Summary

The decision to hold this first thermal insulation conference was prompted by three major factors; namely, the impact of thermal insulation for energy conservation purposes, the successes of the previous ASTM C16.30 heat transmission symposia, especially those held in 1973[1] and 1977,[2] and the publication in 1978 of the first draft of U.S. Department of Energy/Department of Commerce (DOE/DOC) National Plan for Thermal Insulation Materials and Systems.[3] This latter document recognized clearly both the need for education in thermal insulation topics and that one of the means of attaining this educational goal was to help sponsor technical meetings.

The organizing committee decided to widen the scope of the meeting to cover all aspects of thermal insulation performance—both of insulation materials and of the systems containing such materials. In addition to seeking information on past and present performance criteria and problems, an attempt was made to obtain from various industrial and governmental sectors some idea of what the future holds with respect to research and development needs in the thermal insulation field. As in 1973 and 1977, the organizers made a considerable effort to obtain the active involvement of their international colleagues.

The fact that in the end there were over 500 participants with more than 10 percent being from outside the United States and Canada indicated clearly the considerable national and international interest in the subject. Some 50 papers were presented, though not all are published in the present volume. Many lively and controversial topics were discussed both formally and informally. Everyone who attended left the meeting with a better understanding of general and specific thermal insulation performance. If they in turn disseminate this understanding to others, then a very important part of the required education process is being attained.

The content of the conference, as in the earlier symposia, and hence of this volume is dominated by topics associated with the performance of materials and systems used for buildings. This no doubt reflects where the major activity is being or has been concentrated. However, insulation performance in

[1] *Heat Transmission Measurements in Thermal Insulation, ASTM STP 544*, American Society for Testing and Materials, 1974.

[2] *Thermal Transmission Measurements of Insulation. ASTM STP 660*, R. P. Tye, Ed., American Society for Testing and Materials, 1978.

[3] *The National Program Plan for Building Envelope Systems and Insulating Materials.* DOE/CS-0059, Department of Energy, Washington, D.C., Jan. 1979.

the so-called industrial applications areas plays just as important or an even more important role in energy conservation and thus should not be neglected. The comment that "there are more voters owning or living in buildings than there are involved in industrial processes" from a rather cynical participant in one of the discussions is a totally apt summary of the present situation. Clearly there is a need for a similar meeting to discuss topics other than buildings. It is gratifying to know that the next conference in this ASTM C16/DOE series, to be held in 1981, is to be devoted to the subject of industrial insulation performance topics.

Since the early seventies building insulation use has grown considerably. However, not everyone has been satisfied that any of the thermal insulation materials and systems performs as well as claimed, while it has become clear that there are some very relevant performance properties of the materials for which little or no information exists.

The first paper, by Tye et al, a critical summary of the information available in 1977 for existing thermal insulation materials used in buildings, sets the stage for specific materials discussion. The various factors influencing thermal, chemical, fire, and environmental performance are discussed both in general and in particular. The assessment highlights areas where further information is needed on performance properties and characteristics experienced in the various climatic zones of the United States and discusses the inadequacy or lack of many of the existing fire and chemical tests.

Following this, further contributions are made on specific materials both as formal papers and prepared contributions to discussion. Settling of loose-fill insulation after application and its effect on R-value are important. Derbyshire discusses in detail this particular problem in relation to cellulose insulation. He both defines the need for and proposes a less burdensome test method to provide reproducible and representative results for the settled density of this material.

Corrosion of building materials by chemicals contained in thermal insulations, particularly cellulose, has become more prevalent. Shen outlines some of the problems associated with current test methods for corrosion characteristics and his work confirms one of the conclusions of the earlier assessment that criteria need to be established for a general test method for corrosion characteristics of insulation materials.

Another facet of thermal performance of insulations is that of the effects of moisture. Tye and Spinney describe briefly qualitative and quantitative measurements of thermal performance of wall and ceilings insulated with cellulose subjected to fixed and cyclic moisture gradients. Cellulose does indeed pick up and transfer water from the environment with consequent reduction in effective performance, but the establishment of drying conditions releases the moisture and the thermal performance improves.

Thermal performance characteristics of systems insulated with urea-based

foam insulations has become a very controversial subject. There appears to be no doubt that urea-based foams do shrink, but the extent of the shrinkage and its effect on overall performance is a hotly debated topic. The causes and effects of shrinkage in these materials are among the topics discussed by Bowles and Shirtliffe in a paper describing their work in developing a Canadian Government Standard for urea formaldehyde wall insulation. Clearly more laboratory and field studies need to be undertaken in this area in order to provide more definitive results.

While it is important indeed to have detailed information on various performance characteristics of insulating materials in order to make a choice for an application, the total performance of the system into which it is applied is the critical subject. This has been realized for some time and results of work on component systems and complete houses are now appearing. Several such studies are reported here.

It is both an advantage as well as interesting to be able to draw on the past experiences of others in any subject. In the particular field of a system performance the information is somewhat sparse due presumably to the complexity and cost of such investigations. Nevertheless, some information is available. Carroll has provided a real service to those workers wishing to enter this field by providing us with a comprehensive, annotated bibliography covering past work on systems. Existing and new approaches in the areas of steady-state transient and dynamic tests and test methods are all summarized together with information containing current thermal and electrical analogs. Referral to this work will save some people a great deal of time and wasted effort. It is encouraging to learn that this bibliography is to be updated from time to time as part of the Department of Energy education process.

Two papers from Canada drawing on prior experience from Scandinavia describe the use of thermal insulation on the exterior of basement walls of residential structures. Provided the thermal insulation material is protected from the deleterious effects of external water, there are considerable performance advantages to be attained over its use on the corresponding internal walls of the basement. Tao and his colleagues describe their use of high-density glass fiber material on basements of buildings in central Canada. They show that the application of the material requires little change in construction techniques and that current basement insulation standards can be met without the need of further interior insulation. Bomberg in his separate paper provides more details of the attributes of the particular insulation material used in the aforementioned studies. In particular the effects of water and age are discussed in relation to thermal and mechanical properties.

Vinieratos and Verschoor provide us with some rather startling figures relating to the reduction in thermal performance of wall and ceiling insulations containing flaws. Voids and gaps such as those due to poor installation

practices, shrinkage, compression, or settling can contribute to a significantly larger reduction in thermal performance than the one-to-one relationship currently assumed by much of the construction industry.

Berlad et al continue this topic a stage further by indicating that there can be further significant reductions in thermal performance caused by the effects of air intrusion into installed low-density thermal insulations. This is another area where further work is known to be continuing. It is hoped that the results of these additional studies will enable more accurate prediction of performance to be made without the need for continuous testing.

The ultimate test of performance is that for a complete building. While this is obviously impractical for all cases, it is of interest to see directly how energy can be saved by prudent use of thermal insulation installed to realistic levels using current or only slightly modified products and installation techniques. The paper of Johnson and Lee describes the results of the project sponsored by Department of Housing and Urban Development whereby the actual and projected energy consumption for heating and cooling periods for a home built to the aforementioned requirements is seen to be considerably lower than that of a similar conventional structure insulated to current standards.

Thermography is becoming a more widely used tool for the qualitative investigation of thermal performance of structures. There is no doubt that the technique is very sensitive to differences of temperature across surfaces. Stainton focuses attention on the advantages and disadvantages of the infrared scanning technique. Errors can arise due to the effects of surface emittance and of solar heating of the surfaces on the readings obtained with the camera. In particular Stainton discusses the general problems associated with the interpretation of thermograms obtained on insulated structures. Standardization of inspection and interpretation procedures is proposed. This is a worthy goal and it is known that the subject is being pursued actively within the International Organization for Standardization (ISO) 163 Thermal Insulation Committee. Canada is to be commended for her considerable contributions in this field.

In both previous ASTM C16.30 symposia held in the seventies, papers describing new calibrated hot-box facilities were presented. There is no doubt that this versatile hot-box procedure is becoming more widely used and accepted for investigating performance characteristics of walls, ceilings, and roof sections. Other further hot-box facilities have been installed recently and are detailed herein. Still others are known to be in the course of construction or are planned for the near future.

Mumaw in 1973 described the first calibrated hot-box wall tester developed in the United States. After the considerable experience gained in the intervening years he now details the design and development of an even larger, more complex and versatile facility for full-scale evaluation of massive roof, floor, and other similar horizontal constructions. This facility is one of

the first to have the capability of undertaking both steady-state and dynamic testing.

Such is the importance of this systems evaluation technique that in less than six years the number of calibrated hot boxes in North America has grown from two to more than ten with several more under construction or being planned. All workers in this field have derived considerable benefit from the experiences of Mumaw and his colleagues. We must commend Owens-Corning Fiberglas Corp. for their decision to be involved with this evaluation technique and for being at the forefront of research and development in this important field. There are still problems with the method and unanswered questions arising from the results of some of the prior work. As more people become involved, however, we should see a resolution of many of these uncertainties. We look forward with considerable anticipation to the publication of the results of studies undertaken both with the present boxes and those described in the earlier volumes (footnotes 1 and 2).

The insulation sector needs continued improvements in both a better understanding of heat-transfer mechanisms on insulations and more accurate and reliable measurements of thermal resistance. The present conference contained a number of contributions which addressed both subjects and which contributed to many lively discussions during the course of the meeting.

Since 1976 when the very significant philosophical revisions were made to the ASTM Tests for Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate (C 177-76) and Heat Flow Meter (C 518-76), the materials specification of most current thermal insulation products used in buildings has called for thermal performance values obtained from measurements on specimens at thicknesses where the thermal resistance is shown to change linearly with thickness. However, a certain amount of controversy has arisen concerning the differences between values of thermal resistance measured on specimens of some products at actual thickness and those derived mathematically from measurements on thin specimens at different compressions.

The major contention here is that there are no thick specimens of suitable reference materials available to either verify absolute hot-plate equipment or to calibrate secondary heat flow meter equipment. Further, it is suggested that possible equipment errors are of the same order as the differences in resistance due to the thickness effect. It is perhaps worthwhile here to mention that as early as 1970, ASTM Committee C16.30 drew specific attention to the pressing needs for more and representative reference materials while the two C16.30 position papers in 1973 and 1977 further amplified both the reasons and the needs for reference materials.

It is thus very regrettable that approximately a decade has passed and little or nothing has been accomplished in this vital area and that measurement controversies having direct impact on energy conservation can exist. We

should also be aware that there are no reference materials at all for temperatures outside the approximate range 250 to 330 K but the needs at higher and lower temperatures are even more pressing than those within that temperature range.

The contribution of Shirtliffe is a very comprehensive discussion of the effect of thickness on thermal properties in relation to low-density thermal insulation materials in general. Bhattacharyya with an analytical model, and Hollingsworth separately by experiment, examines the effects for one fibrous glass product. Bomberg relates the Canadian experience with thick specimens tested by both guarded hot-plate and heat flow meter methods adequately verified and calibrated. McCaa and Pelanne separately describe their work with fibrous glass products with one type of commercial heat flow meter equipment while Siu discusses an investigation on the existing high-density fibrous glass reference material with the same equipment. In each case the results obtained are well within the accuracy of the basic ASTM C 518 method. A comprehensive set of papers is thus available to us. Each paper in its way advances the subject a little further but does not solve all of the problems. Once again further work is seen to be necessary, especially round robins on different thicknesses of a material or materials.

The heat flow meter method is now in very wide use worldwide. It is, in every respect, a very good technique for evaluating the thermal performance of thermal insulation materials provided it is used correctly. A very important factor with respect to the use of the method is heat flow meter calibration, especially of the whole apparatus. DePonte and Maccato present a very comprehensive paper covering different types of apparatus. Anyone involved in such measurements can benefit greatly from the experiences of our respected colleagues from Italy.

Heat flow meters themselves are being used more and more for qualitative and quantitative heat flow measurements in building components. Hedlin and his colleagues discuss the use of these devices for measurements of thermal performance of roof systems. They show that large errors can result from incorrect use of the temperature and heat meter output measurements. However, they do indicate how correct thermal resistances can be derived by comparison of some results with those undertaken by the guarded hot-plate method. The paper of Shuman describes work carried out many years ago. He examines thermal performance of roof systems with heat flow meters to show the qualitative effects of moisture rather than from a quantitative standpoint. While techniques and equipment have improved in the intervening years, his results show that heat flow meters can provide meaningful information.

In an entirely different area Sherman illustrates tellingly a practical method of sampling large pieces of cellular plastics in order to obtain results from a representative number of small specimens to provide reliable product thermal performance information. The advantages of using thick foil facings to avoid aging effects on these materials are also illustrated. Bomberg in a

related paper also discusses the aging of faced polyurethane cellular plastics and proposes some relatively simple means of measuring and predicting performance from climatic exposure and gas cell composition at different times. If proven generally applicable, such a method would be of considerable value to the cellular plastics industry.

Two very diverse papers covering testing of materials other than those used in buildings are papers by Chaille and Wahle and Rohles and Munson. The former have undertaken an analytical and experimental investigation on ceramic fibers at high temperatures using the present ASTM Test for Thermal Conductivity of Refractories (C 201-68) plate water calorimeter normally used for refractory bricks. Comparisons of results with information obtained from actual furnace installation are also made. The agreement is reasonably satisfactory but further work is necessary, and in this respect the results of a current round robin using both ASTM C-201 and C-177 will be of very great interest. The second paper referred to is of interest to those appreciating the feeling of comfort in one's surroundings. It describes the use of a heated mannequin for measurements on sleeping bags together with means to measure or predict thermal performance of fabrics and wearing apparel.

Insulation of storage tanks for cryogenic fluids and for a variety of other low-temperature applications has increased considerably in recent years. Cellular plastics are widely used materials for many of these purposes. Sparks provides us with a very useful, critical summary of the major thermal and mechanical properties of polystyrenes and polyurethanes down to 90 K. Various factors which influence these properties are discussed, in particular the anisotropy, aging, and gas permeation within the materials. Large variations in property values may be expected and can be explained to some extent if materials are characterized fully. In an associated paper, Cunningham extends the knowledge of properties to liquid hydrogen temperatures for a number of selected cellular plastics. The application to LH_2-fueled aircraft development is of particular interest and importance.

Factors influencing the economics of insulation use are discussed both directly and indirectly. Simmons and Beckman analyze the heat transfer from hot pipes to determine the optimum thickness of insulations to be used. They show that the often-assigned constant thermal resistance at the surface is in error and yields a low value for the optimum thicknesses. Their analysis introduces both a varying radiation and convection coefficients which depend on insulation thickness and which yield a greater optimum thickness than the more simple model. Although the differences are not large, they are significant particularly in economic terms.

Chinneck and his co-workers provide another new model for more realistic life-cycle costs in using thermal insulation. This model includes the full costs of manufacturing the insulation. Their results showing that there is a "cut-off" point where the addition of further thickness consumes more energy than is saved is a sobering thought indeed.

Eilhardt and his colleagues from Germany describe a new, continuous,

flexible thermal insulation system for pipelines in industrial processes. Any insulation system which does not include a large number of potential heat-loss areas such as joints has considerable economic impact in energy conservation. Continuing on the subject of insulated pipe systems, Barton discusses the various computational methods for calculating heat losses from underground systems and their economic effects relative to annual owning/operating costs.

It is always gratifying to learn where one is but sometimes disturbing to consider how far one has to go to realize the ultimate end point. The papers published in this volume are certainly of help in the telling of where we are and indicating directions to follow. In the conference itself, local, state, and Federal authorities provided broad-brush pictures of current or proposed research areas. While of considerable interest, these presentations are not published herein. The presentation of Stenger, however, from a major insulation manufacturer, is included since he outlines the rationale for a research program and the very definite course that his company views as being necessary to remain one of the leaders in this important field.

In summary, these papers continue the educational process concerning thermal insulation performance which was started by ASTM C-16 over 25 years ago. During this time the thickness of the *Proceedings* volumes has grown considerably as the subject has grown in complexity. Materials and systems, particularly in the buildings regime, are now better understood. However, there is still need for further work leading to additional improvement in total performance. Much more effort needs to be concentrated upon thermal insulation performance at higher and lower temperatures.

We trust that the reader of this and the previous *STP*'s on thermal insulation will be stimulated to undertake the research and development which is necessary, and we expect the results of their work to be published in future volumes of this continuing series.

R. P. Tye

Senior scientist, Dynatech R/D Co., Cambridge, Mass. 02139, current address, Fiber Materials, Inc., Biddeford, Me. 04005; symposium cochairman and editor.

D. L. McElroy

Metallurgist, Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, Tenn. 37830; symposium cochairman and editor.