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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)

The Center for Building Technology (CBT) of the National Bureau of Standards (NBS) is the national building research laboratory. It works cooperatively with other organizations, private and public, to improve building practices. It conducts laboratory, field, and analytical research. It develops technologies to predict, measure, and test the performance of building materials, components, systems, and practices. This knowledge is required for responsible and cost-effective decisions in the building process and cannot be obtained through proprietary research and development. CBT provides technologies needed by the building community to achieve the benefits of advanced computation and automation. CBT does not promulgate building standards or regulations, but its technologies are widely used in the building industry and adopted by governmental and private organizations that have standards and codes responsibilities. CBT programs include: computer-integrated construction, structural safety, earthquake hazards reduction, building physics, building equipment, quality of building materials, and cement hydration.

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1983-1984 BUILDING TECHNOLOGY PROJECT SUMMARIES

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FOREWORD

The building research program of the National Bureau of Standards, the Nation's central engineering measurements laboratory, is conducted by its Center for Building Technology (CBT). CBT works cooperatively with other organizations, private and public, to improve building practices. It conducts laboratory, field, and analytical research. It develops technologies to predict, measure, and test the performance of building materials, components, systems, and practices. This knowledge is required for responsible and cost-effective decisions in the building process and cannot be obtained through proprietary research and development. CBT provides technologies needed by the building community to achieve the benefits of advanced computation and automation. CBT does not promulgate building standards or regulations, but its technologies are widely used in the building industry and adopted by governmental and private organizations that have standards and codes responsibilities.

Construction is one of the Nation's largest industries. It amounted to about $260 billion, 9 percent of the GNP, in 1983. About 70 percent of the Nation's wealth is invested in constructed facilities that shelter and support almost all human activities. Effective building decisions require sound technical bases. CBT is the only comprehensive, non-proprietary laboratory in the U.S. dedicated to meeting the measurement needs of the building community.

CBT research provides knowledge for decisionmaking. This knowledge includes characterization of the environments in which buildings must operate (such as wind loadings), characterization and definition of the performance of buildings, components, and systems (such as the mechanisms for heat loss through a window or wall cladding element), and methods of testing for performance qualities that will apply equitably to a whole family of potentially competitive proprietary materials and components.

The CBT staff of 160 includes 100 professionals, of whom 30 are registered professional engineers and 50 hold doctorates. The principal disciplines are structural, geotechnical, materials, electrical, and mechanical engineering, physics, and chemistry. CBT programs include: computer-integrated construction, structural safety, earthqake hazards reduction, building physics, building equipment, quality of building materials, and cement hydration.

Among the variety of special facilities and equipment at CBT are a universal testing machine with a 12-million-pound capacity that is capable of testing structural components 60 feet in height; a tri-directional structural testing facility capable of applying displacements in three directions simulataneously to full-scale structural components and systems; seven environmental chambers, including a 30 x 40 x 50 ft. chamber, for developing thermal performance modeling

techniques required for predicting human comfort and energy efficiency of buildings; a guarded hot-plate that measures insulation performance to thicknesses up to 14 inches; a calibrated hot-box to provide precise measurements of heat and moisture transfer in full-scale building wall and roof sections; a five-story plumbing research laboratory with high-speed computer data acquisition system to study the performance of water supply and drainage systems; reverberation and anechoic chambers, each 15,000 ft^3, to define acoustical parameters for building materials and methods to evaluate acoustical performance; daylighting laboratories; illumination color laboratory capable of presenting eight light sources independently; outdoor solar-collector test-method development area, including a passive solar test house and facilities for experimental solar heating and cooling systems; a network of outdoor material exposure sites; and a materials research laboratory with a scanning electron microscope and other instruments for materials characterization.

This report summarizes CBT's research for 1983-1984, and is arranged according to CBT's seven research programs. Each summary lists the project title, its progress, point of contact in CBT, and sponsor. The reader is encouraged to review the companion document, NBS Special Publication 457, Building Technology Publications, and its supplements. Final reports on the projects described here will be listed in future issues of Building Technology Publications.

ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ABBE	Advisory Board on the Built Environment
ACI	American Concrete Institute
AEC	Architecture-Engineering-Construction
AIA	American Institute of Architects
AMRL	AASHTO Materials Reference Laboratory
ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASCE	American Society of Civil Engineers
ASSE	American Society of Sanitary Engineers
ASTM	American Society for Testing Materials
ASHRAE	American Society for Heating, Refrigerating, and Air-Conditioning Engineers
ASME	American Society for Mechanical Engineers
BECC	Building Energy Conservation Criteria
BEPS	Building Energy Performance Standards
BLAST	A Computer Program Dealing with Building Energy Loads
BNL	Brookhaven National Laboratory
BOCA	Building Officials and Code Administrators International, Inc.
BOM	Bureau of Mines
BSS	Building Science Series
BSSC	Building Seismic Safety Council
BUR	Built-Up Roofing
CABO	Council of American Building Officials
CAD	Computer-Aided Design
CBT	Center for Building Technology
CCC	Codes Community Committee
CCRL	Cement and Concrete Reference Laboratory
CERL	Construction Engineering Research Laboratory (U.S. Army)
CIB	International Council for Building Research, Studies, and Documentation
CICC	Construction Industries Coordinating Committee
CIE	International Commission on Illumination
CRI	Color Rendering Index
CSA	Community Services Administration
CSI	Computer Systems, Inc.
CPSC	Consumer Product Safety Commission
CPT	Cone Penetration Test
DoD	Department of Defense
DoE	Department of Energy
EIA	Energy Information Agency
EMCS	Energy Monitoring and Control Systems
EPA	Environmental Protection Agency
EPDM	Ethylene Propylene Diene Monomer
ESI	Equivalent Square Illumination
ETTU	Envelope Thermal Testing Unit
FAA	Federal Aviation Administration
FCC	Federal Construction Council
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FHWA	Federal Highway Administration
FPL	Forest Product Laboratory
GSA	General Services Administration
HHS	Department of Health and Human Services
HUD	Department of Housing and Urban Development
HVAC	Heating, Ventilating, and Air-Conditioning
IAQ	Indoor Air Quality
ICBO	International Conference of Building Officials
ICSSC	Interagency Committee on Seismic Safety in Construction
IEEE	Institute of Electrical and Electronic Engineers
IERI	Illuminating Engineering Research Institute
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America

IGES	Initial Graphics Exchange Specification
ISO	International Standards Organization
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
NAHB	National Association of Home Builders
NBS	National Bureau of Standards
NBSIR	National Bureau of Standards Interagency Report
NBSLD	National Bureau of Standards Load Determination (A Computer Program)
NCSBCS	National Conference of States on Building Codes and Standards
NDE	Nondestructive Evaluation
NIBS	National Institute of Building Sciences
NIOSH	National Institute of Occupational Safety and Health
NML	National Measurement Laboratory
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRC	Nuclear Regulatory Commission
NRCC	National Research Council (Canada)
NSF	National Science Foundation
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
PBS	Public Buildings Service
PBS/BSP	PBS Building Systems Program
PMMA	Polymethylmethacrylate
PVC	Polyvinyl Chloride
RILEM	International Union of Testing and Research Laboratories for Materials and Structures
RSV	Reduced-Size Venting
SAE	Society of Automative Engineers
SASE	Standards Analysis, Synthesis, and Expression Software
SERI	Solar Energy Research Institute
SPI	Standard Penetration Tests
SRM	Standard Reference Materials
TARP	Thermal Analysis Research Program
UBC	Uniform Building Code
USGS	United States Geological Survey
USNC/CIB	United States National Committee/National Council for Building Research, Studies, and Documenation
VA	Veterans Administration

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COMPUTER-INTEGRATED CONSTRUCTION

In this new research area, CBT is advancing the state of the art of expert systems and other computer-based technologies for building design and construction. This knowledge will assist in developing methods to assess building standards and techniques, to improve building diagnostics, and to raise the quality of the built environment.

- Representation and Analysis of Construction Standards and Specifications
- Format for Model Building Codes
- Standards Interface for Computer-Aided Structural Design
- Computer System for Concrete Forming and Shoring
- Expert System for Durable Concrete
- Expert System to Diagnose Air-Leakage Problems in Complex Buildings
- Prototype Expert System for Optimizing Building Operation
- Construction Project Information Technologies
- Economic Methods for Building Standards

REPRESENTATION AND ANALYSIS OF CONSTRUCTION STANDARDS AND SPECIFICATIONS

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Sponsor: National Bureau of Standards

CBT has sponsored with the Office of Product Standards Policy the development of Standards Analysis, Synthesis and Expression Software (SASE). SASE is built upon the work of CBT researchers and others, and is a systematic method for the analysis of standards, codes, and specifications. SASE now supports key standards analysis work in progress within CBT and is directly associated with other CBT research on the standards interface for computer-aided design, and on the development of expert systems for building design, construction, and operation.

During FY 83, CBT researchers proof-tested the SASE software in connection with various application tasks, most notably an analysis of ACI 318-1977 (Chapter 4) and a project sponsored by the Federal Trade Commission intended to develop a common format for the model building codes. The proof-testing exercises contributed substantially to an understanding of SASE's capabilities, and led to the formulation of SASE modifications and enhancements.

During FY 84, work will focus on specifying links between SASE concepts and project-specification-consistency analysis (under a cooperative research program with Carnegie-Mellon University), CAD standards interface technology (under a cooperative research program with the University of Illinois), and expert system technology.

FORMAT FOR MODEL BUILDING CODES

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The three U.S. model codes exist in three formats. These differences tend to increase costs and risks for designers, builders, and manufacturers working in multiple code jurisdictions; increase regulatory barriers to the introduction of new technology; increase costs and risks of losses for building owners; make comparisons of technical requirements in the model codes extremely difficult; and provide barriers to reconciliation of differences in the model codes. In addition, imperfections in the format of each individual code make it difficult to find provisions applicable to specific technical situations. As a result, the user is often unsure if all provisions have been found, and whether relationships among the provisions have been interpreted correctly. Such imperfections tend to increase errors and costs in construction, and to create costly barriers to the introduction of new and improved technologies.

Associated with this project, a Codes Community Committee (CCC), including persons knowledgeable in model code development and use, has been organized under the auspices of the National Institute for Building Sciences. The CCC's function is to develop a consensus recommendation for a uniform model code format. CBT will provide technical support for the project in: analyzing the qualities required of the format; providing information for defining the scope to be reflected in the model codes; providing alternative organizations from which the CCC may select one or more fitting the needs of model code users; and providing an index that will define the location of all attributes and entities covered by the scope of each of the three model codes.

Improved format for model building codes offers possibilities for improving the quality of building regulations, enhancing opportunities for the introduction of new building technology, and reducing building costs.

STANDARDS INTERFACE FOR COMPUTER-AIDED STRUCTURAL DESIGN

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Sponsor: National Bureau of Standards

Computer-aided design (CAD) is critical to the improvement of construction productivity. Computers increasingly are being used in the production of engineering drawings and related contract documents; however, the effective use of computers during design remains impeded by inefficient automated procedures for checking project-specific design conditions against generic requirements couched within building codes, standards, and project specifications. In particular, designers of commerically available structural engineering software systems have "hard coded" generic requirements into their programs, and as result, such software periodically are rendered obsolete as standard-writing bodies alter the contents of provisions. The need to maintain design software both current and also applicable across jurisidictional boundaries is critical to the effective use of CAD systems. However, the periodic maintenance of "hard coded" standards data can be extremely costly.

Currently CBT research on the standards interface for CAD suggests that this problem can be reduced by physically separating generic standards data from checking and other routines within CAD software systems. A prototype system based on this concept is under development, and FY 83 work has resulted in the initial elements of an experimental CAD standards interface. The remaining impediment blocking a functional interface, the lack of data mapping techniques for linking generic data described in standards with contextual data contained in a design project database, is the subject of FY 84 work.

Concepts developed here are expected to significantly reduce the time required to produce more optimal building designs, to make CAD systems less costly to develop and maintain, and to enable the comparative evaluation of building designs under alternative versions of standards.

COMPUTER SYSTEM FOR CONCRETE FORMING AND SHORING

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Sponsor: National Bureau of Standards

To enhance the productivity and safety of multi-story concrete construction, a computer-based system will be developed to enable the contractor to make timely decisions regarding removal of shores and formwork, placement of construction loads, and requirements for temporary bracing. The key aspect of such a system is that it will incorporate a methodology to predict, on the basis of field data and in-situ measurements, the margin of safety resulting from a planned construction operation. This system will be based on real-time strength gain characteristics and loading conditions. It will incorporate findings of previous work at CBT on maturity of concrete and expand on the CBT model for loads on a structure due to forming and shoring. With such a system, the contractor will have the capability to determine such things as "If the temperature for the next few days averages about 30 degrees below the seasonal normal, will it be safe to remove the reshores on the fifth floor as scheduled?" In this way, the computer system will provide both analytical and predictive information to the contractor. Ultimately, such a system could take the form of a consultation-type computer-based expert system. The information conveyed to the contractor will use state-of-the-art computer graphic technology to ensure that such complex situations are fully understood in time to respond.

EXPERT SYSTEM FOR DURABLE CONCRETE

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Sponsor: National Bureau of Standards

Because of the potential importance of expert systems in selecting durable building materials, knowledge of generic aspects of their development and use is needed. Concrete was selected for developing a prototype expert system for building materials selection for the following reasons. Concrete is the most widely-used man-made construction material in the world. In the United States alone over 700 million tons of concrete are placed each year. Although a large knowledge base for selecting constituents for making durable concrete is available, the knowledge is not easily available to all who need it. The purpose of this project is to contribute to the generic aspects of the methodologies for creating expert systems for selecting building materials. This would be done by developing a pilot expert system of artificial intelligence that will provide recommendations for the selection of constituents for concretes subjected to a broad range of service conditions based on an existing knowledge base. When successful, a more complete system will be developed which, through the improved selection of materials, should result in more durable and predictable concrete. Its development should be possible because a large amount of specialized knowledge on the effects of constitutents on the durability of concrete is possessed by material scientists and engineers. This knowledge will form the bases for "if-then" rules.

In developing the expert system, the effects of the constituents of concrete on its major deterioration processes will be identified. Deterioration processes that will be considered include freezing and thawing, sulfate attack, corrosion of reinforcement, and expansive reactions between cement and aggregates.

EXPERT SYSTEM TO DIAGNOSE AIR-LEAKAGE PROBLEMS IN COMPLEX BUILDINGS

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Sponsor: National Bureau of Standards

CBT has recently developed a sophisticated computer program called TARP to simulate simultaneous transfer of air, heat, moisture, and contaminants on a dynamic basis. The program is a research tool and not suitable for use in a design or control process. Introduction of an Expert System is needed to improve the program.

The first phase of this research is to develop a framework for using the concepts of the Expert System in building air-circulation analysis and conduct a feasibility study for incorporating its algorithms into TARP. Representation of air motion, its phenomenological characteristics as well as known physical principles, will be compiled into a data base, that can be used in forming the decisionmaking algorithms.

Different combinations of strategies for room geometry, openings, and ventilation based upon a predetermined set of inference structures will be developed. The decision strategies will be updated or referenced by the TARP analysis. The results will then be used to determine the optimum method for controlling air leakage and ventilation.

PROTOTYPE EXPERT SYSTEM FOR OPTIMIZING BUILDING OPERATION

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Sponsor: National Bureau of Standards

Most building managers and operators lack the experience necessary to analyze the energy performance of existing buildings and their HVAC systems, evaluate the benefit of various energy conservation measures, make decisions on controls, measurements and instrumentation, and develop building-level strategies that optimize the performance of entire building systems on an annual basis. As a result, most buildings are operated very inefficiently and consume considerably more energy than is necessary for maintaining comfort.

Under this project, energy consumption information will be generated as a function of building design, HVAC system selection, operating strategies, climatic conditions, and other important variables. Guidelines and recommended practices will then be developed and incorporated into a prototype Expert System that will provide guidance to building managers and operators in the analysis, measurement, and decisionmaking processes necessary to develop strategies for upgrading building/HVAC/control systems performance, to procedures that optimize the annual energy performance of buildings, and to use diagnostic analysis/audit system performance.

CONSTRUCTION PROJECT INFORMATION TECHNOLOGIES

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Sponsor: National Bureau of Standards

Considerable work toward development of a uniform construction information format already has been undertaken by such industry organizations as AIA, CSI, and the McGraw-Hill Information Services Company. Techniques for modeling and organizing the content of specifications have been developed at CBT, and these form the technical basis for linking generic standards, project specifications, and analytical data applications. However, there currently exist no standard protocols for organizing building descriptive data within a CAD environment. As a result, each CAD vendor has developed and implemented its own unique building data structure, and no two competing systems can communicate with one another.

The need for effective data exchange between different CAD systems first was expressed in connection with the manufacture of components for aircraft and other mechanical systems. To mitigate this problem, ANSI has incorporated a version of the Initial Graphics Exchange Specification (IGES) into its standard "Engineering Drawing and Related Documentation Practices--Digital Representations for Communication of Product Definition Data" (Y14.26M). Most recently, CBT explored the need for Architecture-Engineering-Construction (AEC) extensions to IGES, and has formed the IGES/AEC technical subcommittee. The central substantive issue underlying project description data exchange concerns the nature of geometric and nongeometric building characterization and measurement.

The objectives of this project are to explore the scope of IGES/AEC requirements, to develop a technical framework of AEC attributes for implementation under EGES, to identify needed research in the areas of building characterization and measurement, and project information interfacing.

ECONOMIC METHODS FOR BUILDING STANDARDS

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Sponsor: National Bureau of Standards

The building community needs sophisticated, practical methods and guidelines for evaluating alternative building technologies in a consistent manner. The need for standardized, improved methods and guidelines to help the building community achieve affordable buildings that meet performance objectives stems in large part from the rising costs of building materials, the high costs of construction due to safety/environmental regulations, the alleged decline in construction productivity, and the uncertain costs of energy.

In this project, economic methods and supporting analysis will be specially developed for application to building problems. A background paper including the topics of sensitivity analysis, probability analysis, risk analysis, and assumptions will be prepared for use by the ASTM E06.81 Subcommittee on Building Economics. Additional technical work to be performed in support of E06.81 will be the preparation of standard economic methods based on CBT technical reports, for various stages of balloting in the ASTM standards-making process. These standard methods will include the net benefits and internal rate of return methods, discounted and simple payback methods, and benefit-to-cost and savings-to-investment ratio methods. Administrative support in responding to technical criticisms in the ASTM balloting process will also be provided. An important element in the CBT support is integrating ASTM and CBT inputs so that the resulting standard is useful and consensus can be reached by ASTM.

Technical support will also be provided to the International Council for Building Research, Studies, and Documentation (CIB) W.55 Working Commission on Building Economics and the CIB W.67 Working Commission on Energy Conservation in the Built Environment. For W.55, contributions will be made in developing measurement methods in three areas: life-cycle costs, construction productivity, and impact of building regulations. Technical leadership will be provided the U.S. Counterpart to CIB Working Commission W.55 in bringing CBT and ASTM work on building economics to the attention of CIB W.55 and CIB W.67.

STRUCTURAL SAFETY

Design loadings are a major factor in building safety and reliability. The American National Standard A58, Minimum Design Loads for Buildings and Other Structures, is used as a basic resource by model building codes and regulatory authorities. CBT research results included in the standard contribute directly to safer, more reliable designs. CBT is developing computer-based prediction and measurement techniques to assist in achieving safe, serviceable, and cost-effective structures and foundations.

- Criteria for Structural Loads and Design
- Analysis of General Combinations of Loads
- Criteria for Design of Cladding Subjected to Wind Loads
- Behavior of Glass Cladding Subjected to Wind Loads
- CBT Wind Tunnel
- Probabilistic Risk Assessments of Tornado Missile Damage
- Reliability-Based Design of Containments and Category I Structures
- Assessment of the Uncertainties and Risks Associated with the Dynamic Behavior of Compliant Offshore Structures
- Mat Foundations for Offshore Gravity Structures in Arctic Regions
- Punching Shear Capacity of Reinforced Shell
- Soil Test Probe
- Gage for Measurement of Dynamic Soil Stresses
- Measurement of Thermal Soil Properties
- Standards for Foundations and Excavations
- Development of Safety-Net Standards for Construction
- Impact Loads in Concrete Building Construction
- NDT Methods for Concrete
- Structural Condition Assessment Standards
- Assessment of Emerging Technologies for Future Office Building Structural and Enclosure Systems
- High-Technology Federal Office Buildings

CRITERIA FOR STRUCTURAL LOADS AND DESIGN

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Sponsor: National Bureau of Standards

Current structural design standards rely on different approaches to design, depending on the material or construction technology used. This tends to complicate design when different technologies are employed in the same structure. Differences in design philosophy (e.g., ultimate strength vs. working stress design) and a failure to consider uncertainties explicitly cause a lack of consistency in the reliability and performance of different buildings. Considerable effort has been devoted in the U.S., Canada, and Europe to solving these problems using the unifying concept of limit-states design, along with a probabilistic treatment of the uncertainties invariably found in engineering design.

Serviceability limit states include cracking in concrete members, slip in bolted connections, and excessive static and dynamic deflection of floor systems and frames. Engineering variables basic to serviceability limit states are identified and statistically described from data in existing literature, where possible. Full distribution and advanced first order, second moment reliability analysis methods and load combination techniques are used to select appropriate loads and load combinations for serviceability checking. Alternate design formats for checking serviceability are also being investigated for the vibration limit states, where preliminary research suggests that a factored load format may not be appropriate.

Limit-states design criteria for wood structures and for engineered masonry have yet to be developed. Tentative resistance criteria for these construction materials are being developed that would be suitable for use with the probability-based criterion contained in ANSI A58.1-1982.

The development of technology-independent design criteria for all limit states would reduce building costs by simplifying the design process and stimulating market competition between construction technologies. Improved serviceability requirements would also result in less maintenance and increased occupant satisfaction.

ANALYSIS OF GENERAL COMBINATIONS OF LOADS

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Sponsor: National Bureau of Standards

The prediction of extreme effects of structural loads has improved significantly in recent years as a result of advances in two related areas: probabilistic modeling of load processes and load combination analysis. Nevertheless, further research is needed in this area because of the complexity and other limitations of the methods available for load combination analysis. For example, these methods become difficult to apply when three or more loads are acting simultaneously, can examine only linear combinations of independent loads, with a few exceptions, and are generally based on simplistic models developed to capture only load extremes.

The research is conducted jointly by the National Bureau of Standards and Cornell University. The project proposes to continue efforts in the area of probabilistic analysis of structural loads and will attempt to overcome some of the limitations of the current methods for load combination analysis. A major objective of the project is the development of a simple and general approach for approximating the largest value distribution and other descriptors of individual load effects and their combinations.

Eventually, the improved loading criteria would reduce building costs in instances where current provisions are unnecessarily conservative, and would lead to more uniform performance of buildings. Improved load requirements would ensure safety, reduce maintenance, and increase occupant satisfaction.

CRITERIA FOR DESIGN OF CLADDING SUBJECTED TO WIND LOADS

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Sponsor: National Bureau of Standards

Modern analytical and experimental tools from the fields of wind engineering (directional extreme wind climatology, aerodynamics of bluff bodies in turbulent boundary layer flows), nonlinear mechanics of plates, structural reliability, and materials testing will be used in this project with a view to developing rational criteria for cladding design. Data from full-scale and wind-tunnel investigations of wind loads on cladding will be reviewed and studies will be conducted to determine the effect of pressure time history (including frequency content) on glass cladding load capacity. Research will also be conducted into the feasibility of inferring glass cladding load capacity from testing of small glass samples, rather than from destructive testing of actual cladding panels. This research will be of use to the cladding industry, codes and standards organizations, and Federal agencies charged with developing criteria for reliability and serviceability of structures.

BEHAVIOR OF GLASS CLADDING SUBJECTED TO WIND LOADS

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Sponsor: National Science Foundation

This project will obtain data on the magnitude of the constants in the relation between rate of subcritical crack growth and stress intensity factors, and on the parameters of the probability distribution of initial glass strengths. This will be done in cooperation with the Inorganic Materials Division, NML. A reliability-based format for designing glass cladding for wind loads will be developed that accounts realistically for both load and strength variability.

Consistent design procedures will reduce economic losses and the number of accidents due to cladding damage in windstorms, and will lead to improved economy by reducing overdesign in instances where current provisions are unnecessarily conservative. This work also could lead to revisions of ASTM Standard E330 dealing with standard test methods for exterior glazing and curtain walls.

CBT WIND TUNNEL

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Sponsor: National Bureau of Standards

This project will support the aerodynamic and structural design of a NBS/NSF regional boundary-layer wind tunnel facility, liaison with the NBS Plant Division concerning space modification, coordination of equipment procurement, and construction contracts. The effort will be coordinated to consider mechanical engineering applications for the completed facility. Facility design will be based in part on test data obtained from previous studies carried out on a 1/4-scale model of the proposed tunnel, and on the recommendations of an NSF-supported ad hoc advisory committee. In addition to providing new opportunities for competence development, this facility will enable CBT to more effectively respond to the wind-engineering research needs of other Federal agencies.

PROBABILISTIC RISK ASSESSMENT OF TORNADO MISSILE DAMAGE

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Sponsor: Nuclear Regulatory Commission

Among the possible causes of damage to nuclear power plants is the impact of objects, usually referred to as missiles, that are propelled by tornado winds. The Nuclear Regulatory Commission (NRC) requires that the probability of tornado-borne missiles attaining critical speeds and hitting various nuclear-power plants should meet certain criteria. This project is concerned with assessing reports submitted by utilities to NRC concerning the effect of tornadoes on the safety of various components of nuclear power plants.

The assessments will be carried out using probabilistic, statistical, and numerical simulation tools, as well as information concerning frequency of occurrence and physical characteristics of tornadoes, and aerodynamic characteristics and potential number and location of objects susceptible of becoming tornado-borne. This work will assist NRC in ensuring acceptably small risks of accident in the operation of nuclear-power plants.

RELIABILITY-BASED DESIGN OF CONTAINMENTS AND CATEGORY I STRUCTURES

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Sponsor: Brookhaven National Laboratory

The unpredictable nature of the possible loads on nuclear power structures, as well as uncertainties in structural properties and behavior, suggest a probabilistic approach to an assessment of structural safety and performance. This means that safety and performance should be determined according to acceptable levels of risk or required levels of reliability. Structural reliability theory already has been applied to earthquake engineering, wind engineering, ocean engineering, aerospace structures, and in the development of load factors, load combinations, and resistance factors for ordinary building construction.

In the nuclear industry, there has also been a trend toward the use of statistical analysis and probability theory for safety evaluations. This is particularly the case for seismic Category I structures for which rational methods for reliability evaluation of strength and loads are urgently needed. It can be expected that structural designers and regulatory authorities will take advantage of these methods if they do not lead to significant additional complexities at the design level.

Under this joint project with BNL, CBT will has responsibility for the analysis of service and extreme environmental loads and for developing the basic load combination methodology and procedures for calculating the load factors. BNL has responsibility for analyzing accidental loads, postulating accident scenarios, dynamic structural analysis of the nuclear structures, and testing the design procedures.

ASSESSMENT OF THE UNCERTAINITIES AND RISKS ASSOCIATED WITH THE DYNAMIC BEHAVIOR OF COMPLIANT OFFSHORE STRUCTURES

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Structures Division

Sponsor: Minerals Management Service

Modern structural reliability techniques will be used to estimate nominal failure probabilities of such structures and to assess their structural safety. For selected types of compliant offshore structures, this project will provide detailed mathematical models of the limit states that may occur as a result of their dynamic behavior under wind and wave action.

Researchers will review fundamentals, practical methodologies, and computer programs pertaining to structural reliability, will obtain suitable computer programs for estimation of failure risk based on Monte Carlo simulations, and maintain close contact with the American Bureau of Shipping, Det Norske Veritas, Navy Department, and other agencies with an interest in structural reliability of compliant offshore structures.

MAT FOUNDATIONS FOR OFFSHORE GRAVITY STRUCTURES IN ARCTIC REGIONS

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Sponsor: Minerals Management Service

Offshore gravity structures that are planned for the Beauford Sea will have to survive in one of the most hostile environments on earth. The structures will be built in moderate ocean depth (60m range) and will rest on mat foundations. There is no past service record on which the design of the structures can be based. The structures will have to resist very large dynamic environmental loads which include ice thrust and ice floe impact, waves, wind and earthquake. Extremely difficult soil conditions will be encountered, including unstable deposits which are frozen but close to the melting point and thus sensitive to minor changes in thermal regime. Very little is known about the problems associated with these deposits, such as characteristics of permafrost in a saline environment and possible effects of gas hydrates under melting conditions. Other problems include bottom irregularities resulting from ice gouging and soil liquefaction caused by wave action and other dynamic loads. There is a need to define design limit states and associated load and resistance functions.

CBT will conduct a state-of-the-art study and a review of planned design procedures. Design limit states will be identified and defined and an assessment will be made of the uncertainties associated with the determination of the relevant load and resistance parameters. Gaps in our knowledge and data base will be identified, which limits our ability to deal with the problem in a manner which will ensure safety and environmental protection at a reasonable cost.

PUNCHING SHEAR CAPACITY OF REINFORCED SHELL

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Sponsor: Minerals Management Service

Concrete offshore structures offer great potential for the safe and economical development of mineral reserves in the Arctic region. These structures are normally built in temperature climates and towed to the Arctic. It is desirable that these structures be built of lightweight high-strength concrete. Under high intensity load, these structures may experience punching shear failure, which would expose reinforcing bars and prestressing strands.

Existing design criteria, such as ACI 357R (Guide for the Design and Construction of Fixed Offshore Concrete Structures), are based on research data of relatively thin and lightly reinforced members such as building slabs, roof shells, and footings. Typically, the exterior shell of an offshore structure is greater than 3-feet thick and is heavily reinforced on both faces. If designed in accordance to existing design guidelines, the exterior shells would become extremely thick so that it would not be possible to tow the structures through relatively shallow waters.

This research will include tests of concrete shell elements subjected to high local forces. It will also examine the scale effects of using small-scale specimens, in the range of 6- to 12-inch thick shells. Careful planning of the proposed test program, which will include 1/6-, 1/3-, and full-scale specimens, will produce structural performance data over a range of geometric and material variables.

The experimental program will be supplemented with analytical studies to predict the expected performance of the test specimens. The analytical models will simulate the multi-axial stress states within thick members and will incorporate non-linear material behavior.

SOIL TEST PROBE

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Sponsor: Tri-Services Committee

The problem of soil exploration at shallow depths (less than 3m) has been generally neglected by the geotechnical profession. Existing methods for use at these depths are either inaccurate or too expensive. Since most residential structure foundations and utility lines are located at shallow depths, there is a need for an accurate, practical, and inexpensive method of exploring and classifying soils at shallow depths.

During a study of soil anchors, CBT identified an ideal tool for this purpose consisting of a small diameter helical screw which can be inserted by one man. The torque necessary to turn the screw can be correlated with the shear strength of soil. In the first stage of the project, three sizes of test probes for different soil strengths will be built, and test probe readings will be correlated with cone penetrometer, plate loading, and laboratory tests. This will enable CBT to model and calibrate the device. In the second stage, operational prototypes will be built and design charts for practical applications will be prepared. Use of the soil test probe will substantially reduce the cost and improve the quality of site exploration and foundation design.

GAGE FOR MEASUREMENT OF DYNAMIC SOIL STRESSES

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Sponsor: Air Force

The in-situ measurement of stress in a soil mass poses difficult problems because stress gages stiffer than the surrounding soil introduce disturbances that distort the stress field. Also, the traditional method of determining stresses via the measurement of strains does not work well in soils since stress-strain relationships are complex and poorly understood. The problem is magnified in the measurement of dynamic effects, which is compounded by the poor frequency response characteristics of available gages.

There is an opportunity for advancing the state-of-the-art in this measurement area by the use of piezo-electric polymer material developed by NBS. This material possesses two properties that make its use as a soil-stress gage attractive. The polymer gages can be thin and flexible, minimizing the disturbance in the stress distribution in the soil mass. And also the gages have favorable dynamic response characteristics and could pick up high-frequency pressure pulses.

The development of the gage also poses difficult technical problems, such as uncoupling of stress and adiabatic heat effects, and uncoupling of compressive and shear stresses. If the gage is successful it will be widely used by industry, government agencies, the armed forces, and research laboratories. The gage will also improve the state-of-the-art in soil dynamics by providing an accurate signature of pressure pulses.

MEASUREMENT OF THERMAL SOIL PROPERTIES

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Sponsor: National Bureau of Standards

The thermal conductivity of soil is significantly affected by soil moisture. The correlation between moisture content and thermal conductivity must be known for accurate predictions of energy dissipation of buried transmission lines and other structures surrounded by soils. Conversely, the correlation between moisture content and thermal conductivity may be used to measure soil moisture content in-situ and to determine the plastic limit of clays in the laboratory.

Under this project, CBT will determine the relationship between moisture content, the index properties of soils and thermal conductivity of soils, and use the information for: accurate mathematical modeling of heat and moisture flow through soils; development of in-situ measurement methods for moisture content and/or density, as well as other index properties; and improved measurement techniques for thermal properties.

STANDARDS FOR FOUNDATIONS AND EXCAVATIONS

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Sponsor: National Bureau of Standards

Even though most structural failures and distress are associated with inadequate foundations and very large sums of money are invested in excavation work, there is currently no national standard for foundations and excavations in the U.S. As a consequence, effective code regulations are either absent or differ from location to location, causing difficulties and confusion in the introduction of new technologies and in the application of standards systems.

CBT assists ASCE in the development of standards for foundations and excavations by serving as a secretariat for the Committee on Foundation and Excavation Standards and supporting the activities of the working committees by providing leadership and technical input. Pending availability of adequate financial resources, CBT will also take the initial steps in the development of a probabilistic code format for foundation and excavations. Additionally, CBT provides the technical basis for standards developed by other agencies outside the ASCE. At the present time these include: Mobile Home Foundations (ANSI A225) and Excavation Safety (OSHA, an eventually ANSI A10.12), and will probably extend into various areas of geotechnical in-situ measurements and laboratory testing.

DEVELOPMENT OF SAFETY-NET STANDARDS FOR CONSTRUCTION

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Sponsor: Occupational Safety and Health Administration

Falls from elevated surfaces during construction are the principal source of worker casualties. Safety nets are used to impede falls in many situations where active fall-protection devices, such as guardrails and safety belts, are either impractical, as in congested work areas, or are ineffective due to the absence of an adequate mechanism of support. Currently, there is no technical basis for the application and performance testing of safety nets used in construction. The purpose of this study is to develop comprehensive criteria for the use and testing of safety nets based on research results. This, the second phase of the study, will provide test data needed in evaluating the proof-testing provisions that are currently found in U.S. safety-net regulations. In that there is a minimal technical basis for the currently specified procedure, the test data resulting from this phase should significantly advance the state-of-knowledge in this area.

IMPACT LOADS IN CONCRETE BUILDING CONSTRUCTION

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Sponsor: National Bureau of Standrds

Load factors for concrete structures in service have been in existence in codes and standards for about two decades. Within the past year, ANSI introduced for the first time a common load factor for all construction loads. In this project, field data will be used to examine the statistical distribution of construction loads, particularly impacts from various sources, and their correlation with the recently-adopted load factor by ANSI.

The principal task will be to synthesize from existing field data the components of construction load due to impact from the placement of concrete and stripping of forms, dead loads, and other load effects. The reduced data will be put to use for the development of a simplified approach for predicting impact of concrete and formwork, and a design criterion for impact loads based on their statistical distribution.

NDT METHODS FOR CONCRETE

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Sponsor: National Bureau of Standards

Despite recent advances in concrete technology, there is still a need for effective nondestructive test methods to evaluate the properties and quality of in-place concrete. To meet this need, CBT has been actively pursuing research in this area. The two specific topics that have been addressed include: estimation of the in-place strength of concrete at early ages, and detection of internal flaws such as cracks and honeycombing within concrete members. Past research on the maturity method has led to fundamental understanding of this technique for in-place strength prediction. Current research is being performed to obtain a similar fundamental understanding of the pullout test method, and research has begun in the area of pulse-echo testing.

The results of this project will provide fundamental information on NDT methods, which will increase the user's understanding of the principles and inherent limitations of each method so that results can be properly interpreted.

STRUCTURAL CONDITION ASSESSMENT STANDARDS

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Sponsor: National Bureau of Standards

Throughout the U.S., increasing concern is being expressed for the need to more fully use the existing building stock. Expenditures for improvements to housing nearly matched those for new housing construction in 1981; $46.5 billion vs. $50 billion annual rate. The building rehabilitation process requires many technical decisions by designers, builders, and building officials relative to the condition of the existing building. Such state-of-the-art data required to make these condition-assessment decisions are broadly dispersed and not readily accessible. It is necessary to subject such information to a consensus review and provide the design community with resource standards on building condition assessment for selected materials (concrete, metals, masonry, wood, etc.).

Technical support to the ASCE Standards Committee on Structural Condition Assessment will include preparation of standards outlines and draft information based on CBT and other relevant research, providing CBT staff support to technical issues as appropriate including review of draft standards, and coordination with other related standards activities (ASTM, ACI, etc.). Administrative support will include providing a chairman to the committee, organization of committee membership, holding two meetings of the full committee, and ensuring that ASCE standards process be followed.

ASSESSMENT OF EMERGING TECHNOLOGIES FOR FUTURE OFFICE BUILDING STRUCTURAL AND ENCLOSURE SYSTEMS

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Sponsor: General Services Administration

Because of the lack of a clear indication of the conditions and requirements that will impinge up on future office building design and construction, the GSA/PBS is seeking answers to fundamental questions about designing, rehabilitating, and constructing buildings. Some of the questions to be addressed include:

- What should be the form of future office buildings?
- What new materials for enclosures and structural systems should be considered for use by GSA?
- What technology is needed to measure and evaluate the performance and serviceablity of new and innovative structural and enclosure system materials?
- What are the emerging technologies for building energy and lighting systems?

The first phase of the project involved the solicitation of expert judgment from approximately 100 architects and engineers in private firms and universities across the nation. The second phase of the project will use the results of the first phase as a framework for structuring a trend extrapolation for various types of materials and designs.

HIGH-TECHNOLOGY FEDERAL OFFICE BUILDINGS

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Sponsor: General Services Administration

The Public Buildings Service is committed to the development of a new design approach, referred to as "High Technology." This work emphasizes automation of various building systems and advanced design of others. Since a high-technology building exceeds current state-of-the-art levels of design and performance, a special technical expertise is needed for developing the design criteria.

CBT provided technical support to the development of a research plan and to the development of functional programming issues for two GSA building projects. The research plan consisted of research needs relative to building subsystems, components, and materials that have potential advantages but are not available for immediate use because of insufficient testing or in-use performance data. The results of this project are intended to provide a higher level of environmental performance and support to the building's general users and its operating staff.

EARTHQUAKE HAZARDS REDUCTION

The National Earthquake Hazards Reduction Program, established in response to the Earthquake Hazards Reduction Act of 1977, calls for NBS to conduct research on performance criteria and supporting measurement technology for earthquake resistant construction. CBT is developing the technical base for improved seismic design criteria for new buildings and methods for evaluating seismic safety of existing buildings to meet needs of the National Earthquake Hazards Reduction Program for improved seismic design and construction practices.

- Technical Assessment of Earthquake-Resistant Design Provisions
- Support to the Interagency Committee on Seismic Safety in Construction
- Strength and Response of Structures to Earthquake Loading
- Large-Scale Bridge Columns Subjected to Reversed Cyclic Loading
- Cyclic Loading of Masonry Building Components
- Geotechnical Measurement of In-Situ Soil Properties
- Evaluation and Expansion of Liquefaction Data Base
- Cyclic Strain Approach to the Determination of Liquefaction Potential of Level Sandy Sites

TECHNICAL ASSESSMENT OF EARTHQUAKE-RESISTANT DESIGN PROVISIONS

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Sponsor: Federal Emergency Management Agency

This project is a continuation of work with the Building Seismic Safety Council in its effort to support improved seismic design criteria. CBT will provide support of the technical secretariat of the BSSC Trial Design Overview Committee which is working on resolution of comments to proposed revisions to the Tentative Provisions for the Development of Seismic Regulations for Buildings through a trial design program. This will be done in coordination with the other members of the Committee who will be voluntarily donating their time in the matter. To assure future implementation of the refined provisions, NBS will work closely with and participate with the Building Seismic Safety Council in all phases of the actual conduct of the trial design process.

Working with ICSSC, CBT develops recommendations for future substantive improvements in Federal seismic provisions. An existing draft standard prepared for trial use by the ICSSC is based on current practice. It is the first step in improving Federal standards, with its primary purpose to introduce a uniform practice among all Federal agencies. Substantive improvements in the Federal seismic provisions for buildings will take several years to accomplish and should be coordinated with the eventual improvement in the private sector that will come about as a result of the BSSC activities.

CBT will thoroughly review the proposed guidelines for existing Federal buildings and develop suggested improvements. It is a well recognized fact that hazards that exist in buildings represent a large threat and that the problem is quite complex. CBT expertise in dealing with similar problems concerning the rehabilitation of old buildings and the application of retroactive building regulations will be brought to bear on this problem.

CBT provides the chairman of ICSSC and of the ICSSC steering group and provides the technical secretariat for ICSSC and its steering group. Additionally, staff members serve on various ICSSC technical committees and provide the chair for the Committee on Building Standards.

SUPPORT TO THE INTERAGENCY COMMITTEE ON SEISMIC SAFETY IN CONSTRUCTION

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Sponsor: Federal Emergency Management Agency

The purpose of the Interagency Committee on Seismic Safety in Construction (ICSSC) is to assist the Federal departments and agencies involved in construction to develop and incorporate earthquake hazards reduction measures in their ongoing programs. These will be based on existing standards when feasible and will be consistent with OMB guidelines.

NBS will provide technical and administrative support to the activities of the ICSSC that are aimed at meeting the Committee's specific objectives. Specific objectives cited in the NEHRP include:

- o develop seismic design and construction standards for Federal projects, develop guidelines to ensure serviceability following an earthquake of vital facilities constructed or financed by the Federal Government,
- o develop guidelines that provide for independent State and local review of seismic considerations in the construction of critical facilities constructed and financed by the Federal Government,
- o develope guidelines for the inclusion of earthquake hazards reduction activities in ongoing Federal programs,
- o develop a strategy to identify existing Federal buildings and other structures that pose unacceptable earthquake-related risks,
- o coordinate the development of guildelines for the consideration of seisimic risk in the development of Federal lands.

ICSSC and CBT will cooperate with State and local government and private organizations in the development of nationally applicable earthquake hazard reduction measures. Using consensus procedures, the ICSSC will recommend earthquake hazard reduction practices suitable for use by Federal agencies. ICSSC recommended practices will not be mandated for use by Federal agencies except by Executive Order, but they may be adopted as required practices by the various Federal agencies following their established practices for implementing regulations.

STRENGTH AND RESPONSE OF STRUCTURES TO EARTHQUAKE LOADING

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Sponsor: National Bureau of Standards

The response of structures to earthquake loading and prediction of resistance of buildings and components is essential to seismic design. Two areas being studied are torsional effects in buildings and analytical studies on masonry shear walls.

The need for providing resistance to torsional effects in buildings subjected to earthquakes is known. However, the provisions in the current building codes are based primarily on engineering judgment. A design eccentricity of five percent of the maximum building dimension at each level is used in the Uniform Building Code and the recommended Lateral Force Requirements of the Structural Engineers Association of California.

The purpose of the first area is to develop a theoretical basis for determining the torsional effects. Results will be used to establish a reasonable criteria in seismic design and to implement a reliability-based limit-states approach to seismic load. The analytical results will be used for rationalizing the seismic design criteria in the consideration of lateral load requirements.

In the second area, the process of developing tentative seismic design provisions for unreinforced and reinforced masonry building components reveals a scarcity of information on its ultimate strength characteristics. Since seismic resistance is now based primarily on ultimate strength considerations, the lack of such information for masonry building components is detrimental to its rational design in buildings subject to seismic loadings. The analytical study will be coordinated with CBT's laboratory project on masonry shear walls. Analytical and experimental work will be coordinated to develop methods for predicting strength and behavior of walls. The research will provide the basic understanding of the torsional effects in building and contribute to the basis of seismic design and safety.

LARGE-SCALE BRIDGE COLUMNS SUBJECTED TO REVERSED CYCLIC LOADING

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Sponsor: National Science Foundation

A national workshop on earthquake resistance of highway bridges held in January 1979 identified research needs and established priorities in the area of seismic aspects of highway bridge design. One of the highest priority research needs was to determine the effects of scale factor on bridge column design to determine whether the behavior of small sections can be extrapolated to large cross sections and to examine the performance of selected full-scale details. These two needs can be interrelated.

Experimental programs on large-scale specimens are expensive and difficult to conduct; hence, the limited availability of data in the literature. Careful planning of tests will produce much full-scale performance data over a range of axial loads and column designs. Such a range is necessary to examine the effect of scale factor since such an effect will likely be dependent on the column mode of failure. The program plan will consider columns designed using state-of-the-art techniques. Specimens at full-scale, 1/3-scale, and 1/6-scale will be selected. Many of the tests will be full size to take advantage of the CBT ability to obtain "bench mark" data. The scale tests that are conducted are expected to identify problems of scale effect but may not completely answer them. If necessary, a complete examination of scale effect will be possible in future investigations using the full-scale tests to provide reference data.

CYCLIC LOADING OF MASONRY BUILDING COMPONENTS

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Sponsor: National Bureau of Standards

The process of developing tentative seismic design provisions for both unreinforced and reinforced masonry building components reveals a scarcity of information on ultimate strength characteristics. Since seismic resistance is now based primarily on ultimate strength considerations, the lack of such information for masonry is detrimental to rational design of buildings subjected to seismic loadings. Here, experimental tests will provide vitally needed information not now available that will serve as the basis for development of mathematical models. A number of failure modes will be examined to identify the characteristics of each and the significant parameters affecting the different failure modes.

Analytical expressions for predicting failure as a function of key parameters will be developed. Later experimental testing will determine the generality of the proposed analytical expressions. This research will provide engineers with a sound base not currently available by presenting experimentally verified rational approaches for ultimate strength design.

GEOTECHNICAL MEASUREMENT OF IN-SITU SOIL PROPERTIES

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Sponsor: National Bureau of Standards

The key to ensuring the stability of structures, utilities, and construction sites lies in our ability to accurately characterize soil behavior. Since soil is not a man-made material, its successful characterization depends on its properties in the undisturbed state in the ground. Under this project, tests will be conducted with the acoustic cone and correlated with other in-situ and laboratory soil tests. From these data, the methodology for in-situ measurement with the acoustic cone will be developed.

Design curves will be developed for the use of the cone penetrometer for evaluation of the liquefaction potential of sites subjected to earthquake effects. Also, Japanese Standard Penetration Test methodologies and equipment will be studied to provide a better interpretation of existing Japanese subsurface exploration data from sites that experience liquefaction, which are presently used in our design curves for the Standard Penetration Test. This research will lead to new, more reliable, and more efficient in-situ measurement methods. It will reduce the cost of foundations, reduce foundation failures, and increase the feasibility of construction on unstable sites by providing a more reliable assessment of subsurface conditions.

EVALUATION AND EXPANSION OF LIQUEFACTION DATA BASE

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Sponsor: Bureau of Reclamation

The most important method of determining the liquefaction potential of granular soils subjected to earthquake loading is the use of known correlations between in-situ tests and liquefaction potential. The in-situ tests used for this purpose are the Standard Penetration Test (SPT) and the Cone Penetration Test (CPT). The data base for the SPT is in large part derived from Japanese data. However, it is known that the SPT is poorly controlled and thus the results are variable. In particular, there are not enough data to enable a comparison of U.S. and Japanese SPT practice and thus adequately interpret the Japanese SPT liquefaction data. Very few direct field data are available for the CPT and thus, at present, the CPT is solely based on known correlations between CPT and SPT.

The objective of this research is to better define and expand the data base linking in-situ measurements by SPT and CPT with the determination of the liquefaction potential or cyclic mobility of sites with saturated granular soils. The project is coordinated to coincide with the exploration of Japanese sites where liquefaction occurred on May 26, 1983. The SPT rigs conducting exploration will be calibrated to determine fall height, kinetic energy at hammer impact and energy passing through the drill rod, and CPT exploration will be conducted alongside the SPT. To better define the existing data base, SPT and CPT data will be acquired at the old Niigata liquefaction site, and a correlation between U.S. and Japanese SPT data will be established by determining the energy in the drill rods of Japanese SPT rigs, establishing a correlation between blow counts obtained with Japanese and U.S. and Japanese SPT liquefaction data and establish a CPT liquefaction data base.

CYCLIC STRAIN APPROACH TO THE DETERMINATION OF LIQUEFACTION POTENTIAL OF LEVEL SANDY SITES

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Sponsor: National Bureau of Standards

Relative density is currently used as the most-important parameter in preparing laboratory specimens of sand to model liquefaction potential under in-situ conditions. But, research now indicates that many other characteristics of the soil are important, such as the manner of deposition, history of preconsolidation, and history of vibration. These are collectively referred to as the soil fabric.

In this project, a relationship between cyclic strain and pore-water pressure buildup is established. Anticipated cyclic strain, in turn, can be estimated on the basis of the shear modulus of the deposit which can be approximately determined from shear-wave propagation velocities. Several test series have been performed on Monterey #0 sand, and it has been established that for sand there is a threshold strain below which no pore water pressure buildup occurs. This threshold strain is approximately 10^{-2} percent. It has been also determined that overconsolidation will increase the threshold strain and that in virgin samples which have not been shaken before and which are subjected to a very large number of strain cycles, the threshold strain could be one order of magnitude smaller.

On the basis of these findings, a design approach was proposed which used the threshold strain concept. More recent seismic events, notably the great 1976 earthquakes in Tangshan (M = 7.8) and Ningho (M = 6.93), indicate that liquefaction can be a major problem in alluvial silts and silty sands. Since traditional in-situ measurement approaches to the determination of liquefaction potential are not likely to be very reliable because of the extremely low penetration resistance of those deposits, it is extremely important to develop alternative approaches. It is therefore important to determine whether the cyclic strain approach can also be applied to silts and silty sands. To accomplish this goal, cyclic strain studies will be conducted on silts and silty sands. Since the behavior of silts differs from that of sands, laboratory studies are required to study the response of silty soils to cyclic loads.

BUILDING PHYSICS

CBT is developing performance production and measurement techniques that exploit the potential of advanced computation to assist owners, operators, designers, manufacturers, and contractors in providing functional, safe, and economical thermal, ventilation, acoustical, and lighting systems in new and existing buildings.

- Calibrated Hot-Box Conduction Transfer Functions
- Heat Flux Meter Characteristics
- Convection Within Low-Density Insulation
- Thermal Resistance Calibration Standard
- Envelope Thermal Testing Unit
- Field Measurements of Wall Thermal Mass
- Thermal Mass Effects of Residential Cooling and Heating
- Evaluation of Thermal Anomalies
- Heat Loss Through Thermal Bridges
- Multi-Room Thermal Modeling
- Wall Systems Air Leakage Research
- Field Wall-Component Tester
- Convective Air Movement in Buildings
- Large-Building Air Movement
- Indoor Air Quality of Office Buildings
- Underground Heat Distribution Systems
- Urea-Formaldehyde Foam Insulation
- Thermal Performance of Low-Slope Roofs
- Standards Requirements for the Weatherization Assistance Program
- Acoustic Measurements in Buildings
- Prevention of Traffic Noise Problems
- Daylighting Studies
- CEL-1 Lighting Program
- Opponent-Color Approach to Color Appearance
- Effect of Chromatic Adaption (Color Rendering and Color Appearance)
- Lighting Quality Guidelines
- Lighting Roundtable III
- Color Calibrator for Weather Radar
- Safety Colors and Signs in Workplaces
- Discriminability Features of Secure Documents

CALIBRATED HOT-BOX CONDUCTION TRANSFER FUNCTIONS

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Sponsor: National Bureau of Standards and Department of Energy

The CBT Calibrated Hot-Box apparatus is new and has recently been accepted from the contractor who constructed it. The apparatus needs to be calibrated to determine quantitatively the error associated with the measurements made using this apparatus. A series of calibration tests will be carried out for both static and dynamic temperature differences between the indoor and outdoor sides of the wall and for static and dynamic heat, air and moisture transmission rates. Much of this year's effort will go into calibration work and planning of the series of experimental test walls that will be designed to experimentally investigate parameters such as convection within voids in the walls or materials, thermal mass, and to validate models used to predict performance under a variety of exposure conditions.. The calibration measurements will provide data on the flank loss, that amount of energy that by passes the specimen or is lost through the specimen holder. CBT will participate in a 20-30 laboratory round-robin test program to determine the repeatability and uncertainty in the ASTM 976 method of test.

HEAT-FLUX METER CHARACTERISTICS

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Sponsor: National Bureau of Standards

Heat flow transducers are comparative measuring devices and must be calibrated or referenced back to an absolute measurement. Large errors in calibrations and errors due to the way the transducers are used are prevalent. These transducers are used extensively in research, measurement, and production work. Precision and accuracy in this type of measurement need improvement so that resulting test method specifications are similarly dependable.

In this project, a method or methods for calibration of heat flow transducers will be devised and validated using the NBS guarded hot-plate apparatus as the source for absolute quantitative data. Comparisons will be made with data obtained from other methods or devices such as the CBT calibrated hot box or techniques used by other laboratories. A study of errors for both laboratory and field applications will be made with a view to developing remedial procedures to minimize errors.

CONVECTION WITHIN LOW-DENSITY INSULATION

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Sponsor: National Bureau of Standards

There is a disagreement with the building research community on the significance of convective heat transfer in low-density insulation. Quantitative measurements are needed to determine convective effects and make the information available to practioners, industry, and organizations such as ASTM and ASHRAE. The 1-meter Guarded Hot Plate is well suited to conduct this study because different directions of heat flow up, down, and horizontal, can be applied to insulation materials as thick as 38 cm. Here, specimens of different thickness will be used with differential temperatures controlled up to 40°C to determine differences in measured thermal transmittance (resistance) when the plates are rotated to give different directions of heat flow. The differences of thermal resistance between heat flow down and heat flow up determine the convection effect for each test.

THERMAL RESISTANCE CALIBRATION STANDARD

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Sponsor: Department of Energy

This project will explore the feasibility of developing a new calibration standard for thermal resistance measurement equipment such as guarded hot plates (ASTM C-177) and heat flow meters (ASTM C-518). At present only two materials are available from CBT for calibrating guarded hot plates and heat flow meters. One is a dense fiberglas board and the second is a low-density fiberglas blanket. A need exists to supply the measurement community with calibration samples whose apparent thermal conductivity and thermal resistance is both higher and lower than those now available, either using materials that more nearly resemble those that will be measured in current production or using an entirely new calibration material approach; for example, plastics, insulating concretes, loose fill materials, or something like a variable wall spacing and wall thickness honeycomb type of material, whose thermal conductivity could be changed at will. Given success in this venture, a measurements laboratory desiring calibration would have the flexibility for calibrating their devices at or near the several ranges of values expected to be measured, thus improving the precision and accuracy of their standard test methods. Much money will be saved by the manufacturing industry if their production machines can be set more precisely to produce the R-values required without excessive factors of safety. This, in turn, could lower prices to the consumer.

ENVELOPE THERMAL TESTING UNIT

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Sponsor: Department of Energy

In this project, CBT will determine the usefulness and accuracy of the envelope thermal testing unit (ETTU) developed by the Lawrence Berkeley Laboratory for the Department of Energy. The device will be used on CBT field projects to determine the practical problems and field sources of errors resulting in its use. Guidelines will be developed from this experience for the use of ETTU. Measurements will be made in the six thermal mass buildings and the results compared with the known thermal resistance of these walls. A series of test walls of typical construction will be built and installed in a small test cell in the NBS environmental chamber. Measurements will be made on these walls under various simulated thermal conditions. These walls will be built in such a way that they can be later tested in the CBT calibrated hot-box, if required. From these tests the accuracy of ETTU will be determined under various environmental conditions. The source of error will be determined and the results compared with those of other test methods.

FIELD MEASUREMENTS OF WALL THERMAL MASS

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Sponsor: Department of Energy

There is a real need to measure and experimentally evaluate the energy savings attributable to thermal mass in buildings, so that present energy conservation standards can be modified where appropriate to reflect benefits realized from thermal mass.

Six 20-foot wide and 20-foot long, one-room test buildings (modules) have been constructed at the NBS NIKE Site. All six test modules have the same floor plan orientation and other common features. The wall constructions are as follows:

No. 1 Insulated light-weight wood frame
No. 2 Uninsulated light-weight wood frame
No. 3 Insulated masonry (mass exterior to wall insulation)
No. 4 Uninsulated masonry
No. 4 Log
No. 5 Insulated masonry (mass interior to wall insulation)

These six test buildings were extensively instrumented for measuring the wall heat transmission, heating and cooling energy consumption, and the indoor comfort condition. A comprehensive series of field measurements have been carried out to date including:

- 14-week winter measurements with the thermostat set for space heating at 68°F
- 3-week spring measurements with the thermostat set for space heating at 68°F
- 3-week summer measurements with the thermostat set for space cooling at 76°F
- 14-week winter and spring night temperature setback measurements
- 3-week summer measurements with the thermostat set for space cooling at 65°F
- 3-week summer measurements with with night ventilation used during cool night periods
- Special purpose winter, spring, and summer partition wall tests.

This year, CBT will provide representative data files of measurements of the six thermal mass test buildings covering all of the periods of measurement. The data file will be used by LBL to validate BLAST. In addition, CBT will provide consultation to LBL concerning the CBT field tests and the technical approach to be used by LBL.

THERMAL MASS EFFECTS ON RESIDENTIAL COOLING AND HEATING

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Sponsor: Electric Power Research Institute

The objectives of this project are three: to analyze previously measured test results of the NBS thermal mass test buildings to investigate the effect of building envelope and building operation parameters on reducing and delaying peak space heating/cooling loads; to investigate the effect of the thermal mass of the interior partition walls and interior furnishings on reducing and delaying peak summer cooling loads; and to compare space heating/cooling loads predicted with EMPS and TARP computer programs to corresponding measured heating/cooling loads.

EVALUATION OF THERMAL ANOMALIES

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Sponsor: Department of Energy

Thermographic inspection of insulated buildings has uncovered many thermal anomalies in the insulation system due to improperly installed insulation, convective air movement in the insulation, and moisture damage to the insulation. At present there is no method for quantifying the heat loss due to these anomalies so that the impact of correcting the anomalies can be judged.

This project will investigate the adequacy of several in-situ methods for quanitifying the heat losses due to thermal anomalies. The quantificative use of thermography will be assessed for both the measurement of temperature and the measurement heat flux. Laboratory tests will be performed on representative thermographic systems to determine their characteristics for making quanititative measurements. The in-situ use of heat flow meters and calorimeters will be investigated. Guidelines will be established for each of these methods and an assessment of their accuracy will be made.

HEAT LOSS THROUGH THERMAL BRIDGES

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Sponsor: Department of Energy

As buildings become more insulated, the heat loss due to structural members becomes significant and can degrade the performance of the insulation system by an order of 10 to 20 percent. These parts of the structure are also locations at which condensation can occur and thus are potential sources of building deterioration. Present analysis and models of the building envelope ignore the presence of thermal bridges.

Under this project, methods for detecting the presence of thermal bridges will be developed. Generic type of thermal bridges will be anlayzed using the "Heating 6" finite-difference heat-transfer program. In-situ measurement methods for quantifying the heat loss due to thermal bridges will be developed. These methods will include the use of heat flow meters and calorimeter boxes for measuring both the heat loss due to the thermal bridge and the heat loss of the insulated wall section. These data will be analyzed to determine the degradation in performance of the insulation system due to thermal bridging. The results will be compared with the theoretical predictions.

MULTI-ROOM THERMAL MODELING

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Sponsor: National Bureau of Standards

This project will develop a comprehensive technique for predicting simultaneous transfer of air, moisture, and heat in and through multi-room buildings. Although numerous building thermal modeling techniques and computer programs exist throughout the United States, none of them can handle the following processes simultaneously: envelope heat transfer, envelope air leakage, envelope solar heat gain, room-to-room heat transfer, room-to-room air and moisture transfer, intra-room air movement, energy consumption by the heating/cooling equipment, indoor comfort, water-vapor condensation, and contaminant migration. Existing models are usually single-room models and dynamic coupling between the heated/nonheated spaces and/or the cooled/noncooled spaces are ignored.

Under this project, CBT has developed the Thermal Analysis Research Program (TARP) and has used the program to predict the performance of the six test houses at the NIKE Site and the interzone movement of contaminants. This program is capable of performing the simultaneous analysis of air and heat transfer in multi-zone structures. This year, small scale models will be developed that will permit the validation of TARP for predicting the simultaneous mass and heat transfer in multi-room buildings. Various scaling relationships will be examined which will permit small scale models to be used to simulate actual full scale heat and mass transfer. Data from these small scale models will be used to validate the accuracy of TARP to simulate complex heat and mass transfer.

WALL SYSTEMS AIR LEAKAGE RESEARCH

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Sponsor: Department of Energy

In comparison with residential buildings, little data exist on the air leakage and air movement in large commercial structures. What data does exist indicates that modern office buildings are relatively tight and are operated with little outside air to remove contaminants generated in the building. Even buildings which have a total air exchange rate sufficient to remove contaminants, may have zones which require little heating and cooling energy and therefore use small amounts of air (this can happen in variable air volume systems which are common in modern low energy commercial buildings).

A test method will be developed for measuring the efficiency of ventilation in modern commercial buildings. This method will determine the minimum amount of air exchange which is effective in removing contaminants from the work space. The method will be based on the injection of a tracer gas into various zones of the building and determination of the buildup and decay of the tracer gas in the work space and in the exhaust air. Initially the CBT automatic air infiltration system developed for application to large buildings will be used. Tests will be made in at least three different commercial buildings and the results will be used to determine the effectiveness of the ventilation systems.

In addition, CBT will collect air infiltration and ventilation data on three additional large commercial buildings which have passive solar design features and large atria, in order to increase the data base on large buildings. CBT will also look for other commercial buildings which are being instrumented for their energy usage. If possible, fan-pressurization tests and tracer-gas tests will be performed in these buildings to assess their air leakage characteristics.

FIELD WALL-COMPONENT TESTER

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Sponsor: National Bureau of Standards

This project will develop a field method for measuring the thermal conductance of wall components under transient conditions. At present it is difficult to measure the thermal response of wall components under typical field conditions caused by diurnal climate changes. Existing field methods require large temperature differences and no reversal of heat flux which restricts their use to cold winter months and to surfaces without solar loading. CBT's approach will be to design a portable calorimeter box that will permit the measurement of the thermal conductance of wall components under typical transient conditions. Two designs will be considered. In one, a two-sided calorimeter box will be designed in which one side will be heated and the other will be cooled. In the other design, a single-sided calorimeter will be considered in which both heating and cooling can occur. Mathematical simulation of the performance of these two designs will be done using finite-difference transient heat-transfer programs to assess their field performance and accuracy.

CONVECTIVE AIR MOVEMENT IN BUILDINGS

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Sponsor: National Bureau of Standards

Though great progress has been made in the modeling of conductive and radiative heat transfer in buildings, little work has been done on developing general models for predicting the convective heat transfer either within zones of a building or within the building insulation systems. Most convective transfer models currently used are semi-empirical and not derived from first principles. However, an understanding of the convective transfer process in buildings is important for determining the performance of insulation systems which have air cavities, the intra-room air movement for determining the dispersion of contaminants, and the inter-room movement of air.

In this project, an advanced finite difference scheme capable of solving the Boussinesq approximation to the Navier-Stokes equation will be implemented on an NBS computer. This model is capable of simulating the natural convection heat transfer between room surface and adjacent air, natural convective heat transfer between adjacent rooms, and the forced convection between the building and its external environment. The adequacy of this model for satisfying the future needs of NBS in developing predictive capabilities in such areas as convective heat transfer in insulation systems, the dispersion of contaminants in rooms (ventilation efficiency), and the interzone movement of air will be assessed.

LARGE-BUILDING AIR MOVEMENT

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Sponsor: Department of Energy

Large buildings have complex air movement patterns. Understanding these air movement patterns is required for an assessment of energy performance, for the determination of indooor air quality, for understanding moisture mitigation, and for smoke control. It is difficult to either analytically model this air movement or to experimentally measure the movement of air in multi-zone buildings. Here, the CBT developed Thermal Research Analysis Program (TARP) will be used to predict the inter-zone air movement in several large office buildings in which NBS has measured the air infiltration and ventilation. The results of these measurements will be used to validate the predictions of TARP. The results also will be used for determing future direction in analytical modeling of air movement in buildings and the need for future measurement methods such as multi-tracer techniques for assessing the movement of air in complex buildings.

INDOOR AIR QUALITY OF OFFICE BUILDINGS

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Sponsor: National Bureau of Standards

Indoor air quality in commerical office buildings is degrading due to energy concerns which result in less leaky building enclosures and designs which minimize the introduction of outdoor air for ventilation. Several buildings have been evacuated due to "building sickness syndrome," a term attached to poor air quality causing occupant complaints. In some cases, very little ventilation air was provided. In others, specific pathogens were multiplying in the HVAC systems and infecting the occupants. The increased use in buildings of materials which outgas are also suspected. Randon gas from soils is a known carcinogen. Formaldehyde is suspected carcinogen. Many other cantaminants have been identified as possible health hazards. Definitive IAQ standards and design practices are needed. In this project, CBT will work with EPA on their program reviews and with DoE and NIBS to identify other specific needs. The focus will be on measurement methods for indoor contaminants and ventilating systems for commercial office buildings. What should be measured? What measurement techniques should be used?

UNDERGROUND HEAT DISTRIBUTION SYSTEMS

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Sponsor: Department of Defense Tri-Services Committee

Many underground heat distribution systems in military installations are failing because of the ingress of ground water due to corrosion of the conduit system that covers the thermal insulation around the carrier pipe. Since it is extremely expensive to replace the entire underground system, it is desirable to have an accurate and easy-to-use instrument that will detect only the segments of the system that have failed.

CBT has developed an automated microcomputer-controlled measurement system for such heat losses. The system depends on the ground temperature profile over the underground heat source and thermal properties of the earth cover. A validation of this instrumentation system is needed based on an actual installation where the heat loss from the underground system is known by separate calometric measurements.

UREA-FORMALDEHYDE FOAM INSULATION

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Building Materials Division

Sponsor: Department of Energy

This project will review the technical issues concerning urea-formaldehyde foam insulation in walls and ceilings of residential construction. This includes a review of the properties and composition of these insulations and techniques for their measurement, the types of residential construction, interactions between the foam and wall components, remedial measures such as foam removal to eliminate or reduce problems associated with its presence, and an identification of research needs to resolve the problems caused by urea-formaldehyde foam in residences. Since medical expertise resides outside the NBS, potential health effects will not be addressed.

The review will be based on existing information and building practices. Sources of information will include published literature and reports from Federal, State, and foreign government agencies. Contact will be made with key research personnel to assess current research and to define future research needs. Persons involved with remedial measures including foam removal will also be contacted to obtain information on the procedures involved and the effectiveness of the measures.

THERMAL PERFORMANCE OF LOW-SLOPED ROOFS

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Sponsor: Department of Energy

This study will focus on the four main areas that should be considered in a quantitative assessment of the condition and thermal performance of a low-sloped roofing system. In this study a methodology to determine quantitatively the thermal performance of low-sloped roofs will be developed. Parameters required to characterize roofing thermal performance will be identified. Some of the factors which may affect the total thermal performance of the roof to be addressed in the methodology include: the composition (components) of the roof, type of insulation attached, joints between insulation boards, the amount of moisture in the roof, the number of penetrations in the roof, and the environment to which the roof is exposed. The methodology will include mathematical models for assessing thermal performance and in-situ thermal measurements of roofing systems. Recommendations concerning an on-the-roof test method will be made, and research needs for implementation of the methodology will be identified. Recommendations will also be made as to ways the time required to measure in-place thermal performance may be shortened. Finally, recommendations on how to estimate the thermal performance of the Nation's inventory of low-sloped roofs from data for a relatively small number of roofs will be made.

STANDARDS REQUIREMENTS FOR THE WEATHERIZATION ASSISTANCE PROGRAM

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Sponsor: Department of Energy

The objective here is to revise, update, and expand the criteria for materials and products eligible for the DoE Weatherization Assistance Program. This task includes a review of the DoE Weatherization Measures list regarding eligible materials and products, a review of the existing criteria, including standards, for determining their eligibility, and the development of recommendations for revised criteria for materials and products.

Under this project, the DoE Weatherization Measures list will be reviewed with regard to the appropriateness of the items listed and the completness of the list. Applicable standards for the items listed will also be reviewed to determine if the current versions of these standards are appropriate to the Weatherization Assistance Program. If not appropriate, recommendations will be made to revise and update the criteria that reference these standards. For weatherization measures not included on the current list, but deemed suitable for inclusion, criteria will be recommended. New and revised criteria will be based on factors such as: thermal performance, fire safety, health safety, structural integrity, durability, quality, conformance to building codes, use, and ease of installation.

ACOUSTIC MEASUREMENTS FOR BUILDINGS

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Sponsor: National Bureau of Standards

The acoustical properties of building materials, spaces, and systems and the acoustic power emitted by sources are currently inferred from far-field measurements of sound pressure levels using diffuse sound field theory -- a theory inappropriate for most situations. As a result, laboratory and field data are inaccurate and predictions of in-situ performance from laboratory data unreliable. Under this project, microprocessors and new experimental tools such as Fourier Transform Analyzers, intensity meters, and the newly develped prototype absolute sound power source will be used to develop improved or new test methods for measuring and predicting the absorption coefficients of building materials, the total sound absorption present in a space, the acoustic power emitted by a source located in enclosed spaces, and the flow of acoustical energy in rooms. Use will be made of the NBS semi-reverberant, reverberant, and anechoic chambers to extend acoustical intensity methods to measure the acoustical power emitted by sources, the acoustic energy propagation in rooms, and to study the effects of boundary conditions on both the acoustic emission and propagation. The data obtained using the steps outlined above will be used to reexamine for a limited number of well-defined enclosures the relationships among sound power, absorption, decay rate, and sound pressure levels in rooms. This analysis can help identify sources of errors responsible for our current inability to predict accurately and reliably the acoustic performance of buildings and their components.

PREVENTION OF TRAFFIC NOISE PROBLEMS

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Sponsor: Federal Highway Administration

The purpose of this project is to provide local government staffs with a simple method and a handbook, based upon available technology, including individual steps required to plan land use and building construction compatible with expected noise. The proposed handbook integrates transportation noise prediction, site noise exposure, building envelope noise isolation, and building occupants' noise exposure. The document provides a step-by-step description of the design process indicating how local data are incorporated into the evaluation of the building envelope noise isolation and the technical feasibility of achieving an acceptable environment through land use planning and control. Numerous examples are presented to illustrate the use of the methodology. The text is written in a "how-to-do-it" format using examples and graphics to illustrate the concepts embodied in the method developed. Technical details are presented in a series of appendices. Data summaries and references to available noise isolation data bases for building components such as walls, windows, and doors are also be provided.

DAYLIGHTING STUDIES

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Sponsor: National Bureau of Standards, Tri-Services, and National Civil Engineering Laboratory

The type, size, and configuration of window openings have a strong impact on building lighting, heating, and cooling loads. Daylight has been shown to have good potential for reducing lighting energy requirements; however, the effect of daylighting schemes on building heating and cooling energy requirements must also be considered. Since the luminous efficacy of solar radiation is typically two to three times that of electric light sources, the substitution of the proper levels of daylight for electric lighting can reduce heating and cooling loads substantially, while providing psychological and aesthetic benefits.

This year measurements will be made of the concurrent interior and exterior daylight conditions, including sky and solar radiance, illuminance and luminance, and interior luminance and illuminance distribution under various sky conditions. Additional measurements will be made with a reference lighting system, enabling determination of contrast rendition factors for daylit and mixed daylit/electric-lit spaces. The existing lab conspicuity meter will be modified for field use and measurements will be made under daylight conditions. Interior luminance distribution data will be analyzed to evaluate glare conditions with daylighting. These data will also enable direct computation of the interreflection daylight component, leading to an improved algorithm for predicting illuminance due to internally reflected light.

CEL-1 LIGHTING PROGRAM

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The Conservation of Electric Lighting computer program (CEL-1) was developed as a tool to assist the building designer in determining energy-efficient fenestration and lighting configurations. However, at its present state of development only the lighting energy, daylight illumination, and visual performance aspects of fenestration use can be evaluated. In addition, calculations can only be made for a single point in time (static analysis) as opposed to the annual dynamic analysis required to determine the impact of fenestration systems on net building energy requirements for the entire year.

In contrast, the BLAST program can be used to perform building energy and system loads analyses on an annual basis using hourly increments. However, the BLAST program does not consider the impact of daylighting, so it does not allow for complete evaluation of the effect of different fenestration systems on building thermal and lighting loads and energy. This project will result in a computer simulation program incorporating a hybrid version of CEL-1 and BLAST to enable complete evaluation of fenestration systems on building energy and loads.

OPPONENT-COLOR APPROACH TO COLOR APPEARANCE

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Sponsor: National Bureau of Standards

A mathematical analysis is used in this project to model the interaction of an illuminant with a range of object colors. The assumption that object colors can be represented by a mathematically "smooth" reflection spectrum will be tested explicitly in the analysis. In addition, this analysis uses data from opponent-color sensitivity functions to model the response of the human eye. The overall analysis thus models the effects of illuminants with different color-rendering properties on the appearance of color objects.

The ability of the eye to process object color information in a way that partly compensates for the effect of illuminant substitution has been studied under the heading of "color constancy." A second goal of the present project is to advance understanding of color constancy and, in particular, to put some results of color-constancy research into an illuminant-centered form. An illuminant-centered state ment of constancy would be that "the eye can discount certain features of the illuminant but not others." The present research project is designed to clarify color constancy results by presenting the eye's response by means of an opponent-colors model, rather than the more traditional ones.

A long-range benefit of the opponent-colors approach is that it fits in more logically with the Fourier-transform description of the verison of contrasts, now in common use in visual science. A pilot study last year developed a method for applying Fourier-transform methods to lighting, using existing equipment at CBT. This application should help the development of methods for clarifying the role of color and lighting geometry on contrast. The ultimate goal of the color-rendering research is a comprehensive new method to compute the effects of changing the light source on object color.

EFFECT OF CHROMATIC ADOPTION (COLOR RENDERING AND COLOR APPEARANCE)

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Sponsor: National Bureau of Standards

Only when the light source closely resembles daylight can the appearance of an object's reflection be predicted accurately from the physically measured chromaticity. Because of the phenomenon of chromatic adaption (the eye's "discounting the color of the illuminant"), this coordination between appearance and chromaticity breaks down if the color of the light source departs significantly from that of daylight. A striking example of the shifts that can occur is the case of blue objects seen under high pressure sodium light. At present, no formula is widely agreed-upon as being an accurate prediction of either the effect of chromatic adaption, or the appearance of colors seen under chromatic light sources.

Under this project, a first task will be an attempt to improve the CRI, the Color-Rendering Index. Here, a fresh mathematical approach will be taken to defining a new index that is expected to be equal to the current CRI for most common lamp types, easier to calculate, absolute (rather than relative to one among an infinitude of reference sources, as is the current index), and well-defined for lights of all chromaticities, even spectrally pure lights (unlike the current index). In addition, the form of the new index may also allow for a particularly simple operational measurement of color rendering.

With regard to color appearance, two transitional tasks are planned. First, a research paper on the time course of chromatic adaption will be published, to complete a past project on High Efficiency Lights and Chromatic Response. Second, preliminary work will begin on an approach to a major study of color appearance under a variety of light sources, to be carried out in FY 85 and beyond. Steps to be completed during FY 84 include a literature survey of previous experiments on color appearance, and formulas that have been proposed for predicting it; pilot research into several different experimental procedures for quantitatively measuring color appearance; and a plan for a full-scale laboratory investigation in future fiscal years.

LIGHTING QUALITY GUIDELINES

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Sponsor: Department of Agriculture

In the first phase of this project, the role of color in meat and poultry inspection plants will be documented. A field research study will be conducted in which spectroradiometric measurements of diseased, defective, and normal tissue for four species will be made under a controlled light source. At the same time, tests of the accuracy of identifying and discriminating different meat and poultry tissues will be made under five different light sources, including high intensity discharge lights. This phase is intended to provide interim guidelines to USDA on light-source spectral quality and color rendering.

In the second phase, issues related to the prediction of the effectiveness of color and illumination will be addressed. An approach expanding the basic color science will be defined as necessary for research-based criteria to be the foundation of future guidelines. In Phase 1, the role of color rendering of lights for inspection stations will be documented. Phase 2 will address issues related to color contrasts in meat and poultry tissues as a function of different light sources.

LIGHTING ROUNDTABLE III

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Sponsor: National Bureau of Standards

This project presented a roundtable sponsored by IES, NBS, the Electrical Power Research Institute, and the Lighting Research Institute. The purpose of the roundtable was to identify the user lighting issues that would lead to the establishment of basic and applied research plan for lighting. New issues for the 1980's have been identified as computer technologies in the work place, visually intensive manufacturing and operations, and the impact of high-efficiency sources. The scope of Roundtable III addressed these issues as they apply in institutional, commercial, industrial, and outdoor lighting. Residential lighting was excluded. A summary report on the conference is being prepared.

COLOR CALIBRATOR FOR WEATHER RADAR

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Building Physics Division

Sponsor: Federal Aviation Administration

Under FAA sponsorship, CBT built, and partially demonstrated a color calibrator using a single photodiode. In this follow-on effort, a three-photodiode detector head and related breadboard model circuitry will be designed and fabricated. For this purpose, the detector heads may be fabricated in three separate or one integrated assembly. These photodiodes have a response extended into the blue ultraviolet region. Each photodiode will have an appropriate filter (to be determined) such that the filtered photodiode will have a maximum response in one of the three primary wavelength bands (red, blue, green). A precision operational amplifier will be closely coupled to the photodiode to reduce noise. A power supply (+15, -15VDC), potentiometers, and a 100 mV digital readout meter will complete the color calibrator.

The technical and economic feasibility of the color calibrator approach remains to be fully demonstrated. Among the unknowns are certain technical issues concerning weather radar operational characteristics, expected degradation modes, and manufacturing tolerances (e.g., phosphor variation), that were identified in previous work.

SAFETY COLORS AND SIGNS IN WORKPLACE

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Sponsor: OSHA

In this project, criteria will be developed for the use of safety colors and signs in workplaces. The emphasis will be on developing criteria for the use of colors, including fluorescent ones, to code safety information under energy-efficient (HID) and mixed-light sources, as well as criteria for specifying the size of words and symbols as a function of viewing distance.

A two-phase effort is proposed. In the first 18-month phase, the use of colors to code information will be documented, along with existing sign/color/symbol specifications. Two laboratory research projects will also be conducted. The first project will use the newly renovated illumination color laboratory. In the second phase, which will be defined in greater detail at the completion of Phase 1, methods for predicting the overall effectiveness of safety signs using words, symbols, and innovative colors will be developed, along with methods for predicting color appearance.

DISCRIMINABILITY FEATURES OF SECURE DOCUMENTS

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Building Physics Division

Sponsor: Bureau of Engraving and Printing

The ultimate objective is to determine those features of existing and proposed secure documents (paper currency, postage stamps, drivers' licenses, social security cards, savings bonds, money orders, credit cards) that are most effective in deterring counterfeiting. The objective of this initial phase is to prepare a multi-year research plan and begin to identify experimentally those features of existing counterfeit U.S. paper currency that are most useful in supporting identification of their counterfeit nature.

Based upon the data found and the researchable issues that are identified and that fall within CBT's area of competence, a pilot experiment will be conducted on the discriminability of visual features of selected U.S. paper currency, such as color, reflectance, size, and shape of graphic elements. This experiment will include physical measures of currency such as color, spatial frequency, and lightness.

BUILDING EQUIPMENT

CBT is developing performance prediction models, measurement techniques, and test methods for building controls and equipment to serve the needs of the industry and users.

- Heat Pump and Air-Conditioner Test Procedures
- Performance of Non-Azeotropic Binary Refrigerant Mixture in Residential Heat Pumps
- Refrigerant Mixture Measurements in Two-Phase Flow
- Water Heater Studies
- Furnace, Boiler, and Household Appliance Test Procedures
- Household Appliance Data Update
- Systems and Controls Laboratory
- Test Methods and Evaluation Procedures for Controllers
- Controls Dynamic Modeling
- Controls Modeling Workshop
- Energy Analysis of Control Strategies
- Energy Monitoring and Control System Algorithms
- Measurement of Buoyancy-Induced Liquid Flows
- Numerical Modeling of Multi-story Building Drainage Systems
- Performance Testing of Solar Collectors
- Laboratory Accreditation: Solar Collector Testing
- Investigation of Control Strategies to Improve Solar Systems Performance
- Thermal Test Methods: Solar-Assisted Heat Pumps and Cooling Components and Systems
- Thermal Performance of Passive Solar Apertures and Storage Components
- Evaluation of Integrated Collector Storage Systems
- Consulting and Advisory Services: Active Solar Heating and Cooling
- Passive Solar Energy, Class-A Data Program
- Radiative Heat-Transfer Modeling and Radiation Measurement
- Validation of New Heat Transfer Algorithms
- Second-Law Analysis of Solar Water Heating Systems
- Validation of an Improved Performance Model for Solar Collectors
- Systems Effectiveness Research
- Technical Committee Assistance
- Technical Problem Assessment
- Mechanical Equipment Criteria for Multi-story Buildings
- Thermal Performance Testing: Movable Insulation
- Air Quality Criteria for Archival Storage
- Technical Support to DoE

HEAT PUMP AND AIR-CONDITIONER TEST PROCEDURES

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Building Equipment Division

Sponsor: Department of Energy

The Energy Policy and Conservation Act (PL 94-163) and the National Energy Conservation Policy Act (PL 95-619) require the Department of Energy to prescribe test and rating procedures and minimum performance standards for various residential appliances, including central heat pumps and air conditioners. DoE has, since 1975, relied on CBT to assist in the development of the test procedures. Since then, DoE has been interested in verifying these test procedures and extending their scope to include new designs coming onto the market. Also, since the current procedures have not addressed the case where the components of a given system may be manufactured by different companies and assembled in the field (e.g., replacement air conditioner) DoE has directed CBT to develop a procedure by which these units may be rated. This work encourages energy conservation affecting virtually all new-production residential heat pumps and air conditioners in the U.S.

PERFORMANCE OF NON-AZEOTROPIC BINARY REFRIGERANT MIXTURE IN RESIDENTIAL HEAT PUMPS

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Building Equipment Division

Sponsor: Department of Energy

The objective of this study is to quantify the performance of the typical residential heat pump operating with a non-azeotropic binary refrigerant mixture as a working fluid. The purpose is twofold. First, CBT is currently modifying its heat pump performance simulation model to include non-azeotropic mixtures as the working fluid. This empirical study will be the hardware test verification needed to confirm the new cycle simulation. The second purpose is to measure the potential of these mixtures operating in a heat pump as typically designed today; that is, one designed to operate on single-component refrigerant.

It is anticipated that the adoption of this concept in products being offered to the consumer could come about within three years. In certain climatic zones, this is estimated to offer an annual seasonal performance increase of four to five percent.

REFRIGERANT MIXTURE MEASUREMENTS IN TWO-PHASE FLOW

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Building Equipment Division

Sposor: National Bureau of Standards

The convective heat transfer coefficent is the single most important property for the design of heat exchangers. For those heat exchangers which have internal boiling or condensation coupled with forced convection (e.g., refrigerant systems, steam power systems), the complexity of flow conditions are such that coefficient values are normally completely empirically based. Since this study focuses on binary mixtures which are non-azeotropic (different boiling/condensation points), the problem is complicated even further. In single-component fluids it is typical to establish an empirically-based functional relationship between the convective heat transfer coefficient and the other transport properties (e.g., conductivity, visocity) for a given range of flow patterns and thermodynamic conditions. Once these relationships are established for categories of fluids, it is possible to predict the heat transfer coefficient based on the measurements of other transport properties that are significantly easier to make. In the area of non-azeotropic mixtures, virtually no such relationships among the transport properties exist.

The specific group of fluids that will be studied are fluorocarbons that are used or intended to be used as refrigerants. The apparent advantages of using non-azeotropic mixtures in refrigerant systems are improvement in efficiency, less environmental (ozone) impact, multi-level evaporators, and self-lubricating working fluids. The evaluation of any of these possible advantages entails an overall performance evaluation of the refrigerant system, which in turn requires knowledge of the transport properties of the refrigerant.

The heat transfer data and relationships that evolve from this study will be used by researchers in the refrigeration industry to quantify the advantages of binary mixtures in their future refrigeration systems design. Also, it will provide CBT with a measurement facility that is equally applicable to the wide variety of binary mixtures found in chemical plants.

WATER HEATER STUDIES

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Sponsor: Department of Energy

The Energy Policy and Conservation Act (PL 94-193) has mandated that household appliances, including water heaters, be labeled for energy use using standardized testing methods. Thus, it is necessary to establish standard test procedures that allow the accurate determination of energy efficiency, are repeatable, and not burdensome to perform. The objectives of this project are to expand and/or modify the DoE water heater test procedures where required and to provide laboratory data, analyses, and recommendations related to the test procedures.

FURNACE, BOILER, AND HOUSEHOLD APPLIANCE TEST PROCEDURES

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Sponsor: Department of Energy

This project will provide the industry, via DoE, an equitable testing and rating procedure for determining the seasonal energy performance of central residential furnaces, boilers, and household heating equipment; and will assist DoE in this effort by conducting laboratory studies of furnaces, boilers, and household heaters and their associated equipment. The Energy Policy and Conservation Act (PL 94-163) and the National Energy Conservation Act (PL 95-619) require the Department of Energy to prescribe test procedures for various residential appliances, including furnaces, boilers, and household heating equipment. Test procedures for furnaces were published in the Federal Register in May 1978 (including test procedures for household heaters). Since then, DoE has updated and will continue to update the procedures to include new product designs coming on the market. On June 17, 1983, DoE published a comprehensive revision of the test procedures for furnaces, boilers, and household heaters, including new procedures for modulating controlled equipment, thermal stack dampers, and unvented gas and kerosene fueled heaters. During the course of this development, CBT has supported DoE in defending and/or modifying the test procedures. This work will encourage energy conservation through the production of more efficient equipment for residential space heating.

HOUSEHOLD APPLIANCE DATA UPDATE

Joseph Greenberg
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Sponsor: Department of Energy

The Energy Policy and Conservation Act as amended by the National Energy Conservation Policy Act requires the development of test procedures, labeling rules, and energy efficient standards for consumer appliances. These requirements must be established using representative data when reflecting such items as energy efficiency, energy use, etc. Many of the parametric values used in the initial rulemaking have changed due to energy price increases, changed consumer behavior, availability of more efficient appliances, etc. This project will develop the data needed to update the various rules promulgated by the Energy Conservation Program for Consumer Products using the most current available data.

SYSTEMS AND CONTROLS LABORATORY

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Sponsor: National Bureau of Standards

The focus of this program will be developing mathematical models and measurement techniques for evaluating the performance of building systems and controls, encouraging energy conservation in buildings through improved control strategies and software, and developing guidelines for automated building management systems. This research effort will complement CBT's current DoE-sponsored research program aimed at documenting the energy savings potential of the most commonly employed HVAC control strategies, developing algorithms for building control systems, evaluating the reliability of automated building management systems, and studying the application of sensors in energy monitoring and control systems.

This year's effort calls for the installation of a completed Energy Management and Controls System in the NBS Administration Building and the carrying out of research to verify and refine both the building/HVAC/control simulation model and the EMCS Application Algorithms developed in FY 83 and FY 84. In addition, the integration of building services through the use of simultaneous voice and digital communication systems will be explored.

TEST METHODS AND EVALUATION PROCEDURES FOR CONTROLLERS

Robert D. Dikkers
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Building Equipment Division

Sponsor: Department of Energy

The field performance of many active solar systems has not been as good as expected. Data from instrumented sites indicate that approximately 40% of the monitored systems have performed at one-half or less, of design expectations. Problem areas have included corrosion, leaks, poor design and installation, and poor reliability of control systems (including sensors). Controllers have been identified as the least reliable solar components in various studies of field problems.

As part of the FY 83 Systems Effectiveness Research Program, CBT held a meeting in August 1983 with controller manufacturers to obtain recommendations for future research. One of the high-priority research areas identified was the development of test and evaluation criteria for controller hardware.

In FY 84, using results of previous studies carried out by NBS and SERI, CBT will develop a recommended plan for developing test methods and evaluation procedures for controllers. This plan will outline the types of controllers to be studied, and various tests (i.e., functional, environmental, electrical, sensor interface, etc.) to be performed. Existing test methods will be reviewed and referenced where appropriate. The recommended plan will be developed with industry and other organization input, widely circulated for review and comments, and will be revised as necessary. The resulting plan will provide the basis for a laboratory research program to start in FY 85. The plan will also identify industry and standards-writing organizations that should be involved to process the recommended test methods and evaluation procedures into national consensus standards.

CONTROLS DYNAMIC MODELING

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Sponsor: U.S. Navy and Department of Energy

None of the building simulation programs (e.g., BLAST 2, DoE 2) in existence today account for HVAC control dynamics. As a result of this, there exists very little reliable data on the amount of energy waste in buildings due to control dynamics and absolutely no information on how to design and operate building control systems to optimize dynamic performance. This project will concentrate on developing simulation models that can be used to predict the dynamic, "minute-by-minute" performance of control systems for building air handlers and heating/cooling plants. This will cover the most common types of HVAC systems and will include research to develop simulation models for building equipment, HVAC components, controls, and zones, and the simulation of the entire building/HVAC/control system. Work this year will concentrate on verifying and refining models of the various components found in building air handlers, and developing a simple building shell model and an interactive "front end" for a building/HVAC/control system simulation program.

CONTROLS MODELING WORKSHOP

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Building Equipment Division

Sponsor: Department of Energy

CBT helped organize a workshop on HVAC Controls Modeling and Simulation to review and document the state-of-the-art in the mathematical modeling and simulation of building HVAC systems and controls. Control process simulation aimed at increased understanding and improved products has been and is being carried out by industry, universities, government laboratories, and through the sponsorship of research programs by societies such as ASHRAE. Because of the diversity of the organizations involved and the differing objectives of their work, it is often difficult to determine the status of these activities. This can lead to a duplication of effort, as well as a significant difference in the depth to which models and simulation methods are developed and verified.

ENERGY ANALYSIS OF CONTROL STRATEGIES

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Sponsor: Department of Energy

A study is urgently needed to independently document the potential energy savings of different commonly used strategies. Last year, CBT used the computer program BLAST 2 to evaluate control strategies for a variety of HVAC systems in a large office building and a large retail store in different regions of the country. Typical strategies studied were dry bulb economizer cycle, enthalpy economizer cycle, hot and cold deck temperature reset, zone control, floating space temperature, and scheduled setback. The results of these individual research studies will be combined and summarized in a report suitable for publication in either the ASHRAE Journal or the ASHRAE Transactions.

ENERGY MONITORING AND CONTROL SYSTEM ALGORITHMS

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Sponsor: U.S. Navy and Department of Energy

At present, there are no standardized, nonproprietary EMCS application algorithms avaliable for use by companies entering the building controls field. Many of these companies lack training and experience in HVAC systems, building controls, and algorithm development. As a result, the building owner or manager who purchases their system is often stuck with an EMC system that either doesn't work or only partially works.

To assure a minimum level of performance of EMC systems, CBT plans to develop public-domain algorithms for HVAC/building applications. Past work concentrated on the completion of algorithms for the control of building air handlers, including optimal start/stop, scheduled time of day stop/start, duty cycling, demand limiting temperature reset, and economizer cycle. This year, the effort will involve the validation and refinement of these air handling algorithms and the expansion of this effort to include the development of algorithms for the control of centrifugal chillers.

The development of public domain algorithms for EMC systems should greatly improve their performance, especially for systems made by small manufacturers, and lead to increased energy conservation in commercial buildings. Specifications of such algorithms will help to assure that future energy measurement and control systems provide at least this minimum of capability.

MEASUREMENT OF BUOYANCY-INDUCED LIQUID FLOWS

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Sponsor: National Bureau of Standards

Current techniques for measuring flow rates in closed loop systems include the use of turbine flow meters, venturi meters, and orifice meters. Unfortunately, all of these devices introduce significant flow restrictions which cannot be tolerated in buoyancy-induced flow. The use of noninvasive flow measurement techniques such as magnetic and ultrasonic flow meters require a fluid velocity greater than that obtained in many buoyancy-induced flow situations. The lack of a technique to measure these low flow rates without significantly alternating the flow rate results in a void of experimental data needed to validate various computer simulation tools used in building equipment applications. Under this project, the sensitivity and stability of thermistor sensors will be determined as functions of the bulk fluid temperature, flow rate, and the power dissipated by the self-heated thermistor. Calibration techniques will be developed that present the sensor data in a convenient dimensionless parameter representation.

NUMERICAL MODELING OF MULTI-STORY BUILDING DRAINAGE SYSTEMS

Lawrence S. Galowin
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Building Equipment Division

Sponsor: National Bureau of Standards

This project will develop extensions of the partially-filled pipe unsteady flow network program, derived under the Brunel University contract, to include vertical connection of a number of single-floor networks. The expanded computer program and modeling provides simulations of multi-story building drainage systems. A workshop session will be organized jointly with Brunel University and held at CBT late in 1984 for application demonstrations of the developed model for interested designers and codes/standards and professional organizations.

The extension to multi-story systems will involve development of an energy inlet boundary condition to simulate stack flow entering the building drain at the lowest level network, prior to leaving the building via a main sewer connection. The basis for this boundary condition equation already exists in the simulation of appliance discharage with the existing network model. Developments will be supported by validation tests in the laboratory at Brunel University. The final multi-story program will be suitable for the NBS/CBT computing facility.

PERFORMANCE TESTING OF SOLAR COLLECTORS

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Sponsor: Department of Energy

CBT is performing a major role in the development of test and evaluation procedures for determining the performance of solar energy materials and components used in the heating and cooling of buildings in the United States. The Department of Energy has requested that NBS contribute to the international cooperative research in solar energy organized by the International Energy Agency. The intent of this cooperative research is to provide a common base of validated experience and information for all of the participating countries. This work will contribute to the formulation and evaluation of international standards. Such international standards are currently nonexistent in solar energy.

LABORATORY ACCREDITATION: SOLAR COLLECTOR TESTING

Robert D. Dikkers
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Building Equipment Division

Sponsor: Department of Energy

This project will document the need for a solar collector laboratory accreditation program. This documentation will be based on discussions with solar collector manufacturers, collector testing laboratories, various agencies and research organizations working in solar energy, and state solar energy offices. The results of this work will be vital to further solar-collector testing and certification programs.

INVESTIGATION OF CONTROL STRATEGIES TO IMPROVE SOLAR SYSTEMS PERFORMANCE

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Building Equipment Division

Sponsor: Department of Energy

In this project, CBT will investigate two control schemes for a direct forced-circulation solar system. The two control schemes are on/off control of a reduced, fixed flow rate through the solar collector array and the control of a variable flow rate such that the temperature of the fluid returning to the storage tank minimizes mixing. Only the first control scheme will be investigated in FY 84.

Two identical double-tank direct solar systems at the NBS solar test facilities will be used for this investigation. The major experimental activities to begin in FY 84 are (1) measurement of the collector array efficiency at various flow rates and (2) measurement and comparison of the thermal performance of one system operated in a conventional manner and the second system operated under the alternate control scheme.

In FY 84, an analytical activity will be started to develop the detailed computer simulation model for the complete system. This activity will focus on accounting adequately for the variation of collector array efficiency with flow rate. Later, this investigation will be completed with the comparative measurement of the thermal performance of a system operating under variable flow-rate schemes and with completion of the detailed computer simulation model including the effect of thermal stratification of the storage tank. A detailed comparison of the model and the experimental results will be made.

THERMAL TEST METHODS: SOLAR-ASSISTED HEAT PUMPS AND COOLING COMPONENTS AND SYSTEMS

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Building Equipment Division

Sponsor: Department of Energy

This task draws on previous efforts in solar equipment and building equipment to develop viable test methods and evaluation procedures for solar-assisted heat pumps and solar cooling components and systems. Based on reviews of the work performed at CBT and elsewhere, as well as the existing industry consensus standards issued by ASHRAE and the Air-Conditioning and Refrigeration Institute, modified test methods and evaluation procedures will be drafted. An interagency report will be prepared for the sponsor summarizing the recommendations for test and evaluation procedures for these solar components.

THERMAL PERFORMANCE OF PASSIVE SOLAR APERTURES AND STORAGE COMPONENTS

Michael E. McCabe
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Building Equipment Division

Sponsor: Department of Energy

The objectives of this project are to identify and quantify the basic heat transfer mechanisms that occur in various passive/hybrid solar components and to reproduce these mechanisms under laboratory conditions. Representative passive solar apertures and thermal solar components will be obtained and prepared for testing. Detailed thermal models will be prepared for each of the passive solar components undergoing test. Validation of each thermal network model will be accomplished by comparison of predicted temperatures and heat fluxes with those measured during testing. Each component selected will be tested in the passive solar calorimeter which measures the thermal performance of the test articles under conditions of controlled interior and actual exterior thermal environments. Indoor testing, when appropriate, will be performed for selected components for specific exterior conditions and a controlled interior condition. The results of the experimental testing will be evaluated using the theoretical models.

EVALUATION OF INTEGRATED COLLECTOR STORAGE SYSTEMS

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Sponsor: Department of Energy

The thermal performance of systems using integral collector storage (ICS) is influenced substantially by the surrounding infrared radiation environment, conventionally characterized by an effective sky temperature, to which the system is subjected.

In this project, experimental and analytical research will be undertaken to determine how ICS systems respond to thermal irradiance under both indoor and outdoor operating conditions. In previous CBT studies, two fully instrumented ICS's and a data-acquisition system were developed and these will be used for both indoor and outdoor experimentation. Experiments are planned under indoor conditions that simulate both nominal infrared irradiance and night-time cooldown periods. These results will be compared with data obtained from corresponding outdoor tests. The data and an analytical model will be used to determine how to relate outdoor and indoor test results. A special emphasis is to be on measuring the levels and structures of thermal irradiance (emitted and reflected) indoors and outdoors.

The analytical work will provide the methodology for measuring the background thermal irradiance and normalizing the test data to a more representative outdoor environment of a number of configurations. The findings will then be used to recommend improvements in irradiance simulator design and test procedures.

CONSULTING AND ADVISORY SERVICES: ACTIVE SOLAR HEATING AND COOLING

Robert D. Dikkers
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Building Equipment Division

Sponsor: Department of Energy

Under this task, CBT will provide consulting and advisory services to technically support DoE (Active Heating and Cooling Division). These services include the following activities: active participation in conferences sponsored by DoE, SERI, ASHRAE, and other organizations to discuss performance criteria, standards and various research activities; meetings with representatives of other government agencies (Federal and/or State) and foreign governments at the request of DoE to discuss NBS solar energy program activities; active participation in DoE planning and program review meetings; and review and evaluation of requests for proposals, contractor reports, program planning documents, and other program activities.

PASSIVE SOLAR ENERGY, CLASS A DATA PROGRAM

Bal M. Mahajan
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Building Equipment Division

Sponsor: Department of Energy

The objectives of this project are: to acquire and distribute to the participating researchers, Class-A performance data for various passive subsystems under different experimental conditions for use in detailed building energy analysis and model/algorithm validation, and performance characterization of various passive subsystems. Also, CBT will provide the necessary technical planning and coordination for the effective collection and use of Class-A performance data in support of the Passive Solar Program.

The DoE Passive Solar Energy Class-A Program was established to collect, analyze, and archive detailed laboratory, test-cell, and building performance data of high quality. These data are to be used for the validation of whole-building energy-calculation methods and component models and for the development of new algorithms which characterize the behavior of innovative components, systems, and subsystems in buildings. At present, the NBS Class-A Passive Test Building is one of nine test facilities or buildings in the Class-A network of five passive heating facilities and four passive cooling facilities. In addition, other data are being taken at several other facilities both within and outside of DoE sponsorship.

RADIATIVE HEAT-TRANSFER MODELING AND RADIATION MEASUREMENT

Michael E. McCabe
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Building Equipment Division

Sponsor: National Bureau of Standards

The objectives of this project are to develop a computer code that models the admission and subsequent absorption of the radiant flux from sun and sky in partially transparent enclosures and to obtain detailed measurements of actual sky-radiance distribution.

For the modeling part of this study, a matrix formulation of solar radiative heat transfer in partially transparent enclosures will be developed. The enclosure model will predict the instantaneous rate of solar energy absorption at each surface of an enclosure into which beam and diffuse solar radiant energy is transmitted. A computer code will be developed to model both specular and diffuse internal reflections. Existing algorithms to compute diffuse radiative view factors and beam radiative blockage factors based on configuration geometry will be obtained and incorporated into the code. Tabular values of the optical properties of several typical glazing systems will be provided with the option of user-provided optical characteristics.

For the measurement part of the project, a scanning spectroradiometer will be procured, installed, and checked out. The instrument will be capable of scanning the sky and foreground in both angle and wavelength. The first year of operation will be devoted to exercising the instrument in all its modes of operation and comparing its output to more traditional measurements of irradiance and illuminance. A methodology will be developed for a long-term program of sky-radiance measurement and analysis. This methodology must be able to handle the very large amount of data that will be generated in the program and it will be able to provide adequate characterization of the conditions in which the data are taken.

VALIDATION OF NEW HEAT TRANSFER ALGORITHMS

Michael E. McCabe
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Building Equipment Division

Sponsor: Department of Energy

In this project, the CBT Passive Solar Test Building will be instrumented to measure the distribution of radiant solar flux incident on all of the surfaces of the direct gain room. External beam and diffuse components of flux will be measured at all apertures and input to a detailed solar radiative transfer model. The resulting predictions will be compared with the experimental data for several groundstory and clerestory aperture combinations and for clear and overcast sun conditions.

Additional instruments will be placed on the floor to measure the ground coupling flux during the winter heating season. The CBT and NRC algorithms will be added to CBT's Thermal Analysis Research Program (TARP) to simulate the interaction of the rest of the building with the floor and ground on an hourly basis. The predictions will be compared with the experimental data. The products of this research will be reports describing the validated algorithms for computing the spatial distribution of absorbed solar flux in an enclosure and the earth contact heat transfer for a slab-on-grade floor.

SECOND-LAW ANALYSIS OF SOLAR WATER SYSTEMS

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Sponsor: Department of Energy

The second law of thermodynamics establishes the maximum possible efficiency for a system by revealing the amount of energy that is theoretically usable, called the available energy (exergy), in any process that works between the same temperature limits. A second-law analysis, therefore, provides the means to evaluate the effectiveness of a given system and can guide the optimization of the system performance by identifying which inefficiencies are avoidable and which are exacted by nature.

Second-law analyses are becoming more common in solar engineering, but to date they have focused either on fundamentals such as the appropriate definition of a thermodynamic source temperature for solar radiation or on advanced technologies such as solar cooling. Little work has been done to analyze the performance of simple solar energy systems on a second-law basis and determine if the second-law analysis provides new or more easily-obtained insights about the system performance and its optimization.

In this project, CBT will review the available literature on second-law analysis, summarize the pertinent work and identify fruitful approaches for solar energy systems. CBT will conduct a second-law analysis of typical solar water heating systems, and will consult with recognized experts in the academic/engineering community in developing and verifying this analysis. CBT will compare the results of the second-law analysis to previously verified first-law analyses for the same systems.

VALIDATION OF IMPROVED PERFORMANCE MODEL FOR SOLAR COLLECTORS

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Building Equipment Division

Sponsor: Department of Energy

Previous work at CBT has demonstrated that various solar collectors and collector test methods are sensitive to environmental conditions. Recent work at Argonne National Laboratory has shown, in turn, the environmental sensitivity of system performance. Now what is needed is a multi-parameter performance model for solar collectors that accounts for changes in environmental and operational conditions and that provides adequate predictions of day-long performance. This model is needed to be able to analyze and understand system field performance data and to determine whether augmented testing requirements should be imposed in existing collector test methods.

In FY 83, analytical and numerical studies were conducted at CBT to examine the differences in thermal performance of solar collectors tested outdoors and with solar irradiance simulators. These studies considered the effect of spectral and spatial distributions of the irradiance and the effect of sky temperature, and provide the technical basis for including these factors in a multi-parameter model.

In FY 84, CBT will complete the characterization started in FY 83 of the solar irradiance simulator installed in the large environmental chamber, and conduct experiments with this simulator to verify the findings of the analytical and numerical studies carried out in FY 83. CBT will develop a generalized multiparameter performance model that introduces the variable effects of wind, sky temperature, radiation distribution, and flow rate. The model will be tested using the solar simulator test data and data acquired in previous CBT collector research.

This task will be completed in FY 85 with a validation of the model using evacuated tublar collector test data to be obtained at CBT and system performance data collected at Argonne National Laboratory and at the U.S. and Canadian facilities participating in Task VI of the IEA Solar Heating and Cooling Research Program.

SYSTEMS EFFECTIVENESS RESEARCH

Robert D. Dikkers
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Building Equipment Division

Sponsor: Department of Energy

The experience of the Department of Energy in the National Solar Demonstration Program and information from the private sector has confirmed the existence of serious reliablity and maintainability problems with active solar heating and cooling systems. In addition, the Domestic Policy Review, completed in 1979, concluded that the low reliability of solar energy systems was limiting the growth of the solar industry. During the past several years, CBT, Argonne National Laboratory, and other organizations have been evaluating the various technical problems (e.g., freezing, corrosion, control failures, etc.) which have been experienced during the conduct of the Solar Heating and Cooling Demonstration Program. Data collected on system failures have been collected and stored by several organizations and a comprehensive summarization and analysis would aid in sharply focusing attention to reliability and maintainability solutions. The objectives of this project are to evaluate the R&M of solar heating and cooling systems and to identify research that will improve the effectiveness (performance and reliability) of solar space conditioning systems.

TECHNICAL COMMITTEE ASSISTANCE

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Building Equipment Division

Sponsor: Department of Energy

It is expected that solar standards, being developed by ASHRAE, ASTM, and other organizations, will provide industry, government officials, designers and consumers with a uniform basis for the evaluation, development and selection of solar energy materials, components and systems. CBT will actively participate in various committees of organizations (e.g., ASHRAE, ASTM, ISO, ANSI) now engaged in standards development and planning activities. Where appropriate, CBT staff will provide research data and draft standards to assist these committees in the preparation of voluntary consensus standards.

TECHNICAL PROBLEM ASSESSMENT

Robert D. Dikkers
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Building Equipment Division

Sponsor: Department of Energy

The Solar Federal Building Program (SFBP) offers an opportunity for the identification and characterization of state-of-the-art reliability and maintainability (R&M) problems that need to be addressed. The systems are representative of the current state-of-the-art. In addition, since the systems are just beginning to be operational and since they are owned by the Federal government, it is possible to characterize R&M problems in a controlled manner from the time when system start-up and operation commences. Therefore, CBT will undertake the following tasks:

Task 1: Problem Identification: Maintenance reports from the SFBP will be reviewed by R&M problems identified and tabulated.

Task 2: Problem Characterization: To the extent possible, the actual causes of the R&M problems will be identified. Field inspections will be performed where necessary.

Task 3: Data Evaluation and Analysis: The results of this study will be compared with previous results obtained from analysis and evaluation of solar demonstration program R&M data. Recommendations will be made as to key R&M areas where research would provide the most benefit.

At project's end, an NBSIR will be published documenting the findings of the identification and characterization of state-of-the-art R&M problems in the Solar Federal Buildings Program plus the analysis and evaluation of the R&M data. Recommendations will be made as to key R&M areas where research would provide the most benefit.

MECHANICAL EQUIPMENT CRITERIA FOR MULTI-STORY BUILDINGS

Lawrence S. Galowin
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Building Equipment Division

Sponsor: Department of Energy

This project will develop and prepare the criteria for mechanical equipment installed in multi-story buildings eligible for the DoE Weatherization Assistance Program. This task includes a review of the limited amount of equipment previously included in the DoE Weatherization Measures list regarding eligible mechanical equipment and devices, criteria and standards, and expansion of the criteria for other mechanical equipment and devices.

THERMAL PERFORMANCE TESTING: MOVABLE INSULATION

Michael E. McCabe
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Building Equipment Division

Sponsor: Bonneville Power Administration

The objective of this project is to prepare an interim thermal performance test procedure for use by the Bonneville Power Administration in the Residential Weatherization Program to retrofit windows with movable thermal insulation. Although a number of different procedures for thermal testing components of building thermal envelopes such as walls and windows are available, no concensus currently exists as to which procedure is most suitable for measuring thermal transmittance (U-Factor) of windows and window insulation systems. Comparisions made by the National Bureau of Standards between two existing test procedures conducted in two commerical testing laboratories revealed substantial differences between the measured U-Factors. These differences were attributed to the different techniques used by each laboratory to simulate wind.

It is evident that a laboratory test procedure which is capable of measuring changes in U-Factor of windows with movable insulation is required; however, without the uncertainties introduced by simulating wind. The scope of such an interim test procedure would be limited to winter heating conditions and would not consider the effects of solar gain or wind. To be effective, the interim test procedure should be capable of being performed at a number of independent testing laboratories at nominal cost and with reasonable accuracy and responsibility.

AIR QUALITY CRITERIA FOR ARCHIVAL STORAGE

Robert G. Mathey
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Building Materials Division

Sponsor: General Services Administration

The National Archives Building, which houses many of the nations's basic documentary materials, was constructed in the early 1930's and was one of the first buildings in Washington to provide all-season environmental control. The controlled environment was prescribed to protect the nation's valuable records from the effects of extreme temperature and relative humidity, and from pollutants such as sulfur dioxide and nitrogen oxides. The original system, although designed to meet these objectives, has been modified over the years and has had a history of less-than-satisfactory performance.

Under this project, CBT will measure pollutants in the air at selected locations in the stack area of the National Archives Building to determine baseline performance of the existing environmental control systems. Measurements will also be made in other buildings. Existing data of temperature and relative humidity conditions in the spaces used for records storage will be reviewed and additional data taken, if necessary, to determine current performance for thermal and humidity control.

A search will be made to determine the most up-to-date standards and "operating procedures" used in the design and maintenance of records storage facilities. Experts in the field of gaseous and particulate pollutants will be consulted to obtain their advice on the availability and acceptability of existing standards or the need to establish new limits for contaminants that accelerate degradation of historic artifacts and records. As a result of the investigation, criteria will be drafted for review by the National Archives which give recommended limits for control of environmental conditions. These criteria could be used as the basis for a GSA contract for upgrading the mechanical system of the building.

TECHNICAL SUPPORT TO DOE

Robert Wise
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Building Equipment Division

Sponsor: Department of Energy

The Energy Policy and Conservation Act provides for the granting of waivers from testing for products which cannot be tested in accordance with the currently prescribed DoE test procedures. For DoE to respond to petitions from manufacturers for waiver, DoE must first resolve the question of applicability of currently prescribed test procedures to the products in question and then decide if waivers are to be granted or if testing under present test procedures is in order. CBT will provide DoE with the technical bases to make such decisions.

QUALITY OF BUILDING MATERIALS

CBT is developing laboratory and field test methods to provide more reliable and economical means to predict service lives of building materials and to assure intended performance of cements, concretes, coating systems, and coatings for steel.

- Organic Coatings
- Degradation of Organic Protective Coatings
- Nondestructive Early Detection of Corrosion and Delamination Under Protective Coatings Using the Thermal Wave Method
- Performance of Porous Inorganic Materials
- Application of Life-Test Analysis Concepts to Building Materials
- Effects of Acid Rain on Building Stone
- Development of Tests for Predicting Adhesive-Bond Durability
- Evaluation of Single-Ply Roofing Systems
- Bonded Seams in Single-Ply Roofing Membranes
- Probabilistic Study of Single-Ply Roofing Membranes
- Performance of Residential Siding
- Standards for High-Security Glazing Materials
- Evaluation of Optical Techniques for Measuring Absorber Materials Degradation
- Environmental Degradation of Polymeric Cover Materials for Solar Collectors
- Measurement Techniques for Evaluating Reflector Materials
- Standards for Phase-Change Storage Materials
- High-Specific-Heat Passive-Storage Media
- Tri-Services Technical and Scientific Support
- AASHTO Materials Reference Laboratory (ARML)
- Cement and Concrete Reference Laboratory (CCRL)

ORGANIC COATINGS

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Building Materials Division

Sponsor: Tri-Services Committee

The annual cost associated with the use of organic coatings in the U.S. exceeds $8 billion, more than half of which stems from the use of protective coatings in buildings and structures. If effective criteria for the selection and use of protective coatings are available, as much as 25 percent of these expenditures could be saved. An essential element of selection and use criteria for protective coatings is service life. But currently available methods for predicting service life based upon short-term tests do not adequately meet the need for data to aid selection and use. The objective of this research is to develop improved test and evaluation methods for predicting the service life of protective coatings under in-service use conditions; these methods can be used as part of improved criteria for the selection and use of protective coatings.

This year the project will focus upon extending and refining mathematical models and developing improved test methods to characterize performance properties of water-borne emulsions. Laboratory work will be done to support development of improved tests for application properties and stain resistance. Improved tests are needed to develop an ASTM standard performance specification for interior architectural coatings. Also, advisory and consultative services, based upon laboratory and field tests, will be performed.

DEGRADATION OF ORGANIC PROTECTIVE COATINGS

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Sponsor: National Bureau of Standards

Polymeric coatings are one of the most effective, economic, and widely-used means to prolong the service life of corrosion-prone substrate materials used in the infrastructure. However, the coatings, although interpenetrating and highly polymeric, are frequently susceptible to degradation under in-service environments. Surface-analysis data indicate that degradation of coatings at the substrate/coating interface is responsible for many of the failures of coatings. Interfacial degradation can lead, for example, to the formation and growth of blisters and to the occurrence of corrosion reactions beneath protective coatings. Since the occurrence of blistering and corrosion beneath coatings are important mechanisms of degradation, research is needed to better understand the processes contributing to these mechanisms, to develop improved methods of detection and quantification of blistering and corrosion beneath coatings, and to develop models to aid in predicting their rates of formation and growth.

The research approach focuses upon the identification of mechanisms leading to blister formation and corrosion, and the development of improved methods for detecting blisters and corrosion, particularly at early stages. Previous research has led to the development of preliminary mathematical models for predicting the rate of formation and growth of blisters and corrosion, and to the development of a method, based upon infrared thermography, for detecting degradation beneath coatings. The first part of the research will study the mechanisms of interfacial degradation needed for validating the models. The second part of the research will extend previous research on IR thermography by improving the enhancement and analysis of the thermographic image.

NONDESTRUCTIVE EARLY DETECTION OF CORROSION AND DELAMINATION UNDER PROTECTIVE COATINGS USING THE THERMAL WAVE METHOD

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Current methods to detect and assess corrosion of steel under protective coatings, and delamination at the metal/coating interface involve visibly observing or destructively peeling off the film. Another method, infrared thermography, has recently been used in our laboratory to non-destructively detect corrosion and blisters under protective coatings. All of these methods suffer a major disadvantage: the detection is only possible after the materials have been severely damaged. Thus, one of the objectives in research on service-life prediction of coatings on steel is to develop a nondestructive method to detect very early corrosion and delamination under pigmented coatings. A recently developed method, thermal wave imaging, has been applied in the semiconductor industry to detect and image small subsurface defects, microcracks and dopant regions. It appears from these applications and from our preliminary work that the method is potentially an excellent research tool to detect early corrosion and delamination under coating films.

The objective of the first phase of this research is to investigate the feasibility of using thermal wave imaging for early detection of corrosion of steel protected by coating. Thermal wave detection and imaging are dependent on material properties such as specific heat, thermal conductivity and density, and the modulation frequency of the electron beam used. The effect of these factors will also be assessed.

PERFORMANCE OF POROUS INORGANIC MATERIALS

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Sponsor: National Bureau of Standards

Improved understanding of the deterioration mechanisms and the effects of the environment on the mechanisms is needed to develop models for reliably predicting the durability of porous inorganic materials. The purpose of this multi-year project is to investigate important deterioration mechanisms involving cracking processes in porous inorganic materials and develop analytical models describing the processes. Concrete, mortar, stone, and brick are important examples of porous inorganic materials. In FY 83 a method was developed using fluorescent epoxy thin sections to observe the fracture zone around a propagating crack in the interior of mortar specimens. In addition to providing valuable new information on the microstructural details of the fracture zone, the methods should be extremely useful in elucidating other cracking processes in concrete, including freeze-thaw action, corrosion of reinforcement, and mechanical fatigue.

During FY 84, the fluorescent-epoxy method will be used to investigate cracking processes caused by fatique. Fracture mechanics will be used in conjunction with fluorescent-thin sections to investigate the effects of the microstructure features.

APPLICATION OF LIFE-TEST ANALYSIS CONCEPTS TO BUILDING MATERIALS

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Sponsor: National Bureau of Standards

Reliable prediction of service life is needed to aid the selection and use of polymeric building materials. But major technical barriers to the development of predictive models arise from the complexity of the degradation processes, particularly the synergistic effects of ultraviolet radiation, temperature, moisture, and other factors. Currently, predictive models and accelerated tests do not account for this synergism. The thrust of this research is to develop stochastic models incorporating synergistic degradation effects. These models will be validated against laboratory and outdoor test data.

Prior research has led to the development of a stochastic model as a function of two of the above degradation factors (ultraviolet irradiance and temperature) using polymethylmethacrylate (PMMA) as a model material. This year the model will be extended to include moisture. PMMA specimens will be exposed to several relative humidity levels, keeping irradiance and temperatures constant. The level of moisture in each specimen will be measured using a Fourier transform infrared measurement technique. Degradation of the materials will be measured using gel permeation chromatography. In the mathematical modeling phase of the research, extensions will be made to the current stochastic model. Degradation will be modeled in terms of the chemical and physical changes occurring within the material.

The project will help put durability-related evaluation methodologies on a probabilistic basis, advance the technology of service-life prediction by providing an improved predictive model and by demonstrating an approach that can be used with a wide range of building materials, provide an improved understanding of the mechanisms of degradation, and identify paths of future research for other building materials and components.

EFFECTS OF ACID RAIN ON BUILDING STONE

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Sponsor: National Park Service

The purpose of this project is to assist the Interagency Task Group on Acid Precipitation in coordinating the exposure program for stone and to develop methods for measuring rates of deterioration. It is anticipated that the exposure program will be carried out for ten years and will involve three to five types of stone. It will be the most comprehensive study performed in the United States on the effects of acid precipitation on stone.

CBT is responsible for making available a research stone, development of stone exposure methods, and identification of methods for characterizing the important properties of stone. The first two research stones exposed to acid precipitation are Indiana Salem limestone and Vermont marble. Representative samples are being studied to obtain pre-exposure (baseline) data for comparison with post-exposure measurements. In future years, other stones will be exposed to acid precipitation and their deterioration rates measured.

DEVELOPMENT OF TESTS FOR PREDICTING ASHESIVE-BOND DURABILITY

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Sponsor: U.S. Army

All branches of the military use lightweight, air transportable, rigid structures which serve as combination shipping containers and shelters for many types of tactical and life-support services. The use of these shelters has increased rapidly in recent years and life-cycle costs have become a major consideration. The shelters are fabricated from sandwich panels with either paper honeycomb or foam plastic cores. While honeycomb panels have several potential advantages, field experience has shown many problems. De-bonding of panel components, stemming from poor adhesive performance, is a frequently observed problem. To address poor adhesive performance, a need exists for improved accelerated tests and probability based-mathematical models to aid in predicting service life.

Under this project, honeycomb sandwich panels will be exposed to a cyclic temperature environment at 95 percent relative humidity. The panels will be monitored for delaminations as a function of exposure time. The time, after initiation of exposure, at which delaminations are detected is the service life for the panel. The service life for panels exposed to the same exposure conditions will be used in determining a suitable theoretical life distribution. The parameters of the life distribution will be used in determining the time transformation function relating time to failure and thermal stress. The transformation function will be useful in predicting service life under various environmental stresses.

EVALUATION OF SINGLE-PLY ROOFING SYSTEMS

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Sponsor: Tri-Services Committee

A recent survey projected that single-ply materials will account for 25 percent of low-slope roofing by 1985. Furthermore, there are more than 100 products available and marketed as single-ply membranes in this country. Standards and criteria for single-ply roofing materials have not been established in the United States. The lack of standards, accelerated evaluative test methods, and performance criteria makes the selection and acceptance of single-ply systems difficult. The objective of this investigation is to assess the adequacy of existing requirements given in standards and specifications for single-ply sheet roofing materials. The assessment will provide a technical basis for preliminary criteria and guide specifications for single-ply membranes.

BONDED SEAMS IN SINGLE-PLY ROOFING MEMBRANES

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Sponsor: National Bureau of Standards

Since the mid-1970's, the use of single-ply membranes for low-sloped roofing systems has increased rapidly. These materials now account for more than 10 percent of the roofing membranes applied in low-sloped roof construction. A recent survey has projected that sheet membrane materials will account for 25 percent or more of low-sloped roofing by 1985. Installation costs in 1985 for this amount of sheet roofing will range from $1.8 to $3.6 billion, if the present installation costs of $3 to $6 per square foot are assumed.

Currently over 100 sheet roofing membrane products are being marketed and the number of products is increasing. The major types of membrane materials are synthetic rubbers, plastics, and modified bitumens. Many of these materials are reinforced with a glass or polyester fabric. Seam fabrication techniques vary depending upon the type of material. A major problem has been the failure of seams, especially those produced using an adhesive. In 1980, the National Roofing Contractors Association indicated that the most common problem reported by its members was the delamination of adhesively-bonded seams.

Standard test methods have not been developed for evaluating the performance of adhesively-bonded seams in single-ply membranes. Two methods have been proposed for evaluating the seams: lap-shear and peel tests. The applicability of either test has not been adequately demonstrated, largely because little is known of the stress conditions and the failure mechanisms of the seams. In addition, little information is available on factors controlling the quality of field-fabricated seams. This project will provide the technical basis needed to develop or select a test method which reliably predicts the field performance of seams in single-ply membranes.

PROBABILISTIC STUDY OF SINGLE-PLY ROOFING MEMBRANES

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Sponsor: National Bureau of Standards

In developing and demonstrating the probabilistic method for predicting service life of single-ply roofing membranes, membranes will be subjected over time to both mechanical and thermal stresses. Time-to-failure distributions will be obtained for each experimental condition (minimum of three temperature levels and three mechanical stress levels). The degree of functional dependence of the time-to-failure distribution parameters on temperature and mechanical stresses will be determined through time-temperature superposition and time-mechanical stress equations. Other experimental variables which will be used include membrane characteristics (seam, no seam), and characteristics of the thermal insulation (gap and no gap between insulation boards, no insulation). Both creep and stress relaxation experiments will be performed. EPDM (ethylene propylene diene monomer) will be used as the first test membrane material, representing the rubber-like single-ply membrane family. Other membrane materials which may be used in future studies are modified bitumens and thermoplastics, and other rubber-like materials.

PERFORMANCE OF RESIDENTIAL SIDING

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Sponsor: Tri-Services Committee

The increasing use of residential siding materials, both in new construction and maintenance, has led to the need for performance criteria to aid the selection of materials. Of particular importance are criteria for durability performance. The Department of Defense previously supported CBT research to develop interim performance criteria for siding. During its first year, laboratory tests were conducted on repainting the weathered-siding materials. Adhesion tests using the field adhesion tester developed at CBT were carried out to determine the compatibility of alkyd and latex coatings with the weathered substrates. Adhesion tests were conducted two months after repainting the siding materials, and again after seven months of outdoor weathering. Adhesion tests again will be conducted on the repainted panels after 18 months' exposure. After this exposure of the repainted panels, data will be analyzed, existing criteria evaluated, and new criteria will be prepared for recoating siding materials.

STANDARDS FOR HIGH-SECURITY GLAZING MATERIALS

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Sponsor: Law Enforcement Standards Laboratory

During this three-year project, the status and problems of glazing materials used in high-security applications will be determined, realistic threat levels will be established, and performance tests and criteria will be developed. Based on the information obtained in FY 82, combined mechanical and thermal attack was determined as one of the likely threat scenarios. In FY 83, a performance test simulating combined mechanical and thermal attack was developed. Also, methods were developed to determine the impact characteristics (velocity, force, and energy) of human males using hand held-hammers, and were used to calibrate mechanical impact devices used in combined mechanical-thermal tests. In FY 84, the performance and repeatability of selected high-security glazing materials, including laminated glass, glass-clad polycarbonate, and laminated polycarbonate, will be evaluated using the combined mechanical-thermal test. Preliminary performance criteria will be established based on the test results. Performance tests for other threat types including failure of the glazing as a unit and/or the window assembly are needed but they cannot be accomplished within the scope of this project.

EVALUATION OF OPTICAL TECHNIQUES FOR MEASURING ABSORBER MATERIALS DEGRADATION

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Sponsor: Department of Energy

Presently, integrated solar absorptance (per ASTM E424) and emittance (per ASTM E434) are the primary techniques used by the solar industry to measure changes in the optical performance of absorptive coatings. These methods have been incorporated into ASTM procedures which address the evaluation of absorptive solar receiver materials.

Studies conducted at CBT have shown that integrated solar absorptance measurements are a poor indicator of absorber material degradation. Such changes typically occur in the infrared region of the spectrum and are concealed by the integration process conducted as part of ASTM E424. ASTM E434 measurements are a more sensitive indicator of changes in the performance of selective absorber coatings; however, this technique provides no information about the spectral distribution of changes in optical performance of these materials.

Preliminary measurements made by CBT indicate that infrared spectral reflectance measurements offer considerable promise as a technique for the early detection of absorber materials degradation. Such techniques should be of considerable value to industry in the use of short-term exposure tests as a means for evaluating absorber materials.

The purpose of this research is to investigate the use of optical property measurements for the early detection of absorber materials degradation. The optical properties of typical absorptive solar receiver materials will be characterized using techniques such as diffuse and specular infrared reflection spectroscopy, infrared emittance, and integrated solar absorptance. The sensitivity of these techniques to changes induced by short-term aging tests will be determined. The results of these studies will be published in an appropriate technical journal and presented to organizations concerned with the development of measurement techniques for absorber materials.

ENVIRONMENTAL DEGRADATION OF POLYMERIC COVER MATERIALS FOR SOLAR COLLECTORS

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Sponsor: Department of Energy

Virtually all of the durability testing that has been performed to date on polymeric materials for solar energy applications has concentrated on their degradation when exposed to elevated temperature and ultraviolet radiation. Little emphasis has been placed on degradation caused by moisture or by the combined effects of moisture, temperature, and solar radiation.

Under this project, moisture-related degradation that has occurred in cover materials exposed in previous CBT programs will be characterized. Carefully controlled exposure tests will be conducted for representative materials to determine their degradation mechanisms and degradation rates and to establish a basis for predicting the useful service lives of these materials. Research will be performed to develop the data to a stochastic mathematical model for predicting the synergistic degradation effects of moisture, ultraviolet radiation, and temperature. The model will also be validated for one or more additional materials to demonstrate its broad applicability.

Knowledge gained in this research will assist industry in formulating polymeric materials for solar applications and the evaluation procedures developed, in cooperation with organizations such as ASTM, will aid the selection and use of polymeric materials. The development of validated mathematical models also will significantly advance the current state-of-the-art in predicting the rates of degradation of materials which will, in turn, aid in providing evaluation tools for selecting and using such polymers.

MEASUREMENT TECHNIQUES FOR EVALUATING REFLECTOR MATERIALS

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Sponsor: Department of Energy

Reflector materials are used to increase the solar flux received by solar collectors. These materials include mirrors and metallic and other reflective surfaces. Test methods that can be used to evaluate the performance and durability of reflector materials under conditions of use are urgently needed to aid in the selection and use of the materials. The objective of this project is to prepare a state-of-the-art report which will form the basis for interim measurement techniques and will identify research needs.

STANDARDS FOR PHASE-CHANGE STORAGE MATERIALS

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Sponsor: Department of Energy

Phase-change materials provide energy storage capabilities in terms of latent as well as sensible heat. These materials offer significant potential advantages in the volume of storage required and the thermal losses from storage. Consequently, the use of phase-change materials is increasing as the solar industry searches for more effective storage media. Key problem areas relating to the use of phase-change storage materials involve encapsulation and durability. Examples include rupture of encapsulating materials due to mechanical incompatibility with phase-change materials, thermal or chemical degradation of phase change and encapsulating materials, crystallization and segregation of components of phase-change materials as a result of repeated cycling, and chemical incompatibility between phase-change and encapsulating materials. This project will address these problems through research to develop performance standards and accelerated tests to allow assessment of the long-term performance and durability of phase-change storage materials.

HIGH-SPECIFIC-HEAT PASSIVE-STORAGE MEDIA

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Sponsor: Department of Energy

The objective of this investigation is to fabricate and evaluate the potential of solid-state hydrates as high-heat-capacity sensible-heat storage media. Sensible-heat storage in passive applications may include a variety of storage modes. However, direct gain by insolation of a suitably oriented building element such as a south wall is most common. Various schemes incorporating the inclusion of phase-change storage materials, such as $CaCl_2.6H_2O$, into hollow block walls in order to enhance storage capabilities have been relatively unsuccessful. This is the result of a loss in storage capacity with thermal cycling coupled with the tendency of the containment systems to leak. However, the use of chemically inert solid-state hydrates in this application may hold potential.

Substituted calcium aluminate hydrates of the general composition $3CAO.Al_2O_3.CaX.nH_2O$ will be synthesized and their heat capacities measured. Typical examples of these hydrates include $3CAO.Al_2O_3caSO_4.12H_2O$, $3CaO.Al_2O_3.CaCO_3.12H_2O$, solid solutions of these compounds, and the Fe_2O_3 analogs. Typical densities of these compounds are in the range of 2g/cc. Typical specific heat values range from 0.3 to 0.7 cal/g. Thus these hydrated solids have volumetric heat-capacity values approximately that of water. The most promising compounds identified will be further evaluated to ensure chemical stability and their thermal diffusivities will be measured.

TRI-SERVICES TECHNICAL AND SCIENTIFIC SUPPORT

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Sponsor: Tri-Services Committee

This project will provide technical and scientific support and consultative services on building materials and systems as required by the Tri-Services. The work will include laboratory tests and field investigations for solving building problems. Recommendations will be made on the selection of materials and systems and their application and performance. In the past, problem areas have covered plumbing, masonry, roofing, corrosion, mechanical systems, insulation materials, and underground piping.

AASHTO MATERIALS REFERENCE LABORATORY (ARML)

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Sponsor: American Association of State Highway and Transportation Officials

Under this project, with the support of AASHTO Research Associates working under CBT supervision, measurement services are provided to both public and private laboratories working on transportation studies. At present, attention is focused on the testing of soils and bituminous materials and the measurement of frictional properties of highways. Procedures used in performing conventional quality assurance tests are observed for conformance with applicable national standards. Related test apparatus is checked with inspection equipment traceable to CBT-calibrated devices. Deficiences noted during inspections are brought to the attention of laboratory managers. In addition, proficiency-test samples are distributed at regular intervals to obtain information on laboratory performance. The primary goal of the AMRL is improvement in the quality of testing in bituminous and soils laboratories. Specific products include: a detailed report on each inspection performed; a comprehensive report on each round of proficiency-sample testing; and input to the work of standards committees, such as data which can be used for precision statements for use in standards for testing soils and bituminous materials.

CEMENT AND CONCRETE REFERENCE LABORATORY (CCRL)

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Sponsor: American Society for Testing and Materials, U.S. Army Corps of Engineers

Over $4 billion of hydraulic cements are produced in the United States each year. The value of the concrete construction in which these cements are used is estimated to be on the order of $20 billion. Because of the large amounts of money and critical construction materials involved, standardization of testing to enhance the reliability of quality-assurance measurements is most important. The CCRL contributes to this standarization through on-site inspections of apparatus and procedures used in the testing of cements and concretes, the distribution of proficiency test samples, laboratory investigations of testing problems, and participation in the activities of standards development groups. This work is performed by ASTM Research Associates working under CBT supervision.

Services under the project include the on-site inspection of the laboratory and the distribution of proficiency test samples. Procedures used in performing conventional quality assurance tests are observed for conformance with applicable national standards. Related test apparatus is checked with inspection equipment calibrated by NBS personnel. Proficiency test samples of portland cement, concrete, blended cement, and masonry cement are distributed at regular intervals to obtain information on laboratory performance. Participation in the work of ASTM technical committees by CCRL staff is a mechanism used to provide the standards community with information developed by the inspection and proficiency sample programs.

CEMENT HYDRATION

CBT's cement research focuses on fundamental and generic relationships in cement hydration its purpose being to spur new technology into the market. CBT is developing mathematical models for predicting the courses of reactions of cements in concrete.

CEMENT HYDRATION COMPETENCE PROJECT

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Sponsor: National Bureau of Standards

The objective of this project is to improve understanding of the physics and chemistry of cement hydration and the development of microstructure in pastes of portland and related cements; also, to demonstrate the understanding through development and validation of mathematical models based on probable physical and chemical mechanisms. This research will develop a fundamental understanding of reactions of portland and related silicate cements with water and develop mathematical models for predicting the courses of the reactions under various conditions in the practical range. The work began with studies of the hydration of various preparations of the most important solid phase in portland cements, tricalcium silicate, and have since been extended to other cement phases and mixtures of phases. The work consists of simultaneous development of fundamental mathematical models based on alternative conceptual models. The mathematical models are tested experimentally and revised as needed. Tricalcium silcates and other cement phases used as starting materials are obtained from the few available sources or when necessary manufactured in the laboratory. They are characterized in terms such as chemical composition, particle size and shape distribution, specific surface area, crystallite size, crystal defects, and grain boundary compositions. The materials are reacted with water and solutions of ionic and non-ionic compounds to determine the effects of temperature, and water-solid and water-surface area ratios on the mechanisms and kinetics of the ractions. Techniques used in studying the mechanisms and kinetics, starting from the moment of mixing, are electrokinetic phenomena, heat evolution, volume change, electrical conductivity, x-ray diffraction, differential scanning calorimetry, surface area measurements by gas adsorption, image analysis, and chemical analysis of the aqueous phase. The image analyses are based on results obtained with the scanning electron microscope and the new STEM. This work is carried out in consultation with scientists in CMS on aspects of material science and with mathematicians in CAM on techniques of mathematical modeling. The studies of tricalcium silicate hydration were concentrated in the first two years of the project, and studies of tricalcium aluminate and mixtures of cement phases began in the third year.

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