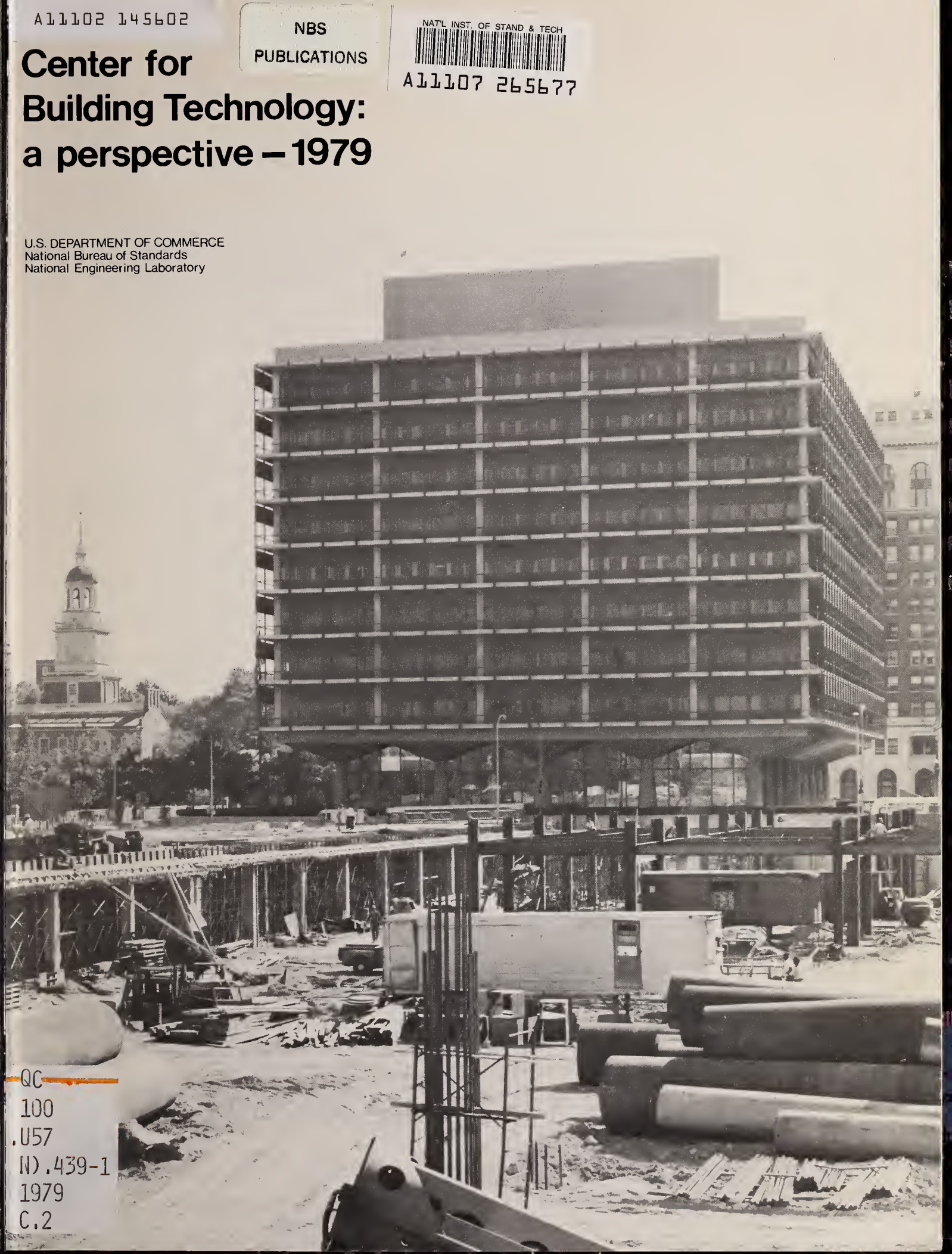
# Center for Building Technology: a perspective – 1979

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory



# Center for Building Technology: a perspective – 1979

NBS SPECIAL PUBLICATION 439-1

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
U.S. Department of Commerce
Washington, D.C. 20234

U.S. DEPARTMENT OF COMMERCE,
Juanita M. Kreps, Secretary
Jordan J. Baruch, Assistant Secretary for Science and Technology

NATIONAL BUREAU OF STANDARDS
Ernest Ambler, Director

Issued May 1979

Library of Congress Catalog Card Number 79-600060

National Bureau of Standards Special Publication 439-1
Nat. Bur. Stand. (U.S.), Spec. Publ. 439-1, 31 pages (May 1979)
CODEN: XNBSAV

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1979

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
Stock No. 003-003-02056-7 Price $1.40
(Add 25 percent additional for other than U.S. mailing).

## Abstract

This report presents an overview of the National Bureau of Standards Center for Building Technology's research, its accomplishments, and ongoing projects.

The mission of the Center for Building Technology is threefold: 1) to advance building technology by providing technical and scientific bases for criteria and standards that improve the usefulness, safety, and economy of buildings; 2) to provide technical assistance to all sectors of the building community; and 3) to develop improved techniques by which the end-users in buildings, communities and industrial processes can conserve energy.

Keywords: Building safety, buildings, criteria, energy conservation, research activities, standards.

# Introduction

## About CBT

The Center is part of the National Engineering Laboratory, of the National Bureau of Standards; it is located in Gaithersburg, Maryland, near Washington, D.C. The Center and its staff of 230—with expertise in more than 30 disciplines that affect the way buildings are designed and built—exist to make buildings more useful, safer, and economical.

The Center conducts programs of research and technical problem solving. It produces technical bases for building performance criteria to meet users' needs, and the methods of evaluation, test, and measurement to assure building performance.

## The Scientific Approach

Building research offers much to improve construction. Thus, at the Center, chemists work to develop improved criteria for materials durability or evaluate methods for preserving historic monuments. Behavioral scientists look at the way sunlight and color affect the way building occupants perform their daily tasks. They have found, for example, that illumination standards are often set too high and that more light does not always result in more production or employee satisfaction.

Here too, mechanical engineers examine alternative building designs for energy conservation and architects study the way that stairways are involved in the many stumbles and falls that cripple the public each year. Next to bicycles, stairs are involved in more accidents than any other object. And structural engineers investigate the way buildings fail: how, for example, reinforced concrete structures may fail because of winds, earthquakes, or by the phenomenon called "progressive collapse," which has been implicated in the failure of some buildings.

At CBT, recent advances in understanding these problems have led to improvements in building codes and standards. But the projects just discussed are rather isolated in their approach—with chemists in their bailiwick, and architects, economists, psychologists, and engineers in theirs.

## Multidisciplinary Approach

More often, the Center's approach is multidisciplinary. Take the topic of windows, for example. The Center has studied them from many viewpoints: How do they affect the design of a building? Do they brighten the rooms? Do they depress or uplift people? How do they affect energy consumption? How do they keep the heat in? Do they keep burglars out? Are they worth the extra cost? How are they related to our sense of privacy? Researchers have also tested chemical coatings to reduce the heat loss through the glass. In this way, professionals from many disciplines work together to improve the fit between buildings and windows. This work has resulted in widely used publications, one of which, *Windows and People,* was reissued by the French National Building Research Institution as *Les Fenetres et les Gens.*

**Multidisciplinary window research activities address building design, energy consumption, economics, security and their effect on people's moods.**

## Laboratory Facilities

One of the Center's major resources is its laboratories. Within its research facilities at Gaithersburg, researchers can subject a building element or system to decades of seasonal climate effects in "accelerated weathering" apparatus. They can measure how well door bolts and locks respond to the pressures that a typical 80 kg burglar might be able to apply. Or they can measure how a steel beam or a concrete column will respond in a 53 MN (12 million pound) test machine.

The Center also has seven environmental chambers, the largest of which is 9x12x18 m (30x40x60 ft), in which whole buildings have been tested for the way they use or conserve energy. These facilities can control temperatures from -45° to 65 °C (-50 to 150 °F) and vary the humidity as well. The chambers have been used to evaluate refrigerator trailers, houses, mobile homes, and military inflatable buildings.

The Center also maintains natural weathering stations at sites from Alaska to Nevada and from Baltimore to Puerto Rico. These have resulted in specifications for building materials that are exposed to time, temperature, humidity, industrial pollution, and sunshine (especially ultraviolet light). The Center has a 15-meter-long wall incorporating over 2400 building stones from around the world. It is used to study the effects of natural weathering. The stones have been in the wall for more than 30 years. In 1977 the wall was moved from the CBT's original site in Washington, D.C. to the new Bureau of Standards campus in Maryland.

The Center also works with other NBS Centers on joint building research problems that use other special-purpose laboratories in fire, acoustics, instrumentation, etc.

## CBT and Community

Another aspect of the Center's impact on the building community is visible from a brief look at the industry and the forces that work upon it. The construction industry is one of the largest in the United States—over 4 million workers. In 1977 new construction totaled more than $170 billion. During the past 5 years, spiraling costs increased the price of the typical new one-family home 50 percent, exceeding substantially the overall inflation rate.

A host of factors affect the building community. Building codes across the country, building standards, Federal specifications and regulations, economic and social changes, individual and family preferences, and long-standing traditions within the industry itself, all affect the building marketplace. Added to these factors are domestic and foreign building innovations and research findings. The Center considers the needs and effects of each of these factors and responds to the most significant problems with technology for their solution.

To foster the application of this new technology CBT is constantly interacting with code groups, professional organizations such as the American Institute of Architects, and industry and manufacturing groups. The Center is able to reach this wide constituency by virtue of its information dissemination programs, participation at conferences, cooperative research, and extensive staff interaction with over 200 domestic and international standards-generating groups.

## Organization

The Center's business is to advance building technology. To do this, it constantly responds with improved ways of observing, recording, analyzing, and developing building performance. All this is especially important now, when demands for buildings are so severe.

Work at the Center is carried out in four laboratory-based divisions:

Structures and Materials
Building Thermal and Service Systems
Environmental Design Research
Building Economics and Regulatory Technology

As part of the National Engineering Laboratory of the National Bureau of Standards, the Center shares the Bureau's modern laboratory complex in Gaithersburg, Maryland, a short distance from the nation's capital. It also draws on the experience, skills, and special laboratories of other NEL and NBS Centers.

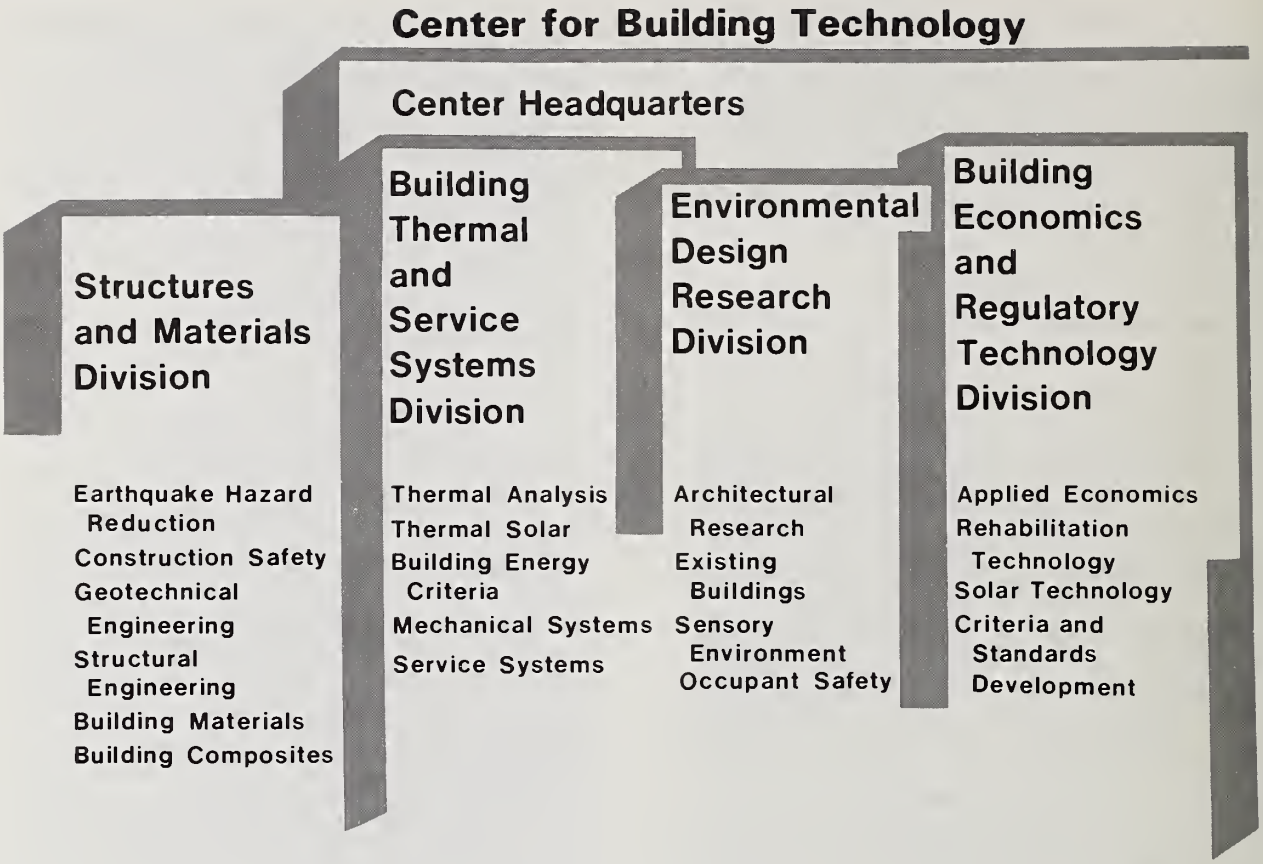
The work of the Center is an integral part of the programs of NEL. A number of the activities cited here are conducted in and with the support of other NEL units:

- Office of Engineering Standards
- Office of Energy Programs
- Center for Consumer Product Technology
- Center for Fire Research
- Center for Applied Mathematics
- Center for Electronics and Electrical Engineering
- Center for Mechanical Engineering and Process Technology
- Center for Field Methods

The studies described here represent only a sample of the Center's research. Additional information is found in companion documents: NBS Special Publication 446, *Building Technology Project Summaries,* and NBS Special Publication 457, *Building Technology Publications.* The Center invites direct inquiries on completed, ongoing, and new research projects. However, some of the projects described here have not yet resulted in a published document.

The chapters of this report were selected merely to group similar projects, not to suggest the way the Center is actually organized, which is shown in the chart. Actually, CBT pursues a set of goals and tasks that are developed at the Bureau level. CBT's research falls into 3 goals—energy conservation, safety, and economics—and 15 tasks that guide its research and the objectives of that research. By contrast, the Center is organized into 19 programs, which in turn manage approximately 150 individual research projects. In all its long-range planning, the Center—like NBS as a whole—resolves societal goals, through its tasks, into specific programs. In this way, multidisciplinary coverage of existing problems and criteria to base future research on are constantly reviewed.

Center research also receives oversight and support from a number of panels of experts from the building industry, coordinated by the National Academy of Sciences/National Research Council and the Department of Commerce to name two.


Center for Building Technology
Center Headquarters
Structures and Materials Division
Earthquake Hazard Reduction
Construction Safety
Geotechnical Engineering
Structural Engineering
Building Materials
Building Composites
Building Thermal and Service Systems Division
Thermal Analysis
Thermal Solar
Building Energy Criteria
Mechanical Systems
Service Systems
Environmental Design Research Division
Architectural Research
Existing Buildings
Sensory Environment
Occupant Safety
Building Economics and Regulatory Technology Division
Applied Economics
Rehabilitation Technology
Solar Technology
Criteria and Standards Development

## Sponsors

The Center's programs are funded primarly by other Federal agencies and by Congressional appropriations through the Department of Commerce. A limited amount of our research is funded by private groups. The organizations who recently funded CBT are listed below:

Agency for International Development
Air Force Civil Engineering Center
Air Force Systems Command
American Society for Testing and Materials
Army Natick Development Center
Brick Institute of America
Community Services Administration
Consumer Product Safety Commission
Defense Civil Preparedness Agency
Defense Nuclear Agency
Department of Energy
Department of Health, Education and Welfare
Department of Housing & Urban Development
Department of State
Department of Transportation
Dow Chemical Company
General Services Administration
Law Enforcement Assistance Administration
Maritime Administration
Masonry Institute of America
National Bureau of Standards
National Concrete and Masonry Association
National Park Service
National Science Foundation
Nuclear Regulatory Commission
Occupational Safety & Health Administration
Tri-Services Committee, Department of Defense
United States Postal Service
Veterans Administration

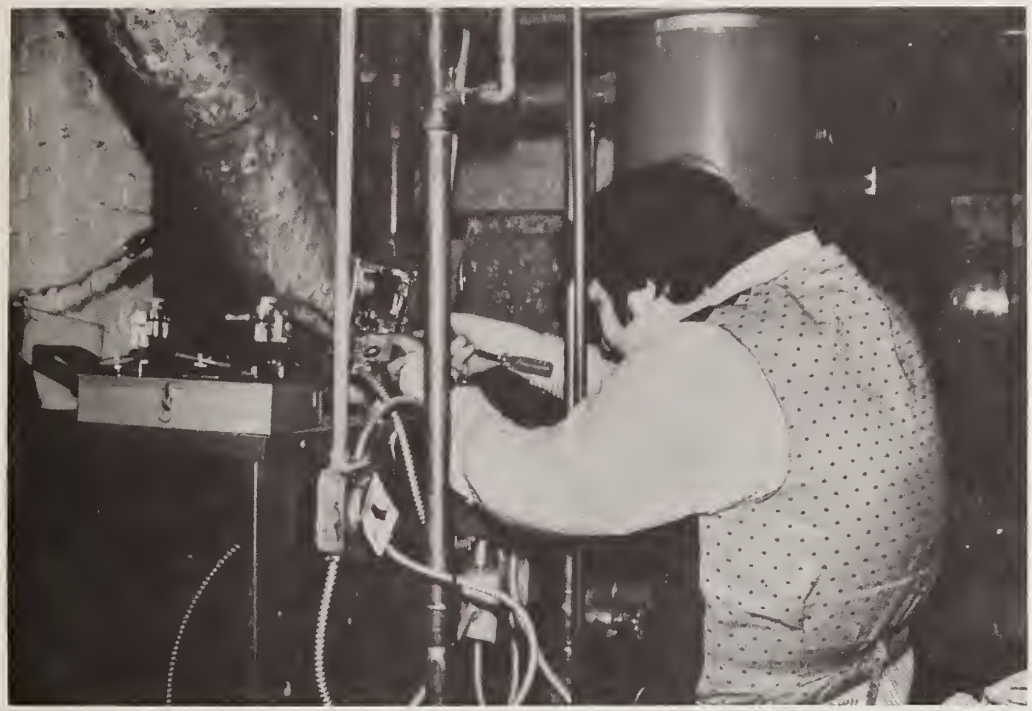
Throughout this document acronyms are used for the various organizations working with CBT in developing research criteria. Those used are:

| | |
|---|---|
| ANSI | American National Standards Institute |
| ASTM | American Society for Testing and Materials |
| DoT | Department of Transportation |
| FAA | Federal Aviation Administration |
| HUD | Department of Housing and Urban Development |
| MIT | Massachusetts Institute of Technology |
| NSF | National Science Foundation |

## Disciplines

Acoustician
Architect
Architectural Engineer
Behavioral Psychologist
Bioacoustician
Ceramic Engineer
Chemical Engineer
Chemist
Civil Engineer
Code Analyst
Communications Specialist
Cost Engineer
Economist
Electrical Engineer
Electronics Engineer
Environmental Engineer
General Engineer
Geologist
Geotechnical Engineer
Housing Technologist
Hydraulics Engineer
Industrial Engineer
Materials Engineer
Materials Scientist
Mathematician
Mechanical Engineer
Metallurgist
Operations Research Analyst
Physical Scientist
Physicist
Psychologist
Public Administrator
Quality Control Specialist
Safety Engineer
Sanitary Engineer
Social Psychologist
Sociologist
Standards Engineer
Structural Engineer
Urban Planner

## Energy and Buildings



**CBT research findings discovered that significant energy savings were possible by reducing nozzle size of oil furnaces.**

Energy is the one CBT research topic that attracts the most public attention. Why? Because one-third of all the energy used by the United States is consumed by commercial and residential buildings. In new buildings about 40 percent of that energy could be saved; in existing buildings about 25 percent could be saved. Put another way, out of every 10 barrels of oil that are now burned, one and a half barrels are wasted because of inefficient building practices. Similar savings are possible in many countries around the world.

Overall, the goals for the Center's energy research are to minimize the life-cycle energy costs by strengthening energy conservation standards, promoting the concept of an energy budget for building designs, and improving design and component criteria.

Energy costs have become so large a factor in personal finances that the press across the nation has referred to CBT's energy studies over 1700 times in the first 6 months of 1978. The focus of much of this attention is CBT's economic analysis that shows how insulation and storm windows may save up to 50 percent or more in energy consumption during the winter. The consumer guide, *Making the Most of Your Energy Dollars,* based on CBT data, has become a best-seller and has been the basis of many feature articles. Center research into the properties and performance of many types of insulation has also attracted wide attention: topics such as moisture migration, urea-formaldehyde foam, and foamed plastic insulation are examples of national issues that have begun to be resolved as a result of CBT research.

A Center contractor went to New England to examine how oil furnaces were used and maintained outside of the laboratory. What they found was surprising. Almost all furnaces had oil nozzles that were too large. An immediate savings of about 4 percent of the winter's fuel bill was thus available to homeowners who replaced their furnace nozzles. Further savings-up to 30 percent-are available by replacing defective oil burners. Even simple tune-ups were shown to result in savings of about 3 percent per year.

Support to the Department of Energy to develop part-load performance-test methods for residential heating and cooling equipment also provided a solid basis for developing part-load performance data for heating, ventilating, and air-conditioning systems for commercial buildings.

Even greater savings are possible from incorporating energy-saving ideas into the design of new buildings. The Center published *Design and Evaluation Criteria for Energy Conservation in New Buildings,* which in turn was used by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the Illuminating Engineering Society, to develop a new national standard on energy conservation for builders. The consulting firm of Arthur D. Little Associates, Boston, estimated the use of this new standard would not only save 60 percent of the energy used in office buildings, but would also reduce initial costs. It seems that the additional costs of insulation and glazing are more than offset by the savings in heating and air conditioning equipment.

The GSA's Norris Cotton Building, an office building in Manchester, New Hampshire, is the first in a new generation of energy-conserving buildings, designed from the beginning with energy efficiency in mind. It has a cubical shape (for the smallest heat loss), a windowless north wall, and tiltable solar panels on the roof. The Center is monitoring the building for its energy consumption through a sophisticated system of instruments. It continuously tracks the variables that affect the energy use of the building. That means continuous measurement of 300 items in 3 categories: the weather, the building, and the way the building is operated. The data are presented to the Center's multidisciplinary evaluation team in the form of profiles of energy use for heating and cooling on an hourly, daily, weekly, monthly, or yearly basis.

Also, CBT is designing and constructing new equipment to measure the thermal performance of insulating material and large scale composite wall, floor, ceiling, and roof sections. This equipment will be used to support the development of test procedures and performance standards on insulating materials.

## Solar Energy

**The performance of an evacuated tube collector is being monitored to develop test methods for solar collectors.**

Solar energy performance standards are one of the primary objectives in the National Solar Heating and Cooling of Buildings Program. This work is vital to the growth of a viable solar industry as well as to our national energy goals. By 1985, it has been estimated by the Department of Energy (DoE) that solar heating and cooling of buildings could displace the consumption of nonrenewable energy sources by 3 quads (1.5 million barrels of oil per day).

CBT's approach has been to evaluate the state-of-the-art in solar heating and cooling and to analyze all available technical data, including information from DoE and the Department of Housing and Urban Development (HUD) residential and commercial solar heating and cooling demonstration projects. Solar systems studied include active, passive, and hybrid types. Components studied include collectors and thermal storage devices. Based on the information obtained, CBT has and is continuing to develop the necessary performance standards as well as testing standards to evaluate system and component performance. These cover thermal efficiency, degradation, durability and reliability, as well as safety.

Functional materials evaluated are cover plates, absorptive coatings, sealants, insulation, hoses, metallic and nonmetallic containment materials. For example, the Center is producing the technical basis for standards on the performance and durability of components of solar collectors. Glass cover plates, rubber seals, coupling hoses, and caulking are targets vulnerable to the weather. If they degrade, so does the performance of the solar collector.

Recently, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) used CBT-developed test procedures for thermal performance as a basis for two recently adopted standards. The standards are ASHRAE 93-77, "Methods of Testing to Determine the Thermal Performance of Solar Collectors," and ASHRAE 94-77, "Methods of Testing Thermal Storage Devices Based on Thermal Performance." Similar work is now underway for solar domestic hot water systems and passive components.

**CBT is developing energy performance criteria.**

Life-cycle costing (LCC) is not a new technique. It is often thought of as a tool the Defense Department uses to procure tanks, airframes, or submarines. Lately, however, the energy crisis has stimulated renewed consideration of LCC when we consider the way our buildings use energy. The basic concept of LCC is simple. It considers not only the initial investment costs, but also the operating and maintenance costs of a building during its lifetime—hence the name, life-cycle costing.

Many other areas of building economics also receive special attention at the Center. For example, the Center has looked into the costs of natural disasters, such as floods, hurricanes, tornadoes, and earthquakes. The economics of protection against building collapse have been studied to determine the benefits and costs resulting from larger investments in safety. CBT has also written guidelines on how to measure the economic benefits and costs of solar energy systems.

The most influential of CBT's economics work made it possible for homeowners to easily calculate the most effective amounts of insulation for their homes. The technical data were reported in a formal NBS publication, *Retrofitting Existing Housing for Energy Conservation: An Economic Analysis.* The consumer booklet, *Making the Most of Your Energy Dollars,* is credited with transferring the guidelines to the general public. Since the publication of these two documents, which recommend higher levels of insulation on the basis of cost-effectiveness, major insulation manufacturers have begun marketing larger insulation batts.

CBT economists, serving as technical advisers to DoE, have prepared life-cycle costing guidelines for use in the Federal Energy Management Program. The guidelines were required by Executive Order 12003, "Relating to Energy Policy and Conservation," signed by President Carter in July, 1977. The guides will be used by all Federal agencies in developing their 10-year plans, annual reports, and budget estimates for meeting the energy consumption goals of the Program: to reduce energy consumption in all existing Federal buildings by 20 percent and in all new Federal buildings by 45 percent by 1985.

The Center has also formulated an experimental design for analyzing the costs of alternative methods for reducing the lead-based paint hazards in housing. Based on this design, an econometric model was developed that permitted the most cost-effective combination of lead paint abatement methods to be identified.

The lead paint hazard raises the equally important question of the rehabilitation of older buildings. Is there, for example, a rational way of deciding whether to abandon or to rehabilitate a building? There are many factors that affect this decision, one that is vital to landlords, tenants, and cities. All of them are now being studied in projects that constitute the first comprehensive look at the choice between tearing down or improving the nation's building stock.

At present, economic research at the Center continues with studies of the economic efficiency of alternative masonry construction, and the question of whether the energy price used in determining energy performance standards should be the actual market price or a price adjusted by corrective factors called Resource Impact Factors.

## Rehabilitation

**CBT is developing evaluation methods and minimum performance standards for rehabilitating existing buildings.**

The national concern for conserving resources and for fighting inflation has prompted the Center's work on rehabilitation of buildings and homes. Rehabilitating older homes in inner-city areas thought to be past their prime will be a more labor-intensive operation, will bring jobs to lower-skilled workers, and will contribute to the revitalization of neighborhoods.

The Center's work in this area begins from the point of view of the building regulator. Major thrusts are aimed at: providing technical support to NCSBCS and to the model code organizations in developing building code provisions and regulatory processes for the State of Massachusetts on a pilot basis, collecting data on the regulatory process for existing buildings in major U.S. cities; developing technical evaluation manuals for existing buildings; co-sponsoring a National Conference on the Regulatory Aspects of Building Rehabilitation; sponsoring MIT to develop technical data on an investigation of regulatory barriers to the re-use of existing buildings; and publishing an NBS report, *Assessment of Current Building Regulatory Methods as Applied to the Needs of Historic Preservation Projects,* developed by the National Trust for Historic Preservation.

Research will lead to the development of test methods, analytical procedures, performance standards for building materials and systems, and evaluation techniques. Studies will be carried out to obtain a more effective understanding of "life style" as well as "life-safety" concerns. Decision tools are being developed to assure wise and cost-effective decisions regarding rehabilitation of buildings. Factors include design aspects, economic aspects, adaptability for re-use, and neighborhood and site influences. This work presents a unique opportunity for CBT to advance building technology into the arena of existing buildings to address a national need issue.

## Materials Studies

**Evaluating equipment for detecting moisture in roofing insulation.**

One of the distinguishing traits of modern man, according to philosopher Eric Hoffer, is that he worries about the maintenance and durability of his monuments. The Egyptians didn't worry about theirs, nor did the Romans or the Druids, so what is left of their cultures today is purely through chance. At the Center, and at other national building research institutions worldwide, research continues in hopes that society can prolong the lives of historic structures so they may be part of the legacy to future generations.

CBT's preservation research has involved paints for the White House, and has provided guidance on maintenance aspects of the restoration of the St. Louis courthouse, and the preservation of several historic forts and adobe dwellings—all under the auspices of the National Park Service.

Materials research at the Center is multi-disciplinary, employing the talents of researchers in the fields of materials science, chemistry, physics, metallurgy, and civil engineering. Together, the materials team has developed new ways of solving problems related to performance and durability.

About $16 billion is spent on concrete in the U.S. each year and the equivalent of about 20 million tons of coal is used in the manufacture of cements. In many design situations, concrete is overdesigned to ensure that safety factors allow for the large uncertainties in estimating the quality of concrete and its service life. The Center is working to improve the state-of-the-art of predicting the performance of concretes in normal and severe environments, including the performance of concretes in which a portion of the cement is replaced by energy-conserving substitutes such as "fly ash."

The $5 billion that the country spends on built-up roofing each year offers a significant area for savings if roof life can be prolonged and failures can be avoided. Among other capabilities, the Center has a hail gun which it developed to simulate the effects of hailstones on roofing and walls. The Center has also developed test methods for the flow properties of roofing asphalt. The performance of energy conserving roofing systems and nondestructive detection of moisture within roofs, are other important areas the Center is investigating.

**CBT research is developing design criteria to limit noise intrusion in and around buildings.**

Tomorrow's cities and urban regions will be even more densely populated than today's. As a result, noise management will become a vital public service. The primary beneficiaries of this work will be the users of buildings and communities; the primary targets of CBT's building and community acoustic efforts are the building and site designers—architects and city planners—and the public agencies that regulate those buildings and sites. Noise management at the early stages of the basic design provides enhanced acoustical performance at little or no cost. Early action will prevent the extremely costly corrective measures needed in already-completed buildings. Take the case of aircraft noise: DOT/FAA estimates $200 million is needed to soundproof just the existing schools and hospitals near airports. Fortunately, the interdependencies between acoustical and energy performance means that these retrofits would yield over $1.7 million in energy savings annually and over $3 million annually in productivity enhancement.

The Center's approach will define the interdependencies among acoustical requirements of buildings and sites and other needs (optimal resource use, occupant satisfaction, and worker productivity) affecting decisions about land-use, site planning, and methods of building construction and operation.

CBT staff have been working closely with several Federal agencies to develop and improve acoustical criteria for buildings. A recent study undertaken for the Environmental Protection Agency evaluated the basis for existing acoustical criteria for buildings.

## Environmental Design

What levels of light do people need for performing various tasks? What size, shape, shading, and glass tint make windows "work" better? What color give unambiguous emergency warnings? Building designers need reliable answers to questions like these. In fact, the choice of light levels and design of windows strongly affect energy conservation as well. In response, the Center has developed a method to measure effects of illumination levels on human performance. Another study addressed the psychological reaction to environments with and without windows and the impact of windows on energy-efficient buildings. Still another codified color nomenclature and classification with the revision of the widely-cited *Color: Universal Language and Color Names.* The results of such work are vitally important in safety engineering and in the manufacture of building products.

Similarly, the Center is investigating how humans behave during fires. Related studies looked at how the crowds in stadiums use exit ramps and stairways under normal conditions.

Thus, in this area CBT is developing the technical basis through laboratory and field research for producing, testing, and recommending revisions to building performance criteria in illumination, visual communication—signs and symbols—building security, interior space requirements, noise and building circulation. Complementary research is underway in the development of field measurement systems to enable these factors to be evaluated under the actual operating conditions.

Since most buildings are intended to support human activity, effective building research is, ultimately, people-oriented. This relating of human behavior to physical environmental conditions underlies environmental design research at the Center.

**Studies of pedestrian movement lead to improved criteria for stair and ramp design.**

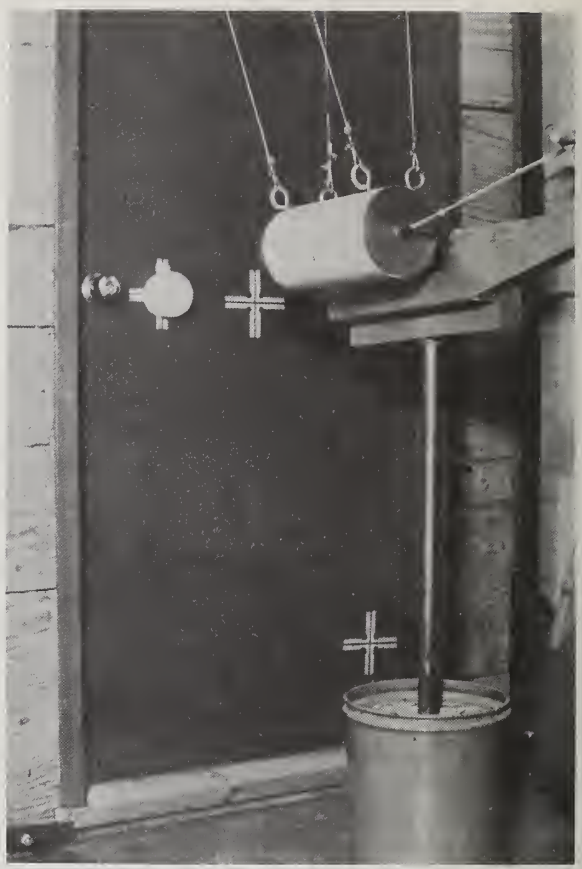
## Safety and Security

Accidents in building construction make this occupation three times more hazardous than the average job. Deaths or injuries to workers in concrete construction, trenching, and excavation have established these as priority areas for improved safety. The Center is developing technical criteria and guidelines for safer work activities as the basis for new regulations for the Occupational Safety and Health Administration. The Center previously developed guidelines for the design and use of guardrails that protect workers. Labor and management groups are assisting CBT in its tasks. Today, CBT is developing a model for predicting lateral forces on bracing elements in shallow trenches, measuring construction loads on concrete construction, improving safe practices in concrete falsework, and cooperating with the ANSI A10 committee in developing improved safety standards.

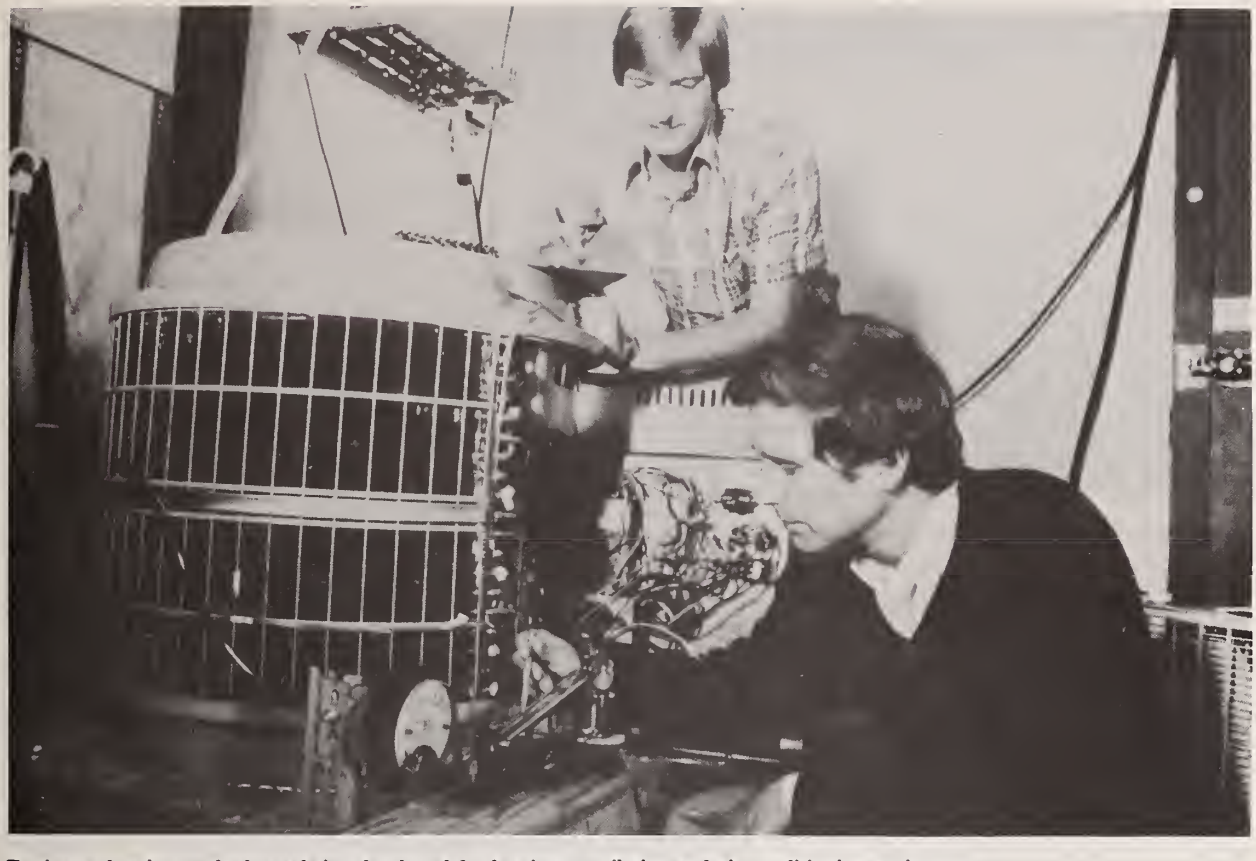
What is a slippery floor? The Center is engaged in measuring slipperiness and has designed and constructed a portable slip tester—to be used in floors, stairs, bathtubs, and swimming pools. This device has been adopted by the American Society for Testing and Materials for use in a standard for measuring the slip-resistance of bathtub surfaces.

Millions of Americans live in mobile homes. But are they a good investment? Are they safe? How do they compare with conventional houses? CBT's research studies are aimed at making mobile homes safer, with particular reference to wind loading; energy conserving; more durability and liveability; and more economical. CBT's environmental chambers for testing the energy efficiency of mobile homes were featured in a national magazine article.

Analyses of the methods used by burglars show that the majority involve low levels of skill. Thus, a great reduction in burglaries could be achieved through only slight improvements in door and window quality. Through extensive laboratory test development, CBT has prepared voluntary security standards for doors and windows; these were published by the U.S. Department of Justice. The test methods for the door standard have also been adopted and published as an ANSI/ASTM standard, after a demonstration program proved their worth at a HUD public housing project.



**Performance criteria were developed for doors to better resist forced entry.**

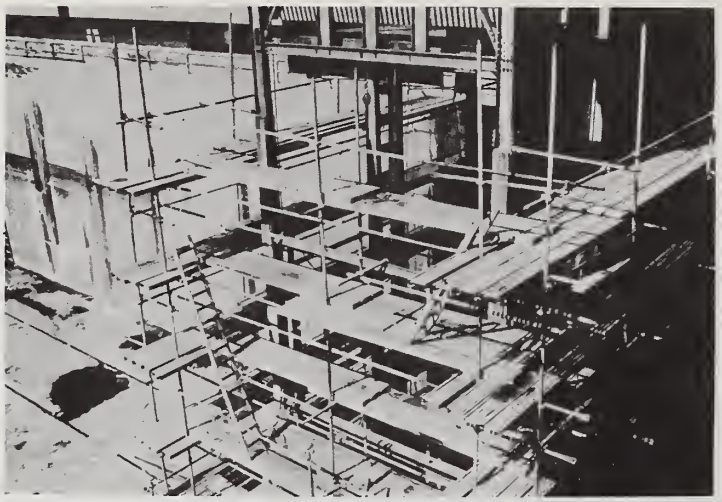


**Testing and rating methods are being developed for heating, ventilating and air conditioning equipment.**

Automated heating, ventilating, and air-conditioning systems can control building comfort, energy use, fire alarms, security alarms, maintenance alarms, and several other functions. Their application has greatly increased since the energy cost rise of 1973. Even though all the systems supplied by different manufacturers use the same basic components, different techniques in system design and application make the selection of the most effective system quite complex. CBT is studying system performance and developing a model purchase specification based on its experience with installing and evaluating the computer control system for the NBS laboratory site.

Equipment selection and energy conservation decisions require that information supplied to consumers be based on the part-load and seasonal performance of equipment as actually used in service—to relate that use to costs, energy consumption, and efficiency. The Center is developing dynamic test procedures to define this performance for residential heat pumps, furnaces, boilers, and air conditioners. These procedures are the basis upon which all appliances will be labeled to indicate their operating costs. This will allow consumers to make purchases on a life-cycle cost basis rather than a first-cost basis only.

The energy crisis and the advances in the solid state electronics field have brought a multitude of new household thermostats into the marketplace. Many of those thermostats are of radical new design and claim significant energy savings. To protect the consumer, the Center is developing a standard test procedure by which all residential thermostats may be evaluated. This will become the model procedure for the industry.



**CBT is developing technical criteria for updating construction safety standards such as scaffolding and safety nets.**

The Center has measured the forces and effects of wind on buildings at sites around the world. The findings are used to verify analytical techniques and wind-tunnel modeling for improved design criteria. The Center was asked by the Australian government to review plans for rebuilding Darwin after its Christmas Eve hurricane of 1974. CBT researchers are also cataloging the probabilities of extreme winds at various locations worldwide to develop improved risk-mapping methods. Researchers at the Center are among the first to study the cross-wind response of tall buildings in high winds. A similar study is concentrating on the accuracy and reliability of wind-tunnel modelling of building designs. As an example of technical support in a program designed to continually upgrade standards, CBT developed criteria for wind loading of mobile homes. The criteria account for regional differences in wind climate, the dynamic action of wind gusts, and anchoring of mobile homes.

It is well recognized that many of the factors that affect structural performance are random. To simplify the design process for different construction materials and make it consistent from a reliability viewpoint, current trends point toward the development and use of probabilistic limit-states design. Toward this end, structural reliability studies that integrate statistical data on resistance and loads have been virtually completed for reinforced concrete and currently are in progress for masonry and wood structures.

The Secretariat for ANSI Standard Committee A58, "Building Code Requirements for Minimum Design Loads in Buildings and Other Structures," is held by CBT. This widely respected standard provides the mechanism for implementing the above research on loads and reliability and provides the opportunity for CBT staff to collaborate with universities, designers, and code officials on a problem of national significance. As a result of these studies, a revised load standard approved through ANSI voluntary consensus standard procedures will be issued in 1980 and a *Loads and General Design Guideline* will be published shortly thereafter.

The properties of unreinforced masonry walls have been studied to better define their resistance—for example, to increase safety in earthquakes. In another study, CBT is attempting to consolidate all the fragmentary standards that now cover masonry construction. Other work is progressing on fire-resistant structural designs, the improvement of honeycomb cores in construction components, and an investigation of the vertical support members of the Alaska Pipeline, among numerous other projects.

## Geotechnical Studies

**Criteria for bracing and sloping of excavations are being developed to protect workers.**

A new research area at the Center is devoted to the interaction of buildings with the earth they rest upon. That is, the stability of sites and foundations. A series of projects in the area of geotechnical engineering study trenches and excavation safety, foundation failures and testing, and the danger of building in areas prone to mine subsidence.

Over 80 percent of all foundations in the U.S. are designed on the basis of results from the internationally used Standard Penetration Test. As part of a program to study *in situ* measurement of soil properties, CBT is measuring the hammer energy delivered to the standard penetration test to determine the parameters which affect test results. These data have been misinterpreted because of differences in energy delivered by different types of equipment. This test plays a major role in U.S. foundation design practice and is currently being used to determine the liquefaction of potential sites. A draft standard for foundations and excavations is being developed in cooperation with the American Society of Civil Engineers.

CBT researchers studied the effects of mine subsidence on structures and utilities and prepared guidelines for the construction of housing in subsidence areas. CBT, together with the University of Texas, conducted a workshop to determine research priorities in the field of soil dynamics (geotechnical earthquake engineering).

Problems associated with the protection of construction workers against collapse of trenches and excavations were studied by CBT researchers. Measurements of transient forces on crossbraces in shallow trenches are now in progress.

The state of knowledge and available data on the capacity of soil anchors used to tie down mobile homes against wind and flood loads has been studied. A field study is now in progress to determine anchor capacities for various soil conditions and flood loads that need to be resisted by mobile home foundations.

**Shower heads are being tested to develop criteria and test methods to reduce water use.**

This program is developing the technical basis for standard test methods, inspection techniques, and criteria to reduce the 100,000 electrical system failures per year that cause building fires; to attain component and system standards to meet the goal of national water conservation; to provide new plumbing pipe sizing designs; and to establish sensor accuracy to better control the interior environment.

The Center is involved in developing criteria for more water-conserving and materials-conserving techniques. For the former, researchers are determining requirements for evaluating the efficiency rating of water devices through standardized test procedures. For the latter, work in reduced-sized vents is exemplary. Savings, which come from the use of smaller pipes (about two commercial sizes smaller, on the average, but up to five sizes smaller in some instances) and fittings and reduced installation costs, are estimated at about $100 per house. An economic analysis indicated potential annual nationwide savings of between $60 million and $200 million (assuming, in the case of the latter figure, full implementation and 2 million housing starts—the 1977 level).

Similarly, the Center has developed performance criteria for plastic pipes and vacuum drainage systems for the Department of Housing and Urban Development. The Center also developed hydraulic performance criteria and submitted recommendations to the American National Standards Institute committee and other standards groups for a performance-based standard under development for the National Plumbing Code.

Among the Center's special laboratory facilities is a five-story plumbing research test tower. This tower is used to study the performance of plumbing systems and components and is equipped with an automated hydraulic load controller and display system. The equipment permits preprogramming of test loads and its display board can be wired directly to show failure points and other operational characteristics within the system. Researchers can then adjust experiments to determine the parameters for optimal performance of the system. Test data are fed into a small computer compatible with the NBS central computer.

In the area of electrical distribution systems, there is a need for a thorough review of the National Electrical Code to study its effectiveness and adapability to new energy sources, energy conservation controls, and new thicknesses of thermal insulation that may bury attic wires. Other innovations, such as flat conductor cable, are also being studied.

**CBT is developing criteria for improving building performance during disasters.**

NBS has the responsibility under the Earthquake Hazard Reduction Act of 1977 to develop and improve seismic design and construction provisions for incorporation into codes and standards. The President's National Earthquake Hazards Reduction Program requires NBS to conduct research on performance criteria and supporting measurement technology for earthquake resistant construction.

After many disastrous earthquakes around the world, a team of engineers from CBT is among the first on the scene. Their objective is to assess examples of successful and unsuccessful building performance to improve future design and construction practices. Researchers are sometimes asked to help assess which buildings should be evacuated and which can be safely re-entered. Two Center engineers were on the first structural research team to reach Managua, Nicaragua, after its 1972 earthquake. Similar help was sent after the Guatemalan earthquake of 1975, the Italian earthquake of 1976, the Romanian earthquake of March 1977, and the Japan earthquake of June 1978. The Center has also been asked to give technical assistance after such domestic disasters as: the Alaska flood, Hurricane Camille, the Lubbock tornado, Hurricane Agnes, the St. Louis Federal Records Center fire, the Fairfax, Virginia, high-rise building collapse, and the West Virginia cooling tower collapse.

Every disaster is different, and can teach researchers anew how buildings perform. Based on these field studies and laboratory research, the Center developed a method for surveying and evaluating buildings for their resistance to earthquake forces. Tentative provisions for the development of seismic regulations in buildings were prepared by the Applied Technology Council, California, under NBS and NSF sponsorship. But what of buildings now underway or soon to be constructed? For example, the largest earthquakes in U.S. history struck near New Madrid, Missouri, in 1811-1812—in an area seldom thought of as a potential site for earthquake trouble. If it were to recur today, property damage losses could well total over $50 billion, with massive human suffering and numerous lives lost.

The Center's five-volume report—resulting from an Agency for International Development sponsored research on improving the design criteria for low-rise buildings to better resist hurricane wind—was being used in India to rebuild the area following their November 1977 cyclone. And CBT's wind engineering program will redefine the basic design wind speeds in coastal and hurricane sensitive regions.

## International Studies

**Researchers perform post-disaster surveys of building failures in foreign countries to improve building practices.**

Building research has application not only domestically but also the world over. The Center participates in a great many international building research projects. Such work usually falls into two categories: individual agreements to jointly pursue research goals with the building research institutes of another nation (such as France's *Centre Scientifique et Technique du Batiment* (CSTB), United Kingdom's Building Research Establishment, or the Institute for Research Technology in Brazil); or, research aimed at specific building problems of developing nations. This latter category recognizes the fact that the same technology that could improve a high-rise in Chicago could also be put to good use in strengthening buildings in the tropics.

For example, the Center has long been involved in investigating the response of buildings to high winds. This work has led to updating standards for predicting wind pressures on new buildings. But it also contributed to improving low-cost housing designs in wind-prone nations worldwide. In Jamaica, the Philippines, and Bangladesh, studies were made of how local construction techniques survived wind storms. The job for the researchers was to develop easy-to-do and practical steps, making use of local materials, that would improve the endurance of a home in such a storm.

The Center's wind project has attracted a wide international readership. The Center's 16-mm sound movie of the results of its Philippine high-wind study was awarded a first prize at a 1976 international film competition in Rome.

The wind project also developed materials for local builders, homeowners, and the general public. These were set forth in *43 Rules: How Houses Can Better Resist High Wind,* which presents guidelines for the home builder by making the technical results more understandable and useable. Also, a poster that depicts damage due to wind and some common mistakes in construction and placement of homes was produced. It illustrated, graphically, ways of reducing damage and injury carried by wind. Most important, it told where to go for further information.

Results from this project have become a part of the Philippine National Building Code and are expected to be used by Jamaica in revising its building codes. The results will also have an impact on codes and standards dealing with winds loads in the United States. Other countries, such as the United Kingdom, Australia, and Japan, are expected to use the study results.

CBT's cooperation with building research groups in other industrialized nations is a prudent attempt to avoid costly and time-consuming duplication of effort. It is also an admission that no country holds an edge over the the others in building research. Some nations, however, do have acknowledged expertise in certain areas: England, for community energy systems; Sweden, for rehabilitation and recycling of buildings; Israel, for water-conserving plumbing systems; and Russia, for the analysis of blended cements. CBT, in turn, has a similar catalog of expertise that is attractive to building ministries in other countries. The Center has also sponsored guest researchers from other countries, France and Brazil among them.

Over the years, the Center has established ties with two dozen national building research groups and is a full member of the Conseil International du Batiment pour la Recherche l'Etude et la Documentation (CIB). CIB's major objective is to encourage and stimulate international cooperation in the gathering, refinement, and dissemination of building research information. Recent collaborations between CBT and CIB have covered plumbing and energy conservation. Likewise, the International Organization for Standardization (ISO) is comprised of the national standards bodies of some 80 countries. The work of ISO is aimed at worldwide agreement on international standards for the purpose of the expansion of trade, the improvement of quality, the increase of productivity, and the lowering of costs. CBT is very much involved in ISO work and currently is contributing by taking part in the discussion on the establishment of an international standards center. CBT also participates in the Reunion Internationale des Laboratories d'Essais et de Recherches sur les Materiaux et les Constructions (RILEM), an international nonprofit association governed by Swiss Law. Its aim is to constitute a medium of exchange and of communication of scientific experience, especially the experience acquired by the study of materials and building elements, by observation, by tests in the laboratory and in-situ, and by research.

## Codes and Standards

In the United States, the authority to regulate the construction and use of buildings rests with the State governments because the Constitution does not assign that authority to the Federal government. Until recently, however, the States have not exercised that authority, but have deferred to local governments. Even though many States have enacted statewide building code programs in recent years, most legal building codes are the laws of cities and towns, and each one has the potential to be, and often is, unique. This tremendous diversity has been decried by many as a millstone around the neck of the construction industry, impeding innovation and efficiency. While there are unifying influences underway that tend to reduce the inconsistency and diversity of building regulations, the fact remains that there are a great many diverse building codes and standards. Where building regulations exist—and nearly all cities with a population over 10,000 have them—they exert strong control over how buildings are designed and built and what they are built with. Because of this, building codes have a tremendous influence on our built environment and thus on society as a whole.

Because the drafting of a building code is usually far too big a job for any but the largest cities to undertake, model codes are in widespread use as the basis for most legal codes. Individual jurisdictions often adopt one of the models as their legal code; but frequently the models are amended, so diversity still exists. The model code associations are not the initial authors of all things in their codes. Indeed, the bulk of technical provisions governing buildings today come directly or indirectly from hundreds of national standards that deal with engineering practice, material specifications, and test methods. These standards are produced by over a thousand different committees in hundreds of different organizations.

Although the Center does not have regulatory power, it participates actively in the code change process and assists in developing a better understanding of our regulatory system to bring about improvements for the public benefit. It provides technical advice to various Federal agencies as well as State and local governments and to voluntary standards groups. The Center participates in the Model Codes Standardization Council and provides special technical support to the National Conference of States on Building Codes and Standards. CBT technical findings—draft regulatory criteria and technical guidelines and criteria—are transferred directly to standards-setting committees in industry, government, and to the model code groups. CBT is also providing significant assistance to the U.S. building community as it enters the metric system of measurement.

**CBT technical data provides a basis for building code provisions.**

## Better Building Performance: an Afterword

The Center's programs have developed to address all aspects of the environments men build to meet societal needs:

- ° usefulness – the degree to which the building serves its intended function, the productivity and delightfulness of the environment provided.
- ° safety – the degree to which the building mitigates natural and manmade hazards to life and property.
- ° economy – the relationship between usefulness and safety performance qualities of building materials, components, and systems and their costs.

Only the second of these usually is a subject of regulations. Primarily, the role of the Center is to provide decision makers in the building community with rational bases for their decisions in all three areas.

An additional area of knowledge is explored by the Center to fulfill this role. That is performance in the building process by building owners, occupants, designers, manufacturers, fabricators, builders, regulators, and maintainers. The Center provides them with performance criteria and measurement technology to strengthen their activities.



☆ U. S. GOVERNMENT PRINTING OFFICE : 1979 O - 291-027

NBS Special Publication 439-1