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Technology for Competitiveness of the U.S. Construction Industry

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National Bureau of Standards became the National Institute of Standards and Technology on August 23, 1988, when the Omnibus Trade and Competitiveness Act was signed. NIST retains all NBS functions. Its new programs will encourage improved use of technology by U.S. industry.

U.S. DEPARTMENT OF COMMERCE
Robert Mosbacher, Secretary
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Raymond G. Kammer, Acting Director

ABSTRACT

Construction is one of the nation's largest industries. Constructed facilities shelter and support most human activities. Their quality affects the competitiveness of all U.S. industry and the safety and quality of life of every citizen. However, U.S. government and private data show that the U.S. construction industry is declining in its share of the gross national product, and losing in both domestic and international market share to foreign competitors. Analyses of causes show that lack of a program for competitiveness and loss of technological leadership are important factors in the declining competitiveness of the U.S. construction industry. This report has been prepared by the Center for Building Technology (CBT) of the National Institute of Standards and Technology (NIST) at the request of the Panel for Building Technology of the Board on Assessment of NIST Programs of the National Research Council. It solicits guidance on the construction community's strategy for developing and maintaining the competitiveness of the U.S. construction industry, and the role for the CBT program within the community's efforts. A strategy based on open systems for construction products and services is proposed for competitiveness. Private and public sector activities in technology transfer, development of improved construction technologies, and research are identified for attainment of international technical leadership. A responsive program, including interactions with other major players in the private and public sectors, is suggested for CBT.

CONTENTS

1. INTRODUCTION

This report has been prepared at the request of the Panel for Building Technology of the Board on Assessment of NIST Programs of the National Research Council. The Panel requested that CBT address the competitiveness issues as it relates to the U.S. construction industry and formulate a plan which will draw upon the expertise of CBT as well as other public and private sector parties. The Panel also requested that the resources currently being used and those required in future years be identified. This report is considered to be a starting point for cooperative planning efforts rather than a definitive plan for CBT. The report assesses the competitiveness of the U.S. construction industry. Competitiveness has three dimensions:

- o The ability of the U.S. built environment to support the competitiveness of all U.S. industry and the quality of life of all citizens.
- o Competitiveness with foreign goods and services in the U.S. construction market.
- o Competitiveness with foreign goods and services in foreign construction markets.

Problems are evident. The U.S. construction industry is losing ground on the three fronts.

Development and maintenance of technical leadership is shown to be vital to U.S. competitiveness in construction. A strategy is offered to achieve the development and application of technologies for competitiveness that is consistent with the dynamic, disaggregated nature of the U.S. construction industry, and the traditional roles of private sector and governmental organizations.

The CBT program plan is focused on the development of the performance prediction, measurement and testing methods needed to support beneficial innovations in construction systems and practices, and on cooperation with other organizations in transfer of improved technologies to practice. Seven program thrusts for CBT are identified as potentially significant in improving the competitiveness of the U.S. construction industry.

2. COMPETITIVENESS OF THE U.S. CONSTRUCTION INDUSTRY

IMPORTANCE OF THE U.S. CONSTRUCTION INDUSTRY

Construction is one of the Nation's largest industries. In 1988 [1][1], new construction put in place amounted to $401 billion, 8.4% of the GNP, providing employment for 6.5 million persons. Constructed facilities shelter and support most human activities. Their quality affects the competitiveness of U.S. industry, and the safety and quality of life of the people. Moreover, the quality of construction strongly affects the wealth of the Nation; over five-eighths of the Nations's fixed reproducible wealth is invested in constructed facilities [2].

NATURE OF THE U.S. CONSTRUCTION INDUSTRY

Construction is a giant, but disaggregated, industry. Small enterprises predominate in construction. There usually is a unique team (owner, architect, structural engineer, general contractor, specialty contractors, etc.) for each construction project. Each participant may have several simultaneous projects. The team for each project usually has not worked together before, and will not again.

This disaggregated structure allows the construction industry to adapt to large, rapid changes in the volume of construction work. This disaggregated nature also gives construction great flexibility for innovation. A small organization can master a new technology or produce a new product, and convince an owner, designer or general contractor to try the innovation on a particular project, without having to break into a highly centralized, monolithic system. However, shortages of capital for research and development, interfaces with other products or practices, liability concerns and regulations are barriers to innovation.

Construction in this report is considered to include the whole life of the project: initial planning and programming, design, manufacturing and site construction, occupancy and maintenance, and renovation or removal. This whole life viewpoint is necessary to give realistic attention to values and costs of constructed facilities. For instance, for an office building, the annual salaries of occupants and other operating costs roughly equal the initial construction cost. The primary value comes from the productivity of the occupants, which depends, in part, on the fitness to use of the building.

TRENDS IN COMPETITIVENESS IN CONSTRUCTION

In 1988, new construction put in place amounted to 8.4 percent of the gross national product, near the average for the decade and down from the 11.9 percent attained in 1966 [1]. In contrast, Japan's is about 16 percent of GNP [3]. The effects of the low U.S. investment are seen in the condition of U.S. infrastructure: "the quality of America's infrastructure today is barely adequate to meet current requirements and insufficient to meet the demands of future economic growth" [4] and in the

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[1] References are listed in Appendix 1

productive capabilities of commerce and industry: "the decline in infrastructure investment can explain half or more of the productivity decline in the U.S." [5].

The cause of the transfer of capital from construction to other investments may be that better returns have been available from other investments. Productivity has not seemed to keep pace in construction. The Bureau of Labor Statistics' index value for output per labor hour dropped from 121 in 1968 to 84 in 1982 [6].

The U.S. construction industry is losing ground to foreign competitors in both the international and domestic markets. Data cited by the Department of Commerce [1] measure the losses. Awards to U.S. contractors in overseas markets declined by 60% from 1982 to 1987. Foreign-owned construction firms won $8.9 billion in U.S. construction contracts in 1987, 3.5 percent of all U.S. construction contracts that year and more than double the amount won in 1982. The 1981 $744 million trade surplus in construction materials became a $2.3 billion deficit in 1987.

A number of factors affect the international competitiveness of the U.S. construction industry. These include: availability of financing for projects, other nations' restrictions on foreign competition for domestic projects, anti-boycott and business practice laws limiting the ability of U.S. firms to operate in some foreign environments, and sometimes higher U.S. wages. However, technical leadership generally is considered essential to competitiveness of the U.S. construction industry [1, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16]. For instance, from the Office of Technology Assessment study of international competition in service industries [14]:

> Taken together, advances in construction technology will, over the next two or three decades, lead to huge increases in productivity. Currently, however, it is foreign companies, not American, that have the lead in fields like tunneling, reinforced concrete construction, and some applications of new materials. Overseas firms - especially the Japanese - do much more research on basic construction processes.

In an all-industry assessment of productivity, Denison [17] emphasizes the importance for productivity of technological innovations brought to practice through capital investments.

Recently, Koehn [18] conducted and reported a survey of leading U.S. and foreign design and construction firms to obtain their views of international leadership in construction technologies. Nineteen areas of construction technology were considered; the U.S. was assessed by the respondents to lead in just four, be even in one and to trail in fourteen. Current articles [19,20] cite specific instances of foreign leadership in innovative materials, tunneling, underground piping, robotics and earthquake engineering.

Comparisons of U.S. and foreign construction research, development and application efforts indicate the U.S. will fall further behind in technology and competitiveness unless actions are taken to change present trends. U.S. research support for construction technology is very limited compared to other nations and industries. A recent study by the National Academies [6] indicates construction R&D is only 0.39 percent of construction value with 82 percent of it funded by the private sector. Private sector R&D for construction focuses on product development from which research investments can be returned in the marketplace. According to a recent study by the Office of Technology Assessment [7], this research for 1985 had an upper limit of $1,088 million, 0.33 percent of sales. Most technology development work by design and construction firms is expensed to specific projects rather than reported as research and development [21], but these efforts are much smaller than the one percent of gross income reported by Japanese design-construction firms [3].

The European Community and the European Free Trade Association will permit free flow of their construction products and services within Western Europe by 1992 [22]. This will be the world's richest single market of 355 million persons. European standards and codes will be used by the member countries for acceptance of products and services, and a European product approval system will allow products made, tested and approved in one of the European countries to be used in all of the member countries without further testing or approvals.

In all of this effort there is little U.S. involvement or input. However, these actions may have profound impact on the U.S. The European standards and product approval system may be a major barrier to U.S. exports of construction products and services, and may influence international standards for other markets to the detriment of U.S. interests. Moreover, there may be a long-term effect on imports of construction products and services to the U.S. European firms successful in the larger European market will be well prepared to be active in the U.S. Reciprocity is needed to gain access to the European and other foreign markets. For reciprocity, the U.S. will need comparable, nationally-recognized practices for acceptance of construction products and services [23,24]. Progress of competitors relative to the U.S. construction industry is not the only threat to competitiveness. Losses in a sudden disaster also threaten U.S. competitiveness in all industries, including construction. The U.S. insurance industry has become aware of the threat a major earthquake poses to the viability of the insurance industry, and the viability of all other industries depending on the insurance industry for protection and capital. The insurance industry has established an Earthquake Project to study vulnerability to earthquakes and develop remedial measures.

A specific instance from a recent newletter [25] gives dimension to the threat: a Richter magnitude 7.5 earthquake on the Newport Inglewood fault in Los Angeles County during working hours, is estimated to cause 17,000 deaths and $50 billion in insured property losses. Based on studies of various regions, there appears to be about a 50 percent probability of such an earthquake, in some U.S. metropolitan area, in the coming decade. An effective earthquake hazard reduction program is vital to U.S. international competitiveness.

STRATEGY FOR U.S. COMPETITIVENESS

How can the U.S. regain technical leadership in construction, advance productivity and lead in international competitiveness? This issue has received wide attention, including that of Congress [26] in considering national technical policy. The following strategy is offered as consistent with the natures of the U.S. and its construction industry. It calls for feasible and appropriate uses of private and public sector resources for investments in improvements of construction technologies. It takes advantage of the flexibility and diversity of the disaggregated U.S. construction industry. It exploits U.S. leadership in information technologies for advanced computation and automation. It fits the "Technology and Competiveness" statement of the National Academy of Engineering [27].

The key element of the strategy is the concept of <u>open systems</u> for construction products and services. The term system here denotes an entire constructed facility, such as a building; an element of a constructed facility, such as its heating system; or a construction process, such as structural design. A system is considered open if well defined requirements for the performance of each component permit appropriate substitutions for individual components. A system is considered closed if it requires the use of a specific and restricted set of components. Closed systems do not permit substitutions, such as a component from another manufacturer, to be made for individual components.

Open systems for construction products and services meet the needs of users for constructed facilities that are useful, safe and economical initially and over the entire service life of the facility. With an open system, an owner can:

- consider alternative suppliers for components of the initial system,
- mix manual and automated functions in a cost-effective manner,
- modify the system to respond to unanticipated requirements or conditions,
- upgrade the system incrementally as technologies and needs evolve.

Open systems stimulate private sector innovation. An entrepreneur can find a market for an improved product or service without having to create a complete, vertically and horizontally integrated, system. For instance, an improved thermostat can be used in existing temperature control systems, or an improved excavating robot can be used on a construction site along with equipment from other manufacturers.

Competitiveness of the U.S. in general requires high quality, cost effective constructed facilities supporting all manufacturing and service industries. To meet these needs, financing must be available to construct such facilities, and the construction industry must respond with quality construction at competitive costs. The disaggregated, flexible U.S. construction industry is capable of responding effectively if open systems for construction products and services provide incentives to innovations. For such open systems, the U.S. needs:

- Performance-based national and international standards and regulations for commerce in, and use of, construction products and services (joint responsibilities of public and private sectors).

- Consistent national and international approval systems for innovative products and services (joint responsibilities of public and private sectors).

To develop and exploit advanced construction technologies competitively, the U.S. construction industry also needs:

- To exploit international and national research knowledge and information technologies (advanced computation and automation) to develop advanced construction products and services (private sector responsibility).

- To apply improved construction products and services through marketing and education (joint responsibilities of private and public sectors).

3. TECHNOLOGICAL NEEDS FOR COMPETITIVENESS

SCOPE OF TECHNOLOGIES FOR CONSTRUCTION

The extensive scope of technologies affecting competitiveness in construction is evident in the requirements for performance of a constructed facility, and in the various activities of the many participants in the life cycle of a constructed facility. The constructed facility in service must be:

- Productive (functional, reliable, maintainable, energy efficient, etc.)
- Environmentally acceptable
- Safe (for occupants, neighbors, investors, etc.)

The whole process of construction (planning, design, manufacture, site construction, commissioning, facilities management, etc.) must itself be efficient and effective for the facility to be competitive. Construction technologies support competitiveness of the constructed facility and competitiveness throughout the whole construction process. Construction technologies include:

- information processing (e.g. computer aided design)
- equipment (e.g. construction robots)
- products (e.g. roofing)

TECHNOLOGIES FOR COMPETITIVENESS

At the request of Congressman Sherwood Boehlert, who serves on the Committee on Science and Technology and the Committee on Public Works of the House of Representatives, Engineering News-Record, SUNY-Utica College of Technology, and NIST sponsored a Roundtable on Construction Technology for the 90's in May 1986. Twenty-five participants represented owners, designers, contractors, regulators, labor, manufacturers of construction products and equipment, educators and researchers. While a one-day meeting cannot produce a complete agenda for research and development, discussions identified critical technical issues for the international competitiveness of the construction industry [28]:

- Information interface technologies supporting the automatic exchange of information among all participants in a construction project, and conducive to open systems of computing hardware and software for the participants.

- Automated communications and control systems for constructed facilities (such as "smart houses" and "intelligent buildings") that are reliable, break down gracefully (such as not causing blackouts), and are open for partial upgrading and to innovations by small manufacturers.

- Low-risk test beds for innovations such as trials of automated equipment, novel materials and systems, in construction programs of Federal agencies.

- Informing public policy makers, such as regulators, of the technical bases for sound public policy decisions.

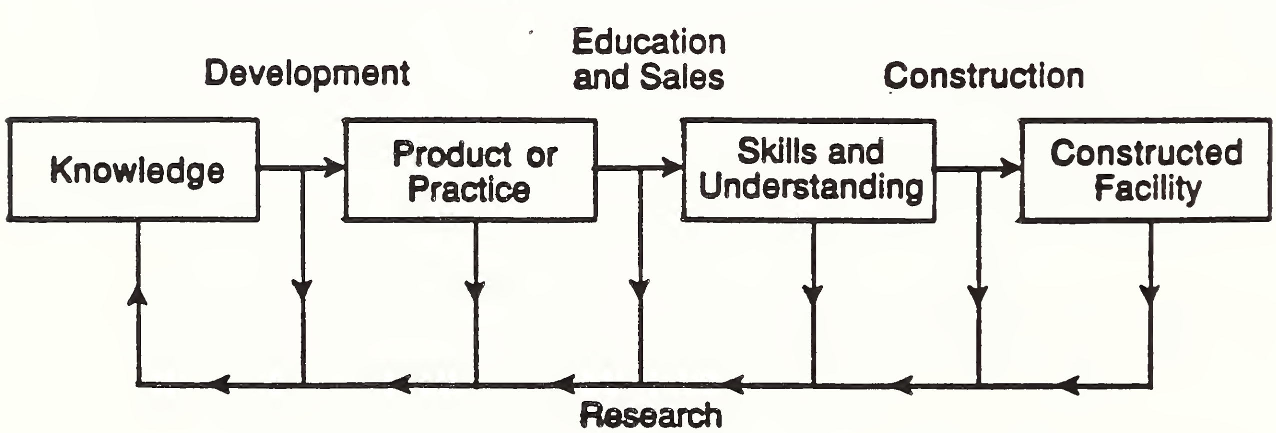
- Learning from foreign research and development and applying results to U.S. practices.

The Roundtable called for collaborative efforts by the private sector, educational institutions and government to respond to these critical issues of construction technology.

TECHNOLOGY APPLICATION

Research alone will not provide for U.S. technical leadership and competitiveness in construction. Research is only one step in the process for obtaining technical leadership. Technical leadership occurs when the most productive technologies are used effectively in practice. Figure 1 illustrates the research application process leading to technology application.

Construction Research Application Process



Needs in the research application process include:

Research

- Includes studies of other fields, the built environment, and the research application process itself.

- Must keep up with advances in other areas of knowledge and other countries.

- Need both problem-focused work to improve practices and longer-term studies aimed at new knowledge.

- Need participation of users in problem-focused work.

Development

- Includes public efforts for development of improved generic technologies and private development of commercial products such as new materials, automated equipment and computer software.

- Must be a much larger effort than the research.

- Public support needed for development of generic technologies (standards, measurement methods, etc.)

- Private sector investment essential to development of improved products and services.

Education and Sales

- Continuing education is needed to bring practitioners to the state-of-the-art. Formal education, for long term relevance, will emphasize principles more than practices.

- Private and public efforts needed to keep practitioners (designers, craftsmen, etc.) at the state-of-the-art.

- Public and private support needed to strengthen education of future professionals and technicians.

- Private sector marketing required to bring innovative products and services to application in practice.

- Exploitation of innovations such as knowledge systems, videotape and videodisk, computer networks, blackboards and electronic mail to greatly facilitate technology transfer.

Construction Practice

- Includes planning, design, commissioning, facilities management, etc. as areas of practice.

- Product approval system needed to facilitate marketing of beneficial innovations.

- Demonstrations may be needed to limit owners' and participants' liabilities in trials of innovations.

4. ROLE OF THE CENTER FOR BUILDING TECHNOLOGY

MISSION OF THE CENTER FOR BUILDING TECHNOLOGY

The Center for Building Technology (CBT) of the National Institute of Standards and Technology (NIST formerly NBS), has the mission, capablility and experience to provide research and technical support to the construction community in the development and application of standards and test methods needed for competitiveness of the U.S. construction industry.

The Technology Competitiveness Act of the Omnibus Trade and Competitiveness Act of 1988 furthers United States technological leadership by giving NIST its new name, an augmented mission, and new resources. The new assignment is to "assist industry in the development of technology and procedures needed to improve quality, to modernize manufacturing processes, to ensure product reliability, manufacturability, functionality, and cost-effectiveness, and to facilitate the more rapid commercialization, especially by small- and medium-sized companies throughout the United States, of products based on new scientific discoveries". The legislative record shows that construction is considered to be an element of manufacturing industry.

New elements called for NIST are: Manufacturing Technology Centers, Technology Extension Program, Advanced Technology Program, and Clearinghouse for State and Local Initiatives. These, and the existing research centers of NIST, provide strong research and technology transfer resources for cooperative efforts with the construction industry. CBT through the advancement of building technology, increases the usefulness, safety and economy of buildings, and enhances the international competitiveness of U.S. building products and services. CBT conducts laboratory, field and analytical research to develop technologies for the prediction, measurement and testing of the performance of building materials, components, systems and practices. The work includes programs in structural engineering, materials, mechanical and environmental systems, and computer-integrated construction.

CBT is the integrated, interdisciplinary national building research laboratory. Its unique and comprehensive laboratory facilities include: the six-degree-of-freedom structural testing facility, the large-scale structural testing facility with the 12 million pound universal structural testing machine, the environmental chambers, the guarded hot plate, the calibrated hot box, the plumbing tower, the image analysis laboratory, and other special facilities.

The CBT program removes technological market barriers of the construction industry, and reduces burdens of unnecessary or ineffective building regulations while maintaining essential levels of safety. Private sector R&D and innovation are stimulated by this program's authoritative, nonprescriptive performance measures for building materials, components, systems, and practices. It is the major nonproprietary source of technical information for the development of voluntary standards for buildings by organizations such as the ASTM, American Concrete Institute, American Society of Heating, Refrigerating and Air-Conditioning Engineers, American Society of Civil Engineers and model building code organizations. CBT staff members hold over 100 active memberships on standards developing committees. The resulting standards are widely used in commerce and in building codes.

With sponsorship from ASTM and the American Association of State Highway and Transportation Officials, CBT provides the laboratory inspection and proficiency sampling program for over 1000 public and private construction materials testing laboratories nationwide that are relied upon by owners, designers, builders, and state and local governments responsible for buildings and transportation facilities.

CBT cooperates with other laboratories in the conduct of its research. Sixty-four research associates from U.S. industry, guest workers from foreign laboratories, visiting faculty members from universities and students worked at CBT during 1988.

CBT works closely with its international peer organizations to provide cognizance of foreign research developments, complementary research efforts and representation of U.S. interests in the preparation of recommendations for international standards and practices. The International Council for Building Research, Studies and Documentation (CIB) represents the public and private building research organizations of more than 70 nations. NIST is active on and leads many CIB working commissions, chairs its Programme Committee and provided the President of CIB for the 1983-86 term. The International Union of Testing and Research Laboratories for Materials and Structures (RILEM), with membership from 80 countries and a prestandardization role for the International Standards Organization, has CBT participation and leadership in many of its technical committees; CBT provides the U.S. Delegate; NIST provided its President for the 1982-85 term.

In the National Earthquake Hazards Reduction Program, NIST is assigned the role of research and technical support for the development and application of seismic design and construction provisions. The Panel on Wind and Seismic Effects of the U.S./Japan Program on Natural Resources brings together 16 U.S. Federal agencies and university and private sector researchers with their Japanese counterparts in an active program of cooperation in research and development. CBT founded the Panel in 1969 and provides the U.S.-side chairman and secretariat.

CONTRIBUTIONS TO COMPETITIVENESS

Results of CBT research have contributed to the international competitiveness of the U.S. construction industry by improving the performance of U.S. construction products and services to make them more competitive in domestic and international markets. Representative, major instances are described in Appendix 2. <u>In no instance has the improvement of U.S. construction products and services resulted from CBT efforts alone.</u> However, CBT has made unique and important contributions in collaborative efforts with private sector and other governmental organizations.

PLAN FOR STRENGTHENING COMPETITIVENESS

This report solicits guidance from the construction community on its strategy for developing and maintaining the competitiveness of the U.S. construction industry, and on the role for CBT within the larger community's efforts. CBT has reviewed its ongoing and planned research program to identify major opportunities for which an enhanced and focused effort by CBT, in cooperation with appropriate external organizations, can produce prompt and significant effects on the competitiveness of U.S. construction products and services. These <u>Competitiveness Thrusts</u> are summarized below, and elaborated in Appendix 3. Potential benefits are noted for each thrust. For each of these thrusts, CBT has established nationally-recognized technical leadership, and is prepared to conduct an effective program producing early, useful results. Guidance from the construction community will indicate which of these thrusts, and which others, should be pursued in cooperation with other organizations in the community.

1. <u>Removal of Barriers to U.S. Trade in Construction</u>

Provide technical support to open global markets to U.S. construction products and services by: (1) developing an active U.S. advocacy role in international standards activities and (2) establishment of a coherent system for acceptance of the innovative building products (those for which there are no national standards or products for which nonstandard use is proposed) and improvement of the acceptance and quality assurance of products for which there are applicable international standards.

The results would assist in reducing the $ 2.3 billion [1] U.S. trade deficit in construction materials.

2. <u>Automated Exchange of Construction Information</u>

Provide technical support for the development and implementation of the family of national and international standards required for automated exchange of construction data (drawings, specifications, etc.) between computing systems of participants in construction projects (owners, architects, engineers, manufacturers, contractors, regulators, etc.).

This would allow each construction participant to invest effectively in automated information processing hardware and software, and exchange information securely, accurately and economically with other participants. Savings in capital investment, efficiencies in the construction project, improvements in performance, and avoidance of errors leading to premature failures, readily could amount to ten percent of the annual value of new construction: $ 40 billion annually.

3. <u>Seismic Design and Construction Practices</u>

Provide research and technical support for development and application of seismic safety practices for new and existing buildings and lifelines to reduce the vulnerability of the U.S. economy to catastrophic earthquakes.

At present, a large earthquake near a metropolitan area threatens direct losses of tens of thousands of lives and tens of billions of dollars in property, and potentially larger indirect losses from interruption of economic activities. Several such earthquakes may occur within the next generation. Present knowledge permits seismic safety in new buildings at little more cost than that of teaching designers, constructors and regulators how to build properly. Additional R&D is needed to make seismic safety similarly practical for new lifelines, to increase the variety of cost-effective seismically-safe building systems, and to reduce costs for identifying and correcting seismically-hazardous existing buildings and lifelines.

4. <u>High Performance Concrete</u>

Provide research and technical support for the development of standards and test methods for safe and economical high-performance concrete in major construction applications.

The performance of almost all U.S. constructed facilities depends on the performance of concrete. New construction is $400 billion annually; replacement cost of existing facilities would be of the order of $20 trillion. Improved practices for high performance concrete can produce annual benefits of 10s of billions of dollars in lower initial and life cycle costs.

5. <u>Reliable Advanced Roofing</u>

Provide research and technical support for the development of performance based, national and international standards allowing U.S. advanced, reliable roofing membranes to compete in the international marketplace with assurance of successful performance provided for building owners.

The U.S. market for low slope roofing exceeds $ 10 billion annually: European and Pacific Rim markets are similar in size. Improved roofing practices can increase the U.S. market share in products and services by billions of dollars and give customers longer-lasting, better-performing roofs.

6. <u>Alternate Refrigerant Technology</u>

Identify new atmospheric-safe refrigerants and refrigerant mixtures that would make them energy-efficient in refrigeration and insulation applications; accurately determine the thermophysical properties of the new refrigerants to support industrial design of equipment using these refrigerants; evaluate alternate refrigeration cycles, systems, and components that will operate efficiently with the new refrigerants; and maintain a data base for the new refrigerants of thermophysical property data, performance data, and information on chemical compatibility with a wide variety of materials.

U.S. production of CFCs and CFC-using products (insulations, air-conditioners, heat pumps, etc.) amounts to 10s of billions of dollars annually. U.S. leadership in alternative refrigerants and products using them can preserve this market for U.S. industry and exploit leadership in larger international markets. Timely action is essential to address the environmental issues. Japan is pursuing strongly these objectives.

7. <u>Communication Protocol for Building Controls</u>

Provide research to assist the building industry in the development, evaluation, and testing of Communication Protocol Standards for the open exchange of information between equipment from different control vendors and between different levels of control in both hierarchical and distributed building management systems.

The $2-billion per year U.S. control industry produces high value-to-weight products that already are subject to intense international competition. Moreover, the quality of control systems has still greater economic effects on the functionality of buildings and their operating and maintenance costs. International leadership in building controls will open the world market place to diverse, innovative U.S. manufacturers, maintain leadership in the U.S. market, and provide multi-billions of dollars annual benefits to building owners and occupants in energy savings and improved workplace productivity.

5. SUMMARY AND RECOMMENDATIONS

TECHNOLOGICAL NEEDS FOR COMPETITIVENESS

Competitiveness of the U.S. construction industry is vital to the productivity of all U.S. industry and commerce and to the quality of life of all citizens. However, the U.S. construction industry is declining in its share of the gross national product, and losing in both domestic and international market share to foreign competitors. Development and maintenance of technical leadership is one, necessary requirement for competitiveness of the U.S. construction industry with:

- o Other opportunities for investment in the U.S.,
- o Foreign organizations in the U.S. market,
- o Foreign organizations in international markets.

STRATEGY FOR COMPETITIVENESS

For historical and practical reasons, the U.S. construction industry is diverse and disaggregated. Most organizations are small to medium sized enterprises, specialized in a particular facet of construction, and involved in a number of projects, usually with a unique team of collaborators on each project. The U.S. in general, and U.S. construction organizations in particular, possess international leadership in information technologies for advanced computation and automation.

Open systems for construction products and services exploit the flexibility of the U.S. construction industry and its leadership in information technologies to obtain:

- o Higher quality and lower costs to attract greater U.S. investments in construction.
- o Openess of the marketplace to stimulate innovation and product development in U.S. industry.
- o Technical leadership for competitiveness with vertically and horizontally integrated, but less flexible, foreign enterprises.

Collaborative efforts among private and public sector organizations in the U.S. construction community are required to develop the national standards, nationally-recognized product approval system, and other practices needed to achieve open systems for U.S. construction products and services. These also will provide the reciprocity required to open international markets to U.S. organizations. Investments in product development by private U.S. industry are needed to exploit the opportunities for competitiveness afforded by open systems for construction products and services.

PROGRAM FOR THE CENTER FOR BUILDING TECHNOLOGY

The traditional role of CBT, and the new emphasis on technology transfer that resulted in the change of NBS to NIST are consistent with an enhanced CBT effort to provide research and technical support for the development of the standards and test methods needed for open systems of construction products and services for the U.S. and the world. Suggestions are made for program thrusts, in cooperation with other private sector and governmental organizations, to achieve timely and significant increases in the competitiveness of the U.S. construction industry.

CBT looks forward to working with other organizations of the U.S. construction community to jointly plan and conduct efforts in research, development and technology transfer to achieve competitiveness for the U.S. construction industry and higher quality of life for people in the U.S. and abroad. This report is considered to be a starting point for cooperative planning efforts rather than a definitive plan for CBT.

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APPENDIX 2. IMPACTS OF THE CBT PROGRAM

Results of CBT research have contributed to the international competitiveness of the U.S. construction industry by improving the performance of U.S. construction products and services to make them more competitive in domestic and international markets. <u>In no instance has the improvement of U.S. construction products and services resulted from CBT efforts alone.</u> However, CBT has made unique and important contributions in collaborative efforts with private sector organizations. A number of examples are cited, with indication of economic benefits where they can be defined.

<u>Advanced Refrigerants and Improved Refrigeration Cycles</u>
In 1987 the U.S. and 30 other countries signed the Montreal Protocol calling for a 50 percent reduction in use of chlorofluorocarbons used for CFC refrigerants by 1998. Concerns for loss of the ozone layer and the greenhouse effect are likely to cause future agreements for greater, more rapid reductions. An international race is underway to develop commercially viable alternative refrigerants, and heat pumps, air conditioners and refrigerators that use the novel refrigerants effectively. CBT has led the world in development of a systematic approach to identification of alternative refrigerants and measurement of their thermophysical properties to permit private sector design of efficient refrigeration cycles. CBT also has shown that thermal efficiency of heat pumps and air conditioners can be increased markedly by use of mixed refrigerants. This work, conducted in close cooperation with U.S. industry, is providing U.S. leadership in advanced refrigerants and advanced space-conditioning equipment exploiting novel refrigerant properties.

<u>Structural Reliability</u>
Results of CBT's research on occupancy, wind and earthquake loads, prediction of structural resistance, and structural reliability have received national recognition, and have been incorporated into national standards such as American National Standards Institute (ANSI) standard A58 "Minimum Design Loads for Buildings and Other Structures," and international standards such as International Standards Organization (ISO) Standard 2394 "General Principles on Reliability for Structures." Improvements in these design standards increase structural reliability and reduce design and construction costs. Consistency between U.S. and international practices for structural reliability prepares U.S. engineers for international practice.

<u>Structural Failure Investigations</u>
CBT has investigated and reported on the physical causes of major structural failures, such as the 1978 cooling tower collapse at Willow Island that killed 51 construction workers, the 1981 walkway collapse in Kansas City that killed 113 hotel guests, and the 1988 collapse of the Ashland Oil tank south of Pittsburgh that contaminated the Monongahela and Ohio rivers, to assure that causes are publicly known and can be avoided in the future. These failures and the widely-referenced CBT reports have sparked major efforts by the American Society of Civil Engineers and other construction-related organizations to improve quality in the constructed project. Quality, in turn, improves competitiveness.

Seismic Design and Construction Standards

CBT has worked with the Applied Technology Council of the Structural Engineers Association of California and the nationally-representative, private sector Building Seismic Safety Council development of nationally applicable, comprehensive seismic design provisions. These have provided the technical basis for updating the national standards referenced or incorporated in model building codes and the building codes of State and local governments. CBT also has led the Interagency Committee on Seismic Safety in Construction in the development of seismic safety practices for Federal building-related programs. This CBT work enhances international competitiveness through cost-effective earthquake hazards reduction.

Rehabilitation Standards

At the request of the National Conference of States on Building Codes and Standards and the State of Massachusetts, CBT developed a more cost-effective approach to regulation of building rehabilitation that has been adopted by Massachusetts and incorporated in rehabilitation guidelines of the Department of Housing and Urban Development, and formulated methods for condition assessment of existing buildings that are being processed as a national standard by the American Society of Civil Engineers. This work supports competitiveness through more economical use of existing constructed facilities.

Building Energy Conservation Standards

At the request of the National Conference of States on Building Codes and Standards, CBT developed a technical approach for a nationally applicable energy conservation design standard for buildings that has been developed as a national standard by the American Society of Heating, Refrigerating and Air-Conditioning Engineers and provides the basis for the building code requirements for energy conservation of all 50 states. Application of the standard saves about 50 percent of the space conditioning energy, relative to practice prior to its development, while actually reducing initial construction costs. Corresponding incremental, energy cost savings are in excess of $19 billion per year. Competitiveness is supported through improvement of the balance of payments by reduction of dependency on imported oil, and through U.S. development of energy conserving products and services attractive in international commerce.

Thermal Performance Prediction

CBT has developed and verified, through laboratory and field studies, dynamic computer simulation techniques for predicting the performance of building enclosures, equipment and controls to make feasible designing to meet economic, functional, air-quality and energy conservation requirements in new and existing buildings. The techniques are publicly available, incorporated in national and international standards, and used as technical bases for commercial computer programs for building design. The resulting U.S. commercial computer software and skilled engineering services are successful in international competition.

Insulation Measurements

Developed a 1000mm line source guarded hot plate to permit direct measurement of thermal insulation performance at thicknesses up to 15 inches (the earlier standard was 1 inch) and provided calibrated transfer specimens to manufacturers to allow them to meet labeling requirements without excessive uses of material. The U.S. Chamber of Commerce has attributed annual savings of $90 million to the availability of this measurement technology. These cost savings improve the international competitiveness of U.S. insulation products.

Appliance Efficiency

CBT developed test procedures for refrigerators, refrigerator/freezers, dishwashers, clothes washers, clothes dryers, water heaters, room air conditioners, home heating equipment, television sets, kitchen ranges and ovens, humidifiers and dehumidifiers, central air conditioners, and furnaces that are used by manufacturers to label their products. These test procedures have supported 10 to 50 percent increases in averages for appliance efficiency. The most efficient, innovative appliances now coming on the market provide additional efficiency increases of 50 to 100 percent. These improved performance characteristics improve the international competitiveness of U.S. appliances.

Residential Plumbing Standards

CBT research on plumbing loads and the hydraulics of drainage and venting provide the technical bases for changes in the plumbing provisions of the One and Two Family Dwelling Code published in 1986 by the Council of American Building Officials. According to the National Association of Home Builders, the changes in plumbing provisions save about $500 per dwelling unit, amounting to $500 million annually for a normal production of one million such dwelling units. The improvements in water conservation and economy of U.S. plumbing products and practices improves the international competitiveness of this industry.

Roofing Standards

In cooperation with the National Roofing Contractors Association, CBT developed the first performance criteria and test methods for reliable low-slope roofing systems, and disseminated them in biannual National Roofing Conferences and in national voluntary standards. CBT has led international prestandardization efforts producing recommendations for performance testing of innovative roofing membrane materials that will open international markets for U.S. producers of elastomeric, thermoplastic and modified bitument roofing.

Corrosion-Resistant Reinforcing Steel

CBT developed performance criteria and test methods for the protection of reinforcing bars in concrete from salt-induced corrosion. These have been incorporated into national standards, supported the development of a new industry producing coated reinforcing bars, and led to their use in most bridge decks in areas subjected to freezing weather. Federal Highway Administration findings indicate that service lives are extended to more than 40 years (from 5 to 10 without coating), which corresponds to annual savings in excess of $300 million. The new, U.S. coated reinforcing bar industry is successful in international marketing and licensing.

Prediction of the Service Life of Building Materials

Formulated a systematic method for prediction of the service lives of building materials that assesses the mechanisms of degradation in the service environment and defines accelerated testing procedures that are representative of performance in the service environment. The method has been adopted for U.S. practice in an ASTM standard and as an international recommended practice. These results permit reliable and equitable selection among innovative and traditional building materials in domestic and international commerce.

APPENDIX 3. COMPETITIVENESS THRUSTS FOR CBT

These are topics for which an enhanced and focused effort by CBT, in cooperation with appropriate external organizations, can produce prompt and significant effects on the competitiveness of U.S. construction products and services.

For each of these topics, CBT has established nationally-recognized leadership and is prepared to conduct an effective program producing prompt, useful results. Approximate milestones are noted to indicate when results could be available for use if adequate resources were available to address the topics.

For each of these topics, currently funded work is noted. For most, substantial additional resources are needed from private or public sources for timely effects on international competitiveness of the U.S. construction industry. The additional resources also would support stronger emphasis on technology transfer to achieve the timely improvements in practice.

1. REMOVAL OF BARRIERS TO U.S. TRADE IN CONSTRUCTION

Objective

Provide technical support to open global markets to U.S. construction products and services by (1) developing an active U.S. advocacy role in international standards activities and (2) establishment of a coherent system for acceptance of the innovative building products (those for which there are no national standards or products for which nonstandard use is proposed) and improvement of the acceptance and quality assurance of products for which there are applicable international standards.

Problem Significance

The global market for building products and services is becoming a reality. The unification of the European market by 1992, the increased international trade in the Pacific Rim, the interest in purchasing Western technology by the Communist Bloc countries, and the growing Third World market each has built-in constraints to U.S. participation. However, the common basis for purchasing and regulating building products and services is standards. National and regional standards typically favor countries or groups of countries. The only widely recognized international standards organization is ISO/IEC. Current participation in ISO standards activities by the U.S. building community is minimal and generally ineffective. This problem must be corrected to open global markets to the U.S. construction community.

The American National Standards Institute's new president, Daniel Peralta, places much concern on globalization of markets and the influence of standards. He said, "The U.S. is no longer in a position to affect standards through its marketplace dominance." "The new realities have placed standardization as an important national priority ... because of its importance to U.S. economic productivity and global competitiveness." "A National partnership involving the voluntary standards community, industry, and government is essential in dealing with the challenges facing the United States." [ANSI Reporter December 30, 1988]

Lack of a national product approval system inhibits innovation and constrains national and international competition for those providing building products and services. An approval system is needed for specifying, purchasing, and regulating building products and their use. The development of such a system has been called for by many including Congress in the establishment of NIBS, which called for a system of "evaluation and prequalification of existing and new building technology." The National Conference of States on Building Codes and Standards, working with the National Association of Home Builders and the model code organizations, is studying the development of a product approval system. The level of effort is nominal. Professional and industry organizations, including the AIA, CSI, ASCE, and industry, have interest in the development of a product approval system.

Various product approval systems are in place worldwide. Underway is the further development of the regional system for the European countries by 1992. Canada, during the past year, established a new product approval system. A U.S. product approval system will be required, for reciprocity, in order to open the European market to U.S. construction products.

Technical Approach

For international standards three areas of activity are proposed: (1) planning and organizing partnerships, (2) managing and active participation in international standards activities, and (3) conduct of research to support standards development. A partnership would be developed with ANSI and standards organizations, such as ASTM, ASCE, ASHRAE, ACI, and others, to develop a program of effective participation in ISO activities. Although ISO is now receiving less attention by Europeans and others because of regional standards activities, ISO will be the center of standards activities in years ahead as globalization of the marketplace increases. This work would be closely allied with ANSI, as ANSI is the member and has overall standards coordinating responsibility for the United States.

Specific ISO standards committees would be identified, TAGS and other means would be organized to obtain U.S. consensus for participation of the representatives. Although existing ISO committees would be targeted, new areas of activity where ISO is not now active would be identified and leadership sought in development of standards. Opportunities for participation in other regional standards organizations, e.g., CEN and ECE, would be sought. Increased participation in prestandardization organizations, e.g., CIB and RILEM, would be planned in order to influence future international standards.

To develop a coherent system for acceptance of building products: A partnership would be formed with the professional societies, regulatory organizations, and industry to develop and operate a coherent product approval system. Early agreement would be reached on the essential elements of such a system. This work would build upon current organizations and strengths which now participate in a general way.

Essential elements of a system are envisioned to include Product Evaluation and Approval, Laboratory Accreditation and Product Certification. Currently there is a CABO product evaluation system. Laboratory accreditation is provided by A2LA, NVLAP, and AASHTO. Certification is provided by approximately 100 different organizations; some effectively, some not effectively. ANSI has certification standards and a means for qualifying certifiers which is not now being used by the building community. During the development of a coherent system, and during its operation, needs for building research would be continuously identified and responded to. An organization would be selected to manage and promote the coherent product approval system. This organization may be governmental or private sector or a combination of both.

Resources

Resources required are $2M per year. There is no current funding for these activities. Research required for advancement of specific international standardization activities would be supported separately through the research programs of CBT and other organizations.

2. AUTOMATED EXCHANGE OF CONSTRUCTION INFORMATION

Objective

Provide technical support for the development and implementation of the family of national and international standards required for automated exchange of construction data (drawings, specifications, etc.) between computing systems of participants in construction projects (owners, architects, engineers, manufacturers, contractors, regulators, etc.).

Problem Significance

Effective automation of information flow throughout the life history of the construction project is essential to the international competitiveness of the U.S. construction industry. Automation protects vital information from loss, and makes it available accurately, promptly and economically to support decisions of the various participants in a project.

Automation of information flow is particularly challenging for the U.S. construction industry. Each project usually has a unique team of participants, and each participant normally is engaged, simultaneously, in a number of other projects, each with a different team. Each participant can have _a_ system of computer hardware and software to support his activities, a system he has been able to afford and has learned to use effectively. A participant cannot afford to acquire different hardware and software for compatibility with other team members on each project, nor is it feasible to use unfamiliar systems efficiently and reliably. In contrast, many foreign competitors are large, vertically and horizontally integrated organizations that can have consistent information systems throughout an organization and project.

Thus, the U.S. construction industry needs advanced, neutral information interface technologies that ensure the reliable exchange of information between distributed, heterogeneous computer systems and programs. Test methods and performance criteria are required to ensure that information interfaces are functioning properly. These interface technologies need to be reflected in national and international standards to allow U.S. firms to be nationally and internationally competitive through effective use of automation.

Approach

CBT will provide continued and strengthened technical support to the Architecture, Engineering and Construction (AEC) elements of the Initial Graphics Exchange Specification (IGES) and Product Data Exchange Specification (PDES) organizations. These are voluntary national standards activities with links to the International Standardization Organization (ISO). Major aspects of the work are:

- o Conceptual information modeling
- o Formulation of application protocols
- o Test and validation methods for proprietary translators

This work is applicable to all areas of automated data exchange, not just construction. However, because of the importance of the need for the construction industry, CBT is leading in this research and development for the whole IGES/PDES organization.

An extensive, application-specific, expert effort is needed to formulate information models and application protocols for each area of application. For instance, for construction, information models and application protocols will be needed for: excavation, lighting, sheet metal work, etc. <u>It will be necessary to develop IGES/PDES standard methods for formulating information models and application protocols, and then delegate the development of application-specific information models and application protocols to the standards organizations existing for the various areas.</u>

Using its strong links with the IGES/PDES organization and the national construction standards community, CBT will formulate standard methods for developing and testing information models and application protocols, formulate prototype information models and application protocols, encourage establishment of application-specific standardization efforts in the construction standards community, provide training and technical assistance to these activities, and support the adoption of these standards as the basis for international standardization activities.

Milestones

1990

- o Proposed standard method for formulating and testing information models.
- o Proposed standard method for formulating and testing application protocols.
- o Prototype information model and application protocol for 3D piping for industry and buildings.

1991

- o Organization of standardization efforts for information models and application protocols in architecture, civil engineering, and heating, ventilating and air conditioning.
- o Adoption of standard methods for information models and application protocols by IGES\PDES.

Resources: Resources required are $1M per year. The present level of effort is about half of this amount.

3. SEISMIC DESIGN AND CONSTRUCTION PRACTICES

Objective

Provide research and technical support for development and application of seismic safety practices for new and existing buildings and lifelines to reduce the vulnerability of the U.S. economy to catastrophic earthquakes.

Problem Significance

A catastrophic earthquake is our greatest, single-event natural hazard. The Earthquake Project of the insurance industry estimates that a Richter magnitude 7.5 earthquake on the Newport Inglewood fault in Los Angeles County during working hours might cause 17,000 deaths and $ 50 billion in insured property losses. The magnitude is higher than expected for most eastern earthquakes, but most structures in California are designed and constructed for earthquake resistance, while few structures east of the Rockies are designed and constructed for earthquake resistance. Yet, in the past 235 years, the eastern U.S. has experienced five earthquakes similar to or larger in magnitude than that which devastated Soviet Armenia in December 1988.

A large earthquake threatens more than great local losses of life and property. The viability of the insurance industry, the productive capacity of a region of the country, and the national defense posture also are threatened. Consider that a large Mississippi Valley earthquake, for instance, could destroy St. Louis, Memphis and cities in between, cut off oil and gas pipelines from the southwest to the northeast, and cut off river and rail traffic between New Orleans and Chicago. Earthquakes are an inevitable natural hazard, but disasters can be prevented by providing adequate seismic resistance in new and existing buildings and lifelines.

Approach

NIST in the National Earthquake Hazards Reduction Program has responsibility for research and technical support for the development of improved seismic design and construction practices. With funding from FEMA, NIST provides the chairman and technical secretariat for the Interagency Committee on Seismic Safety in Construction that coordinates seismic safety activities of Federal construction agencies. These include practices for: Federal buildings, lifelines and site hazard assessment; domestic assistance, leasing and regulatory programs; and post-earthquake investigations.

With funding from FEMA, NIST provides technical support for the Building Seismic Safety Council and other private sector organizations in the development and application of seismic safety practices for the private sector and State and local governments. These include development and application of practices for: design and construction of new buildings and lifelines; assessment and strengthening of hazardous existing buildings and lifelines; and the Plan for Federal Response to a Catastrophic Earthquake.

With appropriated funding, NIST conducts research to improve performance prediction, measurement, and test methods needed for seismic standards, and provides the chairman and technical secretariat for the U.S. - Japan Panel on Wind and Seismic Effects which organizes cooperative activities of sixteen U.S. and six Japanese agencies to reduce damages from strong winds and earthquakes.

Milestones

1990

- Recommendations for the design of reinforced concrete masonry structures for seismic loadings.

- Revision of Seismic Design Guidelines for Federal Buildings.

1991

- Recommendations for the design of precast concrete structures for seismic loadings.

- Publish handbooks on evaluation and strengthening methodologies for existing buildings.

1992

- Recommendations for load history and test configuration for laboratory studies of seismic resistance of structures.

- Publish 1991 edition of NEHRP Recommended Provisions for the Development of Seismic Regulations for Buildings.

<u>Resources</u>: Present funding is $1M per year, half directly appropriated and half from FEMA. Present funds do not allow significant effects on practices for lifelines in the planning period. Additional resources of $2M per year, beyond funds available to NIST or FEMA, are needed for timely development of recommended practices for new and existing lifelines.

4. HIGH PERFORMANCE CONCRETE

<u>Objective</u>

Provide research and technical support for the development of standards and test methods for the safe and economical use of high performance concrete in major construction applications.

<u>Problem Significance</u>

Concrete is vital to the Nation's infrastructure, and its repair and rehabilitation. At present, about 500 million tons of concrete are used in the U.S. each year. Technological advances taking place in the U.S. and other countries show the potential for production of concrete of much improved performance, not only in terms of strength but, often more important, in durability. To exploit the opportunities provided by high-performance concrete, the U.S. must make concrete more predictable than it now is. This will require a more complete understanding of the factors which limit strength and durability in critical applications, e.g. high rise buildings, bridges, hazardous waste containment.

Although the potential for development of high-performance concrete is apparent, the practical performance limits are not known, and there are no nationally-accepted guidelines for the design of high-performance concrete, or the design of structures using such concrete. For the U.S. to be able to exploit the potential, the necessary engineering standards and associated research data must be provided.

New standards will have to recognize that high-performance concrete will be more brittle and more durable than traditional concrete, and will require different information for its design. The new durability standards will be particularly difficult to develop for high-performance concretes because of the difficulties obtaining reliable estimates of service life from short-term tests. Structural behavior, e.g. failure mechanisms, will be affected by changed concrete properties. Behavior must be understood and criteria formulated for safe, functional, economical structures.

In this rapidly developing computer age, the user, e.g. designers and constructors, will need integrated knowledge systems consisting of simulation models, data bases, and expert systems. Such systems will support the much needed link between education and practice.

Approach

CBT will establish a program to develop the technical basis for engineering standards and education for high-performance concrete, including test methods, tools for prediction of performance, and guidelines for materials selection. Standards for high-performance concrete must eventually include methods for materials characterization, and laboratory and field tests for strength-development, stiffness, shrinkage and creep, durability, fracture toughness, and bond to reinforcement, and the effects of curing conditions and service environment on long-term structural performance.

CBT's activities will be coordinated with complementary activities carried out by the cement and concrete industries, users of concrete, and standards committees in ASTM and the ACI. The program will be structured so as to produce early benefits to the concrete and construction industries. However, because of the need for long-term data about the behavior of high-performance concrete, the program will have to be sustained for at least 10 years.

Milestones

1990

- o Preliminary guidelines for the testing of high-performance concrete

1991

- o Draft standard for selection of aggregates for use in high-performance concrete

- o Preliminary guidelines for evaluating the long-term behavior of high-performance concrete

1992

- o Mathematical model for predicting the effect of environmental conditions on strength development in high-performance concrete

- o Identification of needed combinations of properties for high-performance concrete for use in automated construction

Later years

- o Draft standard for determining the fracture toughness of high-performance concrete.

- Draft standards, for use in service life prediction, for defining the environmental stresses to which high-performance concrete is exposed.

- Mathematical model for predicting the service life of concrete under specific environmental conditions.

Resources: Resources required are $1.5M per year for 10 years. Current funding is about one-fifth of this amount.

5. RELIABLE ADVANCED ROOFING

Objective

To provide research and technical support for the development of performance-based, national and international standards allowing U.S.-manufactured, advanced roofing membranes to compete in the international marketplace with assurance of successful performance.

Problem Significance

Good roofing is essential for good buildings, yet roofing systems account for about one half of all building construction law suits, with water ingress being the main problem. Water ingress through low-slope roofing results from problems with the roofing membrane, whether due to water migration through the membrane material itself, or through failed seams and flashing. After many decades without substantial change in membrane technology, and as a result of advances in materials science and engineering, over 300 new membrane products have appeared on the U.S. market in the last 10 years. A substantial number of these products have been introduced by foreign companies. There is intense competition between the membrane manufacturers, and the domestic industry faces increasing foreign competition both in the number of products being imported and in their quality. Among the products, some appear to perform well under most service conditions, while many are not so reliable. Because of the rapid changes in membrane technology, new and improved standard test methods and performance criteria are urgently needed to make possible objective comparisons of performance. The standard test methods and criteria will help U.S. companies face foreign competition in the U.S. and overseas. Manufacturers of superior products need to be able to demonstrate the durability and reliability of their products and show that they can avoid the premature failures which give U.S. products a bad name (to the detriment of all our industries). At present, the U.S. leads the world in the technology of elastomeric membranes; and, in the technology of modified bitumen membranes, the U.S. is catching up with the European companies which first introduced them to the U.S. The proposed program will assist the U.S. construction industry to be competitive in roofing technology by providing soundly based tests of membrane quality, membrane uniformity, and quality of seams and flashing.

Approach

The work will focus on the development of standards for the two major types of recently-introduced roofing membranes, elastomeric and modified bitumens. Since most failures in elastomeric membranes are in the adhesively-bonded seams and flashing, test methods and guidelines will be developed to assure reliable, long-term performance of seams and flashing. Further, since the major problems with modified bitumen membranes are in the quality and uniformity of the membrane materials, test methods for determination of quality and uniformity will be developed for these materials. In each case, the methods and guidelines will be quickly moved into the standards process as draft standards. The research will build on the results of earlier research on factors affecting the performance of adhesively-bonded seams and methods for characterizing membrane materials so that results may be put into practice as soon as possible. The test methods developed will enable U.S. manufacturers of roofing membranes to better evaluate the performance of their products against objective performance criteria and aid their product development and improvement activities. The test methods will also assist users of roofing membranes to make better-informed decisions on the long-term reliability of the products they select. Assistance in expediting the program will be sought from the National Roofing Contractors Association and the Asphalt Roofing Manufacturers Association.

Milestones

1990

- Proposed standard test method for evaluation of seams in elastomeric roofing membranes

- Proposed standard criteria for selection of modified bitumen membranes

1991

- Proposed standard criteria for the uniformity of blending of the modifiers in modified bituminous roofing membranes

1992

- Proposed standard performance criteria for single-ply roofing membranes

- Proposed standard practice for selecting single-ply roofing membranes on the basis of service life

1993

- Proposed standard practice for assessment of the condition of elastomeric roofing membrane

Resources: Resources required are $1M per year, which is approximately twice the present level of effort.

6. ALTERNATIVE REFRIGERANT TECHNOLOGY

Objective

Identify new atmospheric-safe refrigerants and refrigerant mixtures that would make them energy-efficient in refrigeration and insulation applications; accurately determine the thermophysical properties of the new refrigerants to support industrial design of equipment using these refrigerants; evaluate alternate refrigeration cycles, systems, and components that will operate efficiently with the new refrigerants; maintain a data base for the new refrigerants of thermophysical property data, performance data, and information on chemical compatibility with a wide variety of materials.

Problem Significance

The depletion of the ozone layer in the upper atmosphere has had a major influence on the type of refrigerants that will be used in the future. The U.S. has signed an international treaty for a near-term freeze followed by scheduled 50% reductions in the manufacture of certain fully halogenated chlorofluorinated hydrocarbons (CFC's). New halocarbons of the ethane family will most likely be replacing current fully halogenated ones of the methane series. Relatively little information is known about these new refrigerants and the Federal Government and the refrigeration industry are working together to evaluate likely candidates.

During 1987, NIST completed a study of alternatives to the harmful CFC's. The study showed that, when considering a total of 14 criteria that are required for a working fluid in a refrigeration system, the chlorofluorocarbon family of compounds remains the clear and, most likely, the only choice. They are chemically stable, are nonflammable, have a very low order of toxicity, and have the necessary thermodynamic and transport properties. They also have the essential practical characteristics such as solubility in oil, a freezing point below the lowest expected system temperature, compatibility with common materials of construction, easy leak detection, and low cost. Clearly, some of the compounds, such as CFC-11 and CFC-12, contribute to ozone depletion in the upper atmosphere. Alternatives must be found. There are a few CFC compounds that are simultaneously nonflammable, of low toxicity, and environmentally acceptable. This is because of their lack of chlorine, or because they contain hydrogen (as in, for example, chlorodifluoromethane (HCFC-22)) and thus have atmospheric lifetimes lower than the harmful CFC's by up to three orders of magnitude. This set of "acceptable" pure refrigerants is very limited but can be expanded by considering mixtures of them and "tailoring" the properties.

Approach

The search for alternative refrigerants is an iterative process that involves (1) identifying new environmentally-safe refrigerants, (2) determining their thermophysical properties necessary to evaluate their use and to design refrigeration equipment, (3) determining their compatibility with other materials in the intended applications, and (4) determining to what extent processes, systems, and components must be modified to use the new refrigerants and obtain acceptable performance. Candidate refrigerants identified in step (1) may be eliminated upon evaluation in steps (2), (3), or (4) therefore requiring further candidates to be identified.

Identification of Candidate Refrigerants: Based on the NIST study in 1987 and similar analysis done within industry, many candidates have been identified and are now being pursued as replacements for CFC-11 and CFC-12 in refrigeration and insulation foam-blowing applications. These include R-32, R-123, R-124, R-125, R-134, R-134a, R-141b, and R-143a. Additional candidates must be identified because of the strong possibility that each of the above refrigerants may fail to meet at least one of the required criteria. NIST will complete a comprehensive analysis of chemical blends or mixtures of environmentally-safe refrigerants. Binary and ternary mixtures of the relatively few environmentally-safe refrigerants identified above greatly expands the number of possible replacements and provides the potential for "tailoring" the properties of replacements to meet design constraints.

Determination of Thermophysical Property Data: Both thermodynamic and transport properties of the candidate refrigerants will be determined.

Thermodynamic property data include vapor pressure, liquid and vapor density, critical point conditions, liquid and vapor heat capacity, and velocity of sound. The data will be used to develop an equation of state that will in turn be used for predicting derived quantities such as entropy and enthalpy. All the above data are necessary for any analysis of the refrigeration cycle to predict efficiency, capacity, or energy transfer during individual processes of the cycle such as condensation, evaporation, and compression. In addition, they are used to determine operating conditions such as temperature and pressure at various points in the cycle. Through knowledge of these conditions, potential operating problems such as thermal instability of the compressor lubricating oil can be predicted.

Transport property data include liquid and vapor thermal conductivity and liquid and vapor viscosity. Whereas the thermodynamic properties above determine the refrigerant's performance in the cycle, these properties directly impact the design of the hardware, particularly the heat exchangers where evaporation and condensation occur. They determine the effectiveness of the heat transfer processes and have a major influence on determining the size of the heat exchangers.

Thermodynamic data for the leading replacements, R123, R134a, and R141b, will have been determined by measurements, released, and published by the middle of fiscal year 1989. Transport property data determination will be underway for these same refrigerants by mid-1989. Measurement of the thermophysical properties of the other refrigerants will not begin until fiscal year 1990.

Development of a state-of-the-art property estimation program that would predict the thermodynamic and transport property data of a refrigerant with only a limited set of experimental data will also begin in fiscal year 1989. This would enable the data described above to be obtained in half the time and expense of present experimental techniques. Thus a variety of fluids could be screened and a much smaller set identified for more extensive measurements and characterization.

The property data determination will be guided throughout by sensitivity analyses of the intended applications. For example, centrifugal refrigeration compressors will be studied in 1989. This involves analysis of compressor design and test and rating processes to determine the impact of fixed errors in refrigerant properties. The results will indicate the required accuracy of the property data.

Evaluation of Alternative Refrigeration Cycles, Systems, and Components: The use of new refrigerants must result in equal or better performance than occurs with existing refrigerants. Manufacturers of some refrigeration equipment are required by law to meet minimum standards of efficiency by 1992. Any degradation of performance with the new refrigerants will require major redesign and manufacture of products within an unusually short time period (for industry). In addition, less efficient equipment would require more electrical power generation, hence more emission of CO_2 and a larger contribution to the global warming phenomena, sure to be the next major environmental problem to be solved.

The focus of this task will be to use research tools already in place to assure equal or better performance of the new refrigerants in refrigeration applications. These tools include simulation models and breadboard refrigeration systems that can be reconfigured as modified cycles or to include modified components that would be particularly suited to the new refrigerants. NIST has unique experience in the modification/design of cycles that perform well with non-azeotropic refrigerant mixtures. We documented a 32% increase in efficiency of residential-size heat pumps operating in the cooling mode in one of the breadboard systems in 1986. Unfortunately, one of the refrigerants in the mixture used is now slated for elimination. Future plans call for cooperative research with the Electric Power Research Institute (EPRI) and other industrial partners to examine mixtures of environmentally-safe refrigerants in residential air-to-air heat pumps, home refrigerator/freezers, and commercial building water chillers.

Data Base of Refrigerant Properties: The Air Conditioning and Refrigeration Institute (ARI), the industry association of 170 manufacturers of air conditioning and refrigeration equipment, has made a major new commitment to research on CFC's. They have requested NIST to establish a data base of thermophysical data, performance data, and information on chemical compatibility with a wide variety of materials in the NIST Office of Standard Reference Data. ARI has asked its member companies to release their refrigerant data to NIST for evaluation and inclusion in the data base.

Resources: Present funding is $1M per year. Resources of $6.0M over the next two years are needed for timely results.

7. COMMUNICATION PROTOCOLS FOR BUILDING CONTROLS

Objective

Provide research that will assist the building industry in the development, evaluation, and testing of Communication Protocol Standards for the open exchange of information between equipment from different control vendors and between different levels of control in both hierarchal and distributed building management systems.

Problem Significance

Over the last 15 years, automatic control systems in buildings have changed from predominately pneumatic control systems to supervisory Energy Management and Control systems (EMCS) to distributed direct digital control or DDC systems. Recently, the development of local area networks has now made it possible to distribute "intelligence" throughout a building with more of it being placed at both the highest and lowest levels. Centrifugal chillers and package air handling systems are now being manufactured with their own digital controls. In the future, integrated building services, combining EMCS, fire detection, security, data processing and communications, are likely to be increasingly in demand due to their potential to reduce first costs, simplify maintenance, and make operator training easier and quicker.

This decade and a half of progress in building controls has been made in spite of the fact that the previous and present generation of EMCS and DDC systems all tend to employ proprietary communication protocols which prevent systems supplied by different manufacturers from communicating with each other. This has resulted in "captive customers" who, upon buying a control system, are unable to upgrade or expand it without going back to the same manufacturer. This lack of communication capability between control systems made by different manufacturers also prevents the building owner from obtaining the most capable building service by not allowing him to choose, regardless of the manufacturer, the best EMCS system, the best digital controllers, the best security system, the best fire detection system, or the best telecommunications system. To do so today would result in incompatible, parallel systems, with redundant wiring and equipment, conflicting control functions, excessive costs and a nightmare of different maintenance and operating procedures.

The solution to the problems described above lies in the development of standard communication protocols for BMCS and DDC building control systems. The computer, data processing, and communication industries are already hard at work on standard network protocols through such standard writing organizations as ISO, IEEE, and CCITT. IBM has shown with their GPAX-D program and their FCN protocol that if an organization buys enough controls it can dictate the protocol to be used and control manufacturers will develop the required translation software. The Public Host Protocol introduced by American Auto-Matrix indicates that some manufacturers are clearly interested in seeing communication between different BMCS and DDC systems standardized. In addition, ASHRAE has established a Standards Project Committee, SPC 135, to try and develop standard Messaging protocols for EMCS.

Approach

(1) Assist ASHRAE in drafting and developing the specification of communication protocols for the exchange of building service information between different vendor systems and between different levels of intra-system communication. NIST staff will serve as Secretary to the Committee and Chairman of the key Subcommittee.

(2) Develop and verify "reference implementations" of all proposed and finalized protocol standards. Develop procedures for both performance and compliance testing.

(3) Provide testing and evaluation facilities which can be used by both NIST and industry for studying different protocols and for determining compliance of vendors' equipment to proposed or finalized standards.

A variety of building control systems are being obtained from different leading manufacturers covering all levels of building communication and services. Communication networks involving different types of physical media will be assembled and used to interconnect different control systems with both actual building equipment and system emulators. Research aimed at achieving the above objectives will be carried out. Private industry will be encouraged to aid in this research and to use the NIST facilities to evaluate the interconnectability of their systems to those of other manufacturers.

Milestones

1990

- Software diagnostic techniques for evaluating building performance and alerting an operator of operational, equipment and maintenance requirements.

1991

- Emulator for testing and rating large building HVAC controls systems.

1992

- Protocols for communication between electronic controls used for HVAC systems.

Resources

Current funding of approximately $1M annually appears to be adequate to meet the objectives in a timely manner.

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

Construction is one of the nation's largest industries. Constructed facilities shelter and support most human activities. Their quality affects the competitivness of all U.S. industry and the safety and quality of life of every citizen. However, U.S. government and private data show that the U.S. construction industry is declining in its share of the gross national product, and losing in both domestic and international market share to foreign competitors. Analyses of causes show that lack of a program for competitiveness and loss of technological leadership are important factors in the declining competitiveness of the U.S. construction industry. A strategy based on open systems for construction products and services is proposed for competitiveness. Private and public sector activities in technology transfer, development of improved construction technologies, and research are identified for attainment of international technical leadership. A responsive program, including interactions with other major players in the private and public sectors, is suggested for the Center for Building Technology of the National Institute of Standards and Technology.

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