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Results of Workshop to Develop Alternatives for Insulations Containing CFCs Research Project Menu

J. E. Christian
D. L. McElroy

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Results of Workshop to Develop Alternatives for Insulations Containing CFCs Research Project Menu

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December 1988

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ACKNOWLEDGMENTS

The authors acknowledge the help of a number of people who contributed to the success of this workshop. The workshop provided members of the technical community the opportunity to discuss a number of research and development projects relevant to the current chlorofluorocarbon (CFC) issue. The authors thank the attendees for contributing to the discussions and for voting to rank the importance of the projects and who should do the projects.

Special thanks are extended to the Planning Team members and their organizations for allowing them to meet in Atlanta on April 20, 1988 to plan the June 1988 workshop. The Planning Team members and guests who attended are listed at the end of the acknowledgments.

Over 20 public and private progress reports on current and planned research were presented at the first session of the workshop. The authors thank each speaker for their presentation. The research menu topics were presented and discussed at the second session. The authors thank each of the presenters and discussion leaders for their clear and factual coverage of each project. We are sure the attendees join us in this expression of gratitude for their efforts.

Contributors to the Research Menu Discussion

	Topic	Presenter	Discussion Leader
C1	Insulation with Alternative Blowing Agents (12 Projects)	R. P. Tye	G. Bauman
C2	Alternative Insulations (6 projects)	H. A. Fine	R. W. Barito
C3	Recovery/Recycling/Disposal (6 projects)	J. E. Christian	T. Nelson
C4	Implementation and Information Exchange (5 projects)	G. E. Courville	F. Lichtenberg

We would like to thank Mr. John P. Millhone, Director of the Office of Buildings and Community Systems, U.S. Department of Energy, for his welcoming remarks to the workshop attendees. He identified Department of Energy responsibilities for research related to CFC in three areas: Building Equipment Research and Appliance Efficiency Standards, Building Research, and Transportation Research. He noted that DOE is cooperating with the Environmental Protection Agency and he expressed hope that public and private interactions at this workshop would yield productive and cooperative areas for joint research projects. In addition, the authors would like to thank him for approval to conduct this workshop. This report and the workshop were conducted under both the DOE Building Materials, and Walls and Foundations Research Projects.

Ms. Raydean M. Acevedo, Program Manager, National Computer Systems, Washington, DC is due a special thanks for her role in the balloting process. National Computer Systems provided the ballot sheets, used their facilities to count the ballots, and helped provide the attendees with a hard copy of the results. We thank Dr. H. A. Fine, who worked with Ms. Acevedo to complete this process. In less than two hours over 55 ballots, each containing 29 projects were processed and the project ranking summary was presented to the attendees.

A workshop such as this does not just happen without the support of a dedicated staff. The authors appreciate the efforts of four special people whose behind-the-scenes work in completing assignments allowed this workshop to proceed: G. L. Coleman, correspondence, arrangements, and registration; K. R. Grubb, correspondence; P. M. Love, arrangements and registration; and S. D. Samples, correspondence. We also thank Margaret Rogers, Society of Plastics Industry, who assisted in completing the arrangements.

Finally, we would like to express our thanks to H. A. Fine and D. W. Yarbrough for their review of this report. The report was prepared by G. L. Coleman and we thank her for doing so.

ATTENDANCE SHEET
April 20, 1988
Planning Team Meeting for Workshop on
Alternatives for CFC Insulations

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EXECUTIVE SUMMARY

Background

A workshop was held to provide a forum for representatives of industry, academia, and government agencies to recommend research on acceptable alternatives to the currently used CFC insulations. The scope of the research discussed focused on finding alternatives for plastic foam insulation currently containing primarily CFC-11 and CFC-12. CFC-11 and CFC-12 are used as blowing agents in the production of plastic foam insulations for buildings and appliances. ORNL staff worked with representatives from private industry, academia, and government agencies to develop draft research projects prior to the June 9-10, 1988 workshop. A draft research menu and sample ballots were sent to 86 potential attendees for review a month before the workshop. Sixty nine participants representing 43 organizations attended this workshop.

Objective

The purpose of this report is to document the prioritized research project ranking produced by the Joint Public/Private Workshop on Alternatives for Insulations Containing Chlorofluorocarbons (CFCs). The major goal was to have the attendees representing all of the major insulation industries affected by CFC restrictions produce a list of research needs that is relevant, comprehensive, and prioritized. A secondary goal of the workshop was to provide the opportunity for a description of current technical activity that is occurring in both the private and public sectors. Another motive behind the workshop was to prompt cooperative public/private interactions to develop CFC alternatives, and provide guidance on the role of the federal government. In the long term it is hoped this document will help accelerate the resolution of CFC in insulation issues and minimize both the economic and the energy impact of CFC restrictions.

Approach

The methodology was to develop several draft versions of the Alternatives for Insulations Containing CFCs Research Project Menu (Appendix C), and circulate the drafts prior to holding the workshop. Each project was then discussed at the workshop and voted on by the attendees of the workshop to assign an importance ranking, and indicate who should do the research project. The balloting results were electronically compiled immediately and presented to the attendees.

Results

More than 75% of the research projects were identified as candidates for joint private/public sector research effort. The prioritized list of 29 research projects generated from all the ballot results is shown below grouped in categories of above average, average, and below average importance.

Executive Summary (cont'd)

Above average importance

C.4.1 Public/Private Research Menu
C.4.2 DOE/ORNL/Industry Workshop
C.1.12 Data Base of Physical Properties
C.1.11 Protocol to Predict Thermal Performance
C.1.4 Identify New Blowing Agents

Average importance

C.1.6 Environmentally Acceptable Blowing Agents
C.2.6 New Facing Materials
C.4.5 Energy Impact for Walls and Roofs
C.3.1 CFC Manufacturing Recovery Processes
C.1.2 Low k Standard Reference Material
C.1.3 Data Base for Alternate Blowing Agents
C.1.1 Accelerated Foam Aging for Design R-values
C.2.2 Evacuated Panel "Super Insulation"
C.2.3 Components for Super Insulations
C.1.5 Field Test Project
C.2.1 Composites with High Thermal Resistance
C.4.4 Establish Essential Material Properties
C.3.4 CFC Destruction
C.1.8 Thermal Resistance Measurements
C.4.3 Critical Assessment of Product Property Tests
C.3.2 CFC Incineration
C.3.6 CFC Adsorbents
C.3.5 CFC Recapture at Refrigerator/Freezer Retirement
C.1.10 Manufacture of Environmentally Acceptable Foams

Below average importance

C.1.9 Thermal Conductivity of Expanded Polymers
C.2.4 Non CFC Systems
C.2.5 Non CFC Foundation Insulation
C.3.3 Recycling Panels
C.1.7 Calculation Methodology - Flammability Testing

The top two items are the development of this research menu and continued workshops on alternatives for insulations containing CFCs. Other top priority research projects are development of a data base of physical properties of substitute blowing agents; protocol to predict thermal performance of foam insulation products; identify new chemical blowing agents; environmentally acceptable blowing agents and a means to achieve equivalent efficiency; new facing materials; energy impact for walls and roofs; CFC manufacturing recovery processes; and low k standard reference material. Based on the data base produced by all the ballots, the top five research projects shown in the above list have statistically above average importance and the last five have below average importance. The remainder have average importance.

Results of Workshop to Develop Alternatives for Insulations Containing CFCs Research Project Menu*

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ABSTRACT

Sixty nine individuals from 43 organizations impacted by CFC restrictions in the production of insulations met for two days to produce a relevant, comprehensive and prioritized list of research needs. Of the 29 one page research project descriptions, about 75% are candidates for joint private/public sector research ventures. Top priority research projects are: development of a data base of physical properties of substitute blowing agents; protocol to predict thermal performance of cellular foam insulation products; identify new blowing agents; environmentally acceptable blowing agents and means to achieve equivalent efficiency; new facing materials; CFC manufacturing recovery processes; and low k standard reference material. Based on the data base produced by balloting, five research projects have statistically above average importance, five have below average importance, and the remainder have average importance.

Clearly the desire is to first try to find an acceptable alternative set of blowing agents and develop protocol for predicting long term thermal performance of plastic foam insulation. There was considerable interest from the public sector attendees to develop evacuated panel insulations. There was very modest interest by the private industry participants to consider evacuated volumes in plastic foam boards. Those insulation manufacturers most impacted by CFC restrictions indicated by their balloting that they do not have as much to gain by development of alternative insulation technologies to plastic foam insulation with environmentally acceptable blowing agents.

The prioritized research list presented in this report should be considered as only one of a number of inputs for allocating research and development resources. There are many promising activities outlined in this report and this material should be useful in developing research plans and formulating research work statements. It is obvious that there are numerous areas were cooperative research ventures could be established. Hopefully this document will form a starting point in accelerating the solution to the CFC problem for insulations.

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*Research sponsored by the Office of Buildings and Community Systems, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

1. INTRODUCTION

1.1 OBJECTIVES

The purpose of this report is to present the prioritized research project ranking produced by the Joint Public/Private Workshop on Alternatives for Insulations Containing Chlorofluorocarbons (CFCs) that was held on June 9-10, 1988, in Washington, DC. Fully halogenated CFCs have all chemical bonds with fluorine, chlorine, bromine, or iodine. They are particularly harmful to the stratospheric ozone because they have such a long "lifetime" in the atmosphere. The HCFCs are not fully halogenated. They are distinguished by as few as a single hydrogen atom. The HCFCs are not as inert as the fully halogenated species, and they break down in the lower levels of the atmosphere due to the weak hydrogen-carbon bonds.

This workshop was attended by 69 representatives from public and private organizations that are impacted by the CFC issue. The attendees represented manufacturers of insulating foam systems as well as their chemical constituents, and building researchers from the U.S. and Canada. The main objective of the workshop was to permit an on-the-spot critique and prioritization of 29 research projects. The procedure to meet this goal included presentations of the scope, approach, and products of each project; a review of each project by a discussion leader with solicitation of questions and comments from the workshop attendees; and voting by each attendee on each project to determine a workshop ranking of technical importance and who should do the research. The ballot results were provided to each attendee at the meeting and are analyzed in Chapter 4 of this report.

A second goal of the workshop was to provide the opportunity for a description of current technical activity that is occurring in both the private and public sectors. These progress reports provided technical results and identified research needs, the primary CFC-related concerns, and areas for cooperative public/private interactions.

1.2 SCOPE

This activity focused on the development of a research menu for finding alternatives for plastic foam insulation currently containing primarily either CFC-11 or CFC-12. CFC-11 and CFC-12 are used as blowing agents in the production of plastic foam insulations for buildings, appliances, refrigerated transportation, and cold storage facilities. The research projects covered are grouped into four categories; foam insulation with alternative blowing agents; alternative insulations, which may include some materials used for insulation other than plastic foam; recovery/recycling/disposal of CFCs, and potential alternatives; and implementation and information exchange to accelerate the development of acceptable insulations which do not depend on CFCs.

1.3 PROBLEM SIGNIFICANCE

Stratospheric ozone acts as a shield against harmful solar ultraviolet (UV) radiation. A significant reduction in ozone in the upper atmosphere could result in long-term increases in skin cancer and cataracts, and probably damage the human immune system. Evidence also supports the conclusion that reductions in the total abundance of stratospheric ozone could reduce crop yields and alter terrestrial and aquatic ecosystems (Perry, A.M., 1986).

Chlorine from the fully-halogenated chlorofluorocarbons (CFCs) and bromine from halons have been found to be the primary cause for decreasing stratospheric ozone. CFCs are used as blowing agents in plastic foam products (cushioning, insulation, and packaging), as refrigerants, as solvents, as sterilants, and in aerosol applications. Halons are used as fire extinguishing agents. To protect the ozone layer, the United States, 23 other nations, and the European Economic Community signed the Protocol on Substances that Deplete the Ozone Layer on September 16, 1987, in Montreal, Canada. This agreement controls the production and consumption of five CFCs and three halons (EPA, 1988).

The Montreal Protocol calls for a freeze in CFC-11 and CFC-12 blowing agents at 1986 consumption levels beginning in July 1989; and reductions of 20 percent from 1986 levels of blowing agents by July 1, 1993, with reductions of 50 percent required by July 1, 1998. Since the plastic foam insulation has experienced phenomenal growth since 1986, the impact in going back to 1986 CFC usage in July 1989 to this segment of CFC users will actually be about a 10-25% cutback (Putnam, Hayes, and Bartlett, Inc., 1988). To illustrate the problem significance even further, the most technically promising alternatives to CFC blowing agents, if found not to be toxic, will not be available in commercial quantities until 1992-93. By 1998 it is estimated that the plastic foam industry will lose more than $500 million in annual revenue and 4000 jobs. However, EPA's economic impact estimates are not as severe as those found in the Putnam, Hayes, and Bartlett report (Putnam, Hayes, and Bartlett, Inc., 1988).

Foam insulations using the relatively low thermal conductivity blowing agents such as CFC-11 and CFC-12 that are partially retained in the final product offer the highest commercially available R-value per inch. Industry, and particularly the insulation industry, has made remarkable improvements in energy efficiency by using CFCs. Restricting the use of these materials without developing alternatives will remove a highly successful and highly visible energy conservation measure.

The impacts of CFC restrictions on the energy efficiency of foam insulations currently using CFC-11 and 12 are significant. The worst case scenario of the long range effect on building applications associated with the elimination of these CFCs is an increase in energy consumption of 0.65 quads/yr[a]. Taking into account the insulation impacts in refrigerators and freezers, water heaters, beverage vending-machines, and refrigerated transport adds another 0.95 quads/yr. The total worst case scenario of the long range effect on building and appliance applications is 1.6 quads/yr (Fischer 1988). Based on $18 per barrel of oil, this energy impact is about $5 billion per year[b].

(a). 10^{18} joules is 0.947 x 10^{15} Btu or 0.947 QBtu or 0.947 quad.
(b). The energy capacity of one gallon is 1.3 x 10^{5} Btu, so 1.6 quads is equivalent to 293 million barrels of oil.

1.4 MERITS OF PUBLIC/PRIVATE COOPERATIVE PROGRAMS

Ozone depletion has resulted in global CFC restrictions. If technology can produce cost-effective insulation alternatives without CFCs, the entire planet gains.

The CFC problem is enormous. No one company has the resources to solve the entire problem on its own. Many of the foam plastic insulation manufacturers using CFCs had been preoccupied with the thermal aging issues until the signing of the Montreal Protocol. Now both CFC substitutes and thermal aging must be addressed simultaneously. Thermal aging refers to the R-value dropping over time, depending on product and application. An accepted protocol for determining life-time design R-values is needed. Alternative products will also be introduced into this uncertain environment, since they too will likely have some thermal drift.

A national goal is to use energy resources efficiently and in an environmentally safe manner. Energy conservation has been one of the enduring shining stars in the accelerated energy technology development effort over the last several decades. Despite a temporary relaxing of energy cost escalation, conservation continues to gain market acceptance in the building and appliance industries. Many "lead" builders and almost all appliance manufacturers are using more CFC insulation products than ever before to obtain cost effective energy efficiency. A significant increase in constraints to achieving energy efficiency is taking place. An effective increase in R&D resources needs to be applied to develop equivalent alternatives within the new set of constraints.

CFC restrictions have transformed the largely "commodity" oriented insulation market into one of accelerated product development. Many new approaches will be tried. Product development is costly and time consuming. The time period for bringing new products to market must be kept to a minimum. Yet, the market conditions for accepting new products are more demanding than ever. Clearly some element of cooperative programs will enhance the accelerated in-house product development efforts currently under way.

Foam insulation research at the Massachusetts Institute of Technology under the leadership of Dr. L. R. Glicksman has benefited from close cooperation with industry. Dr. Glicksman (Glicksman 1987) has indicated the following:

"From its inception, this work has been carried out in close association and with financial support from numerous companies active in the rigid foam industry. The initial phase of this work was sponsored by the Urethane Division of the Society of the Plastics Industry. The next phase was supported by the Energy Conservation and Utilization Technology Program; and the most recently completed phase has been sponsored by the Office of Building Energy Research and Development, Department of Energy. During this phase, several companies have provided direct assistance by allowing students access to their laboratory facilities, providing special foam samples (in some cases made to our specifications) and performing tests of the sample materials using special test facilities. This cooperation has assured that the goals of the research are set to meet industry's needs and that the results of this program are rapidly disseminated and used by industry." Appendix A is an example of private industry interest in cooperative projects.

There is only one set of basic fundamental heat transfer principles involved in understanding the thermal performance of plastic foam insulations. The detailed understanding of this process is not complete. A better understanding of the long term performance of foam insulations will reduce costly trial and error experimentation. Every insulation manufacturer dependent on CFCs needs this information, now even more than before September 16, 1987.

1.5 BACKGROUND

The workshop was held to provide a forum for representatives of industry and government agencies to recommend research on acceptable alternatives to the currently used CFC insulations.

On March 28, 1988, ORNL staff provided DOE (HQ) staff a briefing of BTESM Program activities related to the CFC issue. This included a 1977 to 1988 chronology that is given in Appendix E, and a draft research menu which suggested the Joint Public/Private Workshop on Alternatives for CFC Insulations as a project. Subsequently, DOE (HQ) staff approved the hosting of this workshop. A key reason for the workshop was to prompt cooperative public/private interactions to develop alternatives.

During the period April to June 1988, ORNL staff worked with representatives from private industry, academia, and government agencies to develop the draft research menu of projects; hosted a meeting of a planning team for the workshop; and organized and arranged the workshop agenda. The first letter of invitation was distributed on April 29, 1988 to 78 potential attendees to announce the workshop and included Draft 3 of the research menu (22 projects). A second letter sent to 86 potential attendees on June 1, 1988 included the workshop agenda, a sample ballot, and Draft 4 of the research menu (28 projects). Those interested in attending the workshop on June 9 and 10, 1988, had sufficient time to prepare for participation.

The agenda is shown below. The list of attendees is shown in Appendix B.

Agenda
Joint Public/Private Workshop on
Alternatives for Insulations Containing CFC

Days Inn Downtown, Washington, DC

June 9 and 10, 1988

June 9, 1988

First Session: Public/Private Progress Reports on Current and Planned Research

1:00	Registration (Pat Love and Gabrielle Coleman)	
1:25	Call to Order	D. L. McElroy, ORNL
1:30	Welcome	J. P. Millhone Director, OBCS, DOE
1:45	Workshop Goals and Methodology	G. E. Courville, ORNL
2:00	Public Sector Progress Reports	
	ORNL/DOE	J. Christian
	NBS/ORNL	H. Fanney
	EPA	D. Smith
	NRC-C	M. Bomberg
2:45	Coffee Break	
3:00	Private Sector Progress Reports	
	Allied Signal	Ian Shankland
	DuPont	Joe Creazzo
	Polyisocianurate - Dow Chemical	D. Bhattacharjee
	Spray-Foam - SPI	R. Sellers
	SPI	F. Lichtenberg
	PIMA	J. Clinton
	Holometrix	R. P. Tye
	Drexel	H. Lorsch
	ORNL	S. K. Fischer
	DeGussa	K. Cwick
	SERI	T. Potter
	Extruded Polystyrene - Dow Chemical	D. Keeler
	AACHEN (September 1987) Symposium Summary	Leon Glicksman, MIT
5:30	Research Menu and Balloting Procedure	J. Christian, ORNL

Agenda (cont'd)

June 10, 1988

Second Session: Research Menu Discussion and Ranking.

8:30 C.1 Insulation with Alternative Blowing Agents (12 projects)
Presenter: R. P. Tye
Discussion Leader: G. Bauman

C.2 Alternative Insulations (6 projects)
Presenter: A. Fine
Discussion Leader: R. W. Barito

10:30 Coffee Break

10:45 C.3 Recovery/Recycling/Disposal (6 projects)
Presenter: J. Christian
Discussion Leader: Tom Nelson

C.4 Implementation and Information Exchange (5 projects)
Presenter: G. Courville
Discussion Leader: Fran Lichtenberg, SPI

12:15 Collection of Ballots

12:45 Lunch

Third Session: Recommended Future Activity - D. L. McElroy

1:45 Future Activities
Useful Technical Interactions
Suggestions
Plans for Next Workshop

2:15 Workshop Ballot Results and Discussion - J. Christian

3:15 Departure

2. CFC INSULATION RESEARCH PROJECTS

The detailed descriptions of the research projects are given in Appendix C. The format used to describe each research project consists of:

Research project title
Scope
Problem significance
Technical importance ranking by workshop attendees and who should do it
Technical approach
Major inputs (includes technical references as well as potential cost sharing and useful facilities)
Research products
Cost and time estimate (when available)

The research project descriptions evolved from discussions with numerous individuals familiar with the plastic foam insulation industry. The DOE/ORNL Building Thermal Envelope Systems and Materials (BTESM) Program had about a dozen projects in this area in progress or in the planning stages in early 1988. This list was expanded several times after a presentation to DOE Headquarters in March 1988, draft review by the workshop planning team, draft distribution to workshop invitees prior to the June 1988 workshop, and finally, discussions at the workshop to form the final 29 projects.

Some of the research project descriptions are not complete. They are considered a starting point for developing detailed research project work statements.

The research projects have been grouped into four categories. The categories are titled:

C.1 Insulation with Alternative Blowing Agents (Table 2.1),
C.2 Alternative Insulations (Table 2.2),
C.3 Recovery/Recycling/Disposal (Table 2.3), and
C.4 Implementation and Information Exchange (Table 2.4).

In the workshop discussion period, a number of the projects were cross cut within each category according to generic research topics. This cross cutting is also described in this chapter and in Chapter 3.

2.1 INSULATION WITH ALTERNATIVE BLOWING AGENTS

Table 2.1 shows the titles of twelve research projects in this category. Three of these projects cover thermal aging:
C.1.1 Accelerated foam aging for determination of design R-values,
C.1.5 Design and implement a reliable field test project, and
C.1.11 Protocol to predict long term (5 yr) thermal performance of

cellular foam insulation products. The implementation of research on thermal aging should consider combining the most attractive features from all three of these descriptions.

Three of these twelve projects cover the development of an accurate data base of properties of substitute blowing agents: C.1.3 Develop an accurate data base of the thermal properties of the more promising alternative blowing agents, C.1.4 Identify new blowing agents, and C.1.12 Develop accurate data base of physical properties of substitute blowing agents. The implementation steps to develop physical property data on substitute blowing agents should first be to carefully determine what the critical properties are and emphasize the collection effort on those properties determined to be most important.

C.1.6 Environmentally acceptable blowing agents in foam insulation: Means to achieve equivalent efficiency is a project which employs detailed heat transfer models of foam insulation to help guide the development of equivalently performing alternatives which do not use CFCs; such as the use of smaller cell size, more opaque cell walls and inclusion of small vacuum volumes. Project C.1.10 Manufacture of environmentally acceptable plastic foam insulations addresses alternative concepts for development of a CFC foam-in-place insulation alternative. C.1.9 Thermal conductivity of expanded polymers with chemically inactive fill gases pursues reliable input data for all fundamental heat transfer models of heat conduction through the solid polymer in foam insulation. Projects C.1.7 Develop a calculation methodology for flammability testing of new insulations intended for single-ply roofing applications, and C.1.8 Thermal resistance measurements of current CFC - insulations and reduced or non CFC alternatives as they become available, both focus on final product performance. C.1.7 pertains to flammability and C.1.8 to thermal resistance. Finally, project C.1.2 Develop a low k Standard Reference Material (SRM) for calibration of thermal conductivity measuring devices, will enhance the accuracy of the testing equipment for measuring high resistive insulation samples.

Table 2.1 Research Project Category 1. Insulation with Alternative Blowing Agents

Code	Title
C.1.1	Accelerated foam aging for determination of design R-values
C.1.2	Develop a low k Standard Reference Material (SRM) for calibration of thermal conductivity measuring devices
C.1.3	Develop an accurate data base of the thermal properties of the more promising alternative blowing agents
C.1.4	Identify new blowing agents
C.1.5	Design and implement a reliable field test project

Table 2.1 (cont'd)

C.1.6	Environmentally acceptable blowing agents in foam insulation: Means to achieve equivalent efficiency
C.1.7	Develop a calculation methodology for flammability testing of new insulations intended for single-ply roofing applications
C.1.8	Thermal resistance measurements of current CFC - insulations and reduced or Non CFC alternatives as they become available
C.1.9	Thermal conductivity of expanded polymers with chemically inactive fill gases
C.1.10	Manufacture of environmentally acceptable plastic foam insulations
C.1.11	Protocol to predict long term (5 yr) thermal performance of cellular foam insulation products
C.1.12	Develop accurate data base of physical properties of substitute blowing agents

2.2 ALTERNATIVE INSULATIONS

Table 2.2 shows the titles of the six research projects in this category. The first three projects involve the development of vacuum insulation: C.2.1 Production and demonstration of composites with high thermal resistance, C.2.2 Evacuated panel "super insulations" for buildings and appliances, and C.2.3 Evaluation of components for super insulations. How the concept is applied to the final insulation products varies. Two of the six projects in this category focus on the building envelope system performance: C.2.4 Non CFC Systems, and C.2.5 Non CFC foundation insulation application verification. The underlying goal is to add value to insulating products by enhancing properties of the system other than R-value, such as waterproofing, structural integrity, and reflectivity. The last project, C.2.6 Develop facing materials that eliminate out-gassing of CFC substitutes, has the objective to develop even better barriers to both blowing agent and air permeability.

Table 2.2 Research Project Category 2. Alternative Insulations

Code	Title
C.2.1	Production and demonstration of composites with high thermal resistance
C.2.2	Evacuated panel "super insulations" for buildings and appliances

Table 2.2 (cont'd)

C.2.3	Evaluation of components for super insulations
C.2.4	Non-CFC systems
C.2.5	Non-CFC foundation insulation application verification
C.2.6	Develop facing materials that eliminate out-gassing of CFC substitutes

2.3 RECOVERY/RECYCLING/DISPOSAL

Table 2.3 contains the titles of the six research projects in this category. Four of these projects consist of recovery or recycling: C.3.1 CFC manufacturing recovery process, C.3.3 Recycling panels, C.3.5 Recapture of CFCs at refrigerator/freezer retirement, and C.3.6 CFC adsorbents. These are all written specifically for CFCs, but with the cost of substitute blowing agents being three to five times more than CFC-11 and CFC-12, the economics may actually be more attractive for future alternatives. Two of the projects address environmentally acceptable methods of destroying CFCs, with the intention being to extend the Montreal Protocol limited production quantities available in the short term: C.3.2 CFC incineration, and C.3.4 CFC destruction by methods other than incineration.

Table 2.3 Research Project Category 3. Recovery/Recycling/Disposal

Code	Title
C.3.1	CFC manufacturing recovery process
C.3.2	CFC incineration
C.3.3	Recycling panels
C.3.4	CFC destruction by methods other than incineration
C.3.5	Recapture of CFCs at refrigerator/freezer retirement
C.3.6	CFC adsorbents

2.4 IMPLEMENTATION AND INFORMATION EXCHANGE

Table 2.4 shows the list of five research projects in this category. The first two actually have the same ultimate goal, the production of a prioritized list of research projects that can be publicly discussed and formulated into cooperative research efforts to reduce dependence on CFCs in foam insulations. C.4.1 is to produce an appropriate Public/Private research plan for alternatives to CFC Insulation, and C.4.2 is future workshops on alternatives for insulations containing CFCs. Two of these projects cover insulation material properties: C.4.3 Critical assessment of product property tests, and C.4.4 Establish essential thermal insulation material properties by type of application. They differ slightly in scope but have the same ultimate purpose to develop needed properties for determining product acceptance. The last project in this category, C.4.5 Develop energy impact data related to CFC restrictions, was submitted at the workshop after it became apparent that the total energy impact of restricting CFCs in buildings was not uncertain.

Table 2.4 Research Project Category 4. Implementation and Information Exchange

Code	Title
C.4.1	Prepare an appropriate public/private research plan for alternatives to CFC insulation
C.4.2	DOE/ORNL/Industry workshops on alternatives for CFC insulation
C.4.3	Critical assessment of product property tests
C.4.4	Establish essential thermal insulation material properties by type of application
C.4.5	Develop energy impact data related to CFC restrictions

3. WORKSHOP SUMMARY

3.1 INTRODUCTION

The purpose of this chapter is to summarize the workshop. Sixty-nine participants representing 43 organizations met to discuss public and private views on research needed to meet the challenges facing insulations containing CFC. The first sessions included presentations of technical studies and informal progress reports by some of the attendees. The research menu projects were presented and discussed in the second session. The second session ended with attendees voting on two issues for each project: technical importance, and whether the project should be done by the public sector, the private sector, or cooperatively. The ballot results define a prioritized research menu that identifies projects for cooperative interactions.

3.2 GOALS AND METHODOLOGY

The major goal of this workshop was to have the attendees representing all the major insulation industries affected by CFC restrictions produce a relevant, comprehensive, and prioritized list of research needs. The workshop also served to provide guidance on the role of the federal government. In the long term, it was the goal of the workshop to accelerate the resolution of CFC in insulation issues and minimize the energy impact of CFC restrictions.

The methodology was to develop several draft versions of the Alternatives for Insulations Containing CFCs Research Project Menu, circulate the drafts prior to the workshop, solicit additional research descriptions, discuss the research at the workshop, have each of the workshop attendees fill out a ballot assigning an importance ranking to each research project, and decide who should do the project. The balloting results were immediately compiled and presented to the workshop attendees. The ballot and a detailed description of the balloting process is given in Appendix D.

3.3 FIRST SESSION: PUBLIC/PRIVATE PROGRESS REPORTS ON CURRENT AND PLANNED RESEARCH

This session included presentations of technical activity and informal progress reports by some of the attendees. The intent of this session was to exchange results and to identify areas for interactions. The Planning Team suggested that attendees from industry would be more responsive if detailed proceedings were not recorded for publication. Consequently, the proceedings focus on the public agency progress reports and include private industry reports only when permission to do so was granted by the presenter.

D. L. McElroy, ORNL, called the meeting to order, thanked the attendees, identified DOE responsibilities, and expressed hope that fruitful public/private interactions would result from this workshop. John Millhone, Director, U.S. Department of Energy Office of Buildings and Community Systems, encouraged the participants of the workshop to "work cooperatively, energetically, and with imagination to develop a successful approach to resolving the CFC issues." G. E. Courville, ORNL, described the workshop goals and methodology as described in Section 3.2. He described the workshop as an opportunity for cooperative research on CFC by an agreement on a prioritized research menu with appropriate public and private roles.

Four public sector progress reports followed these introductory remarks. First, Jeff Christian, ORNL, described the detailed analysis of the "Impact of CFC Restrictions on U.S. Building Foundation Thermal Performance," ORNL/CON-245 (December 1987). The executive summary from this report is included in Appendix F. The use of extruded polystyrene for below grade insulations is postured for accelerated growth, if alternative blowing agents to CFC-12 can be found. Second, Hunter Fanney, NBS-Gaithersburg, described the analysis he and Steve Petersen did on the Impact of CFC Restrictions on Residential and Commercial

Building Walls and Roofs on U.S. Building Thermal Performance (NBSIR 88-3829). Third, Dean Smith, EPA, described three projects: Purity Standards for Recycled Mobile Air Conditioning Refrigerant; Investigations of New CFC and Halon Alternative Chemicals; and Means to Obtain Improved Foams. EPA goals are to reduce CFC consumption, to minimize social and industrial impact, to minimize energy penalty, and to stimulate private industry. At the time of this workshop EPA was also attempting to prioritize R&D needs. Finally, Mark Bomberg, NRC-C, described research to predict long-term R-values controlled by gas diffusion and research on dimensional changes. A thin specimen technique is being used for the former.

A major question from the attendees during this session was "What is the energy impact of the CFC restrictions to the building and appliance industry?" This question led to the development of an additional project for the Research Menu, C4.5: Develop Energy Impact Data Related to CFC Restrictions.

Nine private sector progress report presenters and their topics are briefly summarized below:

Ian Shankland, Allied Signal, described physical and chemical properties of HCFC 123 and HCFC 141b and contrasted these to those of CFC-11.

J. Creazzo, DuPont, described the steps and the schedule to deliver commercial alternatives to CFC-11 and CFC-12.

D. Bhattacharjee, Dow, described properties of board stock produced with various gases including HCFC-123, blends of HCFC-123 and CFC-11, HCFC-141b, and CO_2-CFC-11 blends.

G. Sievert, SPI, emphasized the loss of 1400-1800 small businesses if no substitutes are found for the CFC-11 currently used in the field applied spray polyurethane.

F. Lichtenberg, SPI, indicated they had sponsored forums at their annual meetings in 1986 and 1987. She suggested the second workshop could be held prior to the next annual meeting, October 18-20, 1988, in Philadelphia. SPI sponsored an Economic Analysis (Putnam, Hays, and Bartlett) that shows a 1989 freeze at 1986 levels is actually a 30% cut in available material.

John Clinton, PIMA, expressed concern about being in business five years from now. PIMA has petitioned the Department of Justice for a joint research program on properties.

R. P. Tye, Holometrix, described studies on aging of foams in roofs and walls, participation in round robin tests, in-situ tests at the Roof Test Research Apparatus (RTRA), and a bibliography containing more than 200 aging articles in the Journal of Thermal Insulation (January 1988). This bibliography is included in Appendix F by permission of C. Gilbo, Editor, Journal of Thermal Insulation.

K. Cwick, DeGussa, described silica powders made by DeGussa as an alternative insulation.

D. Keeler, Dow, noted that Dow had a recent press release indicating they have a non-CFC solution for extruded polystyrene foam. A copy of this is included in Appendix F by permission of D. Keeler, Dow.

Four additional public sector reports were given, including:

H. Lorsch, Drexel University, described in-situ tests on roof and wall spray-applied systems. These showed various R-values due to thicknesses ranging from 3/4 to 1½ inches. Some in-situ tests of foams show no change in R-value with age.

S. K. Fischer, ORNL, described a report being prepared for DOE that shows the energy impact is largest for building equipment, possibly 1.8 quad/year and minimal for building insulation, less than 0.2 quad/year. This sparked a controversy from the audience. Conversations after the meeting have resulted in modifications to his impact figures for buildings. The new executive summary is given in Appendix F.

T. Potter, SERI, described compact vacuum insulation (CVI) that obtains R-15 for 0.1 inch. A demonstration in Portland is planned in 1989.

L. Glicksman, MIT, summarized the Aachen Symposium (September 1987) and described research in progress at MIT. Dr. Glicksman indicated that it was clear that U.S. near term problems due to CFC restrictions will be more severe than in Europe, because the U.S. restricted propellents in the 1970's.

Discussion from the attendees emphasized the need for additional energy impact analysis on walls and roofs. L. Aulisio, Celotex, indicated this was needed now for a Senate hearing.

The last presentation in the first session was a review of the Research Menu and the balloting procedure by J. E. Christian, ORNL. He distributed a set of ballots to each attendee. Appendix D contains a sample ballot and a description of the ballot processing by H. A. Fine of the University of Kentucky, and R. M. Acevedo of National Computer Systems.

3.4 SECOND SESSION: RESEARCH MENU PROJECT PRESENTATION, DISCUSSION AND RANKING

The second session provided the opportunity for each of the 29 projects to be presented to the attendees and discussed by the attendees. Each presenter covered the projects in his category consecutively, using viewgraphs to give the project title, scope, approach, and product. Following the presentation, the discussion leader lead a discussion of each topic. This format allowed each topic to be placed before the attendees twice.

C.1 Insulation With Alternative Blowing Agents (12 projects).

Mr. R. P. Tye, Holometrix, presented the 12 projects listed in Table 3.1. Dr. G. Baumann, Mobay, was the discussion leader and regrouped similar projects as listed in Table 3.1, which includes some of the comments made by the attendees for each project or group of projects. Most of the comments were incorporated into the research project descriptions shown in Appendix C. The added changes are underlined in the text.

C.2 Alternative Insulations (6 projects).

Dr. H. A. Fine, University of Kentucky, presented the 6 projects listed in Table 3.2. Mr. R. W. Barito, R. W. Barito and Associates, led the discussion and showed the attendees an evacuated powder-filled panel that was produced in December 1986.

C.3 Recovery/Recycling/Disposal (6 projects).

J. E. Christian, ORNL, described the 6 projects listed in Table 3.3. Tom Nelson, Radian Corp., led the discussion and suggested that a 30% reduction could be achieved by recycling/recovery. John Clinton, PIMA, described an operating CFC recovery process that is recovering 7 or 8% of the total input.

C.4 Implementation and Information (5 projects).

G. E. Courville, ORNL, presented 5 projects listed in Table 3.4. The new topic, C.4.5, dealt with energy impact analysis. F. Lichtengerg, SPI, led the discussion.

The second session ended with attendees marking their ballots to vote on two issues, technical importance, and who should do the research on each project. The ballots were collected and counted electronically using equipment and facilities provided by National Computer Systems.

3.5 Third Session: Workshop Ballot Results and Discussion

The results of the balloting were presented to the attendees. A hard copy of the results given in Table 4.1 (see next section) was given to each attendee. This table provides the overall ranking of 29 projects by technical merit by all voters.

Table 3.1 Research Project Category 1. Insulation with Alternative Blowing Agents – Comments by Attendees

Code	Title	Comments by Attendees
C.1.1	Accelerated foam aging for determination of design R-values	Outdoor exposures are needed for many conditions. Lab tests do not include enough variables. A single R-value is problemmatic. Products do differ in responses. Thin tests are worth pursuing. Product lifetimes need to be defined. Industry needs a method for 2 and 5 year aging test prediction.
C.1.5	Design and implement a reliable field test project	
C.1.11	Protocol to predict long term (5 yr) thermal performance of cellular foam insulation products	
C.1.2	Develop a low k standard reference material SRM for calibration of thermal conductivity measuring devices	Need an SRM with similar density. Guarded hot plate results on new SRM are 0.0214W/m•K and 0.0216 W/m•K at two labs. Heat flow meter tests using SRM 1450b were (600 mm: 0.0219 and 300 mm: 0.0220) within 3%.
C.1.3	Develop an accurate data base of the thermal properties of the more promising alternative blowing agents	Manufacturers are doing this and finding 20% variability for HFC 134a.
C.1.12	Develop accurate data base of physical properties of substitute blowing agents	
C.1.4	Identify new chemical blowing agents	Delete the word "chemical" before blowing agent.
C.1.6	Environmentally acceptable blowing agents in foam insulation: means to achieve equivalent efficiency	Need new concepts and new models.
C.1.7	Develop a calculation methodology for flammability testing of new insulations intended for single-ply roofing applications	Difficult if not impossible task.
C.1.8	Thermal resistance measurements of current CFC - insulations and reduced or non CFC alternatives as they become available	Few comments.
C.1.9	Thermal conductivity of expanded polymers with chemically inactive fill gases	Few comments.
C.1.10	Manufacture of environmentally acceptable plastic foam insulations	Do not restrict to phenolic foams only.

Table 3.2 Research Project Category 2. Alternative Insulations – Comments by Attendees

Code	Title	Comments by Attendees
C.2.1	Production and demonstration of composites with high thermal resistance	Need to list applications.
C.2.2	Evacuated panels "super insulations" for buildings and appliances	Do paper studies first. Concern exists about panel lifetime, and parallel heat transfer.
C.2.3	Evaluation of components for super insulations	Others are studying various types of silica.
C.2.4	Non CFC systems	Others are doing, why deplete CFC effort. Composites may meet more needs than just thermal resistance.
C.2.5	Non CFC foundation insulation application verification	Was not discussed by presenter.
C.2.6	Develop facing materials that eliminate out-gassing of CFC substitutes	Can food packages achieve 20 year lifetime? Design target seems to be 1-2 years.

Table 3.3 Research Project Category 3. Recovery/Recycling/Disposal – Comments by Attendees

Code	Title	Comments by Attendees
C.3.1	CFC manufacturing recovery process	Recovery processes are new to the industry. Disposal of spent carbon may require special handling under RCRA. Dust restricts greater recovery. Costs vary by factor of five. Requirement for greater air ventilation during summer months for worker comfort in factory dilutes source strength.
C.3.2	CFC incineration	Commercial incinerators operate at high temperatures to avoid phosgenes. Shredders leave 50% of the product unreleased. Burning can yield $HC\ell$ and corrosion problems.
C.3.3	Recycling panels	Can this be done? Sweden will have a total ban in 1994.
C.3.4	CFC destruction by methods other than incineration	If recaptured and impure may be hard to reuse.
C.3.5	Recapture of CFCs at refrigerator/freezer retirement	Economics of recapture may be poor.
C.3.6	CFC Adsorbents	Costly operation.

Table 3.4 Research Project Category 4. Implementation and Information Exchange – Comments by Attendees

Code	Title	Comments by Attendees
C.4.1	Prepare an appropriate public/private research plan for alternatives to CFC insulation	Menu will accelerate research.
C.4.2	DOE/ORNL/Industry workshops on alternatives for CFC insulation	Let steering committee decide time until next meeting. A great deal of research is occurring now.
C.4.3	Critical assessment of product property tests	Identify critical tests as in DTR 9774 (Appendix F).
C.4.4	Establish essential thermal insulation material properties by type of application	No comment.
C.4.5	Develop energy impact data related to CFC restrictions	Energy impact statement is key issue.

4. RESEARCH PROJECT RANKING ANALYSIS

4.1 OVERALL

The intent of this section is to show the results of the balloting. The interpretation of the results is in the eye of the beholder. A number of observations are made by the authors. These ballot results should only be one of a host of inputs used prior to making R&D resource allocations.

Figure 4.1 is a plot of all the averaged votes, both the technical merit and the indicator of who should do the work. One of the observations from Figure 4.1 is that there appear to be numerous opportunities to cooperate on the majority of research projects discussed in this menu. More than 75% of the research projects, 24 of 29, were identified as research project candidates which could be accomplished by a joint private/public sector research effort. The attendees were instructed to assign a 0 if they felt the research was best conducted by the public sector and a 5 if by the private sector, and those areas which could be done by both in the middle ranges. A somewhat arbritrary division of private, public, and joint efforts to fulfill the research was made prior to the voting. The voters were informed that a value greater than 3.33 would be considered private, below 1.6 would be considered public, and everything in between would be considered joint. Six research projects were identified as most likely to be addressed by the private sector; C1.10 Manufacturing of Environmentally Acceptable Foams, C3.1 CFC Manufacturing Recovery Processes, C1.4 Identify New Blowing Agents, C2.6 New Facing Materials, C1.3 Data Base for Alternate Blowing Agents, and C1.12 Data Base of Physical Properties. The only research project felt to be clearly within the public sector is C1.2 Low k Standard Reference Material.

Figure 4.2 shows the means along with the 95% confidence interval of each research project in the menu of the suggested sector to do the research. The 95% confidence interval suggested that if another group or a larger group with similar interests and backgrounds were to vote on these research projects, the mean value of the group would, with 95% probability, still fall within the indicated range. The horizontal dash "-" represents the mean, and the vertical line through each dash represents the 95% confidence interval.

Table 4.1 shows the overall ranking by technical merit using the ballot results from all the workshop attendees. The top two items are the development of this research menu and continued workshops on alternatives for insulations containing CFCs. Other top priority research projects are development of a data base of physical properties, protocol to predict thermal performance, identify new blowing agents, environmentally acceptable blowing agents, new facing materials, energy impact for walls and roofs, CFC manufacturing recovery processes and low k standard reference material. Histograms of the top ten

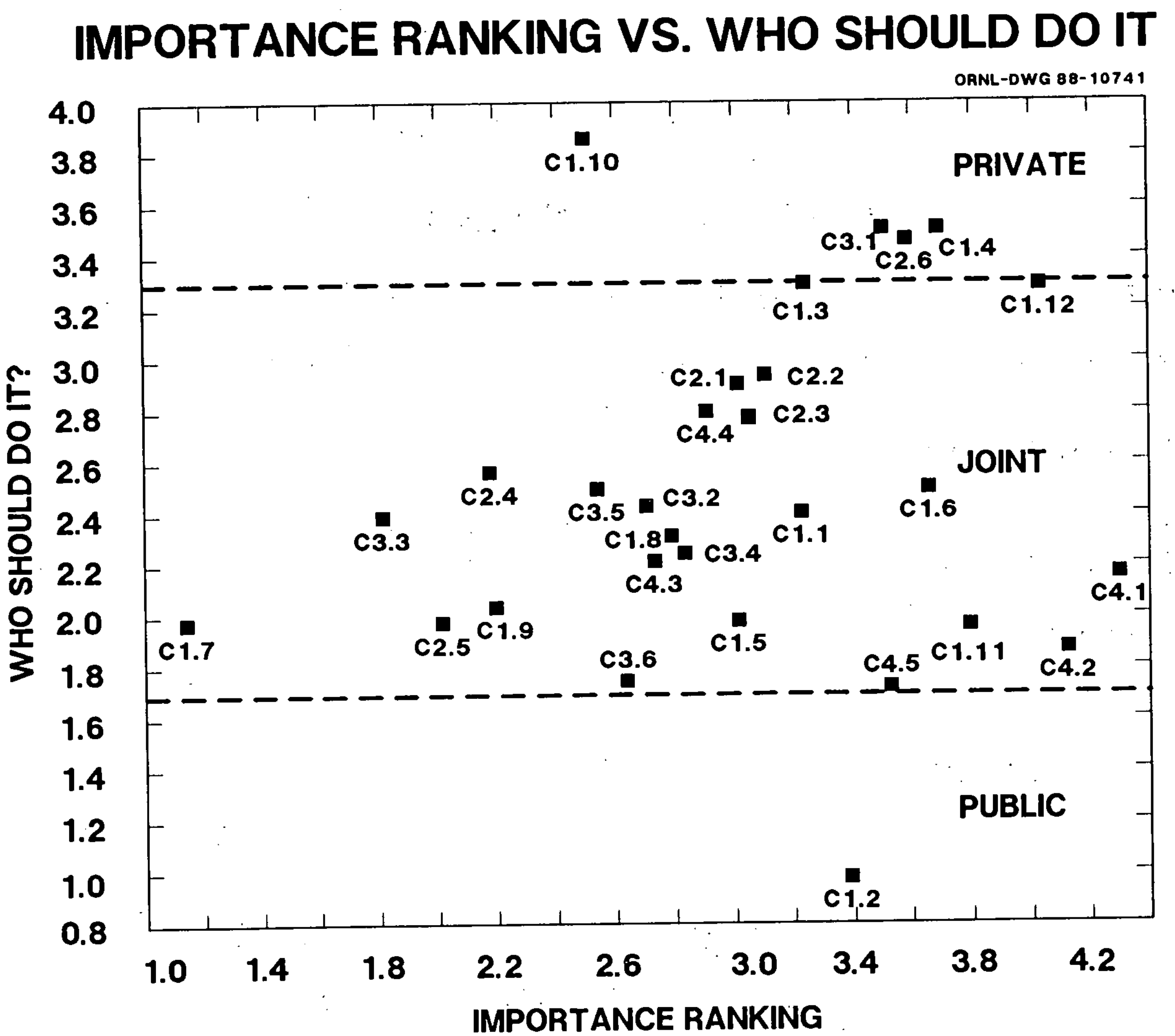

Figure 4.1 Technical Importance Ranking Versus Who Should Do It

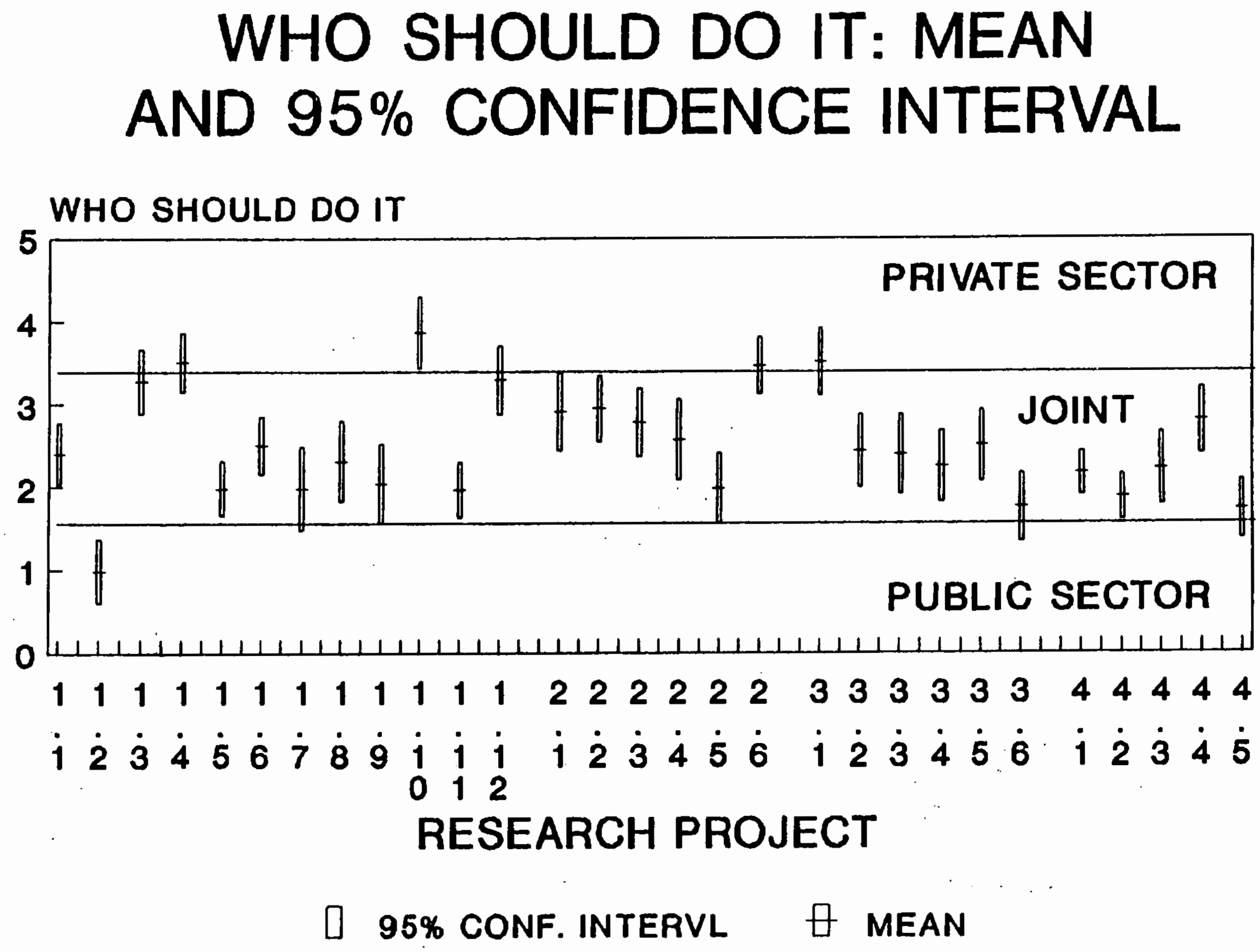

Figure 4.2 Who should do it: Mean from all voters and 95% confidence interval.

TABLE 4.1 OVERALL RANKING BY TECHNICAL MERIT: ALL VOTERS

CODE	RESEARCH PROJECT TITLE	SCORE TECH.	SCORE PUB/PRI
C.4.1	Public/Private Research Menu	4.3	2.16
C.4.2	DOE/ORNL/Industry Workshop	4.13	1.87
C.1.12	Data Base of Physical Properties	4.04	3.29
C.1.11	Protocol to Predict Thermal Performance	3.8	1.96
C.1.4	Identify New Blowing Agents	3.7	3.51
C.1.6	Environmentally Acceptable Blowing Agents	3.66	2.5
C.2.6	New Facing Materials	3.59	3.46
C.4.5	Energy Impact for Walls and Roofs	3.53	1.72
C.3.1	CFC Manufacturing Recovery Processes	3.51	3.51
C.1.2	Low k Standard Reference Material	3.39	0.98
C.1.3	Data Base for Alternate Blowing Agents	3.24	3.27
C.1.1	Accelerated Foam Aging for Design R-Values	3.23	2.41
C.2.2	Evacuated Panel "Super Insulation"	3.11	2.94
C.2.3	Components for Super Insulations	3.05	2.78
C.1.5	Field Test Project	3.02	1.98
C.2.1	Composites With High Thermal Resistance	3.02	2.91
C.4.4	Establish Essential Material Properties	2.91	2.8
C.3.4	CFC Destruction	2.84	2.25
C.1.8	Thermal Resistance Measurements	2.79	2.31
C.4.3	Critical Assessment of Product Property Tests	2.74	2.22
C.3.2	CFC Incineration	2.71	2.43
C.3.6	CFC Adsorbents	2.64	1.75
C.3.5	CFC Recapture at R/F Retirement	2.55	2.5
C.1.10	Man. of Environmentally Acceptable Foams	2.51	3.86
C.1.9	Thermal Conductivity of Expanded Polymers	2.2	2.04
C.2.4	Non CFC Systems	2.18	2.57
C.2.5	Non CFC Foundation Insulation	2.02	1.98
C.3.3	Recycling Panels	1.82	2.39
C.1.7	Calculation Methodology - Flammability Testing	1.145	1.98
	AVERAGE SCORE	3.01	2.52

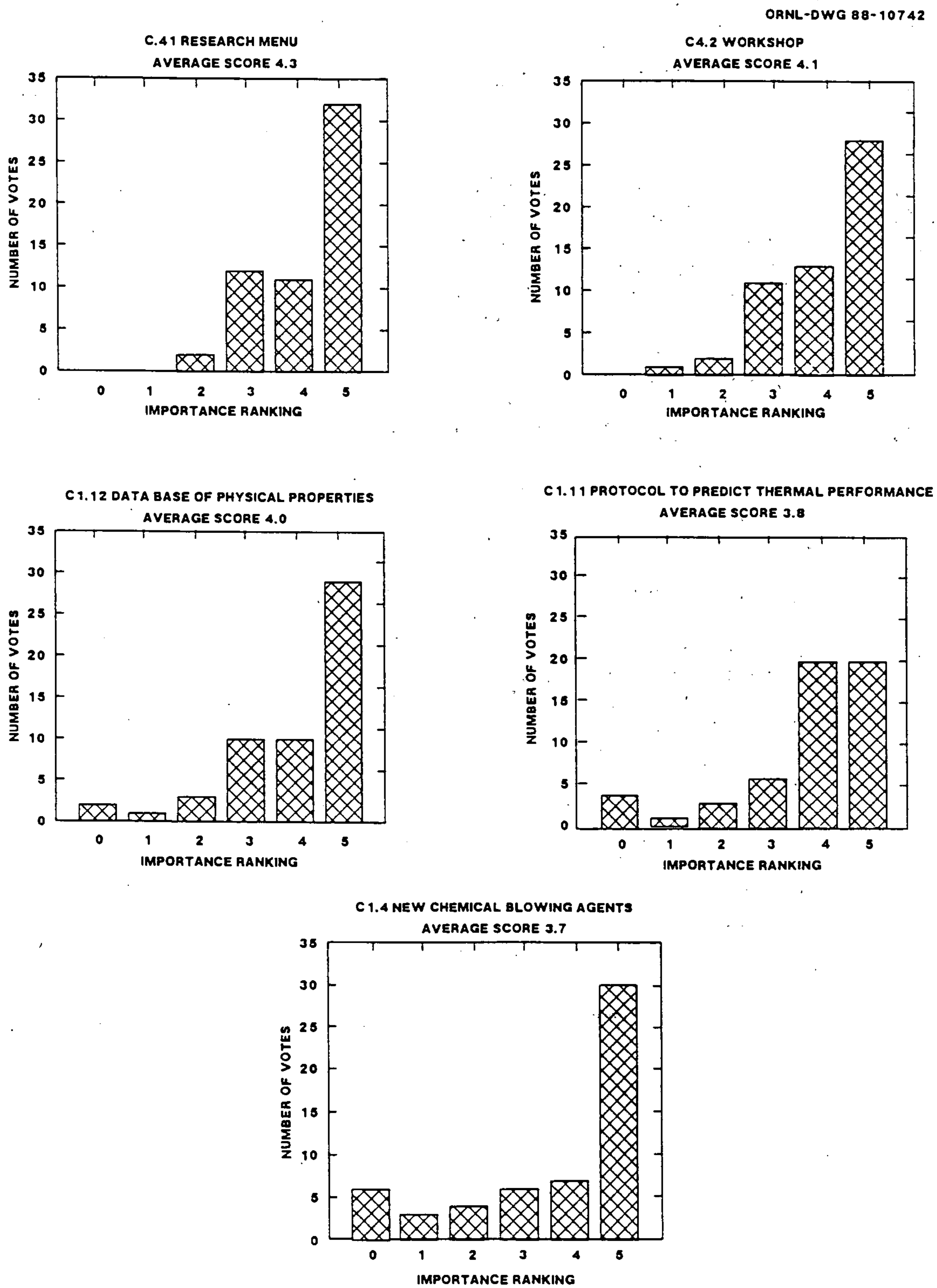

Figure 4.3 Histograms of top ten research project importance ranking ballot results from all voters.

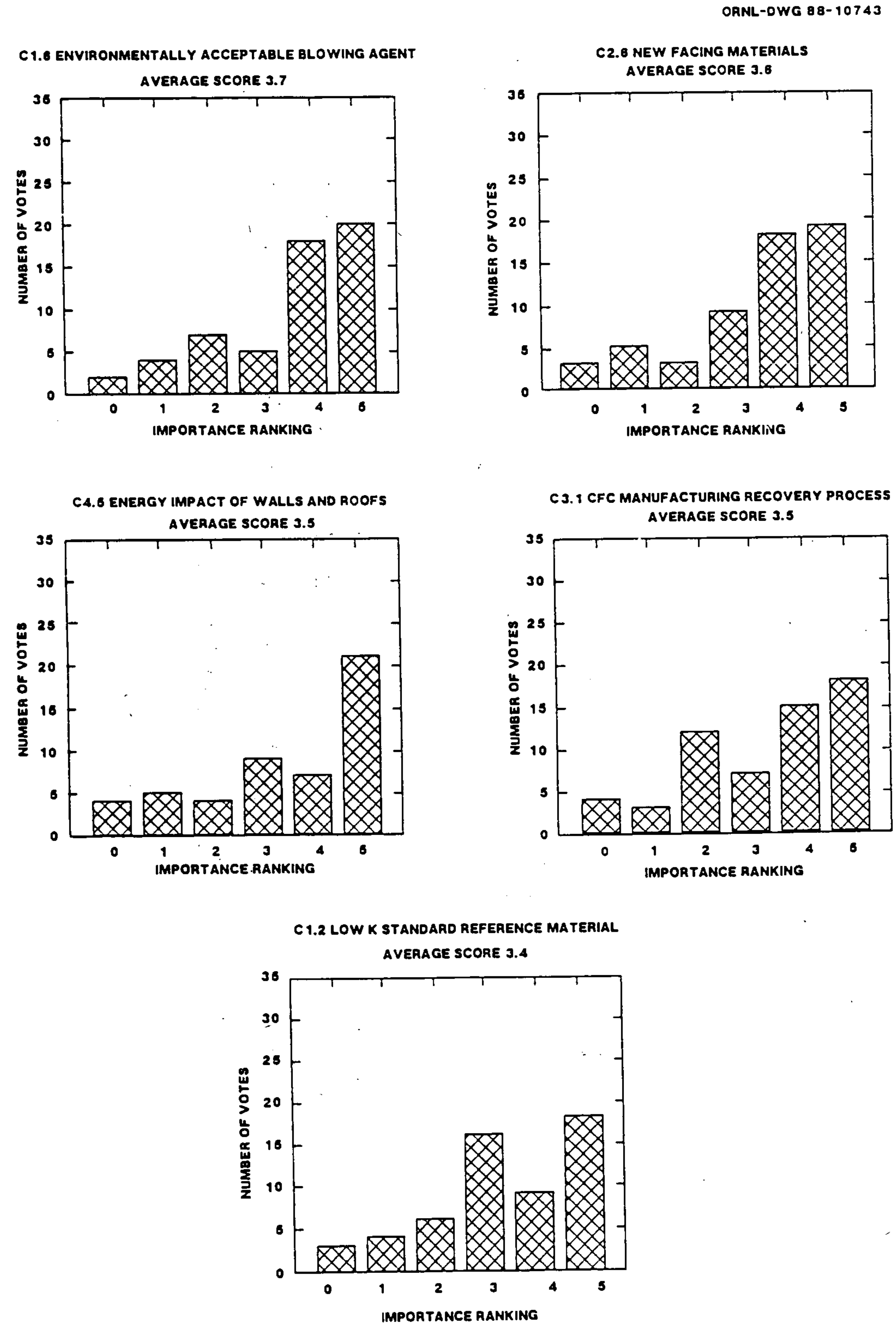

Figure 4.3 (cont'd)

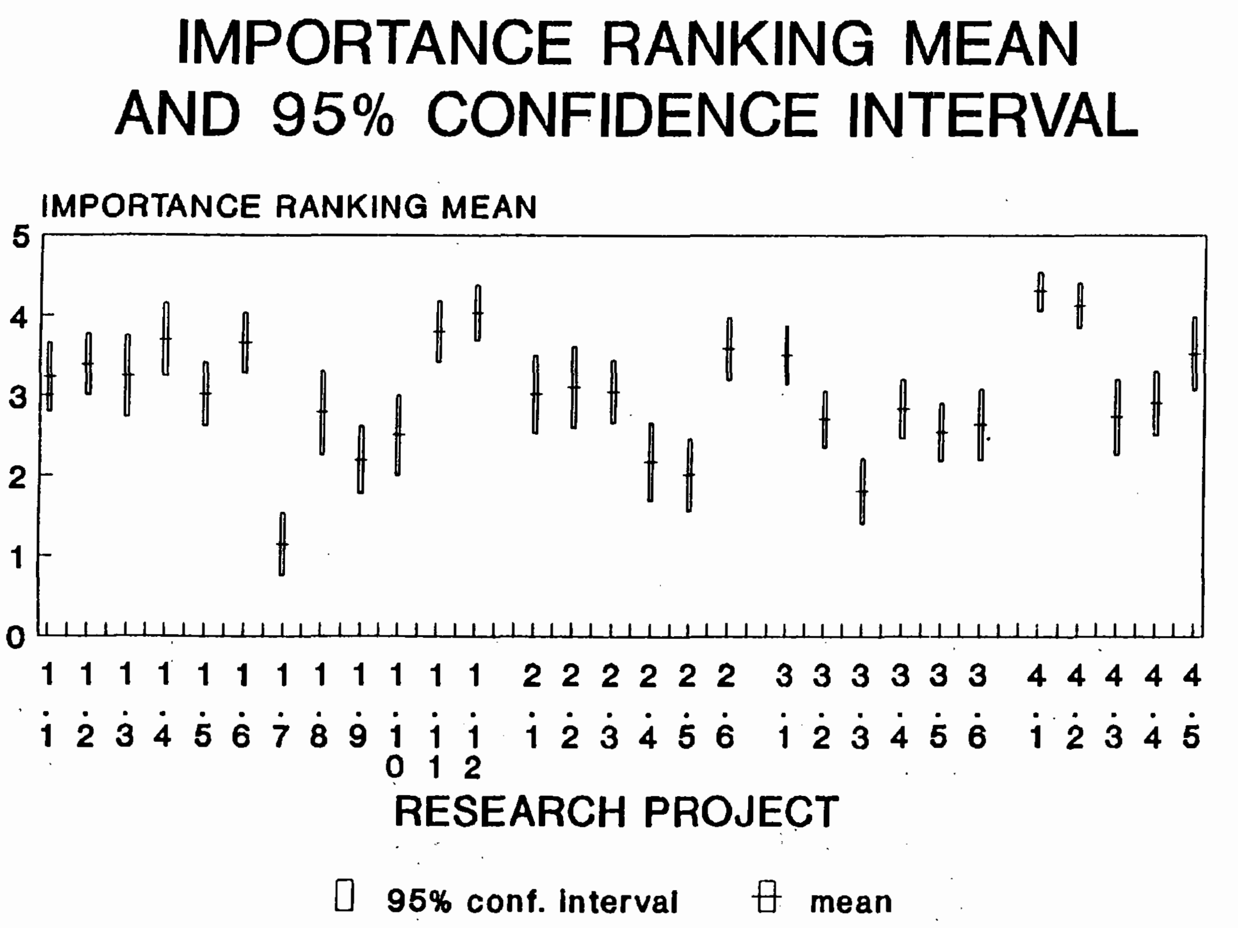

Figure 4.4 Importance ranking mean and 95% confidence interval using all voter ballots.

research project importance ranking ballot results are shown in Figure 4.3. The top projects accumulated around 70% technical merit values of 4 or higher. Figure 4.4 shows the importance ranking mean value for each research project as well as the 95% confidence interval. The average technical merit value of all voters across all 29 research projects is 3.012. One very simple statement that can be made about Figure 4.4 and Table 4.1, overall ranking by all voters, is that the top 16 research projects have above average technical merit and importance. Twenty-three of the research projects have confidence intervals that at least partially extend above a technical merit of 3.0. The average public/private sector value of all voters across all projects is 2.52.

Analysis of variance is a statistical technique used to divide all the research projects into meaningful categories, with statistical significance for above average, average, and below average importance rankings. This analysis takes the overall average importance value across all research projects and, using the variances within each research project, calculates the pooled estimate of the variance. A confidence interval is then calculated for which the mean value of all importance ranking values is 95% certain to fall within, if the similar group were to reballot the same research issues. The interval for which the statistically (95% probability) represents an average mean importance was found to be from 2.33 to 3.69 with 95% confidence. This interval leads to the statement that the top 5 research projects listed in Table 4.1 have above average importance, the next 19 have statistically average importance, and the last five have below average importance.

Table 4.2 is the same overall ranking by technical merit from the private sector workshop attendees only. Since the private sector represented 70% of the total voters, the two rankings should be similar. However, two significant shifts occurred. The first is that two of the research projects (C2.2 Evacuated Panel "Super Insulation" and C2.1 Composites with High Thermal Resistance) which dealt strongly with the development of evacuated insulation dropped 5 or 6 places when ranked by private sector voters only. The second major difference is that the private sector ranked C.3.4 CFC Destruction and C.3.2 Incineration higher than the overall group ranking. Both of these differences illustrate the urgent need for private industry to survive the short term, so they will be around for the long term.

Table 4.3 shows the overall ranking by technical merit of the voters indicating they were from the public sector. The most significant difference between the public and private sector ranking is that the private sector ranked C.2.2 evacuated panels nineteenth compared to the public sectors number one. A second major difference is C.1.3 Data Base for Alternate Blowing Agents was ranked twelfth by the private sector and second by the public sector voters. This may reflect that participants from the public sector are not fully aware of the extent of private industry research in this area. Another significant difference between the private and public sector rankings is C.1.8 Thermal Resistance Measurements, which was ranked number 23 by the

TABLE 4.2 OVERALL RANKING BY TECHNICAL MERIT: PRIVATE SECTOR

CODE	RESEARCH PROJECT TITLE	SCORE TECH.	SCORE PUB/PRI
C.4.1	Public/Private Research Menu	4.32	2.22
C.4.2	DOE/ORNL/Industry Workshop	4.24	1.86
C.1.12	Data Base of Physical Properties	3.92	3.37
C.1.4	Identify New Chemical Agents	3.74	3.3
C.1.6	Environmentally Acceptable Blowing Agents	3.64	2.59
C.1.11	Protocol to Predict Thermal Performance	3.63	2.05
C.4.5	Energy Impact for Walls and Roofs	3.58	1.76
C.3.1	CFC Manufacturing Recovery Processes	3.56	3.54
C.2.6	New Facing Materials	3.54	3.36
C.1.2	Low k Standard Reference Material	3.36	1
C.1.1	Accelerated Foam Aging for Design R-Values	2.85	2.4
C.1.3	Data Base for Alternate Blowing Agents	2.82	3.52
C.2.3	Components for Super Insulations	2.77	2.13
C.1.5	Field Test Project	2.74	2.18
C.3.4	CFC Destruction	2.67	2.08
C.4.4	Establish Essential Material Properties	2.63	2.73
C.3.2	CFC Incineration	2.62	2.16
C.4.3	Critical Assessment of Product Property Tests	2.6	2.21
C.2.2	Evacuated Panel "Super Insulation"	2.54	3.3
C.3.6	CFC Adsorbents	2.53	1.53
C.2.1	Composites With High Thermal Resistance	2.51	3.03
C.3.5	CFC Recapture at R/F Retirement	2.46	2.39
C.1.8	Thermal Resistance Measurements	2.1	3.77
C.1.10	Man. of Environmentally Acceptable Foams	2.1	3.77
C.1.9	Thermal Conductivity of Expanded Polymers	1.95	2
C.2.4	Non CFC Systems	1.7	2.64
C.2.5	Non CFC Foundation Insulation	1.56	2.08
C.3.3	Recycling Panels	1.46	2.2
C.1.7	Calculation Methodology - Flammability Testing	0.9	1.65
	AVERAGE SCORE	2.79	2.51

TABLE 4.3 OVERALL RANKING BY TECHNICAL MERIT: PUBLIC SECTOR

CODE	RESEARCH PROJECT TITLE	SCORE TECH.	PUB/PRI
C.2.2	Evacuated Panel "Super Insulation"	4.4	2.36
C.1.3	Data Base for Alternate Blowing Agents	4.36	3.07
C.4.1	Public/Private Research Menu	4.36	2.14
C.1.11	Protocol to Predict Thermal Performance	4.33	1.8
C.1.12	Data Base of Physical Properties	4.33	3.33
C.4.5	Energy Impact for Walls and Roofs	4.17	1.83
C.1.1	Accelerated Foam Aging for Design R-Values	4.07	2.53
C.4.2	DOE/ORNL/Industry Workshop	3.86	1.86
C.1.4	Identify New Blowing Agents	3.8	4
C.2.3	Components for Super Insulations	3.8	1.93
C.1.8	Thermal Resistance Measurements	3.77	1.92
C.2.1	Composites With High Thermal Resistance	3.75	2.63
C.1.5	Field Test Project	3.73	1.2
C.2.6	New Facing Materials	3.69	3.69
C.3.1	CFC Manufacturing Recovery Processes	3.67	3.8
C.1.6	Environmentally Acceptable Blowing Agents	3.6	2.47
C.1.2	Low k Standard Reference Material	3.53	0.8
C.4.4	Establish Essential Material Properties	3.5	2.93
C.1.10	Man. of Environmentally Acceptable Foams	3.36	4.07
C.2.4	Non CFC Systems	3.33	2.33
C.3.4	CFC Destruction	3.33	2.67
C.4.3	Critical Assessment of Product Property Tests	3.25	1.92
C.2.5	Non CFC Foundation Insulation	3.13	1.67
C.3.2	CFC Incineration	3.13	3.13
C.3.5	CFC Recapture at R/F Retirement	3.07	2.86
C.1.9	Thermal Conductivity of Expanded Polymers	2.86	1.93
C.3.6	CFC Adsorbents	2.86	2.14
C.3.3	Recycling Panels	2.67	2.93
C.1.7	Calculation Methodology - Flammability Testing	1.86	3
	AVERAGE SCORE	3.57	2.52

private and eleventh by the public sector. A likely role desired by the public sector research is to evaluate the thermal performance of private industry produced alternative products.

The public and private sector independently chose 6 of the same research projects in the top 10. C4.1 Public/Private Research Menu, C4.2 DOE/ORNL/Industry Workshop, C1.12 Data Base of Physical Properties, C1.4 Identify New Blowing Agents, C.11 Protocol to Predict Thermal Performance and C4.5 Energy Impact for Walls and Roofs.

4.2 RESEARCH CATEGORIES

Table 4.4 lists the ranking within categories based on technical merit for all of the voters. The overall highest ranked project in the category C.1 Insulation with Alternative Blowing Agents is to produce a data base of physical properties. The overall highest ranked project in the category C.2 Alternative Insulations is to develop new facing materials. The highest ranked project in the category C.3 Recovery/Recycling/Disposal is to develop blowing agent recovery processes during the insulation manufacturing. The two highest projects in the last category C.4 Implementation and Information Exchange are the publishing of this research menu and future workshops on alternatives for insulations containing CFCs.

Tables 4.5 and 4.6 show the ranking within categories based on technical merit for the private and public sector, respectively. There are less significant differences between the private and public sector rankings within categories than in the overall rankings compared in Section 4.1

TABLE 4.4 RANKING WITHIN GROUPS BASED ON TECHNICAL MERIT: ALL VOTERS

CODE	RESEARCH PROJECT TITLE	SCORE TECH.	PUB/PRI
C.1	Insulation with Alternative Blowing Agents		
C.1.12	Data Base of Physical Properties	4.04	3.29
C.1.11	Protocol to Predict Thermal Performance	3.8	1.96
C.1.4	Identify New Blowing Agents	3.7	3.51
C.1.6	Environmentally Acceptable Blowing Agents	3.66	2.5
C.1.2	Low k Standard Reference Material	3.39	0.98
C.1.3	Data Base for Alternate Blowing Agents	3.24	3.27
C.1.1	Accelerated Foam Aging for Design R-Values	3.23	2.41
C.1.5	Field Test Project	3.02	1.98
C.1.8	Thermal Resistance Measurements	2.79	2.31
C.1.10	Man. of Environmentally Acceptable Foams	2.51	3.86
C.1.9	Thermal Conductivity of Expanded Polymers	2.2	2.04
C.1.7	Calculation Methodology - Flammability Testing	1.15	1.98
C.2	Alternative Insulations		
C.2.6	New Facing Materials	3.59	3.46
C.2.2	Evacuated Panel "Super Insulation"	3.11	2.94
C.2.3	Components for Super Insulations	3.05	2.78
C.2.1	Composites With High Thermal Resistance	3.02	2.91
C.2.4	Non CFC Systems	2.18	2.57
C.2.5	Non CFC Foundation Insulation	2.02	1.98
C.3	Recovery/Recycling/Disposal		
C.3.1	CFC Manufacturing Recovery Processes	3.51	3.51
C.3.4	CFC Destruction	2.84	2.25
C.3.2	CFC Incineration	2.71	2.43
C.3.6	CFC Adsorbents	2.64	1.75
C.3.5	CFC Recapture at R/F Retirement	2.55	2.5
C.3.3	Recycling Panels	1.82	2.39
C.4	Implementation and Information Exchange		
C.4.1	Public/Private Research Menu	4.3	2.16
C.4.2	DOE/ORNL/Industry Workshop	4.13	1.87
C.4.5	Energy Impact for Walls and Roofs	3.53	1.72
C.4.4	Establish Essential Material Properties	2.91	2.8
C.4.3	Critical Assessment of Product Property Tests	2.74	2.22

TABLE 4.5 RANKING WITHIN GROUPS BASED ON TECHNICAL MERIT: PRIVATE SECTOR VOTERS

CODE	RESEARCH PROJECT TITLE	SCORE TECH.	SCORE PUB/PRI
C.1	Insulation with Alternative Blowing Agents		
C.1.12	Data Base of Physical Properties	3.92	3.37
C.1.4	Identify New Blowing Agents	3.74	3.3
C.1.6	Environmentally Acceptable Blowing Agents	3.64	2.59
C.1.11	Protocol to Predict Thermal Performance	3.63	2.05
C.1.2	Low k Standard Reference Material	3.36	1
C.1.1	Accelerated Foam Aging for Design R-Values	2.85	2.4
C.1.3	Data Base for Alternate Blowing Agents	2.82	3.52
C.1.5	Field Test Project	2.74	2.18
C.1.8	Thermal Resistance Measurements	2.37	2.5
C.1.10	Man. of Environmentally Acceptable Foams	2.1	3.77
C.1.9	Thermal Conductivity of Expanded Polymers	1.95	2
C.1.7	Calculation Methodology - Flammability Testing	0.9	1.65
C.2	Alternative Insulations		
C.2.6	New Facing Materials	3.54	3.36
C.2.3	Components for Super Insulations	2.77	3.13
C.2.2	Evacuated Panel "Super Insulation"	2.54	3.3
C.2.1	Composites With High Thermal Resistance	2.51	3.03
C.2.4	Non CFC Systems	1.7	2.64
C.2.5	Non CFC Foundation Insulation	1.56	2.08
C.3	Recovery/Recycling/Disposal		
C.3.1	CFC Manufacturing Recovery Processes	3.56	3.54
C.3.4	CFC Destruction	2.67	2.08
C.3.2	CFC Incineration	2.62	2.16
C.3.6	CFC Adsorbents	2.53	1.53
C.3.5	CFC Recapture at R/F Retirement	2.46	2.39
C.3.3	Recycling Panels	1.46	2.2
C.4	Implementation and Information Exchange		
C.4.1	Public/Private Research Menu	4.32	2.22
C.4.2	DOE/ORNL/Industry Workshop	4.24	1.86
C.4.5	Energy Impact for Walls and Roofs	3.58	1.76
C.4.4	Establish Essential Material Properties	2.63	2.73
C.4.3	Critical Assessment of Product Property Tests	2.6	2.21

TABLE 4.6 RANKING WITHIN GROUPS BASED ON TECHNICAL MERIT: PUBLIC SECTOR VOTERS

CODE	RESEARCH PROJECT TITLE	SCORE TECH.	PUB/PRI
C.1	Insulation with Alternative Blowing Agents		
C.1.3	Data Base for Alternate Blowing Agents	4.36	3.07
C.1.11	Protocol to Predict Thermal Performance	4.33	1.8
C.1.12	Data Base of Physical Properties	4.33	3.33
C.1.1	Accelerated Foam Aging for Design R-Values	4.07	2.53
C.1.4	Identify New Blowing Agents	3.8	4
C.1.8	Thermal Resistance Measurements	3.77	1.92
C.1.5	Field Test Project	3.73	1.2
C.1.6	Environmentally Acceptable Blowing Agents	3.6	2.47
C.1.2	Low k Standard Reference Material	3.53	0.8
C.1.10	Man. of Environmentally Acceptable Foams	3.36	4.07
C.1.9	Thermal Conductivity of Expanded Polymers	2.86	1.93
C.1.7	Calculation Methodology - Flammability Testing	1.86	3
C.2	Alternative Insulations		
C.2.2	Evacuated Panel "Super Insulation"	4.4	2.36
C.2.3	Components for Super Insulations	3.8	1.93
C.2.1	Composites With High Thermal Resistance	3.75	2.63
C.2.6	New Facing Materials	3.69	3.69
C.2.4	Non CFC Systems	3.33	2.33
C.2.5	Non CFC Foundation Insulation	3.13	1.67
C.3	Recovery/Recycling/Disposal		
C.3.1	CFC Manufacturing Recovery Processes	3.67	3.8
C.3.4	CFC Destruction	3.33	2.67
C.3.2	CFC Incineration	3.13	3.13
C.3.5	CFC Recapture at R/F Retirement	3.07	2.86
C.3.6	CFC Adsorbents	2.86	2.14
C.3.3	Recycling Panels	2.67	2.93
C.4	Implementation and Information Exchange		
C.4.1	Public/Private Research Menu	4.36	2.14
C.4.5	Energy Impact for Walls and Roofs	4.17	1.83
C.4.2	DOE/ORNL/Industry Workshop	3.86	1.86
C.4.4	Establish Essential Material Properties	3.5	2.93
C.4.3	Critical Assessment of Product Property Tests	3.25	1.92

5. CONCLUSIONS

Overall, judging from the fact that more than 80% of those invited to this workshop attended and that completion of this research menu ranked number one suggested that there is a desire to formulate the means in which to attack the CFC issue. The willingness to cooperate and interest in having the public sector involved is supported by the fact that 75% of the research projects are suggested to be completed by either or both the private and public sector. Additional evidence that there is interest in research cooperation is supported by the second highest ranked menu item, Future Private/Public Workshops on Alternatives for CFC Insulation.

Above average importance is also assigned to:

(1) The data base of physical properties of promising alternative blowing agents, which is not complete. These data are needed not only to better understand technical suitability, but also to better plan for process modifications.

(2) A protocol to predict thermal performance is needed. The k-value of plastic foams with alternative blowing agents is still likely to drift. A procedure is needed to predict long-term performance in a short time period.

(3) New blowing agents not yet thought of as leading alternatives to CFC-11 and CFC-12. There is some belief that even a blowing agent with higher thermal conductivity could produce a better final product by reducing cell size or having lower permeability in the polymer.

About 70% of the workshop attendees voting on the importance of each research project were from private industry. The public and private sector voters independently chose six of the same research projects in the top ten. C4.1 Public/Private Research Menu, C4.2 DOE/ORNL/Industry Workshops, C1.12 Data Base of Physical Properties, C1.4 Identify New Blowing Agents, C1.11 Protocol to Predict Thermal Performance, and C4.5 Energy Impact for Walls and Roofs. One significant difference between the public and private sector ranking is that the private sector ranked C2.2 Evacuated Panels nineteenth compared to the public sector's number one. There was some interest by the private industry participants to consider evacuated volumes in plastic foam boards, but clearly the desire is first to try to find an acceptable alternative set of blowing agents and develop a protocol for predicting long-term thermal performance. Those insulation manufacturers most impacted by CFC restrictions indicate by their balloting that they do not have as much to gain by development of alternative insulation technologies as compared to plastic foam insulation.

The prioritized research list presented in this report should be considered only as one of a number of inputs for allocating research and development resources. There are many promising activities outlined in this report and they should be useful in developing research plans and formulating research work statements. It is obvious that there are numerous areas where cooperative research ventures could be established. Hopefully this document will form a starting point to accelerating the solution to the CFC problem.

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APPENDIX A

Private Industry Interest in DOE Cost Sharing Development of Alternatives for Insulations Containing CFCs

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Dear Mike:

On February 9, 1988, a group of AHAM members visited Oak Ridge National Laboratory (ORNL) to review the appliance research projects in progress or under consideration. This visit was followed on February 10, 1988, with a trip to the Solar Energy Research Institute (SERI) to review their work on metal vacuum panel insulation. The work we reviewed has in the past been funded by the Department of Energy (DOE) although there was an indication that the present funding level was significantly less than original funding levels.

As a result of those meetings and further discussions by AHAM, it has been agreed that AHAM should:

1. Encourage DOE to continue funding of generic type research on evacuated panels, advanced insulation materials, refrigerant mixtures and chlorofluorocarbon (CFC) substitutes.

2. Volunteer AHAM's Refrigerator-Freezer Engineering Committee to serve as an advisory committee to ORNL and SERI if called upon by these organizations.

AHAM believes that the vacuum panel research is significant because it could lead to reduction of CFCs used as polyurethane foam insulation blowing agents and at the same time contribute to reduced energy consumption through improved insulation. However, much work needs to be done to develop the basic data and material characteristics that will allow manufacturers to select proper combinations of materials for their applications. A short term test to predict reliability of evacuated panels would also be of benefit to all manufacturers.

The metal panels using a "hard" vacuum presents an interesting concept but AHAM believes that application of that concept is further out not likely to be of immediate assistance in the energy program.

In summary, AHAM urges DOE to continue funding generic type research that will benefit the industry as a whole. However, application type research is still an area that should be done by each manufacturer for its own uses.

If you wish to discuss this further or need addtional information, please contact me.

By copy of this letter to Phil Fairchild, ORNL, and Tom Potter, SERI, I am advising them of AHAM's readiness to provide advice on matters that they believe warrant it. Their contact for this advisory committee activity should be through me at AHAM headquarters.

Sincerely yours,

Jack Wezeovich

JTW:ms

cc: Phil Fairchild, ORNL
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APPENDIX B

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APPENDIX C*

Detailed Alternatives for Insulations Containing CFCs
Research Project Menu

There are four categories in which the research projects are grouped. The categories are entitled C.1 Insulation with Alternative Blowing Agents; C.2 Alternative Insulations; C.3 Recovery/Recycling/Disposal; and C.4 Implementation and Information Exchange. The specific projects are presented below by category.

C.1 Insulation with Alternative Blowing Agents

C.1.1 Accelerated Foam Aging for Determination of Design R-values

C.1.2 Develop a Low k Standard Reference Material (SRM) for Calibration of Thermal Conductivity Measuring Devices

C.1.3 Develop an Accurate Data Base of the Thermal Properties of the More Promising Alternative Blowing Agents

C.1.4 Identify New Blowing Agents

C.1.5 Design and Implement a Reliable Field Test Project

C.1.6 Environmentally Acceptable Blowing Agents in Foam Insulation: Means to Achieve Equivalent Efficiency

C.1.7 Develop a Calculation Methodology for Flammability Testing of New Insulations Intended for Single-Ply Roofing Applications

C.1.8 Thermal Resistance Measurements of Current CFC - Insulations and Reduced or Non CFC Alternatives as They Become Available

C.1.9 Thermal Conductivity of Expanded Polymers With Chemically Inactive Fill Gases.

C.1.10 Manufacture of Environmentally Acceptable Plastic Foam Insulations

C.1.11 Protocol to Predict Long Term (5 yr) Thermal Performance of Cellular Foam Insulation Products

C.1.12 Develop Accurate Data Base of Physical Properties of Substitute Blowing Agents

*Underlined words or sentences are additions to the document resulting from workshop discussions.

C.1.1 Accelerated Foam Aging for Determination of Design R-Values

Scope. To develop, within two years or less, realistic lifetime R-values for cellular plastic insulation materials or products which have thermal properties that are dependent on time and other parameters.

Problem significance. Current laboratory conditioning and experimental test procedures for materials alone bare little resemblance to the environment in which the products will eventually be used. The thermal performance of insulation products, which vary with time, cannot be adequately predicted solely from short-term measurements made on systems under real-life conditions. As a result, there are conflicting claims regarding "aged" thermal performance characteristics of cellular plastic insulations. These conflicts arise due to the differences in approach; on the one hand, reliance on the results of laboratory tests on artificially aged specimens versus those derived from in situ studies often on poorly characterized materials. An accelerated aging technique is needed to accurately predict design R-values in the laboratory.

An improved, accelerated aging test technique, such as the thin sliced specimen technique currently being studied in Europe as a basis for an ISO Test Method is needed in order to provide additional points on the curve in a much reduced time period (Tye 1987).

Tye reports correlations of various aging conditions and times were possible in order to illustrate that elevated temperature accelerated aging for up to ninety days was equivalent to room temperature aging for two years or more.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 3.23; Average for 29 Projects: 3.01
2. Public/Private Sector: 2.41; Average for 29 Projects: 2.52
3. Technical Merit Ranking Out of 29 Projects: 12

Technical Approach. This project should include taking insulation samples from the same batch, and aging the samples in the laboratory under several promising conditions. The thermal conductivity, k, of these samples will be measured. In addition, k for these samples will be compared to the k-values of field samples from roofs, walls (several orientations), and foundations.

Major inputs. Holometrix, Inc., DOE/ORNL

Research Products. Accelerated aging tests to simulate insulation performance over time for non CFC foam insulation.

C.1.2 Develop a Low k Standard Reference Material (SRM) for Calibration of Thermal Conductivity Measuring Devices.

Scope. Complete the development of a Thermal Standard Reference Material (SRM) having a low thermal conductivity (k) of 0.023 W/m·k (0.16 Btu·in/h·ft²·°F, R-6 per inch).

Problem significance. Low k SRM is needed for accurate determination of thermal properties of materials having low k values, such as CFC-insulations. A low thermal conductivity SRM is needed for use in calibration of heat flow meter apparatuses and to certify guarded hot plate apparatuses.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 3.39; Average for 29 Projects: 3.01
2. Public/Private Sector: 0.98; Average for 29 Projects: 2.52
3. Technical Merit Ranking Out of 29 Projects: 10
4. Comment: This is a clear signal that this should be completed by the public sector.

Technical approach: An industry-government advisory group suggested fumed-silica insulation products were low k SRM candidates (Tye, 1977). NBS-Gaithersburg evaluated lots from four manufacturers and selected one material for further SRM development. The apparent thermal conductivity of the material depends on three independent parameters - material density, barometric pressure, and mean-specimen temperature, 0 to 100°F. Measurements will be made to quantify the effect of these parameters on the apparent thermal conductivity of fumed-silica insulation. After the measurements are completed, regression analysis will be used to fit the apparent thermal conductivity data to a linear model dependent on these three parameters. This information will be used to develop certified values of thermal resistance for the SRM. About 70 specimens will be made available for distribution to the public during 1988.

Major inputs. DOE/ORNL, NBS-G, Department of Commerce/Office of SRM

Research products.

1. 70 low-k SRM specimens, 0 to 100°F for distribution to the public in FY 1988.

2. A possible high temperature SRM after further testing. None exist above 100°F.

3. An improved guarded hot plate at NBS-G (automated data acquisition system for round the clock unmanned operation).

4. Technical reports/papers.

C.1.3 Develop an Accurate Data Base of the Thermal Properties of the More Promising Alternative Blowing Agents

Scope. CFC-123, FC-134a, CFC-141b, and other identified substitute fluids including mixtures needed for use as a rigid insulation blowing agent.

Problem significance. The current data base shows some variability. Alternate blowing agents are needed that not only reduce or eliminate potential ozone depletion but also result in insulations with the equivalent R/$.

There is now an urgent need for better information on engineering properties of substitute blowing agents. Insulation manufacturers have traditionally depended upon suppliers for materials and information on their properties, but suppliers are not always providing as much support as in the past (Creswick 1988).

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 3.24; Average for 29 Projects: 3.01
2. Public/Private Sector: 3.27; Average for 29 Projects: 2.52
3. Technical Merit Ranking Out of 29 Projects: 11

Technical approach.

1. Develop information on laboratory determined viscosity, specific heat, and thermal conductivity.

2. Evaluate materials compatibility with other foamed insulation constituents.

Major inputs.

Research products. Expanded data base on engineering properties of most promising alternative blowing agents.

C.1.7 Develop a Calculation Methodology for Flammability Testing of New Insulations Intended for Single-Ply Roofing Applications

Scope. A reliable calculation methodology should be developed which might lead to a reduction in combustion testing cost.

Problem significance. One of the most costly set of tests for manufacturers introducing a new insulation is to gain UL fire rating by testing the new insulation with a large number of various potential system configurations. Reducing product introduction costs without compromising health and safety might lead to more alternative insulations in the future. <u>This is an extremely difficult problem to solve. A number of participants in the June 1988 Workshop on Alternatives for Insulations Containing CFCs felt this may not be doable with todays knowledge</u>.

Importance ranking (value from 0 to 5, 5 being most important)

1. <u>Technical Importance: 1.15; Average for 29 projects: 3.01</u>
2. <u>Public/Private Sector: 1.98; Average for 29 projects: 2.52</u>
3. <u>Technical Merit Ranking out of 29 projects: 29</u>

Technical Approach. Review currently available calculation methodologies. Select most promising. Enhance and validate.

Major inputs.

Research product. Validated calculation methodology for accurately predicting results from flammability testing.

C.1.4 Identify New Blowing Agents

Scope. In general, rigid foams have a cellular structure that is created by an expanding gas, or blowing agent, present during the foaming process. The blowing agent can either be an inert volatile compound that is added to the reactive plastic mixture -- a physical blowing agent -- or it can be a product of the polymerizing reaction itself -- a chemical blowing agent. CFCs are classified as physical blowing agents. A uniform, closed-cell structure is formed from the expanding gas, trapping the CFC gas in the tiny cell. The CFC gas has a very low thermal conductivity, which helps make the foam an excellent material for insulation applications. In addition, the cellular structure provides structural rigidity and strength, which is desirable in many insulating applications. If a desirable chemical blowing agent could be developed which produced very small cells and yet a structurally strong board, CFCs would not be needed. This area should be fully explored.

Should not include CFC-123, CFC-141b, FC-134a. Could include CO_2 and flourine-containing compounds. Should have the following characteristics:

low ozone depletion potential
satisfactory boiling point, uniform closed-cell formation, diffusion rate, solubility in formation and final product, thermal conductivity
low toxicity and flammability
cost-effective

Problem Significance. Thermal conductivity values of foams can be improved by reducing cell size, which would help offset the fact that the alternative blowing agent could have a higher conductivity.

Importance ranking (value from 0 to 5, 5 being most important).

1. Technical Importance: 3.7; Average for 29 projects: 3.01
2. Public/Private Sector: 3.51; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 5
4. Comment: Suggests strong participation from private industry.

Technical Approach.

1. Select most promising set which private industry is not already working on.

2. Obtain or synthesize compounds.

3. Determine properties

4. Identify process which produces acceptable rigid boards.

Major inputs. EPA

Research products. Expanded data base on potential CFC blowing agent alternatives.

C.1.5 Design and Implement a Reliable Field Test Project

Scope. Develop protocol for field testing long-term performance of insulations. This includes a detailed design and cost estimate for an instrumented facility for obtaining field performance data on insulation systems for roof, walls, and foundations. The second phase will cover construction of several units. This will involve performance of foam insulation in combination with other construction materials under exposure to dynamic thermal, moisture and mechanical stress conditions. Establish a data base of the thermal properties at different conditions for foam products currently on the market and most importantly for new foam products as they are introduced.

Problem significance. Field performance of insulation systems is needed for realistic product comparisons. Architects and building owners lack information on the real thermal properties of foamed board insulation products after being installed for extended time periods. Field testing is a complex subject, but successful units exist, such as the Roofing Thermal Research Apparatus (RTRA) and include fruitful analysis methodology. The results from this project would permit a more informative choice of insulation products. Field results often differ from laboratory results; resolving this difference is critical to establishing design R-values for existing and new products.

Field measurements on building envelope components is a complex subject still in the early stages of development. What type and placement of various sensors should be used? How should the sensors be calibrated? What should be the monitoring period for the data collection? What analysis method should be used for the data for different types of components? It is most important that CFC alternatives get into the field at least on an experimental basis immediately to assure energy conscious builders that their building practices involving plastic foams will continue to be acceptable in the future.

Importance ranking (value from 0 to 5, 5 being most important).

1. Technical Importance: 3.02; Average for 29 projects: 3.01
2. Public/Private Sector: 1.98; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 15
4. Comment: Good project for joint public/private sector effort.

Technical approach. The design would incorporate the best features of existing field demonstrations. This would be the initial phase of a field test program for various climates with uniform facilities for data acquisition and analysis. A prescribed set of pre- and post exposure lab tests would compliment the field tests.

Major inputs. DOE/ORNL

Research products.

1. Field performance for products: design R-values
2. Uniform reliable test facilities for roof, wall, and foundations envelope performance.
3. The clear message to builders that alternatives to CFC-insulations will be available.

C.1.8 Thermal Resistance Measurements of Current CFC - Insulations and Reduced or Non CFC Alternatives as They Become Available

Scope. Establish a properties data base at different mean temperatures for current and future foam insulation products.

Problem significance. A thermal conductivity data base for the existing CFC foam products and potential future products is needed as a base for comparison of thermal property measurements, comparison of different agents in the foam cells, and after different times at 24°C: 28 days, 90 days, and 180 days. It has been proposed that these measurements be made on a 1 x 1 meter calibrated hot plate. The larger measurement areas will reduce variability obtained with commonly used smaller samples.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 2.79; Average for 29 projects: 3.01
2. Public/Private Sector: 2.31; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 19

Technical approach. A survey will establish what thermal conductivity data is available for current foam insulation products. Industry will help select representative foam insulation products of four types [extruded polystyrene EXPS (R-12), PI (R-11), Phenolic (R-111 and R-113), and expanded polystyrene EPS (air)] at available densities. Tests will be conducted at 10, 24, and 38°C, and at 24°C after 28 days, 90 days, and 180 days.

Major inputs. DOE/ORNL, NBS

Research Products.

1. Accurate measurements of thermal conductivity of currently available foam products.

2. Accurate measurements of thermal conductivity of potential new foam products.

3. A basis for extended aging tests.

C.1.9 Thermal Conductivity of Expanded Polymers with Chemically Inactive Fill Gases

Scope. Determine thermal conductivity from 100 to 350 K of expanded polymers with gases of known behavior to establish data base for models to analyze different modes of heat transfer as a function of temperature.

Problem significance. Data base over a broad temperature range supports and extends analyses and models used for a limited temperature range. Using different gases of known behavior helps identify quantitatively modes of heat transfer, nominally total k is 20% radiation, 30% solid conduction, and 50% gas conduction. Component knowledge is needed to guide product evaluation.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 2.2; Average for 29 projects: 3.01
2. Public/Private Sector: 2.04; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 25

Technical approach. Use existing low temperature guarded hot plate apparatus at NBS-Boulder to test three expanded polymers containing different gases from 100 to 350 K. Analyze results and compare to data for CFC-blown polyurethane of various densities.

Major inputs. DOE/ORNL, NBS

Research products. Thermal conductivity data base of expanded polymers at temperatures from 100 to 350 K.

Cost and time estimate. $35K, 1 year.

C.1.10 Manufacture of Environmentally Acceptable Plastic Foam Insulations

Scope. Phenolic foam insulations are claimed to not age. In addition, claims have been made that these insulations can be made with CFC-substitutes and/or non-CFCs, such as CO_2 blowing agents. The resulting products are also claimed to have thermal properties better than aged polyurethane foams. Most interest for the phenolic foams appears to be in board stock. Some work has been done on foam-in-place applications. This research could be expanded to foam products other than phenolics.

Problem Significance. The foam insulation users are faced with the loss of CFCs for the production of insulation and the resulting loss of thermal performance. At least one end-use industry, the appliance industry, is also faced with mandated increases in energy efficiency. As foamed in place insulations are essential to the manufacture of many appliances, alternative foaming agents must be found.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 2.51; Average for 29 projects: 3.01
2. Public/Private Sector: 3.86; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 24

Technical Approach. Aid in the development of foam in place phenolic insulations. Work with a manufacturer of these materials and have samples made. Work with a testing laboratory to get thermal testing and aging tests done. Supply results to industry, and other researchers to validate models, etc.

Major Inputs. Koppers, Fine (University of Kentucky)

Research Products. Samples of phenolic foams made with non-CFC and environmentally acceptable CFC blowing agents. New and aged test results on phenolic foams.

C.1.11 Protocol to Predict Long Term (5 yr) Thermal Performance of Cellular Foam Insulation Products

Scope. To develop a protocol which would predict long term (5 yr) thermal performance for cellular foam insulation products.

Problem Significance. Standard methods already exist for R-value (k-value) of cellular foam insulation products. It is also easy to track the R-value of these products versus time. With the change in blowing agents from CFC 11 to CFC 12 to new compounds, the luxury of taking 5 years to assemble 5 year test data is no longer available. A protocol is necessary which would predict long term (5 yr) thermal performance in a short "real" time period.

Importance Ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 3.8; Average for 29 projects: 3.01
2. Public/Private Sector: 1.96; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 4

Technical Approach. This project should evaluate the ability of several proposed methods to predict long term thermal performance such as, but not limited to, the thin sliced specimen technique currently under study; the technique of elevated temperature aging; the modeling technique under development at MIT, and/or a combination of the above. Project should not be limited to existing technique as a solution but as a starting point.

Major inputs. DOE/ORNL; various testing agencies/companies; private industry; MIT.

Research Products.

1. Protocol to predict long-term performance of cellular foam insulation products.

C.1.12 Develop Accurate Data Base of Physical Properties of Substitute Blowing Agents

Scope. All proposed substitute blowing agents for rigid insulation including, but not limited to, HCFC-123, HCFC-134a, HCFC-141b.

Problem significance: There is a need for physical properties information on substitute blowing agents. Physical properties include:

ozone depletion potential (actual test result)
potential for classification as a volatile organic compound
waste disposal program
flammability data
thermal conductivity vs temperature
safety information for manufacturing safety programs
toxicity program - interim reports

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 4.04; Average for 29 projects: 3.01
2. Public/Private Sector: 3.29; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 3

Technical approach. Conduct appropriate physical property tests on substitute blowing agents.

Major inputs. CFC producers; other chemical suppliers.

Research products. Necessary data base to plan process modifications to use substitute blowing agents.

C.2 Alternative Insulations

C.2.1 Production and Demonstration of Composites with High Thermal Resistance

C.2.2 Evacuated Panels "Super Insulations" for Buildings and Appliances

C.2.3 Evaluation of Components for Super Insulations

C.2.4 Non CFC Systems

C.2.5 Non CFC Foundation Insulation Application Verification.

C.2.6 Develop Facing Materials that Eliminate Out-Gassing of CFC Substitutes

C.2.1 Production and Pilot Study of Composites with High Thermal Resistance

Scope. Evacuated powder panels have a thermal resistance over R-20 per inch. Composites of these have a variety of applications that could eliminate CFC insulations. Automated production is required to show pilot study applicability. This work should include the production of preliminary automatic production designs and unit cost estimates.

Problem significance. Production of composites could yield a non CFC alternative for many applications. Economics, materials, and life-times are issues to be resolved. Industry has initiated non-automated production. A wide variety of applications exist for buildings and equipment.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 3.02; Average for 29 projects: 3.01
2. Public/Private Sector: 2.91; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 16

Technical approach. Develop a plan, schedule, and cost estimate for an initial, but prototypical application, that includes automated production, incorporation into units, and an industrial pilot study of thermal performance. Do first production and pilot study with industry. Extend example to other applications. Release to industry.

Major Inputs. DOE/ORNL

Research products.

1. Letter report in FY 1988 to plan initial production and pilot study.
2. First prototype in FY 1989.
3. Extend Pilot Study to other areas.

C.2.2 Evacuated Panels "Super Insulations" For Buildings and Appliances

Scope. In the vacuum/powder fill concept, evacuated panels are filled with fumed, ultrafine silica powders of varying particle sizes (much like the vacuum-packed coffee currently available in the supermarket). The success of this technology is dependent on developing a membrane that seals the panel preventing air from permeating the panel degrading the R-value. Another concept is to use evacuated ceramic spheres for structural integrity. One other concept is metal vacuum panels as in the unbreakable thermos.

The objective is to conceive and develop alternative insulation systems not dependent upon the use of CFCs that have thermal performance superior to currently used insulations. Potential applications are appliances, refrigerated storage, refrigerated trucks, portable coolers, and building envelopes.

Problem significance. Alternative insulation systems have been identified that offer the potential of much higher R-values per inch than is presently afforded by CFC-blown foam. These are mainly evacuated panels using either a metallic envelope or a plastic jacket and a powder filler. The possibility of very high R-values has been confirmed in the laboratory; low-cost configurations and manufacturing methods need to be developed. Other novel systems may be conceived in the future. The development of practical superinsulation systems could result in substantial energy savings.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 3.11; Average for 29 projects: 3.01
2. Public/Private Sector: 2.94; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 13
4. Public sector voters ranked this number one, compared to 13 private sector voters who ranked it number 19.

Technical Approach.

1. A paper study describing construction and experiments for testing low cost configurations of insulation boards which have some evacuated portions (various filler materials including powders, fibrous materials, and layered materials.) This work should address parasitic heat transfer.

2. Estimate durability and thermal drift.

3. Assist in the development of manufacturing processes for advanced insulation technologies.

Research products.

1. Identified most promising evacuated panel configuration for near-term application.

2. Design of an automated manufacturing facility

C.2.3 Evaluation of Components for Super Insulations

Scope. Manufacturability and reliability of super insulations remain the road blocks to the emergence of this technology. Many alternatives exist for ultra high resistance (UHR) cells that may be incorporated in foams to augment the thermal resistance of the foam. The incorporation of the UHR cells might, for example, be able to compensated for a loss of thermal performance due to a change in blowing agent.

Problem Significance. UHR cells may be incorporated into foam insulations to augment the thermal performance of the foams. These cells can take many forms from large slabs to small lenticular cells. Many factors, including edge losses, manufacturability, reliability and cost, must be evaluated in determining the optimal design. A detailed analysis of the UHR cell concept should be undertaken to establish the priorities for research in this area.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 3.05; Average for 29 projects: 3.01
2. Public/Private Sector: 2.78; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 14

Technical approach. A paper study based on contacts with representatives of the foam industry, the packaging industry and the appliance industry to establish the priorities for research in this area. Development of the highest priority UHR cells, including sample cell preparation, sample foam/cell composite preparation and development of an automated process flowsheet and cost information.

Major inputs. Packaging and foam industry, Fine (University of Kentucky)

Research Products. UHR cell design with highest probability for successful incorporation in foam products. UHR cell samples and UHR cell/foam samples for thermal and aging testing. Flowsheet and cost information for automated production of UHR cells.

C.2.4 Non CFC Systems

Scope. Taking a systems perspective of available non-CFC products in combination with other design factors can lead to equivalent overall thermal performance of conventional systems using CFCs. This should consider the use of other insulation materials such as EPS, insulating block, and fiberglass boards.

Problem significance. If CFC insulations are not available in the future or are restricted, some guidance should be readily available to builders to specify systems which, for about the same cost per R, lead to the same degree of energy efficiency with alternatives.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 2.18; Average for 29 projects: 3.01
2. Public/Private Sector: 2.57; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 26

Technical Approach. The combinations of features which should be considered. One example is combining exterior foundation insulation drainage, waterproofing and radon abatement. For instances, EPS is a viable substitute for EXPS in situations which have minimal risk of high moisture absorbtion. Can a composite product be developed which serves as waterproof membrane on the outside of the insulation when placed on the exterior of foundation walls in moist soils?
Some of the foundation insulation drainage boards have the capability of supplementing waterproofing provisions and radon mitigation strategies. If these features could be positively demonstrated the added drainage capabilities could become the product of choice, despite occasional cost penalties from a simple $/R-value perspective.

Other examples of combining multiple features into single systems would be:

wall R-value and variable emissivity

roof R-value and reflectives

wall R-value and thermal mass

R-value and structural member

Research Products. A builder's guide to energy efficiency without CFC insulation.

C.2.5 Non CFC Foundation Insulation Application Verification

Scope. Foundation insulation has lagged behind the increasing attention given to above-grade walls and roofs. However rapid growth in the use of foundation insulation is anticipated due to increases in foundation insulation levels in a number of major codes and standards and increasing availability of energy efficient construction details. One method of insulating foundations is on the exterior surfaces in direct contact with the earth and one commonly used product is extruded polystyrene. The scope of this project is to determine by independent experimental verification if foundation insulation techniques are available which can provide reliable long-term thermal performance in both new and retrofit applications. Foundation types should include crawl spaces, slabs-on-grade, and basements.

Problem significance. EXPS is the plastic foam product with the least risk of moisture decaying the life time R-value. Some builders and homeowners may not consider insulating foundations with out a reliable insulating product to choose from. A significant energy savings potential is lost, as much as 0.8 quads, if large numbers of foundations are left uninsulated. Inside insulation is not always possible nor desirable in all situations because of not only thermal but also moisture, indoor air quality, and structural considerations.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 2.02; Average for 29 projects: 3.01
2. Public/Private Sector: 1.98; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 27

Technical Approach

1. Employ the use of well-characterized test facilities in which moisture conditions are controllable on both the interior and exterior foundation surfaces. Performance verification data should be obtained on:

   - XEPS with alternative blowing agents
   - Molded expanded polystyrene (MEPS)
   - Fiberglass insulation/drainage board
   - MEPS insulation/drainage board
   - interior batt insulation
   - other innovative concepts

2. Develop a methodology for characterizing the soil at a construction site relevant to foundation thermal and moisture control measures.

3. Develop heat and mass balance model to extrapolate experimental results to other climates.

4. Draft a proposed ASTM standard and/or a builders code for foundation insulation applications based on above data.

Research product. Non CFC Foundation Insulation ASTM Standard.

C.2.6 Develop Facing Materials That Eliminate Out-Gassing of CFC Substitutes

Scope. A lot of work has already been done to better understand the factors that affect product aging, such as the quality of the barrier facing and the integrity of the bond between the facing and the core materials. The facing is the critical component needed to keep the air out.

Problem significance. Research on improved barrier facing needs to continue as well as work to identify and develop new polymers and additives which improve thermal performance. As different blowing agents are considered, the gas diffusion and dilution will remain an issue. Better facing materials could conceivably permit the satisfactory use of a blowing agent that had a higher diffusion rate in polymers than CFC-11 and CFC-12.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 3.59; Average for 29 projects: 3.01
2. Public/Private Sector: 3.46; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 7

Technical approach. Identify candidate facing materials and adhesives. Work with a manufacturer to assemble most promising concepts. Expose samples to roof, wall and possibly foundation applications and measure thermal drift.

Major inputs. The packaging industry has been striving to keep air out of food products for some time and may have something to offer insulation manufacturers, although it is recognized that insulation has a useful life of 50 plus years, whereas packaging containers usually are designed for 1-2 years.

Research product. Foam insulation facing which significantly reduces dilution of blowing agent with air and diffusion of gas from the product.

C.3 Recovery/Recycling/Disposal

C.3.1 CFC Manufacturing Recovery Process

C.3.2 CFC Incineration

C.3.3 Recycling Panels

C.3.4 CFC Destruction by Methods Other Than Incineration

C.3.5 Recapture of CFCs at Refrigerator/Freezer Retirement

C.3.6 CFC Adsorbents

C.3.1 CFC Manufacturing Recovery Process

Scope. From 5 to 20% of the CFCs currently used to blow foam insulation is released within the production facility. If this substantial quantity could be recovered, it would help extend the near term production limitations. This only covers the CFCs released during production which includes site curing. This work could be broadened to include recovery of substitute blowing agents which are likely to have a recovery value 2-3 times more than CFC-11 and 12 using 1988 prices. A more difficult task would be to develop technologies which recover blowing agents during site pouring or spraying applications. Applicator safety and health impacts would need to be carefully assessed. Questions remain as to how to safely dispose of spent carbon.

Problem significance. Carbon adsorption recovery systems are currently available for use in containing or recovering CFC emissions during the foaming process. However, the carbon adsorption process is very energy-intensive, and research is needed to develop more efficient systems. Carbon adsorption technology is well developed, but implementation depends on economics on a plant-by-plant basis.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 3.51; Average for 29 projects: 3.01
2. Public/Private Sector: 3.51; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 9
4. Comment: This was the highest ranked project in this group.

Technical approach. Review carbon adsorption, reverse osmosis, and other promising recovery techniques.

Select most promising, build test facility to determine recovery efficiency.

Major inputs. Hagler, Bailly 1987, PIMA, Patent Office under CFC recovery.

Research Products

1. Assessment of promising CFC recovery techniques
2. Proof of concept test facility

C.3.2 CFC Incineration

Scope. Disposal of halogenated hydrocarbons

Problem significance. The safe disposal of CFCs is a significant technical problem that should be immediately addressed. Ordinary combustion may not be the correct solution since it produces a variety of gas-phase products many of which are toxic. CFCs when exposed to very high temperatures can decompose into highly irritant and toxic gases: chlorine, hydrogen fluoride or hydrogen chloride, and phosgene. The protocol for acceptable destruction of CFCs has not been worked out. Shredding of foam ordinarily releases 50% of the CFC. The shredding process would have to be coupled with the incinerator to assure maximum combustion.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 2.71; Average for 29 projects: 3.01
2. Public/Private Sector: 2.43; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 21

Technical approach. A search should be undertaken for processing conditions that minimize the formation of undesirable compounds. A process that combines combustion and gas-phase scrubbing could reduce the impact of producing toxic Cl or F compounds. An appropriate chemical/thermal dynamic model should be identified to simulate different CFC incineration conditions to predict by-product quantities.

A) The reaction products depend on temperature, pressure, and feed composition with many species potentially formed.

B) The proper catalyst could favor reactions that produce harmless species.

C) Gas-phase scrubbers can be designed to remove harmful combustion products. (This will reduce volume of liquid for disposal.)

D) Absorption processes (activated) carbon or molecular series could be used to trap harmful products.

Items A and C are a matter of focusing existing technology. Item B could involve a research activity (Exxon or DuPont Labs, for example) Item D is a matter of laboratory work with existing materials.

Major inputs. D.W. Yarbrough, Celotex Corp., Lorraine Aulisio

Research products. Environmentally sound pilot plant for destroying CFCs on the earth surface.

C.3.3 Recycling Panels

Scope. One short-term solution to extend the CFC production limits is to develop mechanisms to recover and reuse products containing CFCs. Appliances containing removable insulation panels would seem to hold the greatest chance of being recycled.

Importance ranking (value from 0 to 5, 5 being most important)

Problem significance. If alternative insulations are not developed the price of CFC insulations will rise and the economics of recycling will improve. Most large appliances are disposed of separate from the bulk of the refuse stream so its special handling enhances the possibility of establishing recycling centers. The panels would have to have a useful life greater than that of the initial appliance for this to be worth considering. The concept is attractive in that if a substantial fraction of panels could be recycled, the CFC demand could drop to zero for appliance insulation. Secondly, if an appliance insulation recycling industry could be established, then why not install more durable advance insulation with some evacuation? and if appliances? building insulation panel recycling might not be that far off?

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 1.82; Average for 29 projects: 3.01
2. Public/Private Sector: 2.39; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 28

Technical approach. A concept feasibility study should be the first step. Discuss concept with West Germans, Scandinavians and other Montreal agreement signers with little if no CFC production quotas. Sweden is scheduled to call for a total ban of CFC production by 1994.

Research product. Insulation recycling concept feasibility study.

C.3.4 CFC Destruction by Methods Other Than Incineration

Scope. Disposal of CFC compounds.

Problem significance. The destruction of CFCs by a process which will convert them to benign or useful products will enhance the likelihood that they are destroyed rather than released to the environment. Combustion processes and variations lead to a variety of noxious and corrosive by-products (e.g., phosgene, hydrochloric, and hydrofluoric acid, or possibly dioxins). Shredding releases about 50% of the R-11 in plastic foams of recaptured, is impure, and may be hard to reuse.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 2.84; Average for 29 projects: 3.01
2. Public/Private Sector: 2.25; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 18

Technical approach. Identify chemical reactions of CFC type compounds that have the potential to convert them to benign or useful products. Use a combination of appropriate thermodynamic model and potential product value(s) to screen likely processes. The most likely candidates would be tested in the laboratory. When the best process is identified, evaluation would be performed for use as a basis for decision on proceeding to a pilot scale. The following minimum set of criteria must be met:

1. requirements, established by law, for destruction and removal efficiency must be achieved;

2. products of the destruction process should not themselves present a disposal or other environment problem;

3. the process should be economical compared to alternatives such as recycling;

4. the process should be flexible enough to handle mixtures of CFCs so that process control is not complicated.

Major inputs. DOE/SERI.

Research products. Pilot plant to demonstrate the effectiveness of the technology.

C.3.5 Recapture of CFCs at Refrigerator/Freezer Retirement

Scope. Significant amounts of CFCs in refrigerator/freezers (R/Fs) are thought to remain through their retirement and disposal. Recapturing them for recycling or final destruction could improve the short- to mid-term transition from CFCs.

Problem significance. Some regional programs that early-retire second R/Fs to get them off the utility grid could provide an inexpensive way to test methods for recapturing CFCs. For example, one midwest utility collected 20,000 R/Fs in six months, burying them all in a landfill. A constant and free stream of such units could allow tests of alternative methods to recapture the CFCs in the working fluid, and possibly the foam as well. Five times more CFCs are in insulation than in working fluid. Economical recovery is unlikely unless significant price increases occur. Capitalization will have to pay back rapidly with the likely trend of using less CFC in future appliances.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 2.55; Average for 29 projects: 3.01
2. Public/Private Sector: 2.5; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 23

C.3.6 Recovery of CFCs

Scope. Recovery of CFCs

Problem significance. Recovery of CFCs by adsorption on activated carbon is an expensive process. Development of alternative adsorption media that lowered the overall cost would increase the fraction of CFCs that could be economically recovered during foam blowing and cleaning operations. However, the operation costs can be significant, and research to reduce this cost would also be beneficial.

Importance ranking (value from 0 to 5, 6 being most important)

1. Technical Importance: 2.64; Average for 29 projects: 3.01
2. Public/Private Sector: 1.75; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 22

Technical approach. Identify potential adsorbent materials and screen them based on available data. measure adsorption isotherms for the most promising and those for which inadequate data are available to reject them. Based on the results, prepare a process cost analysis for a conceptual recovery system. This would provide a basis for deciding to go to the next stage of development.

Major inputs. DOE/SERI.

Research products. Development of new CFC recovery process.

C.4 Implementation and Information Exchange

C.4.1 Prepare an Appropriate Public/Private Research Menu for Alternatives to CFC Insulation

C.4.2 DOE/ORNL/Industry Workshops on Alternatives for CFC Insulation

C.4.3 Critical Assessment of Product Property Tests

C.4.4 Establish Essential Thermal Insulating Material Properties by Type of Application

C.4.5 Develop Energy Impact Data Related to CFC Restrictions

C.4.1 Prepare an Appropriate Public/Private Research Menu for Alternatives to CFC Insulation

Scope. Collect, organize, and review a collection of projects to include in a research menu. Interact with private industry and public sector representatives to deliver a consensus plan.

Problem Significance. Activities in finding alternatives to insulation containing CFCs are scattered and fragmented. Secondly, the research project selection should be based on a multitude of inputs to improve the likelihood of success and compliment the product development ongoing in private industry. The research effort needs a focal point to input research ideas and exchange results in a rapid efficient manner. With finite resources a prioritized list of research projects is necessary to promote cosponsored research, effective funds distribution, and optimize the use of facilities.

Importance ranking (value from 0 to 5, 5 being most important).

1. Technical Importance: 4.3; Average for 29 projects: 3.01
2. Public/Private Sector: 2.16; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 1

Technical Approach.

1. Develop a draft menu for initial distribution on April 17, 1988.

2. Solicit additional research projects from potential workshop participants.

3. Request inputs by May 23, 1988.

4. Revise draft menu and add the new projects.

5. Distribute second draft along with an "Importance Ranking Ballot." The participants will be requested to be prepared to vote on the projects at the June 10, 1988 workshop.

6. The ballot results will be compiled at the workshop and presented in the session on Recommendations for Future Activities.

7. Final report will be compiled, distributed, and presented at a future workshop.

Major Inputs. DOE, EPA, CFC producers, Foam Insulation Manufacturers, ASTM C-16 members, CFC Insulation workshop participants

Research products. A consensus research menu

C.4.2 DOE/ORNL/Industry Workshops on Alternatives for CFC Insulation

Scope. Organize, host, and publish proceedings of a semi-annual workshop. To help develop an initial research menu, continuous guidance of ongoing research, and input for future selection of appropriate activities. A second objective is to provide a forum for exchange of results.

Problem significance. It is in the national interest to have buildings and appliances that are energy efficient yet do not cause excessive environmental degradation. The extensive use of CFCs has been proclaimed by the October 1988 Montreal Agreement to be environmentally unacceptable. Through government regulations the production of CFCs will be restricted in the near future. A number of recent studies have found that without an accelerated research effort the CFC restrictions will adversely impact DOE's mission to continue working with industry to improve energy efficiency. It is pertinent that industry and various government agencies interact to find acceptable alternatives to the currently used CFC insulations. A government-sponsored workshop could meet this need.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 4.13; Average for 29 projects: 3.01
2. Public/Private Sector: 1.87; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 2

Technical approach. Form a public/private industry planning team for the first workshop (April 1988), conduct a timely workshop (June 1988), publish proceedings, and plan next workshop. Discussions at the June 1988 CFC Workshop on Alternatives for Insulations Containing CFCs indicated that periodic workshops would be desirable. They should be focused on specific projects in the future and be held every six months to a year.

Major inputs. DOE/ORNL, EPA, Polyurethane Insulation Manufacturers Association (PIMA)

Research products.

1. Proceedings
2. Prioritized research menu
3. Identify areas for interactions

C.4.3 Critical Assessment of Product Property Tests

Scope. Product performance requires a variety of property tests. A critical assessment of these tests is needed to define their accuracy, priority, and potential improvements. This would include test sources. The properties should include:

- moisture absorption capacity
- liquid water transmission
- vapor transmission (ASTM E 96-80 takes 10-14 days, too long)
- freeze-thaw resistance
- corrosion potential
- thermal conductivity (function of temperature, moisture exposure, and time)
- thermal diffusivity (measure rather than calculate from conductivity, density and specific heat)
- thermal expansion (ASTM D696)
- shrinkage
- flammability/combustibility
- toxicity
- fungus resistance
- dimensional stability
- cavity-filling (in case of spray or poured in place)
- cell structure/composition
- density
- offgassing/release of particulates
- compressive strength

Problem significance. The accelerated research effort under way to find substitutes for currently available CFC insulations will stimulate a number of new insulating products to enter the market place. Just which are the most relevant product property tests needed to predict long-term performance? How accurate are the tests? Can test procedures be improved to screen acceptable products at reduced cost and on a shorter time span? Discussions the the June 1988 CFC workshop seemed to conclude that the thermal properties were most critical.

Standard performance criteria for various applications need to be developed to help design engineers select the best material for a given application. It makes sense that the requirements for all materials used in a given application should be the same. Also, it is important to ensure that the performance criteria on which the selection is based are appropriate. For example, a common condition used for measuring dimensional stability is 158°F and 97% relative humidity. This is entirely too severe for most applications and therefore is unduly restrictive (i.e., foundation insulation applications).

Both closed cell and open cell board foam plastic thermal insulations have been known to retain moisture under hot and cold design service conditions (NPP III). Design information as to the amount and distribution of moisture is needed for applications such as low slope built-up roofs, cold storage warehouses, and foundations.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 2.74; Average for 29 projects: 3.01
2. Public/Private Sector: 2.22; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 20

Technical approach. The assessment would be initiated by an RFP to document and critically evaluate available laboratory test capacity. Determine relevant product property tests. A report would be produced, followed by a round-robin testing of various properties to establish accuracy, precision and suggest improvements.

Major inputs. DOE/ORNL, Thermophysical Properties of Freons, Altumin, et al.

Research products.

1. Critical evaluation of current test capacity.
2. List of improvements for enhancing the quality of property testing.
3. Aid users in the selection and specification of in situ foam insulations.
4. Provide a procedure for assessing new insulation materials.
5. Information to assist development of new products.

C.4.4 Establish Essential Thermal Insulating Material Properties by Type of Application

Scope. Efficient product development requires a clearly defined set of essential product properties. For most thermal insulation applications, the essential product properties have not been established. Therefore, this project should establish essential product properties for all applications in which significant quantities of CFC blown cellular plastic thermal insulations are now used.

Project significance. Efficient research requires a clearly defined objective. Perceived thermal insulating material property requirements are currently a combination of federal, state, and local standards and codes, consensus standards (ASTM), and manufacturer's "claims." Some of the properties, perceived as essential, are that. Others are clearly not essential. If the non-essential property requirements are not eliminated, unnecessary effort and undesired delay in developing CFC alternatives will both happen.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 2.91; Average for 29 projects: 3.01
2. Public/Private Sector: 2.8; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 17

Major inputs. Input from owners, designers, code officials, regulators, and manufacturers will be required. To make progress in a reasonable amount of time, a strong, technically competent referee (project manager) is essential.

Research products. The project should produce a standard for each application similar to ISO DTR 9774 and might be in the ASTM format. Applications covered should include at least: (1) thermal insulation in buildings, (2) thermal insulation in refrigerated appliances, and (3) thermal insulation in refrigerated transportation. Other applications considered major uses of cellular plastics insulation should also be defined.

Cost and time estimate. One half man-year (over two year period) per application as project manager, plus willing volunteer support from owners, designers, bureaucrats, and manufactures.

C.4.5 Develop Energy Impact Data Related to CFC Restrictions

Scope. Develop energy impact data for residential, commercial, and industrial insulation applications.

Problem significance. The availability and/or performance of rigid foam insulation products are expected to change as a result of CFC restrictions. Given the historical contribution of these products to energy conservation efforts, it is necessary to determine the energy impact of the following scenarios:

1. Foam insulation using new blowing agents resulting in lower R-values per inch than those currently available.

2. The short term effect of CFC restrictions results in reduced availability in the foam insulation supply (this may happen due to the lack of "drop-in" blowing agent for these products).

3. Other insulation products or building techniques are developed.

Although some information is available, there is no report which represents the total energy impact.

Importance ranking (value from 0 to 5, 5 being most important)

1. Technical Importance: 3.53; Average for 29 projects: 3.01
2. Public/Private Sector: 1.72; Average for 29 projects: 2.52
3. Technical Merit Ranking out of 29 projects: 8

Technical approach. Analysis of existing data and data sources. Data collection for missing information. Preparation of report.

Major inputs. DOE; Private industry; Academic sector.

Research products. Energy impact in quads for each segment (residential, commercial, industrial).

Time. 1-2 months.

REFERENCES

Tye, R., "A Study to Determine Aging Effects and Lifetime Thermal Resistance Values of Cellular Plastics Insulations Used for Building Envelope Components" (November 1987).

Hagler, Bailly and Company, "Alternatives to CFCs: Industry R&D Program Strategy," HBC Reference No. 87-3035 (November 1987).

Creswick, F. A., Fairchild, P. D., Christian, J. E., "A Plan for Research and Development on Chlorofluorocarbon Alternatives in Refrigeration and Buildings Applications" (second draft), ORNL CON- (March 1988).

National Program Plan on the Thermal Performance of Building Envelope Materials and Systems, III, NIBS 1988.

Altumin, V.V., et al, "Thermophysical Properties of FREONS - Methane Series, Part 1," Hemisphere Publishing Corporation.

Tye, R., editor, "Reference Materials for Insulation Measurement Comparisons, Thermal Transmission Measurements of Insulation," ASTM (Americal Society For Testing and Materials Special Technical Publication 660, September 1977).

Appendix D

Sample Ballot and Processing

Initially, we envisioned a much smaller group, with hand tabulation of the results easily managed at the workshop. As the workshop plans solidified it became quite apparent that the number of ballots to be processed would be larger than could be handled manually. Also, at the first planning meeting it was agreed that each of the research projects would be given two values instead of just one; the first an importance ranking from 0 to 5 with five being the most important, and the second a "who should do it?" value from 0 to 5 with a 0 being all public sector, and a 5 being all private sector.

The voters were asked to consider the following criteria when assigning their importance rankings:

1. the technical merit of the task,

2. the importance of the task to national needs,

3. the potential for CFC abatement,

4. the potential energy savings resulting from a successful completion of the task, and

5. the reasonableness of the estimated cost of the task compared to the benefits which may result

Alan Fine, a consultant to the BTESM Program established contact with National Computer Systems (NCS)[1]. This company markets a desk top survey system called "Survey Network." This system combines desktop publishing and optical mark reading. NCS helped us format and than printed the sample questionnaire shown in Figure D.1. The questionnaire, formatted with a desktop publishing software program, is printed out on open-format scannable forms using a laser printer. After the discussion of all the research projects the attendees were given 30 minutes to turn in their ballots. The 60, three-page ballots were then entered into a data base using an optical mark reading scanner. The optical mark reading technology improved the validity and accuracy and helped deliver the results of this ballot in a much more effective manner than sending out the results after the workshop. The data was automatically accessed by a statistical analysis package called StatPac Gold. A six page statistical report on each research project ranking was automatically produced. The statistics enabled analysis of the data by all attendees, as well as those who marked their ballots from the private sector, and a third set for the group which marked their ballots from the public sector. NCS also provided the data on a floppy disk for more detailed analysis after the workshop. Additional analysis of the cleaned-up data base is shown in chapter four of this report.

The overall mean value for the importance ranking and the "who should do it" entree for each research project were then manually typed into a Symphony spread sheet and used in a macro program written by Alan Fine, University of Kentucky, to automatically produce several rankings of the results, overall (across all categories), and ranking within each of the four categories. This was presented live less than two hours after the last ballot was submitted to the workshop attendees, using a Kodak Data Show. The Data Show is a liquid crystal display panel which is placed on an overhead projector and reproduces the Personal Computer CRT screen. A hard copy of the overall ranking was given to each participant at the workshop. There were a few data entrees missed by the optical mark reader because the initial vote was erased and a new one marked. The computer data base usually had a star for those entrees where it could not clearly detect the intended value. Secondly, there were four sheets out of a total of about 175 which were not read into the computer. These corrections were made to the data base and the statistics recompiled using the software program Symphony. The final ballot results changed insignificantly as a result of this manual data base clean up.

1. National Computer Systems, 1101 30th Street, NW, Suite 500, Washington, DC 20007

Survey Network™ "The Desktop Survey System"

Proper Marks — USE A NO.2 PENCIL

NATIONAL COMPUTER SYSTEMS

ALTERNATIVES FOR INSULATIONS CONTAINING CFC'S

Please complete the importance ranking using the following criteria:
1. The technical merit of the task
2. The importance of the task to national needs
3. The potential for CFC abatement
4. The potential energy savings resulting from a successful completion of the task
5. The reasonableness of the estimated cost of the task compared to the benefits which may result

Please assign two values for each project:
1. **Importance** (0 to 5, 5 being the most important)
2. **Who should do it?** (0 to5, 0 all public sector, 5 all private sector)

I am form:
- ○ Private Sector
- ○ Public Sector
- ○ Other Sector

C.1 Insulations with Alternative Blowing Agents

		Importance 0 1 2 3 4 5	Who should do it? 0 1 2 3 4 5
C.1.1	Accelerated foam Aging for determination of design R-values		
C.1.2	Develop a low K Standard Reference Material (SRM) for calibration of thermal conductivity measuring devices		
C.1.3	Develop an accurate data base of the thermal properties of the more promising alternative blowing agents		
C.1.4	Identify new chemical blowing agents		
C.1.5	Design and implement a reliable field test project		
C.1.6	Environmentally acceptable blowing agents in foam insulation: Means to achieve equivalent efficiency		
C.1.7	Develop a calculation methodology for flammability testing of new insulations intended for single-ply roofing applications		
C.1.8	Thermal Resistance measurements of current CFC insulations and reduce or non CFC alternatives as they become available		
C.1.9	Thermal conductivity of expanded polymers with chemically inactive gasses		
C.1.10	Manufacture of environmentally acceptable plastic foam insulations		
C.1.11	Protocol to predict long term (5 yr) thermal performance of cellular foam insulation products		
C.1.12	Develop accurate data base of physical properties of substitute blowing agents		
C.1.13			
C.1.14			

OPTIONAL: Name: ______________________

Page 1 of 3

Figure D.1 Three page sample CFC Workshop ballot

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Form Number 75020-5-72

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NATIONAL COMPUTER SYSTEMS

ALTERNATIVES FOR INSULATIONS CONTAINING CFC'S

Please complete the importance ranking using the following criteria:
1. The technical merit of the task
2. The importance of the task to national needs
3. The potential for CFC abatement
4. The potential energy savings resulting from a successful completion of the task
5. The reasonableness of the estimated cost of the task compared to the benefits which may result

Please assign two values for each project:
1. **Importance** (0 to 5, 5 being the most important)
2. **Who should do it?** (0 to5, 0 all public sector, 5 all private sector)

I am from:
- Private Sector
- Public Sector
- Other Sector

C.2 Alternative Insulations

		Importance 0 1 2 3 4 5	Who should do it? 0 1 2 3 4 5
C.2.1	Production and demostration of composites with high thermal resistance		
C.2.2	Evacuated panels "super Insulations" for buildings and appliances		
C.2.3	Evaluation of Components for Super Insulations		
C.2.4	Non CFC Systems		
C.2.5	Non CFC Foundation Insulation Application Verification		
C.2.6	Develop facing materials that eliminate out-gassing of CFC substitutes		
C.2.7			
C.2.8			

C.3 Recovery / Recycling / Disposal

		Importance 0 1 2 3 4 5	Who should do it? 0 1 2 3 4 5
C.3.1	CFC manufacturing recovery process		
C.3.2	CFC incineration		
C.3.3	Recycling Panels		
C.3.4	CFC destruction by methods other than incineration		
C.3.5	Recapture of CFCs at Refrigerator / freezer retirement		
C.3.6	CFC adsorbents		
C.3.7			
C.3.8			

OPTIONAL: Name: ____________________

Figure D1 (cont'd)

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ALTERNATIVES FOR INSULATIONS CONTAINING CFC'S

Please complete the importance ranking using the following criteria:
1. The technical merit of the task
2. The importance of the task to national needs
3. The potential for CFC abatement
4. The potential energy savings resulting from a successful completion of the task
5. The reasonableness of the estimated cost of the task compared to the benefits which may result

Please assign two values for each project:
1. **Importance** (0 to 5, 5 being the most important)
2. **Who should do it?** (0 to5, 0 all public sector, 5 all private sector)

I am from:
- ◯ Private Sector
- ◯ Public Sector
- ◯ Other Sector

C.4 Implementation and Information Exchange	Important 0 1 2 3 4 5	Who should do it? 0 1 2 3 4 5
C.4.1 Prepare an appropriate Public / Private research plan for alternatives to CFC Insulation		
C.4.2 DOE / ORNL / Industry Workshops on Alternatives for CFC Insulation		
C.4.3 Critical Assessment of Product Property Tests		
C.4.4 Establish essential thermal insulating properties by type of application		
C.4.5		
C.4.6		

Comments

Figure D1 (cont'd)

OPTIONAL: Name: ______________________

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Form Number 75020-5-72   SURVEY NETWORK™

Appendix E

Chronology of Building Thermal Envelope Systems and Materials (BTESM) Program CFC related activities

1977

Participated in a working group of ASTM C-16 which defined the need for Standard Reference Materials (SRM) and recommended a set of candidates for insulation measurement comparisons. This includes SRM for high R insulations.

1981

Publication of Arthur D. Little report "Development of Advanced Insulation for Appliances," ORNL/Sub/81-13800/1. This report concludes evacuated and air-filled insulations show significant energy savings potential. Follow up reports demonstrated that R-values of 20 $ft^2 \cdot h \cdot °F/Btu$ can be achieved by combinations of small particles and reduce pressures. The ORNL project, "Development of Advanced Thermal Insulation for Appliances," yielded ORNL/CON-159 (July 1984), ORNL/CON-199 (May 1986), and ORNL/CON-215 (September 1986).

1982-83

Field tested exterior applied extruded polystyrene EXPS insulation in vertical and horizontal (roof and floor) below grade application. ORNL/TM-8571, "Thermal Envelope Field Measurements in an Energy-Efficient Office and Dormitory," (April 1983).

1984

Initiated funding of basic exploratory research on foaming and heat transfer work at MIT that had been previously funded by the DOE-ECUT Program (1981-1983), the foam industry and by the Urethane Division of the Society of Plastics Industry. In 1981 MIT conducted an assessment of thermal resistance and aging to identify physical mechanisms. In 1981-1984 MIT measured radiation properties (scattering and absorption) of foams, determined foam geometry (percent of polymer in cell wall and cell shape), made initial blowing agent permeability measurements. In 1985-1987 the emphasis was on permeability measurements at room temperature and elevated temperatures for CO_2, N_2, O_2, and CFC-11. Permeability and foam geometry were added to foam aging model. In 1987-1988 opaque flakes were used to improve the R-value of foams and a radiation model was developed which included effect of cell size and density. This work yielded the following report: "Aging of Polyurethane Foams, The Influence of Gas Diffusion on Thermal Conductivity," ORNL/SUB/84-9009/2, (August 1986).

1985

From December 1985 until October 1987 the roofing program conducted a field study of the thermal performance of a phenolic foam insulated roof system on the Roof Thermal Research Apparatus. The testing showed a thermal drift of about 20% over a two year test period. Subsequent to the test, the supplier indicated that the material was from an experimental production run. The value in the program was in showing that reliable in situ thermal measurements were possible.

Developed a simplified design tool for selecting optimal foundation insulation levels. This tool was used in ASHRAE Standard 90.2P to develop recommended foundation insulation levels for all U.S. and Canadian Climates. Some of the curves are based on cost and long term performance of EXPS. If this product is going to have different performance parameters in the future this procedure needs to be rerun with the replacement product R-values and costs. This also provides a strong incentive to help develop a replacement product that equals or exceeds currently available EXPS. This technique was published in the ASHRAE Transactions, Volume 1, in 1987.

1986

Initiated work on a Building Foundations Design Handbook. The recommendations tend to lead builders toward exterior insulation applications and to extruded polystyrene. If CFC restrictions are going to change the performance or price of this product, the handbook which has the potential of becoming a significant information source in future foundation design, must be updated. May 1988, ORNL/Sub/86-72143/1.

Began participation in a foundation insulation retrofit field study. This research involves monitoring about 20 residential buildings for one winter without basement wall insulation and than retrofitting and monitoring the energy performance of these same 20 houses with basement insulation. About half of the basements are going to be retrofitted with a suitable exterior insulation. EXPS is the preferred product but concerns about future availability seriously impact this decision.

1987

On March 16, 1987, The BTESM program submitted a proposal for a joint ORNL/MIT study of thermal drift of foam insulation to the Society of the Plastic Industry. The study included laboratory and field measurements as well as theoretical studies of foam structure. The proposal was set aside because of greater concern in the industry over the CFC issue.

On July 20, 1987, presented potential energy savings impact in foundations as a result of restrictions on extruded polystyrene to EPA staff members Steve Anderson and Dean Smith. Kelly Wert, author of the Radian Impact Study, was also present.

Reviewed Radian report titled "Regulatory Impact Analysis: Protection of Stratospheric Ozone Volume III: Addenda to the Regulatory Impact Analysis Document-Rigid Foam" at the request of EPA in August 1987.

Conducted a detailed analysis of Impact of CFC Restrictions on U.S. Building Foundation Thermal Performance, ORNL/CON-245 (December 1987). Concluded that foundation insulation usage is increasing rapidly. Increasing foundation insulation levels are recommended in ASHRAE 90.2P and the Model Energy Codes. Restricting the availability of EXPS, extruded polystyrene, places the growing acceptance of foundation insulation and resulting energy savings at risk. Extended the ORNL-NBS Interagency Agreement to include an assessment of the energy savings impact in residential and commercial building walls and roofs of CFC restrictions on U.S. building thermal performance in September 1987. NBS analysis of the energy impacts of CFC restrictions on residential and commercial building wall and roofs. Final report to be published in fiscal 1988 (Fanney and Petersen letter report).

Utilized established contacts with foundation insulation manufacturers through the Foundation Program Research Review Panel to review CFC restriction impact assessment in September 1987.

Was an invited participant in the EPA September 21, 1987 meeting on the regulatory impacts of restricting the production of CFCs for board insulations. Was asked to present results from assessment of CFC restrictions on foundation energy savings at this meeting.

Dynatech Scientific, Inc., completed, "Assessment of Foam-in-Place Urethane Foam Insulations Used in Buildings," ORNL/Sub-86/56525/1 (October 1987). This report concludes that foam-in-place urethane insulation has been on the rise in building applications. Invited to present a proposal for future research on foundation insulation tests to the SPI (September 1987).

Summarized results of, "Foundation Energy Savings Impact," ORNL/CON-245 into a chapter for inclusion into "Energy-Use Impact of Chlorofluorocarbon Restrictions in Refrigeration and Buildings Applications," S. K. Fischer and F.A. Creswick in December 1987.

Met with an industry/government group at ASTM Bal Harbor Meeting, December 1987 to discuss research needs resulting from the CFC issue. One of the major points made at this meeting was that a government role might be in development of facilities for generating characterizing data, accelerated tests, models, and validation; but chemistry of products should stay with the industry. The final product would be to determine design R-values for existing and new products. A second important point was that some materials behave differently in the field than in the lab. The majority of industry representatives agreed that loss of R-value was important in non-CFC substitutes, but clearly not the only critical property: toxicity, storage properties, dimensional stability, and manufacturing characteristics.

1988

Invited speaker at the "Substitutes and Alternatives to CFCs and Halons" conference in Washington, D.C., January 14, 1988. Title of presentation given was, "The Future of Foundation Insulation in a Non-CFC Producing Economy." A summary of this presentation will be part of a report covering the work shop on rigid foam alternatives.

Met with members of the Polyurethane Insulation Manufacturers Association (PIMA) to discuss joint research on CFC related issues in January 1988. At this meeting an agreement was made to cooperate in the development of research plans. Interest was expressed by PIMA members on the availability of ORNL thermal testing facilities. A number of members expressed an interest in developing environmentally acceptable methods of CFC incineration.

On January 22, 1988, Dave McElroy sent a letter to Sam Tagore in response to a request for information for J. Millhone regarding DOE's role in the CFC/Energy Issue for a talk at ASHRAE. In this letter some current CFC activities are described and preliminary future directions indicated.

Working with one of the large CFC producers and manufacturers of exterior polystyrene to field test a non-CFC-12 board in below grade insulation application. Delivery of this material began arriving at ORNL in early March 1988. Field tests could demonstrate that exterior polystyrene can be produced without CFC-12. It is expected that the R-value will be about 20% less but the compressive and moisture-resistant properties should be about the same as the current commercially available product.

On March 8, 1988 ORNL took first k-value measurement on a 2' x 2' x 2" CFC-22 blown extruded polystyrene.

In January 1988 began working with State of Minnesota to retrieve and test thermal properties of exterior foundation insulation that have been in the field for 2 to 5 years. The materials to be tested will include EXPS, EPS, Polyurethane board, and spray applied urethane. Density, moisture absorption, and thermal conductivity will be measured.

Research progress on advanced insulations and MIT foam research project was reviewed by Office of Energy Research.

The DOE sponsored development of a low thermal conductivity standard reference material with an R-value near 7 should be available in the Summer of 1988. This sample will be used to calibrate equipment for testing CFC substitute panels.

On February 29, 1988 Dave McElroy sent a list of ten projects on CFC alternates to Jim Smith, DOE. The ten projects represented a preliminary goal of rapidly mobilizing various test facilities to measure properties of industry-produced CFC foams and industry-produced alternates to CFC foams.

Coordinating joint DOE and EPA sponsorship of MIT cell modeling.

Initiated work on a BTESM Program CFC Research Menu in Februry 1988.

Organized the Joint Public/Private Workshop on Alternatives for Insulations Containing CFC held on June 9-10, 1988.

APPENDIX F

Workshop Back-Up Documents

Executive Summary of ORNL/CON-245, "Impact of CFC Restrictions on U.S. Building Foundation Thermal Performance," by Jeff Christian.

EXECUTIVE SUMMARY

OBJECTIVE

The objective of this report is to assess the potential impact on energy efficiency goals and to develop a research plan to mitigate the impacts of restricting the use of chlorofluorocarbons (CFCs) in foundation insulation applications.

APPROACH

The eight-step state level analysis conducted to estimate the impact of CFC restrictions on U.S. residential building foundation thermal performance answers the following questions:

- What is the current energy savings from foundation insulation?
- What effect will ASHRAE Standard 90.2P have on future foundation insulation energy savings?
- What is the energy-saving potential in residential foundation retrofit applications?
- What is the likely market response to non-CFC alternative technologies?
- What is the CFC restriction impact on foundation insulation energy savings?
- What research and development could minimize the impacts of CFC restrictions on national goals of improving the thermal efficiency of U.S. building foundations?

CURRENT FOUNDATION INSULATION USAGE AND ENERGY SAVINGS

The total energy currently being saved by foundation insulation in one year's worth of new housing starts in the United States is estimated at 9.6×10^{12} Btu/year. About 55% of the energy savings occurs from basement wall insulation. Board insulation on basement walls is estimated to save 0.91×10^{12} Btu/year, or 11% of the total foundation insulation savings. The average percentage of exterior foundation wall insulation is 15% of those insulated at all; however, some states, such as Wisconsin, report that up to 72% of the insulated basement walls have exterior insulation.

The total annual estimated energy savings of exterior board insulation for new basements, crawl spaces, and slab-on-grade construction is 2.1×10^{12} Btu/year. This represents a maximum estimated energy savings of extruded polystyrene (XEPS) in current new housing starts. The maximum estimate assumes that all exterior foundation insulation is XEPS and ignores the fact that some exterior insulation is molded expanded polystyrene (MEPS), fiberglass insulation drainage boards, and sprayed urethanes.

FOUNDATION INSULATION IN THE FUTURE

A host of recent events are likely to result in significant increases in the number of buildings with insulated foundations in the future. First, ASHRAE Standard 90.2 will become the new residential building energy standard sometime in 1988. ASHRAE 90.2P uses a systematic procedure based on consumer economics that leads to increases in foundation insulation beyond typical practice in many areas of the country.

Second, the heightened awareness of radon penetration will lead to tighter-waterproofed foundations with better exterior subdrainage. One method of protecting exterior waterproofing is with board insulation. Exterior insulation can also contribute to crack minimization by reducing foundation material expansion and contraction and aid in initial concrete curing by eliminating the need for an interior vapor retarder.

Third, the research findings that large heat losses from properly insulated and sealed heating, ventilating, and air-conditioning ducts in unconditioned basements occur may result in more building owners making the basement a conditioned space. More conditioned basements will lead to more basement wall insulation.

A fourth event that may effect how builders insulate foundation walls is the growing understanding of moisture movement and building damage potential. It is hoped that some research will soon be initiated to test the hypothesis that (1) exterior foundation wall insulation reduces the risk of moisture damage compared with interior insulation and (2) interior insulation can be installed under certain conditions with acceptable risk of moisture damage.

Another significant event that impacts the future use of foundation insulation is the suspended use of termiticides, chlordane and heptachlor, by the Environmental Protection Agency. The increased public awareness of human health risks and costs of termite treatments could result in more dependence on visual inspection for termite tunnels. If reliable mechanical termite barriers and periodic visual inspection methods are not developed, tested, and demonstrated to the public, some potential exists that a negative impact on foundation insulation positioned on either the inside or the outside may result. Recognition of this issue could lead to foundation system development, which includes both properly installed termite shields and foundation insulation.

On the average, basement wall insulation is about four times more effective than floor insulation for all new housing starts in the United States. This accounts for both heating and cooling season performance as well as annual duct losses.

The optimum level of exterior board insulation for basement walls results in about 5% less energy savings to the country than the optimum inside batt level. If exterior board insulation were not available in the future, and if inside insulation gained broad acceptance, the net energy impact to the country could be minimal.

FOUNDATION INSULATION ENERGY SAVINGS POTENTIAL

The future energy savings of foundation insulation for housing built in the United States from 1990 to 2010 in the year 2010 is estimated to be between 0.38 and 0.45 quad/year. By assuming that, in the future, all foundation wall insulation could be board insulation and that all floor insulation is likely to be batts, 80 to 90% of the projected energy savings in the year 2010 could be attributed to XEPS or an equivalent substitute.

If one assumes that the fraction of inside insulation remains around 85% and that all the interior insulation jobs use batts, the energy savings contributions from boards is about 0.08 quad/year, or about 20% of the total foundation insulation energy savings in the year 2010. Another 0.58 quad/year could be saved if 30% of the existing housing stock were retrofitted with foundation insulation.

POTENTIAL XEPS FOUNDATION MARKET

The 1985 production of XEPS is 49,000 metric tons (t). The potential XEPS market expansion estimated in this analysis ranges from 13,000 to 35,000 t for new construction. If 1.5% of all existing residential buildings were retrofitted each year, this would result in an additional XEPS market expansion per year of 46,000 t.

MARKET RESPONSE TO ALTERNATIVE TECHNOLOGIES

The arguments against the use of interior batts are for the most part built on theory which seems to make sense, but without extensive validation. A close examination of long-term performance of inside foundation insulation systems in U.S. housing should be undertaken to help guide builders of interior foundation systems. Interior foundation insulation will continue to be very popular unless a significant number of documented failures develop with inside foundation insulation systems.

If the fiberglass insulation drainage board were sold at the same cost as XEPS, since the installation is almost identical, the net energy savings of basement walls would be the same. Without the installation of foundation drains around slabs and crawl spaces, this product would not be a suitable substitute for XEPS.

The EPS drainage board composite is sold separately and costs almost twice as much as XEPS with R-5, and is 25% higher for R-10, although the drainage layer may displace a cost for specified backfill material. Again, without the foundation drains, this product is not a substitute for XEPS.

For slabs, crawl spaces, and some basements with relatively shallow foundation walls and good drainage characteristics, it would seem that the higher-quality MEPS board is a suitable product.

Without an accelerated research effort, it is estimated that a total of 12 years would be needed to bring a non-CFC XEPS to market (Radian 1987). A substitute blowing agent would seem to be the best control technology and would be welcomed by the marketplace. Builders historically have been reluctant to insulate foundations because of application concerns. XEPS has mitigated some concerns and gained the confidence of some builders.

FOUNDATION ENERGY SAVINGS IMPACT OF CFC RESTRICTIONS IN THE UNITED STATES

Four foundation insulating scenarios are examined, which represent a worst to best case. Clearly, there will be some substitution of other foundation insulations, and eventually an alternative blowing agent will be developed. This analysis concludes that the impact of CFC restrictions on foundation energy savings range from near zero to 0.8 quad/year in the year 2010, with the most likely impact being around 0.13 quad/year.

SUMMARY AND RECOMMENDATIONS

If CFC-12 is contributing to the deterioration of the ozone layer, then alternatives must be found to insulate foundations as well as with currently available XEPS. An accelerated research effort with the goal of developing and demonstrating insulated foundation systems having equivalent or superior performance to exterior XEPS insulated basement wall, crawl space wall, and slab-on-grade systems should be initiated. The research should employ a set of well-characterized test facilities in which moisture conditions are controllable on both the inside surfaces and in the adjacent soil.

Thermal durability and moisture damage potential in well-characterized foundation system applications, including the rim joist, should be measured. These measurements should include condensation, mold, mildew, wood moisture content resulting from different insulation, and vapor retarder placement. All three types of insulated foundation types should be tested: basements, slabs, and crawl spaces. The insulation types which should be tested include

- XEPS with alternative blowing agents,
- MEPS,
- fiberglass insulation drainage board,
- MEPS drainage board,
- interior insulation,
- evacuated panels, and
- other innovative concepts.

Executive Summary of ORNL report on Energy-Use Impacts of Chlorofluorocarbon Alternatives, S. Fischer, et al.

1. EXECUTIVE SUMMARY

PURPOSE AND SCOPE

The United States government recently ratified and signed an international agreement to limit the production and use of chlorofluorocarbons (CFCs) that threaten the stratospheric ozone layer. The U.S. economy uses CFCs in many different applications because they are effective, nontoxic, nonflammable, and inexpensive. These applications include the use of CFC-12 as the working fluid in commercial and residential refrigerators and freezers, automobile air conditioners, and the predominant use of CFC-11 in centrifugal chillers for cooling commercial buildings. Both CFC-11 and CFC-12 are used as "blowing agents" in producing foam insulations for home appliances, residential and commercial buildings, refrigerated trailers, and railroad cars. Restrictions on the availability of materials for these applications are likely to result in less efficient substitutes and an increase in national energy use.

This report presents the results of a scoping study that was conducted to estimate the possible impact of using alternatives to CFC-11 and CFC-12 on national energy use in response to concerns about depletion of the stratospheric ozone layer. The U.S. Department of Energy has requested that this study be conducted for use in assessing whether significant energy-use impacts are likely to result from the use of non-ozone threatening substitutes and whether a federal R&D program is justified to develop technology that can be used in mitigating adverse impacts.

ALTERNATIVES CONSIDERED

The energy-use impacts are examined for applications of CFC-11 and CFC-12 under five different cases:

1) the current technology,

2) the preferred alternatives,

3) a fallback position if the preferred alternatives do not prove viable,

4) a worst case scenario in the event that no chlorine containing compounds or new refrigerants are feasible substitutes, and

5) advanced technologies that need further R&D for proof of concept and to demonstrate their viability.

The current technologies are primarily those that rely on mechanical refrigeration using CFC-12 and foam insulations using CFC-11 and CFC-12. The preferred alternatives rely on the development of new chemical compounds that have approximately the same properties as CFC-11 and

CFC-12 but do not pose a threat to the ozone layer. These would include compounds like FC-134a, CFC-141b, and CFC-123 that have not been produced commercially before. The fallback positions depend on proven compounds and technologies, such as CFC-22 and expanded polystyrene bead board, that are somewhat unconventional for particular applications. The worst case scenario considers the possibility that the list of controlled compounds will be expanded and looks at currently available alternatives that do not rely on chlorine compounds, or new technologies, at all. Finally, the advanced technology options consider the energy saving opportunities of advances in insulations and high efficiency refrigeration equipment.

Preferred Alternative

American industry is aware of the problems and challenges presented by restrictions on CFCs and is actively seeking alternative chemicals and new technologies that are less detrimental to the atmospheric ozone. The preferred response, in many cases, is to develop close substitutes, "near" drop-in replacements (i.e., they will require some small changes in equipment design or use), for CFC-11 and CFC-12 as they are phased out through mandated reductions in production. The most promising of these new compounds are CFC-141b, CFC-123 and FC-134a. Both CFC-141b and CFC-123 come close to matching the properties of CFC-11 while FC-134a is similar to CFC-12, but none of them without problems. All are under scientific scrutiny to determine their toxicity properties. Final results of these tests will not be known for several years. Preliminary experimental data indicate that energy use may be 8-9% higher in appliances when FC-134a is used as a drop-in substitute for CFC-12 [1]. None are as thermally effective in insulating foams as the materials they would replace with a 15% decrease in insulating effect. Finally, no U.S. manufacturer currently has a full-scale manufacturing process for them. In spite of these shortcomings, these compounds appear to be the most promising alternatives on the technological horizon.

Fallback Position

There are technical as well as health and safety concerns that might make it unlikely or impossible to use CFC-123, CFC-141b, or FC-134a in some, or even any, applications. In that case the alternatives are not very attractive because of the necessary changes in design and energy efficiency. The best substitute for CFC-11 and CFC-12 blown foam insulations currently available is expanded polystyrene bead board (EPS), a non-CFC foam insulation which has a much higher thermal conductivity than the CFC foams it would replace and is not readily adaptable to applications like refrigerators. In most cases, the second choice for a working fluid in a vapor compression refrigeration cycle is CFC-22. This chemical is used widely in residential heat pumps and air conditioners, but there are major engineering obstacles to its use as a substitute for CFC-12 in most other applications. CFC-22 operates at much higher pressures and temperatures in applications where CFC-12 is used today and consequently stronger materials and more complicated designs would be needed. It has been estimated that it would cost the auto industry one billion dollars to retool to use CFC-22 in auto air-conditioners. The problems associated with using CFC-22 in household refrigerators and freezers are almost as severe as those faced by the automotive industry.

Worst Case Scenario

The worst case scenario considered here would be if only currently available, chlorine-free compounds were considered acceptable substitutes for the regulated CFCs. This is a possible outcome if there are expanded CFC restrictions due to either real or perceived risks . In this situation CFC-22 would no longer be a viable substitute for CFC-12 in refrigeration systems, and, in fact, there are no known attractive alternatives available. Of the available substitutes that could be used, ammonia and propane are among those that are considered in this study. Each of these has serious problems both in engineering and in social terms that must be addressed if they are used in the future, but only the energy impact has been considered here.

It is also very likely that EPS is not a viable alternative to foam insulations in many applications. This material is not very strong and it could be difficult to work with unless good quality control and facing materials are used when it is manufactured. There may also be problems with flammability that restrict its use too. The next best substitute for foam insulations is then fiberglass batts or boards. The insulative value of these materials is much lower than that of the foams they would replace and there are significantly larger energy losses that cannot always be offset by increasing the thickness of the insulation.

Advanced Technology Alternatives

There are opportunities for reducing energy use with highly efficient substitutes for CFC-11 and CFC-12 blown insulations and refrigeration systems. Recent research has been directed at vacuum insulated panels that give R-20/inch or more when used in conjunction with non-CFC foams in the walls of refrigerators and water heaters and R-10/inch may be possible in other insulation applications. Further development is needed to demonstrate the long term viability of these materials, but they might offer a great energy savings nationwide. Developments in Stirling cycle refrigeration, thermo-electric, and superconducting magnetic heat pump technologies may prove to be more efficient than vapor compression systems currently using CFC-12. It is possible that 50 percent of the theoretical Carnot cycle efficiency can be achieved in some applications. Research and development spurred by the restrictions on CFCs could lead to the development of more efficient equipment than is currently in use.

METHODOLOGY

The energy use of each alternative technology is evaluated in a simplified way, usually on a per unit, daily energy use basis, and is then compared to the energy use of the current, 1988, technology. This is intended to be a long range study and does not address the impacts next year or the year after if the use of CFCs were stopped today. In fact, two cases, the preferred alternatives and the advanced technology, assume the development of completely new products. A national energy impact is estimated by comparing the annual energy use nationwide for the new, substitute equipment (assuming that the ozone threatening CFC is not used at all) with what the energy use would be for the same number of units using the base technology. This means assuming a fixed number of units nationwide representing either a complete turnover, 100 percent market penetration, of equipment or substantial construction of new buildings (equal to projected 1990 building stock) with the new chemical compounds or refrigeration cycles completely replacing the old. This is looking ahead 5-15 years for auto air conditioners and home appliances and 30-50 years for buildings and building HVAC equipment. Finally, only current uses of CFC-11 and CFC-12 have been examined and the impact of alternatives to CFC-22 in heat pumps and air conditioners is not evaluated.

NATIONAL ENERGY IMPACT

The results in Table 1.1 are expressed in terms of quadrillion Btu (quads)/year (10^{15} Btu/year). To put them into perspective, the United States uses about 75 quads of energy per year for all applications: space conditioning, transportation, manufacturing, etc. One quad of energy is enough to heat 14 million homes for one year [2], and "is roughly equivalent to a year's consumption of oil at the rate of 500,000 barrels per day [2]." In dollar terms that is about $3.3 billion (based on $18 per barrel). The worst case scenario, where chlorinated compounds and EPS are not acceptable as alternatives for the fully halogenated compounds represents a significant increase in energy use as well as severe economic and social disruptions.

It should be reiterated that these energy impact estimates do not include current applications of CFC-22 or other CFCs not addressed in the present international Montreal Protocol [2] or proposed Environmental Protection Agency regulations [3] (although the worst case does exclude CFC-22 as a substitute for CFC-12). Obviously due to the widespread use of CFC-22 in air-conditioning and heat pump equipment in homes, stores, shops, and offices the potential impacts of such additional controls would be very dramatic and the economic and social consequences could in fact be quite severe. Evaluation of those applications is outside the scope of this present effort, but is needed as part of a follow on study.

RESULTS AND CONCLUSIONS

The results in Table 1.1 represent an alarming reversal of recent successes in energy conservation. The impacts may appear small, 0.37, 1.08, and 2.37 quads/year, respectively, for the preferred, fallback, and worst case scenarios because they are only 0.5 - 3.1% of total national energy use. This represents 1.5 - 9% of the energy use in the residential and commercial sectors, though, at a time when additional energy conservation is desired.

Table 1.1 National energy impacts of alternative technologies (quads/year)

APPLICATION	PREFERRED RESPONSE	FALLBACK POSITION	WORST CASE SCENARIO	ADVANCED TECHNOLOGY SOLUTION
Building Equipment:				
refrigerators & freezers	0.20	0.56	1.06	-0.64
water heaters	0.03	0.04	0.09	-0.06
beverage vending-machines	0.01	0.03	0.06	-0.03
retail-refrigeration	0	-0.01	0	-0.05
centrifugal-chillers	0.01	0.03	0.36	•
subtotal	0.25	0.67	1.57	-0.78
Building Envelopes:				
residential-walls	0.01	0.02	0.05	-0.04
residential-foundations	0.00	0.17	0.32	*
commercial walls	0.02	0.04	0.08	-0.08
commercial roofs	0.06	0.11	0.20	*
subtotal	0.09	0.34	0.65	-0.12
Transportation:				
refrigerated-transport	0.00	0.01	0.02	-0.01
mobile A/C	0.03	0.06	0.10	0.01
subtotal	0.03	0.07	0.12	0.00
TOTAL	0.37	1.08	2.34	-0.90

* advanced technologies are not evaluated for these applications

A closer inspection is needed to see the causes and effects more clearly than is possible by just looking at the summary in Table 1.1. The major portion of the impact, 63 - 80%, is due to changes in appliance and building insulation. The impact on appliances dominates the results because CFC foams provide all, or almost all, of the insulation in these products while a variety of materials are used in buildings. Buildings applications where foam boards or spray are used alone rather than in conjunction with fiberglass batts, as is the case with foundation insulation and the roofs and walls of some commercial buildings, show fairly large impacts. Those where foams are used in addition to fiberglass batts, like residential walls, have a low impact.

Most of the increases in national energy use are due to insulation and refrigeration efficiency of building equipment, as shown by the first horizontal grouping of applications in Table 1.1. The bulk of the impact, in fact, would be in household refrigerators, freezers, and water heaters. The use of CFC blown foam insulations and improvements in the mechanical systems have led to 40 - 50% reductions in energy use by refrigerators in the last sixteen years. The National Appliance Energy Conservation Act of 1987 requires an additional reduction in energy use of 40% from current levels in these appliances. The alternatives available to replace CFC-11 foam and CFC-12 refrigeration, however, will result in 12 - 30% increases in energy use from the present levels as shown in the first three columns. Substitutes for foam insulation in water heaters also contribute significantly to the energy impact in building equipment as do insulation in soft drink machines and working fluids for centrifugal chillers in commercial buildings.

Some aspects of the energy impacts in building thermal envelopes have already been touched upon. There are large impacts where CFC foams provide the primary insulation from heat losses (or summer heat gains). One subtlety not brought out by these numbers is that the 0.09, 0.34, and 0.65 quads per year for the preferred, fallback, and worst case scenarios for building thermal envelopes are based on current levels of usage in building construction. The trends in residential and commercial construction are towards using higher proportions of CFC blown foams in order to save energy and these lost opportunities for energy conservation are in addition to the impacts identified here.

The energy impacts in the transportation sector are not large relative to the other applications listed, although they are not insignificant to the individuals affected. In refrigerated shipping, for instance, the carrier either has higher fuel costs because of poorer insulations in his trailers or he carries a smaller cargo. Either way costs him money. Each one-inch increase in the thickness of insulation (and more than one inch would be needed to keep fuel costs the same) represents a 5% decrease in useable cargo volume. That is a direct cost to him and to the consumers. The impacts in automobile air conditioning represent decreases of 6 - 24% in efficiency, largely due to the weight penalty of a larger air conditioner.

A rigorous R&D program can successfully alleviate most, if not all, of the adverse energy impacts that could occur as a result of not using CFC-11 and CFC-12 in the applications listed in Table 1.1. The successful development and industry acceptance of vacuum insulated panels for appliance and some buildings applications can lead to significant energy savings. This is particularly true for household refrigerators, freezers, and water heaters as shown under the Advanced Technologies in the last column of Table 1.1. Ideas for advanced concepts need to be developed to improve efficiencies of mechanical refrigeration systems beyond what is currently possible using CFCs. Creswick, et al., at ORNL are developing an R&D plan that addresses these opportunities, maps out what can be done, how it should be done, and what it will cost.

NBSIR 88-3829

TECHNICAL AND ECONOMIC ANALYSIS OF CFC-BLOWN INSULATIONS AND SUBSTITUTES FOR RESIDENTIAL AND COMMERCIAL CONSTRUCTION

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Building Systems Division
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U.S. Department of Energy
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U.S. DEPARTMENT OF COMMERCE, C. William Verity, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Abstract

Rigid foam insulations blown with chloroflourocarbons (CFC's) are among the most thermally efficient materials available for insulating walls and roofs of buildings. While they are more expensive than traditional insulating materials, their usage where space constraints dictate a more efficient insulator have become commonplace. Increasing concern about the effect of CFC's released to the atmosphere may result in restrictions on the availability of these insulation materials. This report evaluates the thermal performance and economics of rigid foam insulating materials containing CFC's and alternative insulation materials that contain little or no CFC. Residential walls (wood-frame and masonry), commercial wall systems (frame, masonry, and curtain wall) and commercial low-slope roof systems are examined in a wide range of climates in the United States to determine the cost effectiveness of rigid foam insulation materials. Economic substitutes for insulation materials containing CFC exist; however, they are not compatible with all types of wall/window and roof systems and thus may make some wall and roof systems impractical.

DOW CHEMICAL U.S.A.

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July 5, 1988

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DOE JUNE 9-10 WORKSHOP

In response to your letter dated June 29, 1988, please find attached "Dow Today", dated May 16, 1988 which contains the prepared press release on our plans to "eliminate" hard CFC's.

In addition, I have included a short article from the May 13, 1988 issue of the "Wall Street Journal" also reporting Dow plans.

Best regards,

Dale

Dale Keeler
Foam Products Research
614-587-4313

DK/ga

DOW TODAY

No. 50—May 16, 1988

Dow Will Sponsor World Senior Tennis Open

The best tennis player in the world over the age of 45 will be determined May 19-22, at the first Dow World Senior Open Tennis Championship.

Sponsored by Dow, the tournament will be held at the Congressional Country Club in Bethesda, Maryland, a suburb of Washington, D.C. Sixteen players will compete for $111,000 in prize money and both singles and doubles titles. The tournament finals will be broadcast live in the United States on ESPN, Sunday, May 22, at 1 p.m. (EDT).

"This tournament is part of Dow's ongoing efforts to increase public awareness of the company among key audiences," said Paul F. Oreffice, Dow chairman. "It will involve employees, customers, suppliers and public officials in a Dow-sponsored event."

The tournament field includes: Ken Rosewall, Roy Emerson, Bob Hewitt, Owen Davidson, Mal Anderson, Bob Carmichael, Marty Mulligan, Cliff Drysdale, Frew McMillan, Keith Diepraam, Mark Cox, Roger Taylor, Dennis Ralston, Marty Riessen and Georgio Rohrich. A qualifying tournament will be held May 16-18 to determine the remainder of the field.

The official hosts for the tournament are two legends of the game—Don Budge, who this year is celebrating his 50th anniversary as the first player ever to win tennis' Grand Slam, and Pancho Gonzales, the game's number one box office attraction for 25 years. Also scheduled in conjunction with the tournament are a tennis clinic for more than 100 Washington-area students and a pro-am competition that will feature Dow representatives, Dow customers and Washington officials.

Dow is sponsoring the tournament in cooperation with Alvin W. Bunis of Sports Marketing Properties Inc., a Cincinnati-based sports marketing firm.

"The Dow tournament will be the first to identify the best senior tennis player in the world. In the process, the public will get a chance to see some of the greatest players of all time play very competitive tennis," Bunis said.

Dow Announces Plans To Eliminate CFCs

Dow will phase out the use of fully halogenated chlorofluorocarbons (CFCs) worldwide in all Dow products that contain them, the company's operating board has announced.

In a newly-published position statement, the board said that Dow will replace fully halogenated CFCs with alternative compounds including non-fully halogenated CFCs, as soon as effective alternative compounds and technology are developed, tested for health and safety, and produced in commercial quantities.

As a result of its decision, Dow will remove all fully halogenated CFCs from the manufacture of its Styrofoam brand plastic foam insulation, replacing them with non-fully halogenated CFCs. Dow's objective is to begin this conversion over the next 18 months and do it at all its worldwide locations.

Dow reiterated its support for the United Nations Environmental Program (UNEP) protocol reached last September in Montreal, and urged other nations to accelerate their ratification efforts. The protocol, which has already been ratified by the United States and Mexico, calls for a 50 percent reduction in CFC production by the year 1998.

The company also repeated its support for the Environmental Protection Agency's proposed regulations regarding CFCs.

Dow scientists have been working for several years to find safe and effective substitutes for fully halogenated CFCs. This includes conducting internal research at Dow laboratories as well as working directly with CFC producers and Dow customers who use CFCs.

Fully halogenated CFCs are used in air conditioning, refrigeration, flexible foams for furniture and packaging, rigid foams for building insulation, and cleaning solvents for the electronics industry. Dow uses them primarily as blowing agents in the manufacture of packaging and insulating foams.

The full text of the position statement appears on page two.

Position of The Dow Chemical Company On the CFC/Ozone Depletion Issue

The Dow Chemical Company is concerned about the potential effect fully halogenated chlorofluorocarbons (CFCs) may have on the stratosphere, especially in light of recent scientific findings showing a correlation between fully halogenated CFC emissions and ozone depletion. Therefore, we intend to phase out the use of these compounds worldwide in all Dow products that contain them, and do it in a responsible manner as alternative compounds and technology are developed, tested, and made commercially available.

Various CFC applications require alternatives with different properties, so it is difficult to forecast when effective substitutes for all fully halogenated CFCs will be commercially available. For our part, we are making good progress in our research efforts and will begin conversion of some Dow products in the very near future.

For example, Dow will begin making Styrofoam brand insulation next year using non-fully halogenated CFCs as replacements for the fully halogenated CFCs currently used in the manufacturing process. This will be a global program, with the timing of each country depending on the available supply of these alternative materials and any other local testing and approvals as required. In the United States, Dow will work closely with CFC producers, the EPA, individual states and customers to begin implementation in 1989.

Dow scientist have been conducting research for many years to develop substitutes for fully halogenated CFCs. In addition, we are lending much technical support to both producers and Dow customers who use CFCs to help find viable alternatives. We applaud the effort by producers and users of fully halogenated CFCs to find safe and effective substitutes, and urge them to continue their efforts.

Dow fully endorses the United Nations Environmental Programme (UNEP) protocol reached last year in Montreal, and the United States Environmental Protection Agency's proposed regulations regarding CFCs. We urge other nations to accelerate their treaty ratification efforts. Because stratospheric ozone depletion is a global issue, all nations must act together to resolve it.

Finally, Dow supports the recommendation by the administrator of EPA that the UNEP group reconvene after the final report of NASA's ozone trends panel is released, to examine the most recent scientific evidence and to develop an appropriate international response to that evidence.

JOURNAL OF THERMAL INSULATION
CHARLES F. GILBO
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July 15, 1988

D.L. McElroy, Group Leader
Metals and Ceramic Division
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37831

Dear Dave:

Thank you for your letter of June 29, 1988.

The June Workshop must have been very interesting. I wish I could have been there.

You may include the bibliography on Aging of Cellular Plastics in your workshop report. I would appreciate a copy of this report when it is released.

Sincerely,

Charles F. Gilbo

CFG:tw

TECHNOMIC 851 NEW HOLLAND AVENUE BOX 3535 LANCASTER, PENNSYLVANIA 17604 USA (717) 291-5609

TABLE OF CONTENTS

Aging of Cellular Plastics: A Comprehensive Bibliography

RONALD P. TYE
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ABSTRACT

Fluorocarbon blown cellular plastics are used widely for insulating building and industrial systems because of their potentially high thermal resistance per unit thickness characteristics. However, due to gas diffusion and other environmental and practical factors involved both during and after installation, changes involving especially the phenomenon described as "aging" take place whereby this high thermal resistance decreases with time to lower values.

This "aging" subject has been, and is being, studied extensively worldwide, particularly in the laboratory. More recently, *in situ* results are becoming available and controversies exist about the results. In order to assist those involved and those planning to become involved in the subject, a comprehensive bibliography has been prepared and is being maintained. This contains well over two hundred and fifty (250) citations of information relating to this complex subject involving materials and products behavior, installed system performance, and testing and evaluation issues.

INTRODUCTION

CELLULAR PLASTICS, INCLUDING POLYURETHANES, polyisocyanurates, polystyrene, and phenolics, have been used extensively as thermal insulations for the industrial and building envelope applications. In the latter context, this has been particularly in the area of roofs of large industrial and commercial buildings, but they are now being considered more for walls and other components. The materials exist in three major forms, bun and board stock, laminated boards, and foam-in-place systems.

They all have excellent strength-to-weight characteristics combined with ready availability and relative simplicity of installation. However, the major factor in the consideration of their use is the potentially much higher ther-

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mal resistance per unit thickness than that exhibited by other commonly used building insulations. This performance characteristic is due to the essentially closed cell structure containing one of the halogenated fluorocarbon gases which have much lower thermal conductivities than air. However, without adequate protection of all surfaces, inward gaseous exchange between the environment and the cells causes both the gas content and pressure to change over a period of time, resulting in a reduction in the thermal performance characteristics, a process referred to as "aging." Over a very long time period (>20–30 years), the fluorocarbon gas starts to diffuse out causing additional aging and potential environmental hazards.

This phenomenon is unique to these material types. It is not seen in other common mass type board insulations such as fiberboards, perlite board, cellular glass, and expanded polystyrene. It is present, to a limited extent, in extruded polystyrene but the aging period for this material is much shorter due to more rapid diffusion process of the gases in the polymers.

Changes in thermal resistance experienced with applied systems containing mass insulation types are due to various factors, including for example, ingress of water due to leaks, etc., air and moisture vapor movement due to lack of or inappropriate barriers, incorrect installations, and poor maintenance. These same factors will also affect the performance of cellular plastics containing fluorocarbon gases in similar ways but for these materials and products, the aging effect is an additional and usually the dominating one.

During the past thirty years, much experimental research work has been carried out on these materials and products, particularly urethanes and polyisocyanurates, in order to determine both their aging characteristics and to develop accelerated aging tests in order to provide designers and users with reliable "aged *R*-values" for their products. Furthermore, in the past ten years, this has been supplemented with extensive theoretical modeling such that the basic aging process of the material is now better understood and the manufacturers claimed "aged *R*-values" appear realistic for the basic material.

However, in recent years, controversies have arisen concerning the actual performance of these materials in the field. Various field studies have been undertaken which illustrate that these materials or products once installed often do not appear to retain their claimed thermal performance value. In addition, it can be argued that current formulations and consequent properties affecting behavior may differ considerably from those on which much of the past work had been carried out.

More recently, both in the USA and in other countries, mandatory requirements have been promulgated for manufacturers to publish and verify claimed *R*-value of insulations used for the building envelope, especially for residential structures. For many cellular plastics, "aged R-values" are required and, in most cases, the means of obtaining such values are described. However, these still relate only to laboratory tests on specimens which have been conditioned according to some "aging" procedure which may or may not be one involving accelerated aging criteria.

Finally, there are moves requiring the designer, manufacturer, and installer communities to provide lifetime energy performance estimates for buildings and building components. Furthermore, in some cases, guarantees of performance of building envelope components and especially roofs have been requested and given but without the establishment of reliable criteria and guidelines on how such performance characteristics may be evaluated.

These materials and systems are being used extensively for insulating building envelope components and their use is expected to grow. The present uncertainties in the thermal performance, combined with the above requirements, places the thermal insulation community in somewhat of a dilemma. What causes the information on "aged R-values" to be uncertain? Is the current widely dispersed information sufficient to resolve the uncertainties? If not, what should be done in order that reliable estimates of performance of urethanes can be made?

Thus, because of the wide use of these materials and the significant impact that they can have on energy conservation in buildings, it is essential that more definitive information be obtained on the performance of these products and especially the real effects of aging.

Due to his involvement in many studies of the aging phenomenon for various organizations, and in support of his activities on the ISO Technical Committee 163 on Thermal Insulation,* the author has prepared and is maintaining this comprehensive bibliography on the subject of aging of cellular plastics. It is believed that this list of relevant citations will be of major assistance to those many workers involved already or to those who are planning work in the subject area.

COMPILATION AND ASSESSMENT OF CITATIONS

At the outset, the problem of aging can be perceived to be a complex one involving three basic, separate, but inter-related subject issues. These are:

(a) Materials behavior
(b) Products and systems performance
(c) Testing and evaluation

*Especially as Convenor Subcommittee 1, Working Group 9 on Measurements of Aging Effects on Performance of Thermal Insulation.

These, in turn, can be sub-divided further into a number of major "topic areas," namely:

- the factors which may affect the total aging process and its evaluation
- theoretical and analytical work relating to modeling of the aging process and to heat transfer in cellular plastics
- laboratory and small-scale studies illustrating aging, particularly of both the basic urethane and polyisocyanurate materials, and the products and systems utilizing them
- gas and moisture transfer in both the cellular plastics materials, and the applied coverings and protective laminates and coatings used for products and systems. Gas and moisture permeance and adhesion issues are also especially important.
- laboratory and field test techniques for evaluating the various relevant properties of installed thermal insulation systems products
- results of past and current field studies and their comparisons

With these subjects as the background, an extensive literature search was undertaken. Well over three hundred and fifty papers and technical reports were identified as potential sources of information. Their contents were scanned in order to establish their direct relevance to the topic areas. As a result of the preliminary review, some three hundred relevant items were selected for more detailed review and are included in this current bibliography.

Based on the review of the subjects and their subdivisions, the bibliography has been divided into three major sections, together with two shorter supplementary sections as follows:

(a) Basic phenomenon, both analytical and experimental (approximately 150)
(b) Gas and moisture diffusion (approximately 60)
(c) Relevant thermal measurement techniques and issues (approximately 50)
(d) Reference books (15)
(e) Related documents, including relevant national and international test documents (approximately 40)

SUMMARY

A current bibliography of some three hundred citations relating to the subject of aging of cellular plastic insulation materials and systems has been prepared and is being continually updated. This present list should be of great assistance as a starting point to all present and future workers involved in this complex subject.

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C 518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter

C 677 Practice for Use of a Standard Reference Sheet for the Measurement of the Time-Averaged Vapor Pressure in a Controlled Humidity Space

C 836 Specification for High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane for Use With Separate Wearing Course

C 1045 Standard Practice for Calculating Thermal Transmission Properties From Steady-State Heat Flux Measurements

C 1046 Standard Practice for *In Situ* Measurement of Heat Flux and Temperature on Building Envelope Components

C XXXX Standard Practice for Determining Thermal Resistance of Building Envelope Components From *In Situ* Measurement of Heat Flux and Temperature (In Draft)

D 412 Test Methods for Rubber Properties in Tension

D 696 Test Method of Coefficient Linear Thermal Expansion of Plastics

D 1004 Test Method for Initial Tear Resistance of Plastic Film and Sheeting

D 1251 Test Method for Water Vapor Permeability of Packages by Cycle Method

D 1434 Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting to Gases

D 1621 Test Method for Compressive Properties of Rigid Cellular Plastics

D 1622 Test Method for Apparent Density of Rigid Cellular Plastics

D 1623 Test Method for Tensile and Tensile Adhesion Properties of Rigid Cellular Plastics

D 1653 Test Method for Moisture Vapor Permeability of Organic Coating Films

D 2126 Test Method for Response of Rigid Cellular Plastics to Thermal and Humid Aging

D 2842 Test Method for Water Absorption of Rigid Cellular Plastics

D 2856 Test Method for Open Cell Content of Rigid Cellular Plastics by the Air Pychometer

D 3079 Test Method for Water Vapor Transmission of Flexible Heat-Scaled Packages for Dry Products

D 3418 Test Method for Transition Temperatures of Polymers by Thermal Analysis

D 3575 Test Method for Cell Size of Rigid Cellular Plastics

D 3985 Test Method for Oxygen Gas Transmission Rate Through Plastic Film and Sheeting Using a Coulometric Sensor

E 96 Test Methods for Water Vapor Transmission of Materials

E 228 Test Method for Linear Thermal Expansion of Rigid Solids with a Vitreous Silica Dilatometer

E 398 Test Method for Water Vapor Transmission Rate of Sheet Materials Using a Rapid Technique for Dynamic Measurement

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Added Citations

The following papers were presented at the ASTM C16/DOE Conference on Thermal Insulation held in Bal Harbor, Florida, 6–8 December 1987. Proceedings of the conference in course of publication by A.S.T.M. as a Special Technical Publication.

(a) Bomberg, M. and D. Brandreth. "Long Term Thermal Resistance of Gas-Filled Foams: A Review"

Glicksman, L. R., M. Torpey and A. G. Ostrogorsky. "Factors Governing Heat Transfer Through Closed Cell Foam Insulation"

Ostrogorsky, A. G. and L. R. Glicksman. "Time Variation of Insulating Properties of Closed Cell Foam Insulation"

Sandberg, P. I. "Aging Extruded Polystyrene Insulation: Classification and Quality Control System in Sweden"

Strzepek, W. R. "An Overview of the Physical Properties of Cellular Thermal Insulations"

Zwolinski, L. M. "Historical Perspective and Outstanding Problems in Foam Insulation Aging"

(b) Shankland, I. R. "Measurement of Gas Diffusion in Closed Cell Foams"

(c) Courville, G. E., P. W. Childs, J. V. Beck, A. R. Moazed, G. D. Derderian and L. F. Shu. "A Comparison of Two Techniques for Monitoring the Field Performance of Roof Systems"

Hagan, J. R. and R. G. Miller. "Long Term R-Values and Thermal Testing Requirements for Rigid Insulating Foams"

Langlais, C., J. Boulant and I. Darche. "Use of a Two Heat Flux Transducer Apparatus for Transient Thermal Measurements on Porous Insulating Materials"

Riley, E. A. and J. R. Hendershot. "Measuring Thermal Conductivity of Foam Insulation Efficiently, Precisely, and Inexpensively"

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   Journal Halpin, J. C. J. Cellular Plastics, 3:432-435 (1967).
   Book Ouellette, R. P. and P. N. Cheremisinoff. Applications of Biotechnology. Lancaster, PA: Technomic Publishing Co., Inc. (1985).

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Table 5. Comparison of state-of-the-art matrix resins with VPSP/BMI copolymers.

Resin System	Core Temp. (DSC peak), °C	T_g, °C	PDT(N_2) °C	Char Yield, %
Epoxy (MY720)	[illegible]	250	[illegible]	[illegible]
Bismaleimide (H795)	282	>400	400	48
VPSP/Bismaleimide copolymer				
C379 : H795 = 1:9	245	>400	400	50
C379 : H795 = 1:4	[illegible]	400	[illegible]	53

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Doc. 18

DTR 9774

PROPERTIES OF THERMAL INSULATING PRODUCTS FOR BUILDINGS ACCORDING TO THEIR APPLICATION

- GUIDELINE FOR THE HARMONIZATION OF INTERNATIONAL STANDARDS OR SPECIFICATIONS -

4th Draft
September 1987

0. FOREWORD

ISO TC 61 SC 10 - Plastics, cellular material
at its Warsaw meeting in September 1985 and
ISO TC 163 SC 3 - Thermal insulation, insulation products for buildings
at its Groningen meeting in September 1985
decided to establish a Joint Working Group to draft a document on application categories and basic requirements for thermal insulation materials for buildings. The document to be drafted shall be a common basis for future standardization in the field of specifications for different insulating products for buildings in both technical committees.

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The Joint Working Group, consisting of members of both technical committees from Canada, France, Germany, India and the United Kingdom met twice,

- in April 1986 in Copenhagen,
- in July 1986 in Berlin

and prepared the Draft Technical Report 9774 (2nd Draft, July 1986).

The form of a Technical Report was chosen to enable the committees to prove, in their future standardization work, whether the basic requirements according to the application of the insulating products are an appropriate basis for specifications.

ISO TC 61 and ISO TC 163 have sent out the Draft Technical Report for comments in autumn of 1986/spring of 1987.

The Working Group at its meeting in London in May 1987 has looked through the comments having arrived until then and prepared a new draft in the light of the comments (DTR 9774, May 1987).

Again this draft was sent to those member bodies who had commented on the Draft July '86 with the question, if their former comments were solved by the Draft May 1987.

In the light of all these comments, the Joint Working Group at its meeting in Berlin on September 22, 1987 has prepared this 4th Draft.

The Joint Working Group asks the relevant SCs of both Technical Committees to agree that the Draft is advanced to the next level.

1. SCOPE AND FIELD OF APPLICATION

1.1 This Technical Report lists common applications for thermal insulating products for insulating of buildings and gives guidance on the selection of minimum performance characteristics.

This Technical Report is intended to serve as a background document for standardization and to assist in the harmonization of specifications for thermal insulating products of different origin.

This Technical Report is not intended to serve as a guide to users or producers to prove the suitability of any particular product or any given application.

The product properties listed for each application are expressed as minimum performance characteristics, which shall be maintained during the expected service life of the insulation within the structure*).

1.2 When standards or specifications are established or existing standards are revised on the basis of this Technical Report, the minimum performance characteristics of this Technical Report should in the standards or specifications be translated into product requirements (specified values) together with appropriate test methods, which must be fulfilled at the time of delivery, in order to ensure that the product fulfills the performance requirements in service. This relationship between specified values for the product and the service performance characteristic of the product in use can be different for different insulating products, depending on the characteristic of the material (e.g. aging or time-dependent behaviour). Not each basic requirement needs to be specified in each product standard, if it is obvious

- that certain requirements are always fulfilled
- that several requirements can be covered by one specified property.

*) Note: The expected service lifetime depends on the application of the insulating product in the construction, taking into account the ease with which the product may be maintained or replaced. Service lifetime should be addressed by the product specifications.

1.3 This Technical Report applies only to prefabricated thermal insulating products. Products are any manufactured mats and boards including any facings or coverings, which may be present. The basic characteristics may also be applied to other insulation products, e.g. in situ, in systems or components, where appropriate.

The Technical Report covers only thermal insulating products for use in buildings within normal climatic conditions. It does not cover insulating products for building services, e.g. plumbing, heating and not for industrial use.

Acoustic properties are not included in the properties given in this Technical Report, although these may be additionally required for some application fields.

2. REFERENCE DOCUMENTS

ISO-DTR 9165 - Practical thermal properties of building materials and products.

3. APPLICATIONS OF THERMAL INSULATING PRODUCTS IN BUILDINGS

A review of the most common applications of thermal insulating products in different structures of roofs, walls, ceilings and foundations is given in Table 1. The applications are illustrated in more detail in Figure 1.

The purpose of Figure 1 is only to illustrate the applications for the various insulating products and to assist in relating the performance characteristics for the products to their application. The Figure will also assist in determining requirements for other applications not listed.

The sketches are for illustration only and are not intended as construction drawings, for example water vapour barriers and air infiltration barriers which may be necessary, are not shown.

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Waterproofings in the roof or foundation area are only shown to clarify the position of the insulation layer - in the area affected by precipitation water or ground water or in the area protected against the penetration of water.

4. PERFORMANCE CHARACTERISTICS OF PRODUCTS ACCORDING TO THEIR APPLICATION

Table 2 lists those properties - according to different applications - which need to be considered when preparing standards and specifications for different products. The performance characteristics for these properties to ensure a serviceable and durable thermal insulation are explained and some values are suggested in Table 3.

Derived from Table 2, Table 2a gives basic necessary properties for thermal insulations in any application, while Table 2b gives specific properties which may be also necessary only for certain applications.

For additional applications in building not shown in Figure 1, the properties for the insulating products are to be determined accordingly.

Necessary properties for insulating products used in constructions or components which are characterized by two or more applications according to Figure 1 are derived from all relevant required properties.

For certain insulating materials, further properties other than those listed can be decisive for a durable behaviour during service, e.g. the stability to the action of adhesives, of solvents or of temperature. The product specification should then deal with these additional properties.

5. APPLICATION CATEGORIES

For simplicity the various applications for insulating products shown in Figure 1 may be grouped into categories having common performance requirements. It is then the task of the insulating material standards or specifications to determine these categories and the applications which are covered by these categories.

Figure 1: Examples of the most common applications of thermal insulating products in buildings

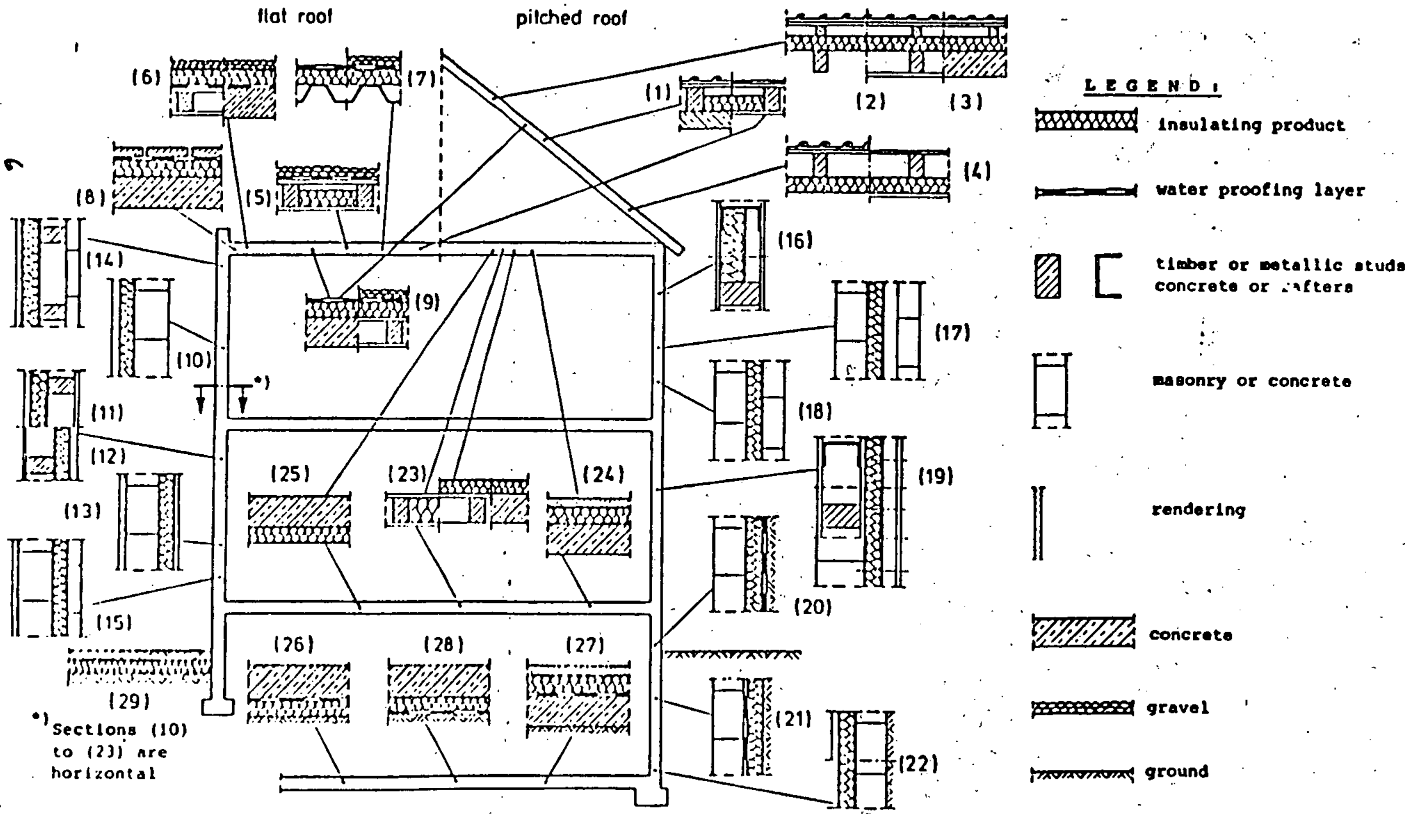

Table 1: Examples of the most common applications of thermal insulating products in buildings; for additional information see sketches in figure 1

		APPLICATION	SKETCH NO.
ROOF	pitched roof	ventilated, unloaded insulation between rafters, fully supported	1
		ventilated, insulation separating rafters and outer covering	2
		ventilated, insulation separating supporting construction and outer covering	3
		ventilated, insulation beneath rafters	4
	flat roof	ventilated, insulation between rafters or beams	5
		inverted, insulation above roofing membrane	6
		on steel deck, insulation beneath roofing membrane	7
		accessible to light or heavy traffic or loads from roof garden (soil layer, plants, etc.), insulation beneath roofing membrane	8
		accessible only to maintenance, insulation beneath roofing membrane	9
WALL		masonry or concrete wall, external insulation covered by rendering	10
		timber stud construction, outside insulation and rendering directly supported by the studs	11
		timber stud construction, insulation at the internal side with rendering	12
		masonry or concrete wall, fully supported internal insulation supporting light protective internal facing (e.g. gypsum board)	13
		masonry or concrete wall, internal insulation supporting light protecting facing, partly supported by studs	14
		masonry or concrete wall, internal insulation with heavy self-supported protective internal facing (e.g. tiles at roomside)	15
		timber or metal stud construction with boards covering, insulation between the studs	16
		cavity wall construction, insulation between the leaves, cavity ventilated	17
		cavity wall construction, cavity fully filled with insulation, outer leave not watertight	18
		timber or metal stud construction with boards covering, insulation supported by boards; with ventilated exterior covering	19
		wall under ground, external insulation behind waterproof membrane with mechanical protection	20
		wall under ground, external insulation with direct contact to the ground	21
		cellar or crawlway hall, internal insulation with or without covering	22
CEILING		insulation over the supporting construction or between the beams	23
		insulation under load distributing flooring, fully supported	24
		insulation under the construction	25
FOUNDATION		concrete, insulation under the slab with direct contact to the ground	26
		concrete, insulation supported by the slab, above waterproof membrane, beneath load distributing flooring	27
		concrete, insulation under the slab above waterproof membrane	28
		frost insulation in or against the ground	29

Table 2 : List of relevant properties to be considered according to the application of insulating material in buildings

	Application of insulation with reference to sketch figure	roof									wall													ceiling			foundation			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
a	Thermal resistance R or thermal conductivity λ	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
b	service temperature: normal -30°C./.+60°C	o	o	o	o	o			o		o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
c	service temperature: elevated -30°./. +80°C						o	o		o																				
d	shape and dimensional stability: under temperature action	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
e	shape and dimensional stability: under humidity action	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
f	shape and dimensional stability: under humidity + temperature action						o																							
g	compressive strength – application: no loading or compression action at …	o			o	o					o			o		o	o	o	o	o			o	o		o				
h	compressive strength – application: compression under uniform load other than svc. load		o	o								o	o		o						o	o								o
i	compressive strength – application – service load: only by maintenance						o	o		o																				
k	compressive strength – application – service load: light traffic (persons)								o																o		o	o	o	
l	compressive strength – application – service load: heavy traffic – cars								o																					
m	compressive strength – application – service load: heavy traffic – trucks								o																					
n1	lateral tensile according to wind load			o				o		o	o									o										
n2	flexural strength according to wind load		o		o							o																		
o	shear strength										o	o	o	o	o															
p	handling property	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
q	bending strength under man load							o																						
r	behaviour under influence of water: not planned, short-term wetted		o	o				o	o	o	o	o						o			o								o	
s	behaviour under influence of water: planned long-term wetted						o												o	o		o					o			
t	frost resistance						o															o					o			
u	influence on health and safety	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
v	fire behaviour	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
w	behaviour under biological attack	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
x	compatibility with other materials	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o

Table 2a: Basic necessary properties for thermal insulation products in any application

Application of insulation with reference to sketch figure		
a	Thermal resistance R or thermal conductivity λ	
b	service temperature	normal -30°C ./. +60°C
d	shape and dimensional stability	under temperature action
e		under humidity action
p	handling property	
u	influence on health and safety	
v	fire behaviour	
w	behaviour under biological attack	
x	compatibility with other materials	

Table 2b : Specific properties for thermal insulation products, necessary only for certain applications

Application of insulation with reference to sketch figure			ROOF									WALL													CEILING			FOUNDATION			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
c	service temperature	elevated -30° ./. +80°C						o	o		o																					
f	shape and dimensional stability	under humidity + temperature action						o																								
g	compressive strength – application	no loading or compression action at all	o			o	o					o			o		o	o	o	o	o			o	o		o				
h	compressive strength – application	compression under uniform load other than service load		o	o								o	o		o						o	o								o
	compressive strength – application – service load	only by maintenance						o	o		o																				
k	compressive strength – application – service load	light traffic (persons)								o																o		o	o	o	
l	compressive strength – application – service load – heavy traffic	cars								o																					
m	compressive strength – application – service load – heavy traffic	trucks								o																					
n1	lateral tensile according to wind load				o				o		o	o									o										
n2	flexural strength according to wind load			o		o							o																		
o	shear strength											o	o	o	o	o															
q	bending strength under man load								o																						
r	behaviour under influence of water	not planned, short-term wetted		o	o				o	o	o	o	o						o			o								o	
s	behaviour under influence of water	planned, long-term wetted						o												o	o		o					o			o
t	frost resistance							o															o					o			o

Table 3: Suggested performance characteristics for the properties listed in Tables [illegible] 2a and 2b

	PROPERTY		PERFORMANCE CHARACTERISTICS*)	
a	Thermal resistance R or thermal conductivity λ		Design values for R or λ should be stated at 10° or 23°C (or 40°C in tropical areas), which will be met throughout the intended service life of the product in the given application. Values required in specifications should be such that due allowance is made for any predictable changings by ageing, moisture uptake, etc. (see ISO DTR - 9165	
b	service temperature (surface temperature)	normal −30° ./. +60°C	The insulation material should be such that, at given range of temperatures, it performs properly in the intended way	
c		elevated −30°C./. +80°C		
d	shape and dimensional stability	under temperature action	shape and dimensional stability e.g. restriction of irreversible shape and dimensional change so that it does not detract from satisfactory performance of the product in use.	between −30°C and upper limit of service temperature
e		under humidity action		at 20°C and R.H. between 30% and 90%
f		under temperature and humidity action		between 20°C and 60°C and 30% and 90% R.
g	compressive strength	application: no loading or compressive action at all	not relevant	
h		application: compression under uniform load other than service load	deformation less than 4 mm under long-term uniform load of 30 kN/m²	
i		application – service load: only by maintenance	deformation less than 4mm under uniform long-term load 2kN/m²; less than 2mm under short-time point load of 1kN on area of 10x10cm² of the product under the temperature range	
k		application – service load: light traffic (persons)	deformation less than 4mm under long-term uniform and repeated load 4kN/m² under the temperature range	
l		application – service load: heavy traffic – cars	deformation less than 4mm under long-term uniform and repeated load 8kN/m² under the temperature range	
m		application – service load: heavy traffic – trucks	deformation less than 4mm under long-term uniform and repeated load 20kN/m² under the temperature range	
n1	lateral tensile strength according to wind load		lateral tensile strength (cohesive strength) and bending strength between supports to cover wind load of 2.5kN/m² (= up to 20 m height)	
n2	flexural strength according to wind load			
o	shear strength		to withstand long-term load of covering etc. of 30 mm thickness (shear lo approx. 0.6kN/m²)	
p	handling property		– strength sufficient to withstand all stresses during transport and application e.g. at least tensile strength > 2 x weight of the product or bending strength to bear 2 x weight of the board – product should be such that it can be shaped and fitted to usual constructions with normal tools	
q	bending strength under man load		sufficient bending strength to perform properly under man load of 1kN at construction and maintenance	
r	behaviour under influence of water	not planned, short-term wetted	limit water absorption and thickness swell caused by a 24 hrs raining period during construction such that the product is still suitable for its purpose	
s		planned long-term wetted	water absorption and thickness swell of the product after long-term water immersion under the range of service temperature should be limited so, that the product is still suitable for its purpose	
t	frost resistance		the product should be such that, upon wetting caused by direct water contact or penetration of water by diffusion, it withstands a sufficient number of freeze-thaw-cycles	
u	influence on health and safety		Until international regulations are available, the product should be such that – upon application with normal methods and precaution procedures – and during use of the buildings national regulations, if any, should be satisfied.	
v	fire behaviour		until international regulations are available, the material shall fulfill the national requirements	
w	behaviour under biological attack		the product should not sustain the growth of fungus and support life of insects and vermin	
x	compatibility with other materials		the insulation product should be compatible with other building materials with which it is designed to come into contact	

*) NOTE: For translation of performance characteristics into product specifications, see clause [illegible].2

Table 3 has not yet been finally discussed

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