILDING INSULATION INDUSTRY

The purpose of this survey is to provide a general characterization of the existing and future building insulation industry and market. The information you supply will be incorporated into a document providing authoritative state-of-the-art information on insulation materials and systems. The intention is for this document to be used by decision makers in government, regulatory bodies, manufacturers, installers and consumers. As a contributor to this survey, you will receive a copy of the final report.

Name of Company

Street

City

State

Zip

Name of person who should be contacted
if questions arise regarding this survey

Telephone Number

INSTRUCTIONS

Please prepare and return one (1) copy of this survey for *each product manufactured*

Dr. Edward Ashare
Dynatech R/D Company
99 Erie Street
Cambridge, Mass. 02139
(617) 868-3050

- If information is not provided because it is proprietary, please so state.
- If information is not available, please so state.
- If more space is necessary, please use back page.

Additional copies of this survey form are available on request from the above address.

Thank you for your cooperation and assistance.

1. Type of Insulation Manufactured (*Please check appropriate box and indicate specific type of material to which this response refers.*)

☐ Mineral Fiber - Batts	☐ Cellulose - Spray Applied
☐ Mineral Fiber - Loose Fill	☐ Foam and Mineral Board Combined
☐ Mineral Boards	☐ Insulating Concrete
☐ Foam - In Place	☐ Inorganic Fill
☐ Foam - Boards	☐ Organic Fill
☐ Foam - Spray Applied	☐ Reflective
☐ Cellulose - Loose Fill	☐ Other
☐ Cellulose - Boards	

Type _____

2. Principal Uses (*What percentage of your product use will be for the indicated markets?*)

a) New Construction ____%; Retrofitting ____%.

b) Residential ____% largely ☐ Single Family ☐ Multiple Family
Commercial ____%
Industrial ____%

3. Manufacturing Facilities (Both Existing and Projected)

Location	Product Produced	Production			General Manufacturing Process
		Present	Projected (1982)	Unit of Measure	

4. Distribution

a) Distribution Channels Principally Used

Distributor _____

Application Contractor _____

Dealer _____

Other (Type _____) _____

b) Do distribution patterns differ by geographical area? If so, how?

c) What degree and method of control do you as a manufacturer have over the quality of your insulation product:

i) during manufacture? -

ii) through the distribution channel? -

iii) during installation? -

d) What is the approximate time between manufacture and installation of your product?

5. Please indicate the average selling price to the end-user in cents per square foot per unit thickness (¢/ft²/in thickness) for the indicated geographical regions.

New England _____
Middle Atlantic _____
South Atlantic _____

East North Central _____
East South Central _____
West North Central _____
West South Central _____

Mountain _____
Pacific _____
Alaska _____
Hawaii _____

Additional information and comments

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APPENDIX B

Questionnaire - "Survey of Building Insulation Material Properties"

SURVEY OF BUILDING INSULATION MATERIAL PROPERTIES

Name of Company

Street

City

State

Zip

Name of person who should be contacted
if questions arise regarding this survey

Telephone Number

The information you supply will be used in a study providing an assessment of thermal insulation materials and systems for building applications. This assessment will provide decision-makers in government, regulators, manufacturers, installers, and consumers with a collective source of authoritative, state-of-the-art information on insulation materials and systems. A document will be prepared which will provide:

- 1. a basis for identifying areas where new test standards or methods are needed*
- 2. a basis for establishing priorities in RD&D*
- 3. a basis for performance standards*
- 4. a basis for predicting performance*
- 5. a basis for design*

INSTRUCTIONS

Please prepare and return one (1) copy of this survey and two (2) copies of your marketing literature for *each product manufactured to:*

Dr. Edward Ashare
Dynatech R/D Company
99 Erie Street
Cambridge, Mass. 02139
(617) 868-8050

Please indicate, where relevant, if information supplied has been generated internally, verified independently, or estimated.

- If information is not provided because it is proprietary, please so state.
- If any question is not applicable to your product, please enter N/A.
- If data are not available, please so state.
- If more space is necessary, please use back page.

Additional copies of this survey form are available on request from the above address.

Thank you for your cooperation and assistance for which you will receive a copy of the project report.

1. Product - Description or Trade Name and Recommended Applications

2. Composition and Form *(Please indicate, where applicable, closed cell content, blowing agent, fiber size, shot content, flame retardant and concentration, and any other pertinent information.)*

3. Standard Sizes or Quantities

4. Density or Unit Weight

5. Thermal Performance *(Please report, if available, values at the indicated temperatures.)*

Property	0°F	75°F	150°F	Other
a) k or λ , BTU-in/hr ft ² °F				
b) thermal resistance, R , °F hr ft ² /BTU				
c) thermal conductance, C , Btu/hr ft ² °F				
d) heat capacity, Btu/lb °F				

Additional information and comments

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APPENDIX C

National Voluntary Laboratory
Accreditation Program

(Reprinted from Federal Register,
Volume 42, Number 47 - March 10, 1977
pages 13326-13336)

U.S. DEPARTMENT OF COMMERCE
OFFICE OF THE SECRETARY

Reprinted from Federal Register, Volume 42, Number 47—Thursday, March 10, 1977.

(Pages 13326-13336)

OFFICE OF THE SECRETARY

**NATIONAL VOLUNTARY LABORATORY
ACCREDITATION PROGRAM**

**Preliminary Finding of Need To Accredit
Testing Laboratories That Test Thermal
Insulation Materials**

Introduction. In a notice published in the *FEDERAL REGISTER* on February 25, 1976 (41 FR 8163-8168), the Secretary of Commerce promulgated procedures for the operation of a National Voluntary Laboratory Accreditation Program (NVLAP). As announced in that notice, the goal of this program is to provide in cooperation with the private sector a national voluntary system to examine upon request the professional and technical competence of private and public testing laboratories that serve regulatory and non-regulatory product evaluation and certification needs. The program will accredit those laboratories that meet the qualifications established under the mentioned procedures. Section 7.4(b) of those procedures sets out the requirements to be met by those persons who seek to have the Secretary find that there is a need to accredit testing laboratories which render services regarding a specific product so that it may be ascertained whether such product meets the requirements of applicable standards.

Pursuant to the referenced procedures, the Thermal Insulation Manufacturers Association, Inc., Mount Kisco, New York; the National Mineral Wool Insulation Association, Inc., Summit, New Jersey; and the National Cellulose Insulation Manufacturers Association, Inc., Elk Grove Village, Illinois, filed with the Secretary of Commerce on December 1, 1976, a joint request that the Secretary find that there is a need to accredit testing laboratories which render services in the field of thermal insulation. The requestors state that they are trade associations which are users of testing laboratories that serve regulatory and nonregulatory product evaluation and certification needs.

Summary of request. The request identifies the product as measurement serv-

ices associated with thermal insulation and classifies such services as measurement of the following properties of thermal insulation:

1. Thermal properties;
2. Dimensions, stability and density properties;
3. Strength properties;
4. Fire properties; and
5. Properties of vapor barriers.

For each classification of measurement service specified above, the request identifies a number of standard test methods, recommended practices, or definition of terms promulgated by the American Society for Testing and Materials (ASTM). The request contends that these standards can serve as a point of reference for ascertaining the technical competence and proficiency of testing laboratories that provide measurement services as classified by the request. Appendix 1 to this notice identifies these classes of measurement services and lists 51 related ASTM standards that were submitted with the request.

The request indicates that the measurement services for which it seeks to have testing laboratories accredited were selected on a priority basis with a view as to what is feasible and practical at this time. In support of its judgment in selecting the measurement services listed above, the request identifies in those measurement services several test methods or recommended practices (identified by asterisk (*) in Appendix 1) that can be served directly or indirectly through the use of existing competences or services of the National Bureau of Standards. In addition, the request states that such measurement services would satisfy the major provisions of 45 identified specifications for thermal insulation and that accreditation of testing laboratories offering such measurement services would serve the initial needs of users of the program. Appendix 2 to this notice lists the thermal insulation specifications contained in the request and illustrates their use of measurement services of the type classified and identified by the request. Appendix 3 to this notice lists the titles of these specifications. The request notes that a laboratory accreditation program for thermal insulation may eventually need to enlarge and expand its classification of measurement services to accommodate the large numbers of specifications, test methods and recommended practices

that are applicable to thermal insulation. The request references 121 test methods or recommended practices and 113 specifications for thermal insulation that may eventually need coverage by an expanded accreditation program for thermal insulation.

The request furnishes numerous documents in support of its belief that a laboratory accreditation program in the field of thermal insulation would benefit the public interest. These documents consist of or otherwise identify policy statements, assessment reports, major standards and codes, surveys of regulations, impact studies, public laws, and consumer guidelines that stress the need for energy conservation and adequate thermal insulation. The request indicates that these attachments illustrate the importance of thermal insulation in energy conservation, demonstrate the involvement of government with the problem, and show the impact of energy conservation and thermal insulation actions upon the public sector and the consumer.

The requestors claim that without accredited testing laboratories to evaluate thermal insulation, conditions exist for product misrepresentation and restraint of trade. The request states that a laboratory accreditation program in the field of thermal insulation would facilitate commerce and benefit the consumer interest without undue intervention of the government in the marketplace. The requestors state that they know of no other existing or contemplated program in either the public or private sector to accredit laboratories that test thermal insulation.

The requestors estimate that between 25 to 40 laboratories would desire to be accredited for the testing of thermal insulation. In support of this estimate, the request reference laboratories listed in the ASTM Directory of Testing Laboratories, the Directory of the American Council of Independent Laboratories, and a report issued by the Energy Research and Development Administration, ERDA TID-27210, *Industrial Thermal Insulation, An Assessment*.

The request further states that the number of users that would desire services of accredited testing laboratories in the field of thermal insulation is difficult to estimate accurately but is believed to be in the thousands. The request claims that manufacturers, and purchasers of thermal insulation, building code jurisdictions and federal agencies concerned

with energy conservation and thermal insulation are all users that have a potential interest in the accreditation of laboratories that test thermal insulation.

Analysis of request. A careful analysis as made of the request which consisted of two volumes entitled, "An Application to the: Secretary of Commerce for a National Voluntary Laboratory Accreditation Program, 15 CFR, Part 7, for Thermal Insulation". The results of this analysis are contained in a report entitled, "Summary and Analysis Report, Thermal Insulation, February 1977", hereafter referred to as the Summary and Analysis Report.

Compliance of request to section 7.4(b) of NVLAP procedures. Any requests submitted under the NVLAP procedures must comply with subsections 7.4(b) (1), (2), (3), and (4). Specifically, these subsections are as follows:

(b) Such a request shall be in writing and will include the following:

- (1) Identification of the product;
- (2) Text of an applicable standard;
- (3) Text of a test method, if not included in the applicable standard identified in paragraph (b) (2) of this section; and
- (4) Basis of need for accrediting testing laboratories that serve the product identified in paragraph (b) (1) of this section. The basis will provide information relative to the items set out in § 7.5 and will include, where appropriate, documentary evidence on such items as:

(i) The number of testing laboratories that is believed will want to be accredited to serve the product identified in paragraph (b) (1) of this section; and

(ii) The number of users of testing laboratories that is believed will desire services of testing laboratories accredited to serve the product identified in paragraph (b) (1) of this section."

While the submitted request conforms to subsection 7.4(b) (4), it does not specifically identify a specific product as required by subsection 7.4(b) (1) for which testing laboratories render services. However, an analysis of the request discloses that in reality the specific product for which testing services would be provided is "thermal insulation materials." The submitted request is also in conformity with subsection 7.4(b) (2) as it identifies 45 specification standards applicable to thermal insulation materials" as set out in Appendix 3 to this notice. Finally, the request complies with subsection 7.4(b) (3) in that test methods are included which are applicable to these 45 specification standards.

The submitted request will, therefore, be accepted on the above basis.

Basis for preliminary finding of need. In accord with section 7.5 of the procedures of the National Voluntary Laboratory Accreditation Program the following information and comment are provided in support of the preliminary finding of need set out in this notice.

a. *Does the establishment of general or specific criteria and other conditions for accrediting testing laboratories that test thermal insulation materials benefit the public interest?*

After careful analysis of the request, and its attachments, it is concluded that

the establishment of criteria and other conditions for accrediting such testing laboratories would benefit the public interest. This conclusion is based upon the following findings:

1. Conservation of energy is in the public interest;

2. Thermal insulation of industrial processes and commercial and residential buildings is generally recognized as an effective approach to conserving energy;

3. Standards and codes now contain or reference, and will increasingly utilize, specifications for thermal insulation materials that require testing of such insulation.

4. A number of acceptable methods exist for testing of thermal insulation, although such methods will need to be increased in number and/or further refined for testing of thermal insulation materials under conditions of realistic use.

5. Methods of testing thermal insulation materials are prone to errors in their application that may be reduced by programs for laboratory accreditation that are not now available.

Statements and opinions in support of these findings were derived from a careful reading and evaluation of the request and its attachments. These statements are contained in the Summary and Analysis Report.

b. *Is there a national need to accredit testing laboratories that test thermal insulation materials beyond that served by any existing laboratory accreditation programs in the public or private sector?*

There is no existing laboratory accreditation program, either public or private, in the field of thermal insulation materials.

The findings listed above point to the importance of adequate thermal insulation in the national energy conservation effort and the fact that test methods applicable to thermal insulation materials are subject to error in their application. As specifications frequently require application of such test methods to determine compliance of thermal insulation material to requirements, erroneous judgments deriving from erroneous test results can be made concerning the adequacy of thermal insulation material.

Laboratory accreditation under the NVLAP can assist in improving the reliability of test results regarding the properties of thermal insulation. This will enhance the ability of users of thermal insulation materials to plan and implement efficient energy-use systems, thereby helping to reduce costs and waste of fuel resources. With more reliable test results, producers will be encouraged to implement more effective quality control procedures to reduce variability of thermal insulation production. Further, certifiers, regulators, and code jurisdictions will have available better quality assurance capabilities.

c. *For thermal insulation materials is there in existence a standard that is deemed by the Secretary as being of importance to commerce, consumer well-being, or the public health and safety?*

In this preliminary finding of need, the specific product involved is thermal insulation material. The standards submitted by the requestors are the 45 specification standards set out in the Appendix 3 to this notice.

This listing of specifications includes Federal, military, maritime and ASTM specifications relating to various forms (blankets, boards, loose fill, etc.) of a wide range of materials used for thermal insulation. The list of specifications applies to both industrial and residential usage related to insulation for pipes, ducts, machinery, and structural panels (floors, walls, ceilings).

It is clearly evident that the listed specification standards as a body are vitally important to the conservation of energy, both commercially and residentially. It is therefore concluded that the listed specification standards are significantly important to commerce, consumer well-being, or the public health and safety.

d. *Is there in existence a valid testing methodology as determined by the Secretary for ascertaining conformity to the 45 specification standards for thermal insulation materials?*

Of the several test methods and recommended practices proposed in the request and shown by appendices 4 through 8 to this notice to be related to thermal insulation specifications, several are considered to be fundamental and/or known to be proven in practice and it is concluded that they are valid. These methods include ASTM standards C177, C518, C335, C236, C653, C687, C167, C302, C303, C519, C520, D1622, C165, C203, C209, C446, D1621, E84, E136, and E95. The titles of these methods are shown in Appendix 1 to this notice.

Other methods proposed by the request and shown to be referenced in thermal insulation specifications relate to definition of terms, sampling techniques or tests and practices used by laboratories to test thermal insulation materials for intended use. These methods include ASTM standards C390, C168, C585, C355, D2842, D2126, D591, C272, D756, C411, C450, D781, D828, C273, D2020, C445, and D777. Titles for these standards are also shown in Appendix 1 to this notice. After an examination of these latter methods it is concluded preliminarily that they are valid.

It should be noted that Appendices 4 through 8 to this notice identify several ASTM standard methods that are not referenced by those thermal insulation material specifications included in the request. As they are not specifically related to thermal insulation materials as defined by specifications listed in Appendix 3 to this notice, they are not demonstrated to be "associated services" as required by the NVLAP procedure's definition of the term "product."

Accordingly, ASTM methods C691, C550, D826, C447, C569, C589, C755, C686, D1623, C677, D1204, D882, D1790, and D1922 are deleted as test methods or recommended practices within the scope of this laboratory accreditation program.

e. Is it feasible and practical to accredit testing laboratories that test thermal insulation materials?

In regard to technical considerations, the proposed laboratory accreditation program is both feasible and practical. As indicated by the requestors, a basis exists for ascertaining conformity of measurement services to several of the ASTM standard methods that would be applicable to the program. There also exists established and interested technical committees in the private sector that are active in the field and whose advice and assistance in establishing needed additional methodology will be invaluable. Several government agencies and industrial entities have programs involved with evaluation and effective utilization of thermal insulation materials and their competence could presumably be relied upon.

In regard to utilization of the program, the requestors estimate that 25 to 40 testing laboratories would desire to be accredited under the proposed program. A review of laboratory directories, surveys and other information described in the Summary and Analysis Report identifies 53 laboratories that are active in testing of thermal insulation. The information reviewed was somewhat limited and insufficiently detailed for the purpose of this review so this latter number may be conservative.

The 37 ASTM standard test methods, including recommended practices, applicable to the proposed laboratory accreditation program will serve the major provisions of the 45 thermal insulation specifications listed in Appendix 3 to this notice. Many of these test methods and recommended practices will also serve the provisions of other thermal insulation specifications. The need for energy conservation and the importance of adequate thermal insulation materials in serving this need should encourage a large constituency of users to utilize the proposed laboratory accreditation program.

Based on the above described examination and analysis, it is hereby concluded that it is feasible and practical to accredit testing laboratories to test thermal insulation materials.

Preliminary finding of need. The request, including the 16 attachments which were submitted in support thereof, has been carefully examined and analyzed. Based on that examination and analysis, which are described above, it is hereby preliminarily found that a need exists to accredit testing laboratories that test thermal insulation materials as required by the 45 specification standards set out in Appendix 3 to this notice. The test methods, including recommended practices, that are included under this preliminary finding of need are those listed in Appendix 9 to this notice.

Request for comments. Interested persons desiring to comment on the preliminary finding of need set out above are invited to submit such comments, in four copies, on or before April 11, 1977, to the Assistant Secretary for Science and Technology, Department of Commerce,

Room 3862, Main Commerce Building, Washington, D.C. 20230.

Any person desiring to express his or her views in an informal hearing relative to the mentioned preliminary finding of need shall do so by communicating that desire in writing on or before March 25, 1977, to the Assistant Secretary for Science and Technology at the address shown in the preceding paragraph. Upon receipt of such request, informal public hearings will be held so as to give all interested persons an opportunity for the oral presentation of data, views, or arguments, in addition to the opportunity to make written submissions. If deemed appropriate, such hearings may be held at two locations, one of which shall be east of the Mississippi River and the other west thereof. Notice of such hearings will be published in the *FEDERAL REGISTER* at least twenty (20) days in advance thereof. A transcript will be made of any oral presentation.

Procedure following receipt of comments. Upon receipt of the comments submitted in response to this notice, including the testimony of any hearings that may be held in conjunction therewith, a full and complete evaluation of such comments and testimony will be undertaken. Upon completion of that evaluation, a notice will be published in the *FEDERAL REGISTER* announcing a final finding of need to accredit testing laboratories that test thermal insulation materials or withdrawing the preliminary finding of need announced in this notice. In either event, the notice will set out the basis for the final finding of need or for the withdrawal of the preliminary finding of need in accordance with sections 7.4 (g) and (h) of the NVLAP procedures.

As an integral part of the process of evaluating the comments received, close communication and consultation will be undertaken with those Federal agencies which are believed to have an interest in or may be impacted by this particular laboratory accreditation program. In this way an effective and meaningful cooperation with interested Federal agencies may be established.

The request submitted by the trade associations, identified earlier herein, to accredit testing laboratories that test thermal insulation materials, is not believed to affect an existing or developing testing laboratory examination or accreditation program of a Federal regulatory agency. Accordingly, no attempt is being made, pursuant to section 7.4(d) of the mentioned procedures to seek from the head of any Federal regulatory agency its views relative to the preliminary finding of need announced by this notice.

Before a final finding of need in this matter is announced, a determination will be made on whether the program to accredit testing laboratories that test thermal insulation materials would have a major inflationary impact under the criteria set out in Department Administrative Order 218-6, dated September 12, 1975, entitled "Inflationary Impact of Legislative and Regulatory Proposal."

Documents in public record. The documents which are part of the public record include the December 1, 1976 request filed by the trade association requestors and the 16 attachments submitted in support thereof, the Summary and Analysis Report and its appendices, which was referred to earlier in this notice, and the referenced Department Administrative Order 218-6. Such documents are available for inspection and copying in the Department's Central Reference and Records Inspection Facility, Room 7068, Main Commerce Building, 14th Street between E Street and Constitution Avenue, N.W., Washington, D.C. 20230.

All written and oral comments furnished in response to the invitation made by this notice will also be made part of the public record. Such comments will be available for inspection and copying at the inspection facility referenced in the preceding paragraph.

Any person having questions or desiring further information relative to the matters covered in this notice may contact Dr. Howard I. Forman, Deputy Assistant Secretary for Product Standards, Department of Commerce, Room 3876, Main Commerce Building, Washington, D.C. 20230. Dr. Forman's telephone number is (202) 377-3221.

Issued: March 7, 1977.

BETSY ANCKER-JOHNSON,
Assistant Secretary for
Science and Technology.

APPENDIX 1

CLASSIFICATION AND IDENTIFICATION OF MEASUREMENT SERVICES AS PROPOSED BY THE REQUEST

Classification 1: Measurement of Thermal Properties

ASTM Standard and Title

- C177—Steady State Thermal Transmission Properties by means of the Guarded Hot Plate
- C518—Steady State Thermal Transmission Properties by means of the Heat Flow Meter
- C335—Thermal Conductivity of Pipe Insulation by Guarded End Apparatus
- C236—Thermal Conductance and Transmittance of Built-up Sections by means of the Guarded Hot Box
- C691—Thermal Transference of Non-Homogeneous Pipe Insulation at Temperatures Above Ambient
- C653—Recommended Practice for Determination of Thermal Resistance of Low Density Mineral Fiber Blanket-Type Building Insulation
- C687—Recommended Practice for Determination of Thermal Resistance of Low-Density Fibrous Loose Fill Type Building Insulation
- C390—Preformed Thermal Insulation Sampling
- C168—Definition of Terms Relating to Thermal Insulating Materials

Classification 2: Measurement of Dimension, Stability and Density Properties

ASTM Standard and Title

- C167—Tests for Thickness and Density of Blanket or Batt Type Thermal Insulating Materials

See footnotes at end of article.

- C302—Tests for Density of Preformed Pipe Covering Type Thermal Insulation
- C303—Test for Density of Preformed Block Type Thermal Insulation
- C519—Test for Density of Fibrous Loose Fill Building Insulations
- C520—Test for Density of Granular Loose Fill Insulations
- C550—Tests for Trueness and Squareness of Block Thermal Insulations
- D1622—Test for Apparent Density of Rigid Cellular Plastics
- C583—Recommended Practice for Inner and Outer Diameters of Rigid Thermal Insulation for Nominal Sizes of Pipe and Tubing (NPS System)
- C355—Test for Water Vapor Transmission of Thick Materials
- D2842—Test for Water Absorption of Rigid Cellular Plastics
- D2126—Test for Response of Rigid Cellular Plastics to Thermal and Humid Aging
- D591—Test for Starch in Paper
- C272—Test for Water Absorption of Core Materials for Structural Sandwich Constructions
- D756—Tests for Resistance of Plastics to Accelerated Service Conditions
- D826—Test for Degree of Wet Curl of Paper
- D1204—Measuring Changes in Linear Dimensions of Non Rigid Thermoplastic Sheet or Film
- C411—Tests for Hot Surface Performance of High Temperature Thermal Insulation
- C447—Recommended Practice for Estimating the Maximum Use of Temperature of Preformed Homogeneous Thermal Insulation
- C450—Recommended Practice for Prefabrication and Field Fabrication of Thermal Insulating Fitting Covers for NPS Piping, Vessel Lagging, and Dished Head Segments

Classification 3: Measurement of Strength Properties

ASTM Standard and Title

- C165—Test for Comprehensive Strength of Preformed Block Type Thermal Insulation
- C203—Test for Breaking Load and Calculated Flexural Strength of Preformed Block Type Thermal Insulation
- C446—Test for Breaking Load and Calculated Modulus of Rupture of Preformed Insulation for Pipes
- C569—Test for Indentation Hardness of Preformed Thermal Insulation
- C589—Test for Apparent Impact Strength of Preformed Block Type Insulating Materials
- C686—Test for Parting Strength of Mineral Fiber Batt and Blanket Type Insulation
- D1621—Test for Compressive Properties of Rigid Cellular Plastics
- D1623—Test for Tensile Properties of Rigid Cellular Plastics
- D781—Test for Puncture and Stiffness of Paperboard Corrugated and Solid Fiberboard
- D828—Test for Tensile Breaking Strength of Paper and Paperboard
- D1790—Test for Brittleness Temperature of Plastic Film by Impact
- C209—Testing Insulating Board (Cellulosic Fiber) Structural and Decorative
- C273—Shear Test in Flatwise Plane of Flat Sandwich Construction or Sandwich Cores
- D1922—Test for Propagation Tear Resistance of Plastic Film and Thin Sheet
- D882—Test for Tensile Properties of Thin Plastic Sheet

Classification 4: Measurement of Fire Properties

ASTM Standard and Title

- E84—Standard Method of Test for Surface Burning Characteristics of Building Materials
- E136—Tests for Noncombustibility of Elementary Materials

Classification 5: Measurement of Properties of Vapor Barriers

ASTM Standard and Title

C677—Recommended Practice for Use of a Standard Reference Sheet for the Measurement of the Time-Averaged Vapor Pressure in a Controlled Humidity Space

E96—Tests for Water Vapor Transmission of Materials in Sheet Form

C755—Recommended Practice for Selection of Vapor Barriers for Thermal Insulation

D2030—Test for Mildew Resistance of Paper and Paperboard

C445—Test for Normal Total Emittance of Surfaces of Materials 0.01 inch or Less in Thickness at Approximately Room Temperature

D777—Test for Flammability of Treated Paper and Paperboard

APPENDIX 2

MEASUREMENT SERVICES REQUIRED BY SPECIFICATIONS LISTED IN ATTACHMENT 12B OF THE REQUEST

SPECIFICATIONS FOR THERMAL INSULATION LISTED IN ATTACHMENT 12B	REFERENCES MEASUREMENT OF				
	Thermal Properties	Dimension Stability Density	Strength Properties	Vapor Barrier Properties	Fire Protection
HNB-00100			X	X	X
HNC-561			NONE		
NHI-521	X	X		X	X
NHI-515	X	X			
NHI-545	X	X			X
NHI-558	X	X	X		X
NHI-574	X	X			
NHI-585	X	O			
NHI-578			NONE		
NHI-1030	X	X			X
NHI-1252	X	O		X	
MIL-STND-769F	O	O	O		
LLI-535	X	X	X		O
MILI-742	X	X	X		
MILI-2781	X	X	X		
MILI-2818	X	X			
MILI-2819	X	X	X		
MILI-5475	X	X			
MILI-22023	X	X			
MILI-22344	X	X			
MILI-23128	X	X			
32-MA-1e	X	X			
32-MA-3c	X	X			
C-262	X	X			
C-391	X	X			
C-516	X	X			
C-517	X	X	X		
C-533	X	X	X		
C-549	X	X			
C-553	X	X			
C-592	X	X			
C-610	X	X	X		
C-640	X	X	X		
C-665	X	X		X	X
C-728	X	O	X		X
C-764	X	X			X
C-739	X	X			X
C-578	X	X	X		X
C-591	X	X	X		X
C-532	X	X	X		O
32-MA-4b	X	X	X		X
32-MA-8	X	X	X		X
NHI-324	X	X	X		X
NHI-530	X	X	X		X
NHI-550	X	X	X		X

NOTE: "X" Direct Reference
"O" Indirect Reference

APPENDIX 3

SPECIFICATIONS LISTED IN ATTACHMENT 12B OF REQUEST

H-H-B-00100—Barrier material vapor for fire retardant reinforced for pipe and duct insulation

H-H-C-561—Cork; compressed (corkboard) (for thermal insulation)

See footnotes at end of article.

H-H-I-521—Insulation blankets, thermal (mineral fiber, for ambient temperatures)

H-H-I-515—Insulation blanket, thermal-acoustical, and insulation thermal, vegetable or wood fiber

H-H-I-545—Insulation, thermal and acoustical (mineral fiber, duct lining material)

H-H-I-558—Insulation, blocks, boards, blankets, felts, sleeving (pipe and tube covering), and pipe fitting covering, thermal

(mineral fiber, industrial type)

H-H-I-574—Insulation, loose fill (Perlite)

H-H-I-585—Insulation, thermal (Vermiculite)

H-H-I-578—Insulation pipe covering an block (Vermiculite)

H-H-I-1030—Insulation, thermal (mineral fiber, for pneumatic or poured application)

H-H-I-1252—Insulation thermal, reflective (aluminum foil)

MIL-STND-769F—Thermal insulation requirements for machinery and piping

LLI-535—Insulation board and block, thermal

MIL-I-742—Insulation board, thermal, fibrous glass

MIL-I-2781—Insulation, pipe, thermal

MIL-I-2818—Insulation blanket, thermal, fibrous mineral

MIL-I-2819—Insulation block, thermal

MIL-I-15475—Insulation felt, thermal, fibrous glass semi-rigid

MIL-I-22023—Insulation felt, thermal and sound absorbing felt, fibrous glass, flexible

MIL-I-22344—Insulation, pipe, and thermal, fibrous glass

MIL-I-23128—Insulation blanket, thermal, refractory fiber, flexible

Maritime No. 32-MA-1e—Insulation: mineral fiber, blanket type (3-8 pounds per cubic foot)

Maritime No. 32-MA-3c—Insulation: felt, fibrous glass

C262—Mineral fiber batt insulation (industrial type)

C391—Amosite asbestos thermal insulation for pipes

C516—Vermiculite loose fill insulation

C517—Diatomaceous earth block and pipe thermal insulation

C533—Calcium silicate block and pipe thermal insulation

C549—Perlite loose fill insulation

C553—Mineral fiber blanket and felt insulation (industrial type)

C592—Mineral fiber blanket insulation and blanket type pipe insulation (metal mesh covered) (industrial type)

C610—Expanded perlite block and pipe thermal insulation

C640—Corkboard and cork pipe insulation for low temperature thermal insulation

C665—Mineral fiber blanket thermal insulation for wood frame and light construction buildings

C728—Perlite thermal insulation board

C764—Mineral fiber loose fill thermal insulation

C739—Cellulosic fiber (wood base) loose fill thermal insulation

C578—Preformed, block-type cellular polystyrene thermal insulation

C591—Rigid preformed cellular urethane thermal insulation

C532—Structural insulating formboard (cellulosic fiber)

Maritime No. 32-MA-4b—Plastic material: thermal, cellular, rigid (urethane)

Maritime No. 32-MA-8—Insulation: pipe covering, thermal, rigid (urethane)

H-H-I-524—Insulation board, thermal (polystyrene)

H-H-I-530—Insulation board, thermal (urethane)

H-H-I-550—Insulation sleeving, thermal (urethane)

APPENDIX 4THERMAL PROPERTY TEST METHODS REQUIRED BY
SPECIFICATIONS LISTED IN ATTACHMENT 12B OF THE REQUEST

SPECIFICATIONS ATTACHMENT 12B	ASTM METHOD REFERENCED BY SPEC								Definitions C168
	C177	C518	C335	C236	C691	C653	C687	C390	
HMB-00100									
HMC-561									
HNI-521	X	X		X		X			
HNI-515	X								
HNI-545	X								O
HNI-558	X		X						X
HNI-574	X								
HNI-585	X								
HNI-578									
HNI-1030	X	O		X			X		X
HNI-1252	X								
MIL-STND-769F	O		O						O
LLLI-535	X	O							
MILI-742	X								
MILI-2781			X						
MILI-2818	X								
MILI-2819	X								
MILI-5475	X								X
MILI-22023	X								X
MILI-22344			X						
MILI-23128	X								
32-MA-1e	X								X
32-MA-3c	X								
C-262	X							X	
C-391			X						
C-516	X								
C-517	X		X						
C-533	X		X					X	X
C-549	X								
C-553	X								X
C-592	X							X	X
C-610	X		X						X
C-640	X		X					X	
C-665	X	X				X			X
C-728	X	X						X	X
C-764	X	X		X			X		X
C-739	X	X		X			X		X
C-578	X							X	
C-591	X		X					X	
C-532	X	O							
32-MA-4b	X								
32-MA-8			X						
HNI-524	X							O	O
HNI-530	X								
HNI-550	X		X						

NOTE: "X" Direct Reference
"O" Indirect Reference

APPENDIX 5

DIMENSION, STABILITY, DENSITY TEST METHODS REQUIRED BY
SPECIFICATIONS LISTED IN ATTACHMENT 12B OF THE REQUEST

SPECIFICATION ATTACHMENT 12B	ASTM TEST METHOD REFERENCED BY SPEC														
	C167	C302	C303	C519	C520	C550	D1622	C585	C355	D2842	D2126	D591	C272	D756	D826
HNB-00100															
HHC-561															
HNI-521	X														
HNI-515	X														
HNI-545	X														
HNI-558	X	X	X												X
HNI-574	O				X										
HNI-585	O														
HNI-578															
HNI-1030	X														
HNI-1252	O														
MIL-STND-769F	O	O	O												O
LLLI-535	O	O							X						
MILI-742	X														
MILI-2781		X													X
MILI-2818	X														
MILI-2819	O		X												X
MILI-5475	X														
MILI-22023	X														
MILI-22344		X													
MILI-23128	X														
32-MA-1e	X														
32-MA-3c	X														
C-262	X														
C-391		X													
C-516	O				X										
C-517	O	X	X												
C-533	O	X	X					X							X
C-549	O				X										
C-553	X														
C-592	X														
C-610	O	X	X												
C-640	O	X	X												

APPENDIX 5, CONTINUED

DIMENSION, STABILITY, DENSITY TEST METHODS REQUIRED BY
SPECIFICATIONS LISTED IN ATTACHMENT 12B OF THE REQUEST

SPECIFICATION ATTACHMENT 12B	ASTM TEST METHOD REFERENCED BY SPEC													
	C167	C302	C303	C519	C520	C550	D1622	C585	C355	D2842	D2126	D591	C272	D756
C-665	X													
C-728	0	0							0					
C-764	0			X										
C-739	0			X								X		
C-578	0		X						X				X	
C-591	0	X	X						X		X			
C-532	0	0							X					
32-MA-4b	0						X						X	X
32-MA-8		0					X							X
HBI-524	0						X		X		X		X	
HBI-530	0		0				X		X	X			0	
HBI-550	0	X							X					X

NOTE: "X" Direct Reference
"0" Indirect Reference

NOTICES

APPENDIX CSTRENGTH PROPERTY TEST METHODS REQUIRED BY
SPECIFICATIONS LISTED IN ATTACHMENT 12B OF THE REQUEST

SPECIFICATION ATTACHMENT 12B	ASTM METHODS REFERENCED BY SPEC												
	C165	C203	C446	C569	C589	C686	D1621	D1623	D781	D828	D882	D1790	C209
HHB-00100									X	X			
HHC-561													
HHI-521													
HHI-515													
HHI-545													
HHI-558	X												
HHI-574													
HHI-585													
HHI-578													
HHI-1030													
HHI-1252													
MILI-STND-769F	O	O	O										
LLLI-535													X
MILI-742									X				
MILI-2781			X										
MILI-2818													
MILI-2819	X	X											
MILI-5475													
MILI-22023													
MILI-22344													
MILI-23128													
32-MA-1e													
32-MA-3c													
C-262													
C-391													
C-516													
C-517	X	X	X										
C-533	X	X	X										
C-549													
C-553													
C-592													
C-610	X	X	X										
C-640		X											
C-665													
C-728	X	X											X
C-764													
C-739													
C-578	X	X											
C-591	X		X										
C-532													X
32-MA-4b		X					X						X
32-MA-8		X					X						X
HHI-524		X					X						
HHI-530	O	X					X						
HHI-550							X						

NOTE: "X" Direct Reference
"O" Indirect Reference

APPENDIX 7

**FIRE PROPERTY TEST METHODS REQUIRED BY
SPECIFICATIONS LISTED IN ATTACHMENT 12B OF THE REQUEST**

SPECIFICATION ATTACHMENT 12B	ASTM TEST METHOD REFERENCED BY SPEC		
	E84	E136	Other
HRB-00100	X		
HHC-561			
HHI-521	X		
HHI-515			
HHI-545	X		
HHI-558	X		
HHI-574			
HHI-585			
HHI-578			
HHI-1030	X		
HHI-1252			
MIL-STND-769F			
LLLI-535	O		
MILI-742			
MILI-2781			
MILI-2818			
MILI-2819			
MILI-5475			
MILI-22023			
MILI-22344			
MILI-23128			
32-MA-1e			
32-MA-3c			
C-262			
C-391			
C-516			
C-517			
C-533			
C-549			
C-553			
C-592			
C-610			
C-640			
C-665	X		
C-728	X		
C-764	X		
C-739	X		
C-578			D1692*
C-591			D1692*
C-532	O		
32-MA-4b			D1692*
32-MA-8			D1692*
HHI-524			D1692*
HHY-530			D1692*
HHI-550			D1692*
ALL BUILDING CODES	X		
SEVERAL BUILDING CODES		X	
*Request proposes alternative use of E84.			
NOTE: "X" Direct Reference			
"O" Indirect Reference			

APPENDIX 8

**VAPOR BARRIER TEST METHODS REQUIRED BY
SPECIFICATIONS LISTED IN ATTACHMENT 12B OF THE REQUEST**

SPECIFICATIONS ATTACHMENT 12B	ASTM METHOD REFERENCED BY SPEC					
	C677	E96	C753	D2020	C445	D777
HRB-00100				X		X
HNI-521	X				X	
HNI-1252	X				X	
C-665	X				X	

APPENDIX 9

**ASTM TEST METHODS, AND RECOMMENDED
PRACTICES APPLICABLE TO PRELIMINARY FIND-
ING OF NEED**

ASTM Designation and Title

- C177—Steady State Thermal Transmission Properties by means of the Guarded Hot Plate
C518—Steady State Thermal Transmission Properties by means of the Heat Flow Meter
C335—Thermal Conductivity of Pipe Insulation by Guarded End Apparatus
C236—Thermal Conductance and Transmittance of Built up Sections by means of the Guarded Hot Box
C653—Recommended Practice for Determination of Thermal Resistance of Low Density Mineral Fiber Blanket-Type Building Insulation
C687—Recommended Practice for Determination of Thermal Resistance of Low-Density Fibrous Loose Fill Type Building Insulation
C390—Preformed Thermal Insulation Sampling
C168—Definition of Terms Relating to Thermal Insulating Materials
C167—Tests for Thickness and Density of Blanket or Batt Type Thermal Insulating Materials
C802—Test for Density of Preformed Pipe Covering Type Thermal Insulation
C303—Test for Density of Preformed Block Type Thermal Insulation
C519—Test for Density of Fibrous Loose Fill Building Insulations
C520—Test for Density of Granular Loose Fill Insulations
D1622—Test for Apparent Density of Rigid Cellular Plastics
C585—Recommended Practice for Inner and Outer Diameters of Rigid Thermal Insulation for Nominal Sizes of Pipe and Tubing (NPS system)
C355—Test for Water Vapor Transmission of Thick Materials
D2842—Test for Water Absorption of Rigid Cellular Plastics
D2128—Test for Response of Rigid Cellular

- Plastics to Thermal and Humid Aging
D591—Test for Starch in Paper
C272—Test for Water Absorption of Core Materials for Structural Sandwich Constructions
D756—Tests for Resistance of Plastics to Accelerated Service Conditions
C411—Tests for Hot Surface Performance of High Temperature Thermal Insulation
C450—Recommended Practice for Prefabrication and Field Fabrication of Thermal Insulating Fitting Covers for NPS Piping, Vessel Lagging, and Dished Head Segments
C165—Test for Compressive Strength of Preformed Block Type Thermal Insulation
C203—Test for Breaking Load and Calculated Flexural Strength of Preformed Block Type Thermal Insulation
C446—Test for Breaking Load and Calculated Modulus of Rupture of Preformed Insulation for Pipes
D1621—Test for Compressive Properties of Rigid Cellular Plastics
D781—Test for Puncture and Stiffness of Paperboard Corrugated and Solid Fiberboard
D828—Test for Tensile Breaking Strength of Paper and Paperboard
C309—Testing Insulating Board (Cellulosic Fiber) Structural and Decorative
C273—Shear Test in Flatwise Plane of Flat Sandwich Construction or Sandwich Cores
E84—Standard Method of Test for Surface Burning Characteristics of Building Materials
E136—Tests for Noncombustibility of Elementary Materials
E96—Tests for Water Vapor Transmission of Materials in Sheet Form
D2020—Test for Mildew Resistance of Paper and Paperboard
C445—Test for Normal Total Emittance of Surfaces of Materials 0.01 inch or less in Thickness at Approximately Room Temperature
D777—Test for Flammability of Treated Paper and Paperboard

FOOTNOTES

¹ Related to existing NBS Competence, Reference Sample or Calibration Services.

² Excluding requirements other than those related to testing of thermal, mechanical, fire, and vapor barrier properties.

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APPENDIX D

Position Statement Regarding A Standard Reference Materials Program for Thermal Insulations (ASTM C-16)

Table D.1 - Recommended Candidates for Reference Materials for Insulation Measurement Comparisons

Material	Probable Temperature Range of Applicability (°C)	Nominal Bulk Density Mg/m ³ (pcf)	Thermal Resistance per Unit Length at 25°C mK/W (hr·ft ² ·°F/Stu·in.)	Need or Use
1. Air Space	-160 to 200			Procedural Use Test Plate Emissance and Plate Orientation Effects
2. High Density Molded Fibrous Glass Board	-175 to 150	0.08 to 0.16 (5 to 10)	31.5 (4.5)	Historical NBS Material Minimum Radiation Effect
3. AA Glass Fiber Blanket Insulation	-100 to 400	0.0096 (0.6)	31.5-28.9 (4.5-4.2)	Radiation Effects, Temperature Coefficient, Geometry (Thickness) Effects
4. Glass Fiber Appliance Insulation Blanket	-100 to 230	0.011 to 0.032 (0.7 to 2)	20.4-28.9 (2.9-4.2)	Similar to Item 3
5. Aged Polystyrene Foam	-180 to 75	0.048 (3)	21.7-22.4 (3.1-3.2)	Provides Useful Comparison to 8.9 cm (3 1/2 in.) Fiberglass Batts; Stable after Aging
6. Silicone Rubber	Glass Point to 250	1.28 to 1.60 (80 to 100)	4.08-2.77 (0.59-0.40)	Opaque Material, Interfacing Resistance Effects, Thickness Edge Loss Effects
7. Borosilicate Glass	-175 to 800	2.0 (125)	0.96 (0.14)	Interfacial Resistance Effects Radiation Effects at High Temperature Thickness Effects
8. Closed Cell Foam Glass	-175 to 350	0.14-0.16 (9-10)	16.5 (2.38)	Stable with Reproducible Properties
9. Silica Aerogel Composite Block	-175 to 900	0.32 (20)	38.5 (5.5)	High Thermal Resistance Per Unit Thickness Tests Steady-State Capacity Temperature Coefficient
10. Rigidized Silica Fiber Tile	-175 to 1000	0.16 (10)	27.8 (4.00)	Radiation Effects Known Reproducibility
11. Zirconia Fiber Board	-175 to 2200	0.48 (30)	11.55 (1.67)	Very High Temperature Use Temperature Coefficient Radiation Effects
12. Alumina-Silicate Refractory Fiber Insulation Blanket	-175 to 1250	0.064 (4)	30.1 (4.34)	Radiation and Thickness Effects High Temperature Geometry Effects Temperature Coefficient
13. Mineral Rock Board	-175 to 650	0.192 (12)	23.1 (3.3)	Radiation Effects Temperature Coefficient Geometry Effects
14. Calcium Silicate	-175 to 700	0.19-0.22 (12-14)	17.3 (2.5)	Generic Insulation Type Radiation and Geometry Effects Temperature Coefficients
15. Powder or Loose-Fill Insulation				Sample Preparation Techniques Radiation Effects Isotropic Nature Temperature Coefficient

Cl6.30 Position Statement Regarding a Standard Reference Materials Program for Thermal Insulations

A wide variety and great quantity of measurements are made to determine various thermal properties of insulating materials of different kinds, under a wide range of conditions. These measurements are made for purposes of quality control, properties certification for materials specifications, advertising data, and other reasons. They are made by materials producers and by private and public independent testing laboratories. The existing data on insulation material thermal properties are sparse and sometimes contradictory. One reason is that accurate performance measurements are complex and difficult.

A primary element in any effort to improve the state-of-the-art knowledge of insulation thermal performance and meaningful data base is a series of well characterized reference materials which have thermal performance properties that span the range of products in the marketplace. This series of materials would also provide a framework for a reliable data base of insulating materials properties. No reference materials with certified properties are presently available. The main body of this report describes that situation in detail and goes on to identify a number of candidate materials potentially suitable for this purpose, along with a summary of their known properties and ranges of applicability.

A number of identifiable groups have an interest in the development of a series of insulation reference materials. These include testing laboratories, insulation producers, consumers, standards promulgating bodies, state and federal agencies who purchase large amounts of insulating materials or who have a regulatory interest, federal agencies responsible for energy-related research, development, and demonstration.

As an example of such an interest, there is no quality assurance procedure to guarantee the reliability and accuracy of the results

obtained by measurement laboratories. Standard test methods for measurement of relevant thermal properties, such as those promulgated by ASTM, provide technical tools, but there is no procedure to assure that these methods are correctly applied by individual testing laboratories. The U.S. Department of Commerce is initiating action for development of a National Voluntary Laboratory Accreditation Program for thermal testing laboratories, in order to increase overall confidence level in such performance measurements.

The provision of Standard Reference Materials having precisely known physical or chemical performance properties falls within the overall scope and objectives of the various National Standards Laboratories. In the USA there is an Office of Standard Reference Materials within the National Bureau of Standards for this purpose. However, the total scope of the requirements in the thermal insulation field involves more than the provision of a few materials or samples having known properties at one temperature or condition. The total amount of work required to characterize the numbers of samples and the temperature ranges and conditions to be covered is well beyond the capabilities of one organization.

We see that, while the National Bureau of Standards will have a vital role in the overall effort, the ultimate solution can only be obtained through a large, well-planned and funded cooperative effort. This will involve not only OSRM, but other Government Organizations and Agencies, the Insulation Manufacturers and Users together with Independent Organizations. In total the expertise of those having experience and knowledge of materials will have to be combined with that of the measurements experts all working together.

Although the roles of the various groups may not be well defined at this time it is possible to see that within the list of materials recommended for study certain programs or plans can be proposed. ASTM C16 stands

ready to provide expertise and to serve in an advisory and coordinating function during any or all of the stages of such plans.

In an effort to stimulate action on the subject, the C16.30 Working Group is proposing the following plan to raise a limited series of materials to the level of having certified properties. The cooperation and involvement of OSRM was sought and has been promised for the initial two phases. It is hoped that the publication of this first proposed plan as part of the C16.30 activities will stimulate other interested parties to work together more actively in order to initiate action to extend and execute this plan and to develop others.

The recommended approach for obtaining, characterizing and disseminating reference materials is one that is phased. The approach should attach highest priority to the development of those reference materials that are required most urgently, as for building insulation applications for example. However, in addition, there are some which it is believed can be characterized faster and at lower cost.

Five phases of such an effort have been identified at this time, and are outlined. They center around the characterization and dissemination of three reference materials: a high density ($80 - 160 \text{ kg/m}^3$) fibrous glass board and a low density fibrous glass blanket material, both for use at moderate temperatures, and a high temperature insulation. These phases are designed to run in parallel as shown on the attached time-table. The identification and screening of new candidate materials for characterization, subsequent to the first three, is included as the last phase.

Descriptions of the phases follow:

Phase I: Systematically examine characterization data for existing NBS stock of high density fibrous glass board. Use this information to certify the remaining stock of this material as a reference material by NBS-OSRM over the limited temperature range 260 - 325K. (January, 1978).

Phase II: Purchase additional new stock of high density fibrous glass board, and complete an initial characterization of this material in the limited temperature range 260 - 325K. Extend the characterization range for this class of material to 125 - 425K. (October, 1978).

Phase III: Purchase a stock of glass fiber appliance insulation blanket for stockpiling by NBS-OSRM. Characterize the properties of this material in two steps, first, in the limited temperature range 260 - 325K (October, 1978), and subsequently over the extended temperature range 125 - 500K. (October, 1979).

Phase IV: Purchase a stock of silica aerogel composite block for a stockpiling by NBS-OSRM. Characterize the properties of this material in two steps, first, in the limited temperature range 260 - 325K. (October, 1978), and subsequently over the range 125 - 1175K. (October, 1979).

Phase V: Starting at present, identify new potential materials, and along with the list of candidate materials proposed in this paper, develop a long-range priority order for subsequent reference material characterization. This will most probably involve obtaining small stocks of all candidate materials that pass an initial screening test, and accomplishing exploratory characterization of their properties. This is envisioned as a continuing effort of at least five year's duration.

It is felt that the observations made above, and the recommendations for action, while obvious, needed to be stated explicitly. The complexity of the interests of the various groups and their potential roles make this statement necessary, since in such a situation, some sort of catalyst is necessary to initiate action. It is hoped that this statement will provide that catalyst, and that all interested groups will follow through and initiate and support a successful plan to provide thermal insulation reference materials.

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