DEPARTMENT OF COMMERCE ★ NATIONAL BUREAU OF STANDARDS ★

NBS BUILDING SCIENCE SERIES 75

Building Research at the National Bureau of Standards 1968-1974

U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

NATIONAL BUREAU OF STANDARDS

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[2]Some divisions within the center are located at Boulder, Colorado, 80303.

The National Bureau of Standards was reorganized, effective April 9, 1978.

Building Research at the National Bureau of Standards 1968-1974

Neil Gallagher, Editor

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FOREWORD

Shelter, one of mankind's basic concerns, has always been a part of the program of the National Bureau of Standards. From its beginning in 1901, the Bureau carried out studies to meet the needs for technical information on properties of building materials. In 1921, the Secretary of Commerce, Herbert Hoover, expanded these studies to include scientific, technical, and economic research in building; simplification and standardization of building materials; and assistance in the revision of State and municipal building codes. These functions, shaped by the demands of today's dynamic building community, are still a part of the Bureau's program.

It was, however, in 1968, that the Bureau began to add additional strengths to its building research activities. Such new and relevant disciplines as psychology, architecture, sociology, urban planning, and economics were added. The performance approach to building was stressed, a concept that has its philosophical roots deep in a desire to satisfy the user's requirements. Consideration was given not only to the generation of knowledge but the delivery of that knowledge to as wide an audience as possible. This action was consistent with both the nature of applied research and the information dissemination obligation of a publicly supported laboratory.

This report, undertaken in that spirit of dissemination and accountability, describes the changes that took place in the Bureau's building research activities from 1968 to 1974. It is a follow-up to the first history of building research at NBS published in 1970. As that document served as a key to the building research work done by the Bureau in the previous 69 years, this document is also intended to be of service to building users, and to builders, engineers, architects, students, Government officials, and others who have an interest in building research.

E. Ambler

E. Ambler
Director

PREFACE

This report is supplemental to Building Research at the National Bureau of Standards through 1968 (designated BSS-0 in the Bureau's Building Science Series). It is also a self-standing account of a specific and unique period in NBS' long and continuing history in building technology. It was made possible through the able contributions of the following NBS staff members: Harvey W. Berger, Sandra A. Berry, James O. Bryson, Dr. Paul G. Campbell, Louis E. Cattaneo, Robert D. Dikkers, Daniel R. Flynn, Dr. Lawrence Galowin, Daniel Gross, Dr. Tamami Kusuda, Charles T. Mahaffey, Dr. Harold Marshall, Thomas E. Pierce, Frank J. Powell, Deborah Raisher, Mary Reppert, Nancy Starnes, Dr. Robert Wehrli, and Robert S. Wyly.

The editor also expresses his appreciation to the Management Group in the NBS Center for Building Technology for its guidance and support.

Neil Gallagher, Editor

ABSTRACT

This report discusses the progress of building research at the Center for Building Technology from the year 1968 to 1974. Starting with the backlog of needed research in building techniques, components, and materials that faced researchers in the 60's, this history covers the evolution of the performance concept for building specifications, cooperation with states and codes-generating organizations, and specific accomplishments. The report continues with discussions of programs involving the building community, research on the needs of the building users, and technology transfer. A special chapter is devoted to energy conservation in buildings and how CBT's test methods and other programs - including solar - were pressed into this vital national struggle.

Key Words: Building technology; Center for Building Technology; history of building research.

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CHAPTER 1

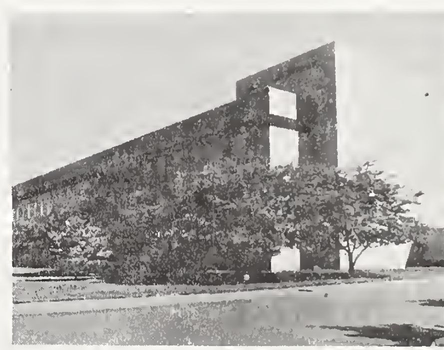
BUILDING TECHNOLOGY AND CHANGES IN DIRECTION 1960's

For building research at the National Bureau of Standards (NBS), the late 1960s and early 1970s was a time of change--change in place, in level of effort, and in research orientation.

The place of building research changed, the Bureau moving in 1966 from its former site in Washington, D.C., to a modern research facility in Gaithersburg, Md.

The Bureau's personnel investment in building technology changed, the building research staff growing from 98 in 1967 to a leveling-off figure of more than 250 in 1971. The research direction changed, with Dr. James R. Wright, Chief of the Building Research Division, infusing his staff with an application-oriented, performance-based, multidisciplinary approach to building research.

Concurrently, both government and the building community were in search of better building procedures and better built environments. A 1966 study by the Advisory Commission on Intergovernmental Relations[1] blamed the system of building regulation for placing "unjustified burdens on the technology and economics of building" and declared that the "economic range of housing" was being circumscribed. Two years later the Douglas Commission[2] reached a similar finding.



The Douglas Commission and later the Kaiser Commission[3] concluded that the building industry was fragmented and incapable of constructing enough buildings for America's needs by the end of the century.

The Housing Act of 1968 asserted a "national commitment" to the production through both rehabilitation and new construction of 26 million housing units in a single

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[1]Established by Congress and approved by President Dwight D. Eisenhower in 1959 to bring together representatives of local, State and Federal governments for the consideration of common problems.

[2]Formally, the National Commission on Urban Problems which was requested by President Lyndon B. Johnson and approved by the Congress in 1967. The Commission's charge was to conduct "a penetrating review" of zoning, housing and building codes, taxation, and development standards, and to recommend solutions to problems unearthed by the study.

[3]Officially, the President's Commission on Urban Housing, established in 1967 to study housing problems and recommend solutions.

decade, a goal that was to prove to be either overdrawn or under-served. Nonetheless, the 1968 Housing Act was to have significant influence on building research at the National Bureau of Standards. The provisions of the legislation for the fostering of new technology within the Department of Housing and Urban Development (HUD) put the Department in greater need of laboratory-based support and inclined HUD toward a technical reliance on NBS.

Change was sought at the popular level. People were demanding and achieving a new importance in the overall scheme of things. And change was urged at the professional level. What the world of building needed was not further technical advances, concluded a 1969 study commissioned by the American Institute of Architects, but "social inventions."[4] In the building enterprise, people--building occupants--gained in importance, and while "sticks and stones" considerations continued to predominate, no longer did this predominance go unchallenged.

The Building Research Division in 1967 had a disciplinary base confined to structural engineering, mechanical engineering, mathematics, chemistry, and physics. There was one notable exception, however. A small project staff was set up to consider building systems and the performance approach to building. Comprised primarily of architects (architecture was considered an exotic discipline for the Division at the time), the group later was to gain organizational status in its designation as the Division's Building Systems Section.

NBS' traditional research strengths in building technology were coupled with a more people-oriented capability. Building Research Division management in a 1968 policy statement contended that "the combined talents of the architect, engineer, physical scientist, and behavioral scientist must be applied to make the building more responsive to the human occupant." The statement called for "greater emphasis on the human being as a meter," i.e., as a register of response in the way of instrumentation.

James Wright promoted the argument for subjective measurement offered originally by John P. Eberhard, Director of the Institute for Applied Technology,[5] who once listed nine examples of human-meter measurement--some humans have 'perfect' pitch, anyone can recognize famous people from caricatures, experts can identify by taste the source vineyard of a wine and the year of harvest, and so on.

At the same time, Wright criticized the use of subjective measurement where objective measurement was possible. And he warned against analyzing subjective data as though they were obtained by objective means.

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[4]William R. Ewald, Jr. in a study for the Future of the Profession Committee, American Institute of Architects, Washington, D.C., 1969.

[5]Eberhard served in this position from 1966 to 1968.

To be sure, the emphasis was placed on the identification of the subjects for, and means of, meaningful measurement, an emphasis reiterated a year later (1969) in a policy statement which asserted that the Division, "as an integral unit of the National Bureau of Standards, has a major responsibility for developing adequate measurement techniques for the nation's building industry, both public and private." According to the policy, the Bureau's resources were to be used in "developing both technical and user requirements for buildings in terms of performance, and to stimulate innovation and application of systems methodology in Federal construction."

The new research philosophy stressed the performance approach to building, an approach setting forth the function to be performed by a building material, component, or system regardless of the means employed. This approach differs crucially from the building industry's traditional prescriptive orientation. Instead of stipulating the performance sought--and letting it go at that--the prescriptive approach specifies how the desired performance is to be delivered. Prescription dictates construction particulars; it limits the solution to these particulars.

A principal advantage of the performance approach lies in its impartiality vis-a-vis traditional and innovative technologies. The performance approach accommodates innovation and by so doing facilitates innovation. When installed in a building regulatory system and made meaningful by a means of evaluating candidate technologies and a willingness to accept validated technologies, performance avoids over-regulation and nurtures benefit-cost gains.

Another value of the performance approach is that it forces examination of the needs of building users, and the consequent evaluation of candidate technologies in the context of those needs. The performance approach encourages multidisciplinary approaches to building questions. Consider the performance questions implicit in the "simple" wall: Is the wall structurally adequate? Would it withstand earthquake forces? What are its privacy implications, visually and acoustically? What are its economic implications? Is it thermally efficient? Is it durable? How do you hang a picture on it when it is made of steel? What are its fire characteristics? What are the psychological implications of its opaque surfaces and voids? Its color? Texture? In short, how should the wall perform in terms of a host of considerations, each of which requires its own disciplinary expertise and all of which lie at the base of design?

Not only does the performance approach imply a wide variety of attributes of walls, for example, but performance also requires the researcher to delve deeply into each and to understand the interrelationships of attributes. In researching acoustic and thermal properties of exterior walls, the researcher first studies properties which add or detract from both acoustic and thermal performance, then studies commonalities and differences. He must be thorough in his analysis of each factor which contributes to or denies acoustic or thermal performance.

The Building Research Division was taken with, but not preoccupied with, the performance philosophy. It also sought to be involved in and have influence on the "real world" of building. The Division extended its hand to Federal agencies having building responsibilities and endeavored to reach the private sector as well. "Building research is applied research," a Division policy statement said. "There is no use doing research unless it gets applied. We ought not sit in isolation on the NBS campus and carry out research of interest to our individual researchers and their peers in science and engineering, whether they are in government, universities, or industry. We must also be part of the total building construction process."

The Division shouldered a greater volume of research for other agencies. Steps were taken to improve communication with the more than 40 Federal agencies which have a role in planning, financing, designing, constructing, and operating buildings. Closer coordination with the other Federal agencies was urged by the Advisory Commission on Intergovernmental Relations (ACIR) and the Douglas Commission, an urging repeated by the Bureau of the Budget.[6]

The Bureau of the Budget in early 1968 asked a selected group of representatives of various Federal agencies to consider an ACIR recommendation that Federal agencies use a common set of building construction standards.

The interagency group in its final report to the Bureau of the Budget said it could not, on the basis of a limited survey it had conducted, trace a relationship between poor construction and differences in standards. The group noted that the Federal Construction Council of the Building Research Advisory Board, National Academy of Sciences, was looking into the subject of Federal standards and that "the more important task" for the Federal building family was "improved communications, cooperation, and coordination."

The Bureau of the Budget requested that NBS conduct activities to improve communications between the Federal agencies. NBS agreed to 1) ensure positive dissemination of its research findings, 2) promote an exchange of information between agencies by distributing technical bulletins or a newsletter, and 3) conduct seminars to ensure that agencies are made aware of the most important developments in standards and practices.

The Division made available to other agencies brief accounts of its research projects and began a series of Federal Building Workshops in which representatives of the Federal agencies could discuss building problems and interests with NBS building research staff. Instrumental in arranging this workshop series was Harry E. Thompson, Deputy Chief of the Division.

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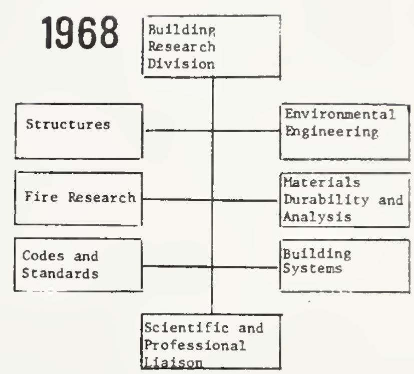
[6]Now the Office of Management and Budget.

The Division continued its participation in the work of more than 200 standards-generating committees and attached a new importance to the concept of appropriate technical support to building regulation. In the latter connection, it helped to arrange a meeting of several States to consider regulatory matters and the advisability of following up with a formal conference for all the States.

A meeting was held in 1967 at NBS with persons from seven States attending along with Division staff members and representatives of the Advisory Commission on Intergovernmental Relations. As a result of this meeting a representative of one of the States called for a meeting of the several States to consider NBS' invitation to assist with a national organization that might be patterned after the National Conference of States on Weights and Measures. The meeting was held and the organization which emerged was called the National Conference of States on Building Codes and Standards ("NCSBCS" and "Nix-Bix" by written and spoken acronym), and NBS became its secretariat.

The revitalized Building Research Division also moved to improve its communication with the building community.[7] It named Dr. William W. Walton to head a newly established Scientific and Professional Liaison Section, focus of communications and liaison with builders and building researchers both at home and abroad. The Division not only sought to broaden its research program but to widen and hasten the diffusion of research results.



It would be misleading to suggest that the Building Research Division prior to 1968 lacked an interest in the performance approach to building, in the support of other Federal agencies, or in the transfer of technology. Accomplishments were achieved in all three areas of concern. Still, it is fair to say that these were concerns which now had become explicit targets of building research at NBS. The building users--always at least an implicit factor in building research and, for that matter, in the building enterprise--was elevated to the level of conscious concern.

"Consideration of the performance requirements for buildings from the user's point of view," wrote Paul Reece Achenbach, "quickly reveals that the occupant is more responsive to such factors as space arrangements, natural and artificial illumination, noise and vibration control, air purity, the thermal environment, and the convenience and effectiveness of the service systems than he is to the more basic characteristics of strength, safety, and

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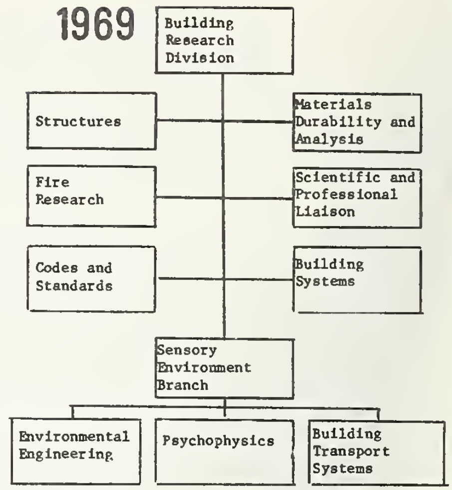
[7]The term "building community" includes the many participants in the design-build process--architects, engineers, developers, contractors, specialty contractors, researchers, planners, standards writers, regulators, financiers, product producers, owners and operators, etc.--plus the users of buildings.

health because he cannot evaluate the adequacy of these latter characteristics directly with his senses."[8]

And so a Sensory Environment Branch was formed within the Division with Achenbach as its Chief. It was comprised of the Environmental Engineering Section, the Psychophysics Section, and the Building Transport Systems Section. The Branch was charged with responsibility for broader, performance directed studies, and its staffing brought to the Division a discipline--psychology--previously missing from building research at NBS.



[8]Achenbach, P.R., Building Research at the National Bureau of Standards through 1968, Building Science Series 0, National Bureau of Standards, Washington, D.C. 20234 (1970).

CHAPTER 2

BUILDING RESEARCH ACCOMPLISHMENTS IN THE LATE 1960's

The Sensory Environment Branch occupied a pivotal role not only in the Division's commitment to performance but in the energy supply/price crunch soon to come. Many of the environmental phenomena to which the occupant is responsive--the thermal and illuminative factors, for example--are also energy sensitive/factors.

Branch studies concerned the thermal, acoustical and visual environment; the systems and equipment that transport energy, fuel, waste, water, materials, and people in buildings; the response of the building occupant to physical stimuli; and the thermophysical properties of materials.

While the focus on energy was sharpened by the harsh new supply/cost realities that so suddenly presented themselves, energy as a subject of building research at NBS extends back through the decades. Indeed, because of the NBS history of energy-relevant research and a management sensitivity to the energy issue, building researchers at the Bureau were considering energy questions well before the energy problem seized the nation's full attention.

The Division over the years sought to improve measurements of the effectiveness of thermal insulating materials. NBS researchers in 1920 developed a guarded hot plate apparatus for such measurements. This apparatus has been used in both NBS' own research and in the supply of other laboratories with measured samples of selected insulating materials for calibration purposes.

The guarded hot plate apparatus had served as the model for a test method of the American Society for Testing and Materials (ASTM). However, seemingly minor differences in design led to differences between test results obtained at various laboratories. That researchers were troubled by inaccuracies proved fortunate. The pursuit of accuracy and precision may have seemed somewhat academic in the days of plentiful and inexpensive energy, but for the future, far more than measurement nicety hung in the balance.

To improve handbook data on insulating materials, researchers wanted an apparatus that possessed not only the qualities of scientific accuracy and precision but one that was simpler, faster-operating, and more readily maintainable than existing equipment. The Thermal Engineering Section produced such an apparatus based on a concept developed by the late Henry E. Robinson, a senior research fellow, and christened it the Robinson Line-Heat-Source Guarded Hot Plate Apparatus (818).[9]

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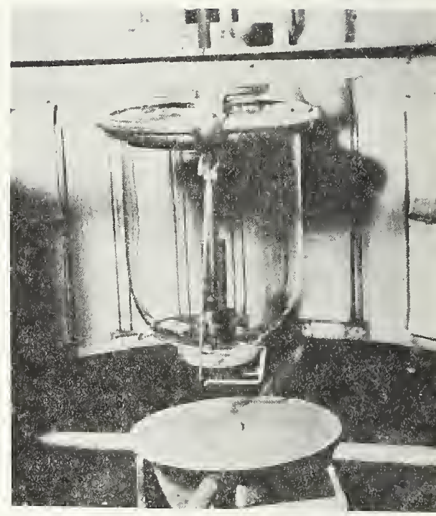
[9] Figures indicate references in the Bibliography.

For the most part, however, the Division's work in the late 1960s focused on longstanding issues embodied in building materials, structures, and mechanical systems. Measurement was the keystone in these studies. And measurement embraced not only the development of techniques and apparatus designed to detect and quantify a property or attribute, but fundamental questions of what should be measured in the first place.

Objective and contributive participation in the standards generation processes of the nation's system of voluntary standards was continued and was accompanied by notable instances of cooperation with other government agencies and the private sector. An example of this cooperation produced a back-up system for the testing technique known as accelerated weathering.

Accelerated Weathering



Early work at NBS led to the development of accelerated weathering devices which today are produced commercially and used throughout the world to measure the performance of materials under controlled laboratory conditions. However, outdoor exposure testing is also necessary to establish a correlation between the effects of laboratory and in-service exposures (339, 408).

Largely through the efforts of the Division's William C. Cullen and the cooperation with the Tri-Services Committee (consisting of building-concerned representatives of the three Armed Service branches), a network of outdoor exposure stations was set up at military bases from Alaska to Puerto Rico; thus an exposure spectrum ranging from the sub-artic to the tropic was established.

The Division's work in materials also involved close association with the private sector. Private industry researchers worked at Gaithersburg under a collaborative program and exchanged technical information with Bureau staff.

The Asphalt Roofing Industry Bureau[10] established a Research Associateship at the Bureau in 1926 which continued formally until 1968. Since then close collaboration has continued between the two organizations in roofing research. The Manufacturing Chemists Association also established a Research Associate Program to study the performance of plastic building materials. This cooperative program involved the exposure of plastic materials to the climates of Arizona, Florida, and Maryland and provided valuable information on the outdoor performance of plastics (416).

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[10]Now the Asphalt Roofing Manufacturers Association.

Porcelain Enamel

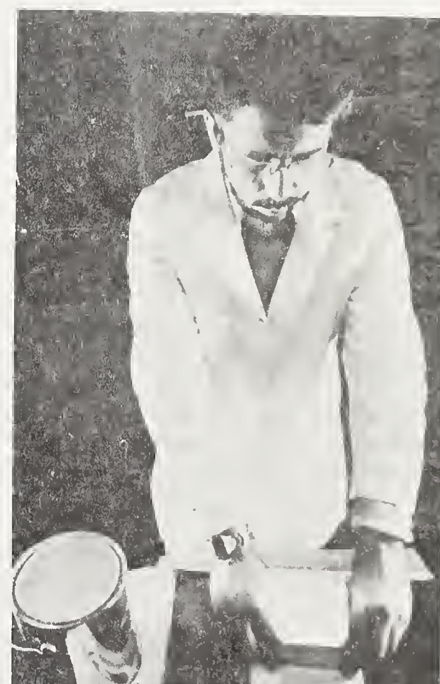
The Research Associate Program initiated with the Porcelain Enamel Institute in 1937 was designed to develop standard tests for the quality control of porcelain enamels, i.e., with respect to weatherability, adherence to steel and aluminum, and cleanability (104, 129, 138, 150, 159, 313). Research results also were furnished through consultative and advisory services to other Federal agencies, manufacturers, and the user.

Organic Coatings

Research programs ongoing in the late 1960s included the upgrading of organic coatings (paints containing carbon compounds in their binders) through the development of performance criteria and the necessary test methods to ensure compliance with these criteria.

A comprehensive text on organic coatings was prepared for the general public (107) and performance specifications were also developed for coatings used on masonry, wood, and metal substrates.

The development of synthetic resins for use in coatings spurred the development of methods for determining resin contents in various coating systems. Among the resin systems studied were styrene-acrylate, styrenebutadiene, and acrylic latex systems (800, 801, 802). These test methods have been incorporated in many Federal and military specifications of the General Services Administration and Department of Defense, respectively.[11]



In cooperation with the Tri-Services Paint Committee, tests were conducted at various military bases to study the field performance of selected coating systems. As an example, results of a field test were used in the preparation of specifications for a lead-free primer and top coat system for exterior wood surfaces.

A coatings manual was developed for the military services which provided guidance for all facets of coatings, e.g., surface preparation, safety, application methods, and which also recommended to the military services coating systems for housing and other facilities (803). The use of the manual expanded to a number of other Federal agencies and the text was made available to the general public.

[11] For example--TT-P-001510 Paint, Latex, Exterior for Wood Surfaces, White and Tints; TT-P-001728 Paint, Latex-base, Interior, Flat, Deep-tone; MIL-P-28577 Primer, Water Reducible, Corrosion Resistant, for Metal Surfaces, May 14, 1971; and MIL-P-28582 Primer Coating, Exterior, Lead Pigment-Free (Undercoat for Wood, Ready-mixed, White and Tints) March 17, 1972.

Additional work on protective coating systems has included the development of performance criteria for industrial and residential siding materials (409), building stone preservatives (459), and waterproofing of concrete masonry surfaces (346).

Inorganic Building Materials

Inorganic building materials have been researched at the Bureau for more than 60 years. This work has yielded many publications covering cement, concrete, gypsum, and lime (102, 108, 115, 135). Recent studies have concentrated on the performance of these materials and have been directed towards an understanding of the relationship between composition, microstructure, and performance.

A study seeking relationships between cement and concrete properties, with particular reference to trace elements, used 199 concrete specimens which had been, exposed outdoors for 16 years (136). The durability of the specimens was determined by dimensional changes, weight changes, changes in appearance, and other laboratory techniques. The results of the work, carried out by R.L. Blaine and H.T. Arni, provide the basis for performance criteria for concrete based upon actual outdoor exposure conditions.

A series of investigations was carried out on the products formed between calcium sulfate and water (gypsum plaster). The analytical techniques used involved scanning electron microscopy, differential thermal analysis, and infrared spectroscopy. The effects of additives on the setting times and on the crystal morphology of hardened plaster were studied and a modified crystallization theory has been proposed (321, 804, 805). The performance of plaster can be improved through improvements in set regulating additives.

Roofing

The Federal agencies with roofing problems and the roofing industry, with which Cullen, the Bureau's leading roofing expert, maintained close contact, looked to Gaithersburg for technical support. NBS prepared guidelines and procurement criteria designed to avoid the expense of overdesign as well as the cost (plus replacement inconvenience) of under-design (155, 328).

Studies addressed the chemistry of photooxidation of coating grade roofing asphalts, hail resistance, insulation, slippage, membrane rheology, and roofing design (300, 302, 344). The performance of roofing felts was investigated (119, 124, 303), and in a continuing study of the chemistry of asphalt, an infrared spectroscopy technique was developed and applied to the preparation of coating grade asphalts.

Hail Damage

Hail causes enormous damage to roofing, especially in the Great Plains where severe hailstorms are common. An NBS study of the problem, which produced new measurement techniques and unique test equipment, e.g., a "hail gun" that fires ice spheres to simulate hail impact damages at terminal and wind-driven velocities. This work established a technical basis for performance criteria for roofing and siding materials (123). The Bureau, supported in this work by the Asphalt Roofing Manufacturers Association, tested traditional as well as innovative roofing systems. In addition, the use of the hail gun was expanded to study the effects of hail on industrial and residential siding.

Performance criteria for hail resistance were developed in time to be applied to a massive housing experiment of the Department of Housing and Urban Development (HUD)--the soon-to-come Operation Breakthrough.

Standards Participation

Materials research findings were incorporated in voluntary standards for roofing, sealants coatings, and flooring systems. Findings in studies of bituminous built-up roofing, the most widely used industrial roofing, were applied to a proposed ASTM standard.[12] Additionally, a rapid, simple method for measuring viscosity and viscosity temperature relationships of asphalts was developed and proposed as an ASTM standard.[13]

Arthur Hockman, a materials engineer, was prominent in stone and sealant activities of ASTM. The Federal specifications Hockman developed for sealants were adopted, with minor modification, by countries around the world--England, Germany, Japan and Australia to name a few.

In fire research, an NBS-developed smoke density test method achieved wide acceptance for measuring the quantity of smoke generated by building materials and aircraft interior finishes (322). The method was proposed to ASTM and the National Fire Protection Association and was incorporated in many specifications and safety standards. In addition, a large amount of technical data, associated directly and indirectly with standards, was provided to the Federal Fire Council, to national and international organizations, and to building code authorities. These activities, led by Irwin A. Benjamin, were concerned primarily with the life safety of building occupants, included such subjects as alarms, detectors, sprinklers, extinguishers, elevators, surface flammability, smoke movement, and structural fire protection.

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[12] Proposed Method of Test for Coefficent of Linear Thermal Expansion of Roofing and Waterproofing Membranes, 1975 Annual Book of ASTM Standards, Part 15.

[13] Proposed for publication in the 1977 Annual Book of ASTM Standards.

Participation in Standards generating activities continued at a high level in the late 1960s for structures researchers as well. NBS's structural engineers served in the chair of the American Standards Association[14] Committee A41, Design of Masonry, included Robert G. Mathey, Robert D. Dikkers, and Dr. Felix Y. Yokel. The contributions to standards made by NBS professionals were based on considerable laboratory and theoretical work (133, 134). Research in the area of masonry construction has been a continuing activity of the Division throughout its history. It was one of the activities of the Structures Section to experience little interruption in the move to Gaithersburg.

The Bureau developed an analytical procedure for predicting the response of masonry wall systems to combined axial and flexural loading. Predicted values correlated closely with those obtained in physical testing. These findings were disseminated to the professional community through a number of publications.

The research effort was continued into the area of shear walls on the belief that masonry design standards did not recognize the beneficial effects of compressive loads on the racking strength of masonry walls. Laboratory-generated data, it was thought, would lead to improved design procedures and more economical construction. Later analysis of test results indicated it was possible to predict ultimate failure loads by rational methods (496).

Investigations of the behavior of masonry structural systems were carried out in collaboration with the Structural Clay Products Institute,[15] the National Concrete Masonry Association, and the Tri-Services Committee. Results were presented to standards-producing organizations such as the American Concrete Institute Committee 531 on Concrete Masonry Structures. NBS personnel served on the technical committees of these organizations, sometimes chairing the committee, as with the American National Standards Institute (ANSI) Committee A41, Design of Masonry.

The same kind of standards participation marked loads research, the Division serving as secretariat to ANSI Committee A58 on Building Code Requirements for Minimum Design Loads in Buildings and Other Structures. Again, this work was directed toward more rational code provisions based on analysis of known conditions, as distinguished from those suggested by experience. During the tenure of the A58 secretaryship by Division wind loads specialist, Richard D. Marshall (130, 309, 310), the Committee worked toward a new edition of ANSI A58.1--American National Standard: Building Load Requirements for Minimum Design Loads in Buildings and Other Structures. This edition contained important changes.

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[14]Now the American National Standards Institute.

[15]Now the Brick Institute of America.

The cooperative efforts of the Committee with the Environmental Data Service are reflected in the section on wind loads which contains a major innovation--the concept of varying wind load requirements both with the dynamic properties of the structure and the nature of the terrain. This enables the engineer to design structures with more uniform safety and therefore with greater economy. In the light of wind losses which yearly run between $500 million and $2.5 billion, the objective of reducing losses was attractive. (Mentioned in another section of A58.1 are works by James Bryson and Daniel Gross (116) involving techniques for the study of live loads and fire loads in office buildings.)

But improved safety and economy of building is a structural research goal with many facets. Many aspects of structural safety and economy were pursued upon settling into the new research facilities. Studies were resumed on prestressed T-beams constructed by the split-beam method (131)--a technique of casting the compressive portion of the beam after the web has been formed and prestressed to effect an economy of materials.

Innovative concepts such as honeycomb core panels (143) were researched with a view to application by the military. Also, performance studies were being made of devices suitable for suspending loads from ceilings in commercial and institutional buildings to optimize expensive floor space utilization, but at safely designed load-carrying capacities (142).

Precoordination

The concept of having a common dimensional module for use by building designers and component manufacturers has been a source of long but sporadic interest on the part of the building community. ANSI Committee A62, Precoordination of Building Components and Systems, was re-activated in 1966 with NBS serving as secretariat. The committee's major objective was to "establish, through national standards, a fundamental theory of coordination which will serve as a format for the application of industrial efficiencies within the building process."

NBS' role with A62 was in a sense a pilot function undertaken with the hope that industry would assume secretariat responsibilities. This was not to occur, and the Bureau eventually terminated its support. As metrication became a more likely prospect for the United States, and as the relationship between metrication and dimensional coordination became pronounced, the principles of coordination were to re-emerge in the mid-1970s with new promise.

Heat Release Calorimeter

Why and how buildings withstand the effects of fire has long been a research subject at NBS. Early on it was found that the severity of a building fire depended on the amount of heat produced by the burning of its combustible elements and contents. If these materials gave off small amounts of heat at a slow rate, the fire would be less severe than if the materials quickly generated large amounts of heat. Thus the measurement of the quantity and rate of heat released by building materials under fire conditions became a major objective.

A heat release calorimeter was developed to measure the rate at which heat is released from burning materials under carefully controlled exposure conditions.

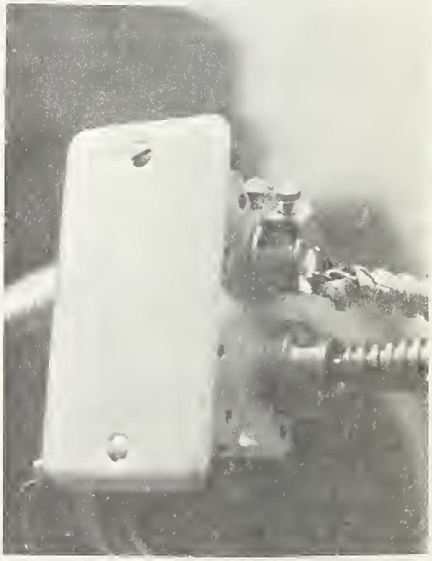
Reference Laboratory

There are two materials reference laboratories at the National Bureau of Standards; the Cement and Concrete Reference Laboratory (CCRL) sponsored by the American Society for Testing and Materials and the AASHTO Materials Reference Laboratory (AMRL) sponsored by the American Association of State Highway and Transportation Officials. Both of these organizations were housed with the Building Research Division until the late 1960s but have since been located elsewhere in the Institute for Applied Technology (now reorganized into the National Engineering Laboratory).

The principal function of CCRL is to promote uniformity in the testing of hydraulic cement and hydraulic cement concrete in materials testing laboratories throughout the United States and Canada. The principal function of AMRL is to promote uniformity in the testing of soils, bituminous materials, and bituminous concrete in primary state and federal transportation materials testing laboratories throughout the United States.

By 1970, CCRL had completed 17 tours of the over 400 participating laboratories and had distributed 30 proficiency test samples of portland cement. It's personnel were actively serving on ASTM committees and the American Concrete Institute, and for over 40 years had performed major secretarial work of ASTM Committee C-1 on Cement and had served as the liasion representative of this committee with serveral other ASTM committees.

AMRL had completed three inspection tours of laboratories and had implemented proficiency sample programs to test aggregates, soils, and bituminous materials. Staff members were actively participating in several ASTM committees and were steadily contributing to improving AASHTO specifications and methods of test for materials used in construction of highways and other transportation facilities.



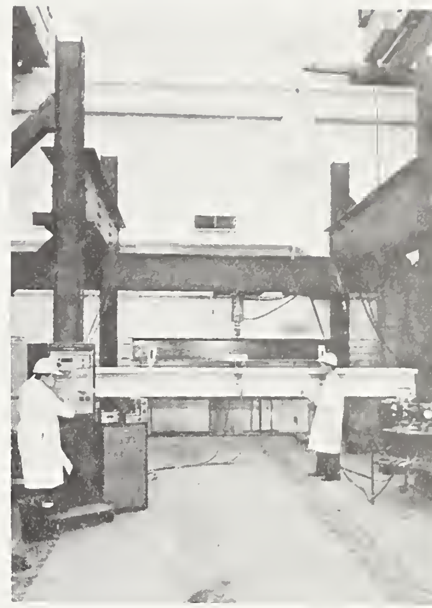
Electrical Codes

Again in support of the nation's voluntary system of standards, NBS for 60 years--from 1913 to 1973--served as secretariat to the National Electrical Safety Code effort, which operates under ANSI procedures. Under the leadership of NBS, three of the electrical code's four parts were updated and the fourth was well along in its recasting at the time of the secretariat transfer to the Institute of Electrical and Electronic Engineers.

NBS personnel--notably William Meese--also contributed to the National Electrical Code developed under the auspices of the National Fire Protection Association. This code ANSI C1, is primarily concerned with the installation of wiring and electrical equipment in buildings.

The Importance of Testing

A 1968 event which was to mean much for the Division's immediate future took place in the structures laboratory. It illustrated the Division's ability to respond within a matter of weeks to a real-world problem faced by HUD, and it was probably influential in HUD's turning to the Bureau for technical support in Operation Breakthrough. The event was Project Phoenix (125).



"Phoenix" was the name of a Detroit housing project undertaken in the aftermath of ghetto rioting. The project was to use an innovative building system of factory-made pre-cast concrete components assembled at the site to create a structural framework. The system involved a number of departures from conventional building practices, its developer mindful of HUD's admonition that each additional $100 in the cost of a house prices some 15,000 American families out of the market.

In conventional structural practice the design usually depends solely on the building's framework to provide strength and stiffness. The developer of the Phoenix system also took into account the structural contribution of walls and partitions.

Detroit's commissioner of buildings, however, could not credit these "skin" components with a structural contribution. HUD, meanwhile, was eager to have the project built and held discussions with the City of Detroit for more than a year. Finally it was agreed to test the system's overall performance to determine whether it met the code requirements. The Building Research Division was chosen to perform the tests.

The housing system was erected on the tie-down floor of the Division's main structures testing laboratory. Hydraulic rams and pneumatic air bags were used to simulate loadings.

Expressing the Detroit building code load requirements in terms of people, research engineers found that a 3.7 by 6 m (12 by 20 ft.) room would have to support a load comparable to 240 persons, in itself a decidedly stern requirement. But the laboratory test showed the floor capable of supporting 540 persons, at which point the test had to be terminated due to the failure of one of the air bags used in loading.

As for lateral loading, the structure had to resist the equivalent of about a 40 m/s (90 mph) wind. The full-scale tests were discontinued when a wind load equivalent of a 67 m/s (150 mph) was reached; the test structure was experiencing excessive uplift rather than internal structural damage.

The tests showed that with skins in place, the innovative system easily met the intent of the building code. They also yielded more knowledge about the structural behavior of buildings and the part played by "non-structural" components. The City of Detroit granted a waiver from its building code, permitting the system to be used.

The Phoenix testing took five weeks. It demonstrated both NBS's capability for short-deadline laboratory support and the kind of measurement necessary to advance the performance concept in building.

CHAPTER 3

THE PERFORMANCE CONCEPT

The performance approach accentuates function. Since buildings serve people and their activities, function is defined by the attributes necessary to satisfy human requirements. The means of delivering attributes is left open. It is in this way that the builder or the supplier of building components is invited to innovate--and indeed, the encouragement of innovation (and the corollary avoidance of overregulation) is sometimes cited as the reason for being of the performance approach. But the philosophy of performance puts its principal emphasis on the satisfaction of human requirements.

The Building Research Division addressed not only the theory of performance, but its practical application as well. It had gained the interest of the Office of Urban Technology and Research[16] in the Department of Housing and Urban Development (HUD). The Department joined with the Division in funding a preliminary study on how the performance concept might be applied to housing.

Housing has long been a research concern at NBS. The first organizational unit established specifically for building research at NBS was named the Division for Housing and Building Technology. That was in 1922.

The HUD/NBS performance-in-housing project sought to identify the knowledge gaps that had to be filled to develop a practical set of performance standards. It sought the formulation of impartial, innovation-inducing standards to replace the prescriptive "cookbook" provisions blamed for needlessly constraining building technology. "It is hypothesized that if adequate performance standards for low-cost housing could be developed, and if they were broadly used," explained the study agreement with HUD, "an important and fundamental way would have been opened to accommodate the introduction of cost-reducing innovations into the design of low-cost housing."[17]

The words "if...broadly used" went beyond "economies of technology." Clearly they suggested scale (mass production) economies as well.

The study probed an idea--performance-that, while hardly pervasive, was not entirely novel, either. As early as the 1930s the Building Research Station in Great Britain

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[16]Now the Office of Policy Development and Research

[17]Eberhard, J.P., The Performance Concept: A Study of Its Application to Housing, Preface, National Bureau of Standards, Washington, D.C. 20234 (1969).

proposed that health and safety considerations be couched in performance terms.[18] A 1938 NBS publication noted that "adequate performance requirements of nationwide acceptance would facilitate the rapid development of new, better, and, it is hoped, cheaper methods of construction."[19] NBS' George N. Thompson in a 1949 paper urged the judicious application of performance in building code formulation and cited advantages to this approach.[20] France, South Africa, and the Nordic countries over the years also made important contributions to the concept and its application.

The first project to use performance requirements in the United States was directed by Ezra Ehrenkrantz. This was the School Construction System Development project, which Ehrenkrantz, who had had previous experience in building systems in Great Britain, began in 1961.

"System," a word often associated with the performance approach, derives from two sources. It comes from building systems--the dimensional and functional coordination of the subsystems of a building which when assembled deliver specified attributes, and from operations research or systems analysis.

While it is generally held that the performance approach and systems analysis are separate and distinct, the two methodologies hold much in common. Both seek a high degree of problem definition; both reject unquestioning adoption of conventional solutions; both seek out and entertain the widest array of possible solutions; both apply an evaluative routine to potential solutions; both emphasize feedback in order that future solutions can benefit from earlier experience; both insist on procedurally organized methods; and both insist philosophically on a comprehensive view of the problem and an open-ended range of possible solutions.

The Division in 1968 held a conference for the building community on the theme, "Performance of Buildings--Concept and Measurement; Man and His Shelter" (101). The conference and its proceedings not only advanced the performance concept but had the effect of spreading the word that the Division welcomed new challenges, especially those that would permit it to move from its traditional materials-testing preoccupation to performance standards for buildings.

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[18] Wright, J.R., "The Performance Approach: History and Status," Performance Concept in Buildings, Vol. 2, Special Publication 361, National Bureau of Standards, Washington, D.C. 20234 (1972).

[19] Whittemore, H.L., and Stang, A.H., Methods of Determining the Structural Properties of Low-Cost House Constructions, Building Materials and Structures 2, National Bureau of Standards, Washington, D.C. 20234 (1938).

[20] Thompson, George N., Preparation and Revision of Building Codes, Building Materials and Structures 119, National Bureau of Standards, Washington, D.C. 20234 (1949).

Significantly, the sub-title of this notable conference began not with sticks and stones but with "Man." The Division was convinced that building research must involve not only physical scientists and engineers but social scientists, research architects, economists, urban planners, and "those who have the specific task of getting results put into practice," i.e., those who understood the needs of the appliers of building technology and of the regulators--the building code officials principally--of this technology.

At HUD, meanwhile, Secretary George Romney was equally convinced that the rationalized and coordinated mass-production techniques of the automobile industry from which he had come could be transferred to homebuilding. Romney wanted to achieve a "break through" to innovative, industrialized housing. And so, "Operation Breakthrough."

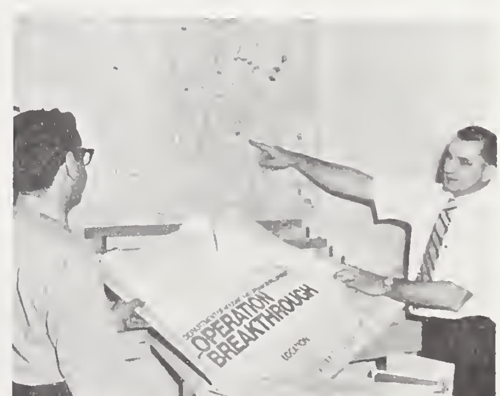
An Operation Breakthrough Request for Proposals, distributed in the summer of 1969 yielded 632 proposals from a wide range of industrial and professional firms and consortia. From these proposals, 22 housing system producers were chosen to participate in the largest housing prototype demonstration program ever conducted in the United States.[21]

HUD's new Assistant Secretary for Research and Technology, Harold B. Finger, told the Bureau in late 1969 that HUD, "in order to establish testing requirements, performance criteria, and the validity of testing procedures and results," required the "advisory, consultative, and operating services of the National Bureau of Standards." Pilot funding followed to enable NBS building researchers to begin work on Operation Breakthrough.

The Division had a clear idea of how to proceed. Its immediate objective was the development of a comprehensive set of performance criteria for the design and evaluation of the entire range of the 22 housing systems selected. A December 22, 1969, meeting between HUD, NBS, and the National Academy of Sciences indicated that the Division would manage the "evaluation program" for Operation Breakthrough and would develop the performance criteria necessary for evaluation--by February 1, 1970.

An interdisciplinary Operation Breakthrough team was formed, its members representing every Section and discipline within the Division. Dr. Edward O. Pfrang, then Chief of the Structures Section, was appointed program manager and Vannie E. Gray, a chemist, was named assistant manager.

Planning for the task of developing a comprehensive set of performance criteria was constrained by the tight schedule imposed on the Division. The development of the criteria in so short a time required disciplined procedures and an ordered framework. It was decided to structure the criteria according to a matrix (707). One axis on the two-dimensional matrix represented the built



[21] The selection panel included two NBS staff members, Paul Reece Achenbach and Thomas Ware.

elements and the other the attributes necessary to serve the user. The intersection of each built element with each attribute was examined in the formulation of performance statements. The matrix also provided a way of organizing these as provisions of the resulting performance specification.

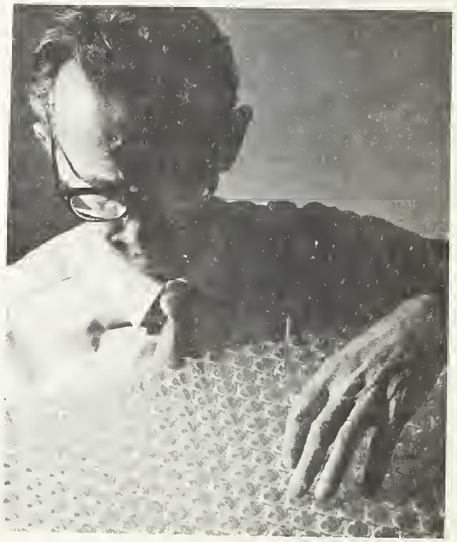
Built elements were lettered and attributes were numbered. The built element "structure" (A) and the attribute "fire safety" (4) formed the intercept A-4. Here could be found all performance statements bearing on the structural/fire safety interrelationship.

Operation Breakthrough activities for a time tended to eclipse many of the Division's other research activities. The conduct of the entire evaluation effort--which was founded on the criteria--proved an absorbing, significant, and meaningful responsibility.

Any assessment of the Division's contribution to housing via Operation Breakthrough on the one hand depends on the value of the program itself, and on the other on the quality of the Division's technical support irrespective of Breakthrough's merits.

To Harold Finger the question of Breakthrough's success was beyond dispute. Three years after the program's launching Finger declared: "Our goal was to accelerate the rate of change, of improvement in housing, to encourage innovation in housing systems, in land planning, and in providing opportunities for all people to live in well-designed communities. In this short time we have accomplished much of what we set out to do, and in many areas we have accomplished more than we expected. We have broken through many of the constraints to the improvements we are seeking."[22]

Finger ascribed to Operation Breakthrough a large measure of credit for the industrialized housing laws or general purpose building codes adopted by 20 States in the first years of Operation Breakthrough.



Certainly the development of performance criteria for Operation Breakthrough was considered an enduring technical achievement. These criteria were published in four volumes covering as many kinds of housing--single-family detached, single-family attached, multi-family low-rise, and multi-family high-rise. Entitled Guide Criteria for the Design and Evaluation of Operation Breakthrough Housing Systems (704) they have influenced building codes, standards used by HUD, and indeed the perspective at NBS with respect to performance and prescription.

The experience of working with new materials and techniques, the opportunity to challenge state-of-the-art technology, and most of all, the greater engagement in real-world problems afforded by Breakthrough, stimulated and redirected building research at Gaithersburg.

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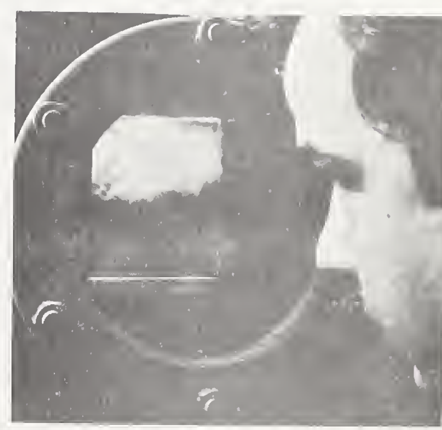
[22]Foster, B.E., Performance Concept in Buildings, Vol. 2, Special Publication 361, p. 819, National Bureau of Standards, Washington, D.C. 20234 (1972).

The performance criteria in addition to health and safety considerations also included issues of durability and livability. Durability and livability had to be addressed since the innovative systems in question had not undergone the test of time or marketplace. Moreover, Operation Breakthrough sought not only safe and healthful housing but housing of improved quality (715).

The Breakthrough team aimed at achieving at least that level of health and safety intended by the codes. "Targets of opportunity" having high payoff also were incorporated, an example being smoke detection. The Breakthrough criteria called for smoke detectors on a much broader scale than did most regulatory jurisdictions. In general, considerable attention was paid to life safety, the Breakthrough team believing that historically regulations placed too little emphasis on protecting housing occupants compared with the stress on protecting property.

It was necessary to identify and measure inherent but unexpressed attributes in conventional housing in order to ensure their presence in innovative housing. For example, for the first time attention was given to the fire safety of innovative materials and construction techniques for single-family residences. Never before had building codes prescribed fire endurance requirements for flooring and wall assemblies, or smoke generation limitations for interior finish materials, or smoke detectors. Since the criteria sought a level of safety at least the equal of that found in conventional construction (708), researchers had to first define and quantify conventional technology in order that the Operation Breakthrough criteria could be assigned commensurate values (312).



The Guide Criteria for the Design and Evaluation of Operation Breakthrough Housing Systems was one of two major performance documents generated at NBS. The other was the PBS Performance Specification for Office Buildings. The Public Buildings Service (PBS) in the General Services Administration funded the specification in an effort to achieve better government office buildings and to generally advance systems know-how in the building community. Arthur F. Sampson, PBS Commissioner, said in 1971: "This new approach to the design and construction process presents a challenge which must be accepted in order to ensure continuing excellence in Federal and private building construction."

The specification was a product of the Building Systems Section which was headed by Robert Blake and which counted among its staff systems and performance thinkers, Michael Brill, Thomas E. Ware, and David B. Hattis (700). It was developed for three payment centers of the Social Security Administration. Earmarked for San Francisco, Philadelphia, and Chicago, the buildings' combined cost was estimated at $110 million.

The performance specification envisaged buildings in part designed and constructed by conventional techniques and in part designed, manufactured, and assembled by coordinated (system) methods. Procurement provisions of the system portions are stated clearly in performance terms rather than in the particular technologies of pre-existing models. The specification is aimed at any or all of the following advantages: increased building quality, decreased building costs, and more efficient construction management techniques.

The specification addresses the volumetric portion of the building, the portion that houses the building's operational reason-for-being as distinct from ancillary spaces, e.g., spaces serving circulation or special-purpose functions, seven of the major elements of the work space: structural frame, HVAC equipment (ductwork, and through a later PBS revision, air-handling equipment), electrical and telephone distribution, lighting fixtures, finished floors, finished ceilings, and partitions.

The performance specification changes the process of building and introduces a new participant--the executive architect. It is the executive architect's responsibility to define the roles of all participants and to maintain open lines of communication between them. The specification encourages the offsite manufacture of coordinated subsystems, this to replace the traditional in-situ, piece-by-piece assembly of the building.

Additionally, the systems building approach with its through-process management "pulls the parts together" within government, countering a tendency of the building process to segment along functional lines--site acquisition, space requirements, design, construction, etc.

Finally, it raises such ideas as life-cycle costing from conceptual to application levels. PBS undertook the development of bid equalization factors so that proposals with attractive first costs--but high maintenance and operating costs--would not necessarily win in the bidding. This is a stark departure from customary practice in an industry dominated by first costs. Moreover, as the cost dynamics in energy became felt, bid proposals were required to be energy sensitive as well as cost descriptive in relation to time.

Two of the three Social Security payment centers were completed by the mid-1970s and the third was under construction. PBS was also applying the specification to two more Social Security buildings in Baltimore with an estimated total cost of $61 million. PBS found that the construction process was speeded up and that the office work environments which resulted were superior to those of conventional construction. Costs were within estimates but did not lend themselves to comparison with conventional construction because of the complicating life-cycle aspect.[23]

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[23]Conversation with James Parksen, Chief, Criteria and Research Branch, Professional Services Division, PBS.

CHAPTER 4

WORKING WITH THE STATES

An NBS building technologist was in Madison, Wis., his day's business at the Forest Products Laboratory completed. It was 1967, and in spite of his having participated in a major building codes study conducted by the Advisory Commission on Intergovernmental Relations, he had in mind no particular thoughts on the subject of building regulation. The technologist, Charles T. Mahaffey, was in Madison on other business.

He met by chance an official of the NBS Office of Weights and Measures who that night was to meet with a group from the National Conference on Weights and Measures, and he was invited to attend the session as an observer.

The cordial but effective nature of meeting with the State representatives impressed Mahaffey. On his return to Gaithersburg he asked Dr. A. Allan Bates, then Chief of the Building Research Division (BRD), to consider formal interaction with the States on the subject of building regulation. Bates first wanted to determine if the States were interested. A telephone survey of 10 representative States was conducted; it revealed a distinct enthusiasm for the idea.

A month later officials of the States met in a two-day session with NBS staff members. The morning went well, but it was at a noon luncheon with NBS Director Allen V. Astin that the State representatives developed an approving attitude toward the National Bureau of Standards. Astin's low-key style and candid manner, but most of all his insistence that NBS's offer of help was on condition that the States assume the leadership role, offset worries over Federal pre-emption.

Among the State representatives on hand was Gene A. Rowland, one of three Commissioners in the Wisconsin Department of Industry, Labor, and Human Relations. Rowland was keenly interested in the notion of interstate cooperation on building regulation; he asked the Governor of Wisconsin to host a meeting of all States. That meeting was held in the fall of 1967.

It should be noted here that building regulation in the United States is, in principle, a State prerogative. However, the actual regulation of buildings has been carried out for the most part by the towns and cities. This localism in regulation stems from two facts. One is that the building enterprise itself was once exclusively local, and the other is that building regulation is a civic matter drawing from the conflagrative and hygienic implications of human settlements, i.e., from the close proximity of one building with other buildings. In short, building was a local enterprise and its regulation a communal concern.

But as the enterprise began to take on a more intercity and even interstate character, the problem of local building codes, often in conflict with one another, required examination. The in-depth study of the Advisory Commission on Intergovernmental Relations produced 11 remedial recommendations,[24] seven of which required some concerted action by the States.

The 1967 Wisconsin meeting resulted in the formation of the National Conference of States on Building Codes and Standards (NCSBCS). The Conference is primarily composed of State officials who have been appointed by their governors as delegates to NCSBCS. Its purpose is to provide a forum to discuss mutual problems and to promote statewide and national uniformity in building codes and enforcement practices. Two months later the BRD's Codes and Standards Section became the Secretariat to NCSBCS. At about the same time, Gene Rowland, having just completed the reorganization of the building codes section in Wisconsin's Industry, Labor, and Human Relations Department, left his State post to become Chief of the Codes and Standards Section at the Building Research Division. Rowland at the time was serving as NCSBCS' first chairman.

The first annual meeting of NCSBCS was held at NBS on May 6-7, 1968. This meeting was for the purpose of establishing objectives, approving the proposed organizational structure, electing officers and committee members, and outlining NCSBCS' initial programmatic directions.

In 1969 the organization's constitution and by-laws were approved by 36 States at NCSBCS' second annual meeting, in Hollywood Beach, Fla. The next year all 50 States, the District of Columbia, and two territories through their respective governors' offices endorsed the concept and scope of NCSBCS and named delegates to the body. While depicted as a forum for the discussion and resolution of problems, NCSBCS in the final analysis was designed to counter the proliferation of building code jurisdictions with their varying requirements. These jurisdictions numbered at least 12,000 with a potential of thousands more.

Not only do code requirements differ from one jurisdiction to another, but so do jurisdictional interpretations of common requirements. Additional differences are found in the administrative practices of regulatory agencies.

This situation was seen as an impediment to the realization of "the two economies"--an economy of scale and an economy of technology. So fragmented a regulatory overlay upon what otherwise might be a cohesive--and sizeable--market discouraged the development of innovative building products.

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[24] "Building Codes: A Program for Intergovernmental Reform," Advisory Commission on Intergovernmental Relations, Washington, D.C., January 1966.

tive technologies made little sense in the absence of an evaluation and acceptance system to guarantee markets of investment-worthy size.

NCSBCS established standing committees each of which was to meet at regular intervals and each of which was assigned an NBS staff member for support. Several joint NBS/NCSBCS projects were undertaken at first, followed by an ambitious, NBS-funded research program launched on NCSBCS' behalf.

NCSBCS influenced the passage of state-wide regulatory legislation as did the Operation Breakthrough program of the Department of Housing and Urban Development (HUD). Both HUD and NCSBCS had a telling influence on greater intrastate uniformity in the regulation of buildings, especially industrialized buildings.

Enhancing the climate for new technology has been the intent of the Bureau's service to NCSBCS. This service enables the States to describe more uniformly their regulatory requirements and to more accurately evaluate new construction materials and techniques, paving the way for the natural evolution of a market area sufficiently large and rewarding to stimulate industrial innovation. In turn, the consumer's choice range is widened. It is the consumer who is the ultimate beneficiary of an improved regulatory climate.

It was as the Bureau maintained this "relatively modest but high priority" program with the States that Secretary of Commerce Maurice Stans asked for a status report on the program and for suggestions on what might be done to "accelerate" it. The report, prepared by the Bureau, noted that NCSBCS had asked for support in the development of 1) laboratory accreditation procedures, 2) a coordinated system for evaluating and processing building innovations, and 3) model legislation on the regulation of buildings.

Funds were made available for all three. Thus were born the Laboratory Evaluation and Accreditation Program (LEAP), the Coordinated Evaluation System (CES), and the model legislation effort.

With the full support of the Bureau, NCSBCS grew in both status and financial resources, achieving a maturity which suggested that the NBS secretariat role need not be extended beyond 1976. A close association with NCSBCS was expected to continue. The Bureau will provide support as appropriate within the scope of the NBS mission. Meantime, a legacy of significant programs conducted by the Bureau for NCSBCS testifies to the close NCSBCS-NBS alliance. These programs included a Laboratory Evaluation and Accreditation Program (LEAP), a Coordinated Evaluation System (CES), model enabling legislation, and the development of criteria for energy conservation in new buildings (462).

LEAP

The Laboratory Evaluation and Accreditation Program had as its backdrop a trend toward greater industrialization through State-level certification of manufactured buildings and toward interstate reciprocity in the certification of buildings and components. The caliber of the laboratories and agencies performing the evaluating and compliance assurance functions for manufactured buildings was subject to some question, however. A way of assessing the capabilities of these organizations on a uniform, interstate basis was needed if evaluations made by one State were to be confidently accepted by another.

NCSBCS in 1970 asked the Bureau to develop a program to accredit laboratories. The need for such a program was recognized and NBS initiated LEAP in January, 1971.

LEAP under the leadership of James O. Bryson produced four research reports which NCSBCS and NBS turned over to ASTM for processing as national consensus standards. Two ASTM committees, E32 Criteria for Evaluating Agencies Concerned with Systems Analysis, Testing, and/or Compliance Assurance of Manufactured Buildings, and E36 Criteria for the Evaluation of Testing and/or Inspection Agencies, were established to process the documents. The E32 Committee produced a standard which in time (1975) was to win consensus agreement--ASTM E541 Criteria for Evaluating Agencies Engaged in Systems Analysis and Compliance Assurance for Manufactured Building. The E36 Committee, meanwhile, pressed ahead with the development of generic criteria for the evaluation of testing laboratories.

Using LEAP evaluation criteria and methodology, pilot efforts were undertaken by the States of Massachusetts and Maryland to demonstrate the benefits of a LEAP approach to building regulation. The results of these demonstrations, along with the on-going deliberations of the ASTM committees, were expected to advance the industrialization of the building process as was the Coordinated Evaluation System (CES) project.

CES

The CES project was directed toward the fostering of regional or national markets through consistency of procedures and documentation. Headed by Robert D. Dikkers, CES was undertaken in response to two requests, one from NCSBCS and another from the Executive Office of the President. Its purpose was to develop, in conjunction with the States, consistent informational documents as a means of facilitating the acceptance of new technology (327).

Among the project's products was a four-volume preliminary report entitled, Model Documents for the Evaluation, Approval and Inspection of Manufactured Building (172).

This and other output from the project were endorsed by NCSBCS and adopted for use by several States and a number of independent laboratories (342).

The National Conference of States on Building Codes and Standards and NBS agreed that model legislation in certain building-related areas was needed. NCSBCS and NBS began the development of the models out of an awareness of the multiplicity of proposals before State legislatures and of the need to upgrade building code programs.

NBS formed four balanced working groups to develop as many legislative models--a Manufactured Building Act, Mobile Home Act, State Building Code Act, and a Registration of Code Enforcement Officers Act. These groups were comprised of representatives of industry, States, local governments, model codes, the Federal Government and the general public. The models were endorsed by NCSBCS and all but the Registration of Code Enforcement Officers Act were included in the 1974 Suggested State Legislation package of the Council of State Governments, the Council believing that additional research was needed on the subject of registration. Several States have used the models in developing their own legislation.

NBS' work in support of NCSBCS has drawn it close to--but not into--the arena of building regulation. Building regulation is the function of the States and their political subdivisions.

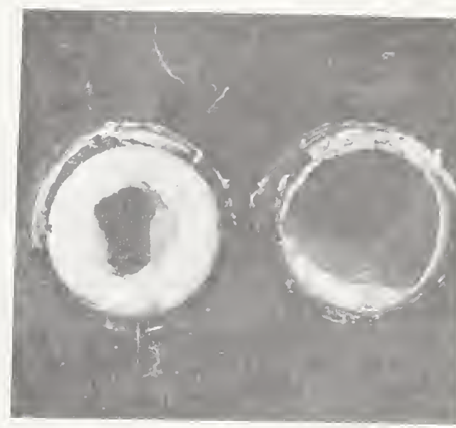
CHAPTER 5

BUILDING RESEARCH ACCOMPLISHMENTS IN THE EARLY 1970's

Building research at NBS in the first years of the 1970s began to consciously address user needs and energy-related technologies, but the majority of investigations involved traditional mechanical, structural, and materials concerns.

Plumbing

Long-range plumbing studies contributed to the development of criteria and methods for the performance evaluation of innovative materials for fixtures and piping. These studies also contributed to the protocol for hydraulic performance evaluations of innovative systems (141). New laboratory capabilities made possible the measurement of typical dynamic transient processes, a significant advance in the measurement technology in this field. Plumbing research prior to the establishment of these new capabilities was conducted largely with instrumentation more suitable for non-typical static or continuous-flow conditions (209).



Development of a procedure for measuring and reporting the essential hydraulic characteristics of plumbing fixtures and appliances was undertaken. Also, studies were conducted to examine the conditions under which plastic pipe may be used in wall and chase constructions with fire requirements appropriate for the safety of occupants and the protection of of property (167, 169).

Reduced-Sized Venting

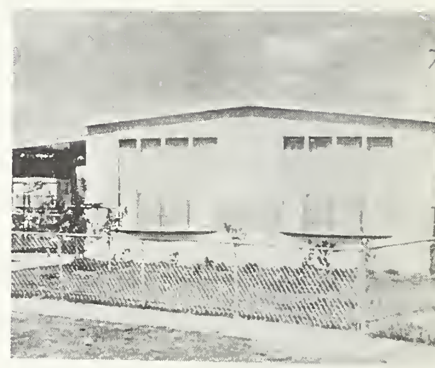
This project was directed toward the potential for using smaller--and thus less costly--vent pipes in drain-waste-vent systems. Potential savings are estimated at between $46 and $125 per dwelling depending on the configuration of the plumbing system and the plumbing code in the jurisdiction of its location. The laboratory research showed that traditional dry vent sizing procedures are unnecessarily restrictive for one- and two-story residential applications (149, 944, 945, 946).

The performance criteria adopted for this work and the sizing procedures derived from it provided adequate assurance against the emission of sewer gases or sewage into the building. This was accomplished through design procedures taking into account retention of adequate water seals in the plumbing fixture traps and limitation of pneumatic pressure fluctuations in the drains connecting to the traps.

The economic benefits are derived from the use of pipes and fittings (for dry vent lines) that are usually two to four commercial pipe sizes smaller than those ordinarily used, i.e., those required by plumbing codes. Further economic benefits are gained through labor savings and reduced values in overhead and profit factoring by plumbing contractors. The design methods derived from this work were recommended for application in any one- or two-story residential drain-waste-vent system, the "wet" piping of which complies with at least one of the model plumbing codes.

Work in reduced-size venting was carried out in the mid-1960s under the sponsorship of the National Association of Home Builders. Criteria generated in these studies were improved and expanded in work undertaken for the military services in the early 1970s by Robert S. Wyly and colleagues. This work confirmed the potential for reduced-size venting and pointed the way to field trials. It also provided criteria to code groups considering changes in venting requirements.

Mobile Homes



Manufactured housing, including most notably the mobile home, became an NBS research subject of major importance in the 1970s. Millions of Americans were turning to this form of shelter. By 1971 mobile homes accounted for 70 percent of the under $20,000 market in America. By 1974, with the average cost of a furnished unit still under $10,000, mobile homes claimed 90 percent of this market sector. Indeed, by 1974 mobile homes were accounting for 20 percent of all new housing in the United States irrespective of cost.

The effectiveness of mobile homes in providing safe, adequate, and low-cost shelter was questioned, however, by consumer groups, members of Congress, and others. In a project sponsored by HUD, building researchers sought to identify the performance problems of mobile homes, and to link these with the provisions of the ANSI A119.1 Standard for Mobile Homes as well as the practices of regulatory and mortgage insurance institutions (486, 493, 494). More than 30,000 problems were identified in the 4105 mobile homes evaluated during the study. Most of these units were purchased by HUD for Wilkes-Barre, Pa., families made homeless by the 1972 Hurricane Agnes disaster.

Seven mobile home projects were in progress at one time, including a study of the States' regulatory programs on mobile homes (492). Many of these projects were in support of HUD's Congressional mandate to produce a Federal mobile home construction standard.

At the same time, NBS was studying fire safety in mobile homes. Full-scale tests were conducted to determine fire spread in mobile home kitchen areas and corridors. In addition, a project was started to determine where smoke detectors should be placed to achieve the best performance. The results[25] were supplied to the mobile home industry and to HUD for use in its mobile home standard.

Floor Coverings

Technical investigations of flooring materials, conducted at NBS for more than 40 years, have been concentrated in the areas of wear and slip resistance. A major problem of resurfacing concrete floors has been the surface contamination of the concrete. When flooring materials were used to renovate the concrete surface, premature failures resulted (806). A study of this problem suggested remedial procedures and materials to prevent premature failure.

Studies were also conducted on the performance characteristics of monolithic flooring systems (338). Performance criteria were developed and applied in cooperative programs with the American National Standards Institute (ANSI) and the American Society for Testing and Materials (ASTM). Both organizations recognized the need for performance standards for floor coverings, particularly in terms of slip resistance and wear. Research findings also were applied through consultative and advisory services to other Federal agencies, manufacturers, and the public (329, 339, 808).

Additionally, floor coverings were examined from a fire standpoint. In full-scale fire tests in corridors, researchers observed that floor coverings, responding to heat radiated from the corridor ceiling, could cause flames to spread rapidly. A test method was developed for simulating the level of heat radiating from ceiling to floor. Called the flooring radiant panel test, it is used (at the Center for Fire Research and elsewhere in the Federal government) to predict the fire performance of flooring when exposed to varying intensities of radiant heat occurring in corridor fires. The test is going through the process of becoming an ASTM test method.

Joint Sealants

Many problems of leakage through building joints accompany present building design and practice. Such leakage causes damage and reduces the efficiency of heating and cooling systems. Some 40 test methods for evaluating improved sealants were developed in cooperation with ASTM and the American Concrete Institute. Performance criteria

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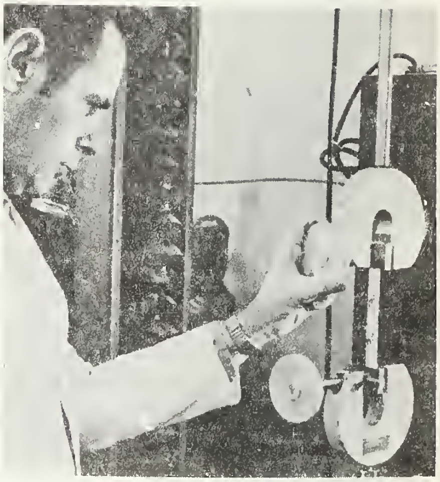
[25] NBSIR 75-788 Evaluation of the Fire Hazard in a Mobile Home Resulting from an Ignition on the Kitchen Range; NBSIR 76-1016 Mobile Home Smoke Detector Siting Study; and NBSIR 76-1021 Fire Spread Along a Mobile Home Corridor.

were developed and incorporated in widely-used Federal specifications[26] for sealants and caulkings. Also, the recommendations of studies to improve joint design were incorporated in Joint Sealants in Aluminum Curtain Walls, a publication of the Architectural Aluminum Manufacturers' Association.

Several theories were proposed in an attempt to explain the phenomenon of adhesion and adhesive failure, and surface studies were conducted to elucidate the mechanism of sealant failure. Study methods included photon activation analysis, neutron activation analysis, and scanning electron microscopy.

Activation analysis indicated merit in the absorption theory of adhesion. It was found that what appeared to be adhesion failure may actually have been cohesion failure in the sealant (808). The results of this study have been applied in the formulation of performance criteria and in the solution of adhesive failures in sandwich panel construction (151, 409).



Reinforcing Bar Coatings

The premature deterioration of concrete bridge decks has been a major concern of highway authorities. Much of this deterioration has been attributed to the corrosion of steel reinforcing bars caused by chloride ions from de-icing salts. Spray-applied, powdered epoxy coatings were identified as being promising coating materials for corrosion protection of reinforcing steel. Test methods and performance criteria were developed to assess their performance. This work is expected to have direct application to concrete buildings subject to reinforcing bar corrosion--reinforced concrete parking garages which inherit de-icing salts from roadways, buildings in marine environments, and industrial buildings subject to reinforcing bar corrosion (164, 452).

Disaster Mitigation

Hurricanes, tornadoes, floods, and earthquakes each year inflict on the United States untold human suffering and

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[26] TT-S-00227E (COM-NBS), Sealing Compound: Elastomeric Type, Multi-Component (for Caulking, Sealing, and Glazing in Buildings and Other Structures); TT-S-001543A (COM-NBS), Sealing Compounds: Silicone Rubber Base (for Caulking, Sealing, and Glazing in Buildings and Other Structures); TT-S-00230C (COM-NBS), Sealing Compound: Elastomeric Type, Single Component (for Caulking, Sealing and Glazing in Buildings and Other Structures); TT-S001657 (COM-NBS), Sealing Compound--Single Component, Butyl Rubber Based, Solvent Release Type (for Buildings and Other Types of Construction); and TT-C-00598C (COM-NBS), Caulking Compound, Oil and Resin Base Type (for Building Construction).

property damages averaging billions of dollars (140, 308, 310). In Hurricane Agnes alone, property losses exceeded $2 billion. These losses were multiplied many times over by disruptions of commerce.

The research program to mitigate life and property losses, headed by Dr. Charles Culver, included laboratory studies to improve building practices in disaster-prone areas, but much stress was placed on field investigations. The field efforts emphasized safety evaluations of surviving buildings, postdisaster emergency measures, evaluation of the performance of buildings--good as well as bad--under abnormal stress, and more reliable measurements of buildings' responses to extreme forces (161, 472, 505, 853, 857, 887). The combined field/laboratory approach was directed toward improved design.

Field work sometimes included on-the-spot advice such as that given in 1967 to some 5,000 Alaskan families whose homes were damaged by the flooding Chena River. Because they were advised to thoroughly dry out their homes before the imminent freeze of the long Alaskan winter, these families were able to resume normal home life and were spared an estimated $5 million in frost damages (735).

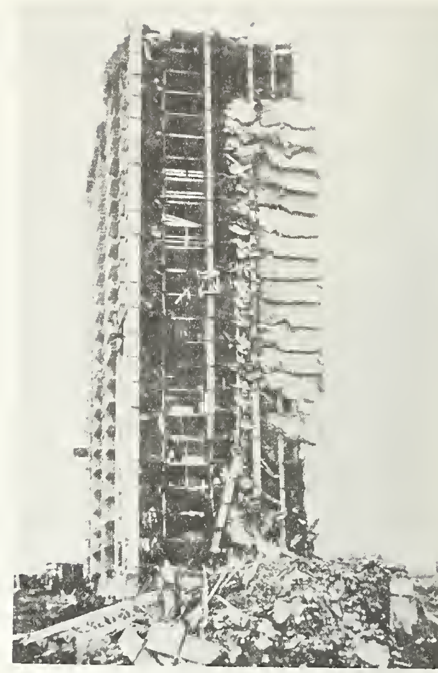
Among other disasters investigated were Hurricane Camille in 1969 (310), the Lubbock, Tex., tornado of 1970 (308), the 1971 San Fernando earthquake (140), the Managua, Nicaragua, earthquake of 1972 (334), the Military Personnel Records Center Fire in St. Louis in 1973 (845), and the 1973 collapse of the Skyline Towers apartment building under construction at Bailey's Crossroads, Va. (439). The report on the San Fernando earthquake included 17 recommendations for improving the seismic resistance of buildings.

The National Science Foundation (NSF) under its Research Applied to National Needs program, the Department of Housing and Urban Development (HUD), the Office of Emergency Preparedness, and NBS in 1972 planned a cooperative Federal program on Building Practices for Disaster Mitigation. The NSF and NBS in the same year conducted a workshop to develop a national plan for disaster mitigation activities. A cross-sectional sample of highlevel experts of the building community participated in the workshop in synthesizing state-of-the-art building practices (146).

Seventy-one recommendations resulted from the workshop. They were grouped into two categories: policies and practices. The former were directed toward government and the financial and insurance communities. The latter were directed toward professional practitioners, standards writers, and researchers. The recommendations were published along with 15 technical papers presented by experts. Activities in implementing the recommendations have begun.

The Defense Civil Preparedness Agency (DCPA), requested the Center to develop a methodology for surveying and evaluating existing buildings to determine risks of damage under natural disaster conditions. The project developed procedures for evaluating the safety of existing buildings from wind and seismic forces. The DCPA is using the procedures, as are the General Services Administration and a number of design professionals (161).

Disastrous fires where structural damage was a significant loss, as in the Military Personnel Records Center, were also investigated. And in an attempt to prevent potential human disasters in high-rise buildings, researchers studied smoke control systems that could blunt the travel of deadly smoke and gases induced by thermal expansion, ventilation ducts, wind, and stack effect (441, 448).



Wind Studies

A continuing wind study, begun in 1968 and funded by NBS with assistance from the Tri-Services Committee, the National Aeronautics and Space Administration, and the Environmental Science Services Administration, sought more rational design provisions for wind loads (130, 309, 341).

An array of meteorological towers was set up alongside the building research laboratory in Gaithersburg. These towers gathered wind direction and wind speed data and also provided information on the turbulence characteristics of surface winds. By attaching pressure transducers to the laboratory building, it was possible to study the mechanism by which velocity fluctuations are converted to pressure fluctuations on buildings. As the project progressed it sought to provide estimates of building response characteristics and an evaluation of the instrumentation and techniques for the acquisition of data by fullscale measurements. Correlations also were sought with wind tunnel modeling which if reliable makes possible the inexpensive prediction of wind effects.

Results from these investigations indicated that localized pressure fluctuations exceed recommended design values, and that the scale of wind tunnel turbulence must be increased to better simulate atmospheric flows (156, 341).

The overall disaster mitigation program includes projects aimed at improving the resistance of low-rise buildings (principally low-cost housing) to wind and earthquake Sponsored by the Department of State's Agency for International Development (AID), this work is directed toward developing countries but has application in many areas of the world, including the United States (148, 156, 505).

The AID effort includes technical support in improving the seismic resistance of low-cost housing using oil-stabilized and bamboo cane-reinforced adobe block construction. The research was performed in collaboration with the Peruvian government and the University of California. Testing specifications for adobe masonry were developed which considered the physical limitations of the testing equipment at the National University of Engineering in Lima (212).

The project produced tentative criteria for stabilized block masonry construction and draft calculations for a prototype housing unit. These guidelines were transferred to the Peru AID Mission and governmental authorities.

Another project assessed state-of-theart housing technology in several developing countries (Peru, Turkey, and the Philippines) (148). Included was an evaluation of these countries' socio-economic and cultural constraints. Technical and socio-economic data gaps in building construction knowledge were addressed. In addition, alternative approaches were studied to improve building designs, material usage, and construction techniques to overcome socio-economic barriers hindering the advancement of technology and improvement of building regulations.

The Center in March of 1973 initiated a project to develop improved design criteria for low-rise, low-cost buildings in developing countries to better resist extreme winds. The project is aimed at learning more about the effects of extreme winds on low-rise buildings. It is intended to develop siting, design, and construction information which would improve the resistance of buildings to extreme winds and which would be culturally acceptable to the user, and to provide training to local professionals and technicians in performing wind measurement and analyses of full-scale and wind-tunnel testing. It is also intended to effect a large-scale transfer of technology to make use of these improvements in design and construction, as supported by new climatological, sociological and economic findings. This study is expected to improve structural design practices, the use of materials in resisting extreme winds, community planning, and wind risk mapping. This would be accomplished through building code adoption of project results.

Long-Range Research

Operation Breakthrough added to the ongoing research effort. In the course of preparing performance criteria and evaluating the 22 housing systems for Operation Breakthrough, researchers uncovered gaps in existing building knowledge (401, 404, 410, 417). These gaps were priority ranked by HUD and NBS, and a research program, formulated and funded by HUD, was set in motion to address the more serious deficiencies.

So-called "long-range" projects (projects requiring from two to four years to complete and therefore falling outside the Breakthrough immediacy) involved a number of technologies. These technologies are discussed below.

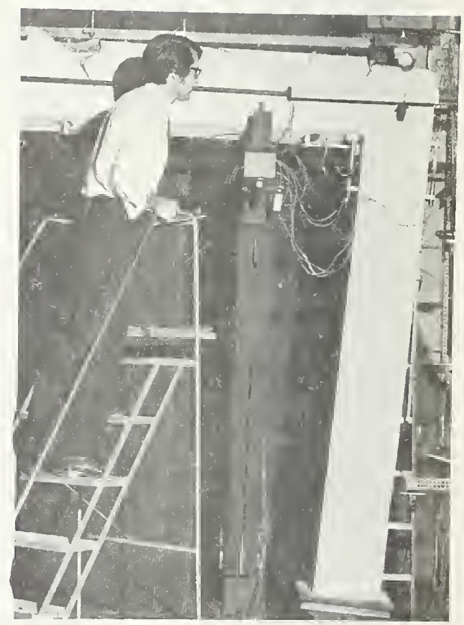
Progressive Collapse

Among the Breakthrough-inspired research projects was one addressed to progressive collapse--a structural failure which, while local in origin, travels through all or much of the building (166). Such collapses can occur when a link is taken out of a support chain--for example, when an explosion destroys a load-bearing module in a nest of modules (189), or when an abnormal load produces advancing failure, e.g., an upper floor collapses, the debris destroys the floor below, the combined debris of the two floors destroys the next floor, and so on (438).

Such collapses represent a serious set-back to the concept of industrialized building which sometimes consists of loadbearing, stack modules. Numerous HUD-supported studies were undertaken under the leadership of Dr. Norman F. Somes, and were pointed toward the development of design criteria to increase resistance to progressive collapse.

Structural Testing

Research structural engineers tested new construction materials and design approaches, their efforts directed toward the generation of performance test methods (158).



Laboratory work aimed at improved in-plane compression testing was supplemented by computer-aided analytical studies. A first draft of a standard compression test method for wall panels was presented to a task group of ASTM which was concerned with the performance of vertical components (504).

A racking test method applicable to traditional as well as innovative wall constructions was developed (173). The principal new features of the test method are: 1) the application of distributed vertical loading, 2) the adaptability of the method of testing panels of various height-to-width ratios, and 3) the provision of top and bottom edge boundary conditions which do not induce unreal modes of failure.

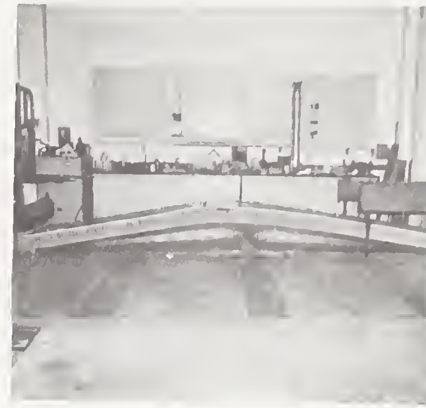
Several racking test parameters in need of further study were identified (158) and information germane to the subject of pre-test environmental conditioning was gathered, studied, and summarized.

Structural Deflections

Another longrange project that was pointed toward the preparation of structural test methods included the development of a methodology for the evaluation of the effects of floor vibration (710, 720).

Studies correlated floor vibrations with available human discomfort data, and computer programs for the analysis of floor vibration data were devised and made operable (349, 350). The overall structural deflections study included a review and compilation of related research findings (147) ranging from deflections in floors to wind-induced drift deflections. This effort led to the development of an electro-optical instrument for the measurement of drift in tall buildings (345).

Performance Standards



As a result of Operation Breakthrough, HUD realized that the development of performance standards had to be expanded to accommodate the evaluation of special and innovative construction.

Building researchers generated performance standards that were the equivalent of HUD's Minimum Property Standards in their intent and requirements and provided a basis for the evaluation of innovative construction for home mortgage guarantee purposes. Drafts of these standards were iteratively reviewed by HUD and the National Conference of States on Building Codes and Standards (NCSBCS).

NCSBCS was enlisted in this effort on the theory that if the standards were adopted by the regulatory community, those standards bearing on health, safety, and welfare--the regulatory community's concern--could be dropped from the Minimum Property Standards. The Minimum Property Standards would retain the performance standards bearing on livability, durability, etc.--on issues outside the police-power concern for the public well-being but of direct pertinence to a mortgage guarantee program.

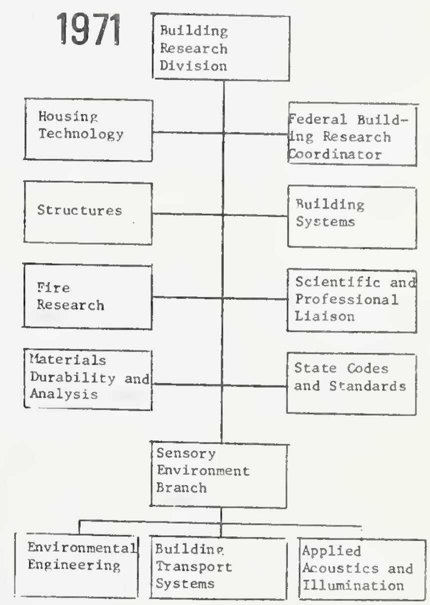
The performance standards were developed and delivered. They were not, however, made part of the Minimum Property Standards.

CHAPTER 6

REORGANIZATION AT NBS TO MEET THE NEEDS OF THE BUILDING COMMUNITY

As the Building Research Division broadened its disciplinary base, took on more varied projects, and assumed a more activist role in the transfer of technology, its organizational structure appeared less and less equal to the expanded task. A different kind of organizational unit--one more accommodating of a broad research approach--was sought for building technology at NBS, and much effort was exerted to bring this change about.

The Department of Commerce on June 12, 1972, issued Department Organization Order 30-2B creating a Center for Building Technology. Dr. Lawrence M. Kushner, Acting Director of NBS, pointed out that the new Center would provide the means for "cooperating with the States, local government, the building industry, and the consuming public in achieving greater benefit from the Bureau's long experience in building science and technology."



The Commerce Department's organization order called for strong real-world connections. "The Center shall consult," it said, "with industry, government agencies, professional associations, labor organizations, and such organizations as the National Conference of States on Building Codes and Standards...."

Moreover, while continuing a program with the National Academy of Sciences/National Academy of Engineering/National Research Council, a program providing for private sector technical advice through the instrument of a Technical Evaluation Panel, the organization order established a Policy Advisory Committee. The latter was set up to furnish policy advice to complement the technical consultation of the Panel.

Named to the Committee for two-year terms were 18 representatives of building design, construction, finance, labor, standards and codes, consumer interests, homebuilding, and building product manufacture.[27] Dr. F. Karl Willenbrock, at the time Director of the Center's parent organization at NBS, the Institute for Applied Technology, was named Committee chairman.

The creation of the Center provided an answer to what was regarded as an inefficient management system, one in which 10 or so Section Chiefs reported directly to the Division Chief. The new Center would be composed of Divisions and Offices. These Divisions and Office Chiefs would report

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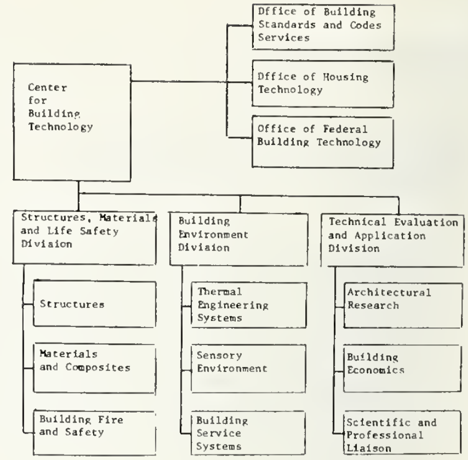
[27] Listings of committee members are presented in "Supplements" which follows the Bibliography.

directly to the Center Director. The Center Director now had more time for performing policy and planning activities.

1972-74



Dr. Edward O. Pfrang, who had headed the NBS' Operation Breakthrough effort, became the Chief of the new Structures, Materials and Life Safety Division. Paul R. Achenbach was the new chief of the Building Environment Division. Porter Driscoll was hired from HUD to head the new Technical Evaluation and Application Division.

The former Operation Breakthrough group was carried over to the new Center organization, becoming its Office of Housing Technology. James Gross became the Chief of this Office.

Two other two Offices were created by upgrading the Codes and Standards Section to Office status (under Gene Rowland's direction) and by establishing an Office of Federal Building Technology for effective collaboration with the Federal agencies. During the Operation Breakthrough effort, the Building Research Division looked for stronger relationships with all Federal agencies concerned with building and the position of Federal building coordinator was created. The Office of Federal Building Technology was an outgrowth of this position. Samuel Kramer, who served the Division as its Federal Building Coordinator, became Chief of the Office of Federal Building Technology.

With its Center status, the new organizational structure meant an enhanced capacity to serve the building community. And it gave greater and more explicit status to two key building technology activities, elevating the subject of standards and codes to an importance commensurate with the expanded program to assist building regulation, and recognizing the growth in NBS' service to other Federal agencies having building responsibilities.

Two important research functions were transferred out of the Center in 1972-74. First, a research capability in building acoustics was located elsewhere in the Bureau, and then building fire safety, was joined with other fire programs in a newly created Center for Fire Research.

An NBS decision to form a unified program in acoustics was announced just five weeks before the Center was established. The applied acoustics work of the building research program was joined with sound-centered research in the Bureau's Institute for Basic Standards (IBS). Fifteen personnel were transferred from building research to a new Applied Acoustics Section in IBS with building research retaining a liaison in acoustics. These personnel continued to be available for building acoustics studies. Meantime, the Center developed a capability in applied psychoacoustics in addition to cooperating in the overall NBS acoustics program.

The Fire Research Center, charged with developing the technical base for improved fire safety standards and design concepts and with recommending fire safety procedures, was established by the Federal Fire Prevention and Control Act of 1974. At the same time, the Congress set up the National Fire Prevention and Control Administration, also within the Department of Commerce.

Ongoing fire research in the Center for Building Technology, including work on plastic pipe, smoke movement, fire endurance of materials, and mobile home fire safety, were transferred to the Center for Fire Research. All fire-related activities were organized as a single unit--learning from one another and working toward one goal--the reduction of fire losses by 50 percent within a single generation (210).

The Center for Building Technology continued providing behavioral science expertise in program development and coordination of related NBS programs concerned with occupant safety in building fires.

CHAPTER 7

RESEARCH FOR THE BUILDING OCCUPANT

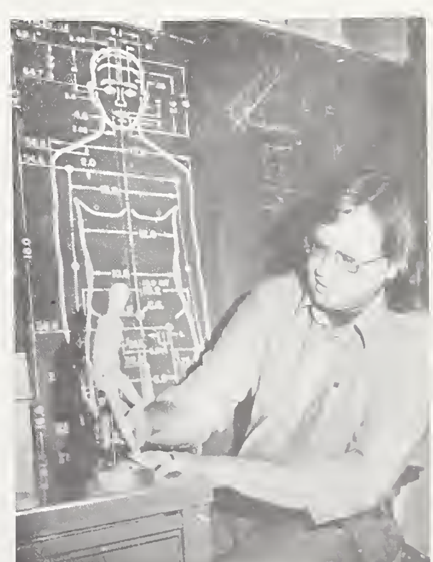
By the early 1970s, building research at NBS embraced a wide spectrum of issues--issues of technological application, building economics, building systems, the performance approach, human accommodation, and human survival.

A 1971 management report dealing with building research trends offered the following profile of how the distribution of effort had changed over a six-year period:

Program Area	1964	1970
Performance Design and Evaluation	7%	30%
Sensory Environment	18	24
Materials and Composites	58	15
Building Fire Research	11	13
Building Research Information	6	18
	100%	100%

The paper addressed the reprogramming of research funds to such research issues as noise problems in and around buildings, the evaluation of industrialized housing, and building economics. Another of the issues was energy conservation--building research management taking a research initiative on energy well before the Middle East oil embargo. (This is a broad topic with varied yet inter-locking components; a separate chapter of this report--Chapter 9--is devoted to energy conservation.)

The emphasis on application and the widened research concerns yielded projects of direct significance to the well-being of building users. These projects were made possible by the addition of new disciplines to the engineering/physical sciences core of competence. Two such projects dealt with stair safety and security.

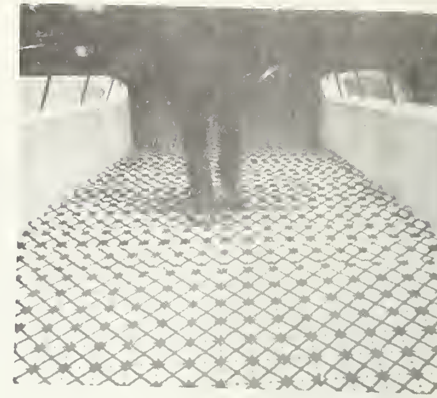


Stair Safety

Center work in the interests of safety included a stairway safety project that combined architectural psychology with the performance approach.

Researchers found that stair accidents (second only to bicycle accidents in inflicting death and injury), while caused in part by human error, are also attributable to deficiencies in either the staircase itself or its surroundings. Deceptive or distractive environmental factors all too often turn stair negotiation into a harming event.

Researchers held in view all factors operating within the behavioral-environmental system formed by the stairway and its setting. This was done with the aid of an "accident behavior model"--clusters of hypotheses formulated from a survey of the behavioral and environmental literature, a review of stairway accident reports, and an examination of codes and standards. The model first reveals the human requirements for safe stair use, then identifies the environmental prerequisites necessary to support them.



The model provides a comprehensive and coherent framework for both the research process and the ensuing performance statements aimed at diminishing the likelihood and consequences of stairway accidents. Its corroboration was achieved through an analysis of 11,000 stair accident reports, and some 50 hours of videotaped stairway use in shopping centers, airports, and similar places where at least a dozen serious accidents and more than 100 noticeable missteps were videotaped.

The performance statements were prepared for issuance by the Consumer Product Safety Commission, sponsor of the research, to guide the safe design and construction of new stairways and stairway surroundings, and the remodeling of existing stairways. However applied, these statements will extend well beyond tread and riser dimensions and the handful of other considerations to which the subject of stair safety has been traditionally confined.

Security

Security was among other "people concerns" addressed by building researchers. The National Institute of Law Enforcement and Criminal Justice funded a Center project designed to develop performance standards and guidelines for door and window security.

Prompted by a 31 percent increase in residential burglaries over a few years with annual losses running to more than $500 million, the Institute sponsored NBS investigations which led to the development of test methods for evaluating the security performance of door and window constructions. Recommended standard test methods were developed for measuring the resistance of doors and windows to forced entry (870, 871).

User Requirements

In recent years designers and builders have been actively attempting objective definition of the requirements of users in the home. Traditionally, the architect has employed his judgment in specifying the needs of users, but the users themselves have wanted a voice in the design process.

If we want to learn what the user needs in the home, why not ask him? Unfortunately, the process of asking has proved more of an art than a science. Simple questions have led to simple answers, and in fact have resulted in many more questions than answers. The design of standardized "test instruments" has proved to be an elusive goal.

The Center prepared a state-of-the-art review to 1) explore questionnaire design, and 2) cover other methods that might be used in developing user information. The review is designed to provide a fairly thorough compilation of the "tools" available to collect data and gives a handbook approach on how to use such "tools." In addition, it introduces methods for collecting related information via other disciplines. Selected studies are illustrated in some detail.

Questionnaires and other techniques developed by architects, psychologists, and sociologists were used to measure occupant response to Operation Breakthrough housing. A principal finding was the occupants' emphatic acceptance of industrialized housing, clear indication that the "prefab" stigma which marked the post-World War II era had all but disappeared.

Another finding of the feedback study challenged the commonly held belief that old people prefer to live amid children. Survey findings suggested a marked annoyance on the part of oldsters with the noise, toy litter, and danger (e.g., colliding with a rollerskater) implicit in a child-rich neighborhood.

Perhaps a key gain in Project Feedback, however, was the development of a methodology for eliciting the response of people to their housing. Researchers began the preparation of a handbook containing the base survey methodology with sections to cover security, safety, and other topics. Although developed for housing, the methodology can be adapted for use with other building types such as office buildings and hospitals.

Psychophysical Approach

One approach used by the Center in man/environment relations is the psychophysical approach. This approach seeks a causal relationship between environmental conditions and human behavior. For example, does noise of 110 dBA awaken a sleeping person? Psychophysics links a behavioral parameter with a physical parameter which can be quantified (in the example, at 110 dBA). Thus it is possible to write design criteria with specific numerical values. Such criteria are meaningful for designer and procurer alike, and if the issue is part of the set of concerns of building regulation, for the regulatory official as well.

Acoustics

Acoustics research has a history at NBS that dates back to 1919. That NBS is regarded as a source of acoustic engineering data is evidenced by yearly sales to architects and acousticians of several thousand copies of publications on noise control. George E. Winzer gave the building acoustics program its early impetus, and Daniel R. Flynn led expanded studies of noise in and around buildings.

The handbook, <u>A Guide to Airborne, Impact, and Structure-borne Noise Control in Multi-family Dwellings</u>, which NBS prepared for HUD, provides an extensive compilation of data on the sound insulation of wall and floor/ceiling assemblies (942). In addition, this publication provides a discussion of airborne and impact noise criteria for buildings and an extensive collection of detailed architectural drawings which illustrate acoustically important building construction and installation techniques.

Other NBS activities in building acoustics included examination of simplified procedures for measuring the airborne noise isolation between rooms (939), a review of procedures for measuring impact noise generation and transmission in buildings (751), and development of an apparatus for measuring the forces applied to floors by human footfalls (938). The NBS reverberation room was instrumented to enable computer-controlled, rapid determination of the acoustical absorption of architectural materials such as acoustical tile and carpet (943). NBS also sponsored an extensive investigation at the Owens-Corning Fiberglas Research Center of the sound insulation of residential exterior walls, doors, and windows (170).

The Environmental Protection Agency, with NBS' cooperation, prepared a report for the President and the Congress on the problem of noise. NBS produced several extensive reports containing backup material for the report (752, 753, 754, 810).

The Congressional and Executive Branch activity reflected the fact that noise had become a matter of national concern. Environmental noise was increasing in pace with the nation's technological and economic growth. Other activities developed improved procedures for measuring noise emission from stationary and moving sources (332, 460, 471, 482, 487, 488, 935, 936, 937), evaluation and development of noise-measuring instrumentation (941), and examination of sampling procedures for community noise measurements (495).

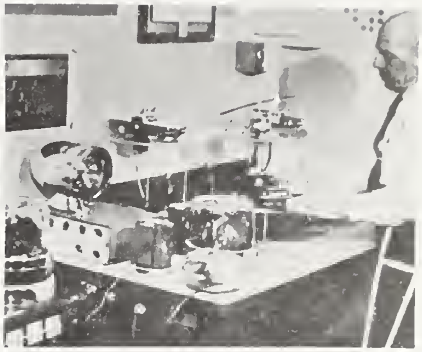
Illumination

The visual environment is another research concern of Long standing at NBS. One investigation was based on the premise that a high-quality lighting system at lower luminance levels can be more effective than a system of high luminance levels but poor distribution, producing veiling reflectance which partially obscures details of the viewed piece. This thesis was preliminarily validated and additional measurements were undertaken.

Another study questioned the validity of the existing method for measuring the relationship of luminance to visibility. In testing human subjects, the research approach used situations that are more "real world," e.g., presenting the customary black type on white paper, than traditional experimental methods. Early findings raised doubts about the validity of traditional methods and suggested that currently specified levels of illumination, based upon these methods, are too high.

Indications are that different levels of illumination are required for different activities. Studies were conducted to determine visibility or legibility of lined gratings and of alpha-numeric charts at different luminance and contrast levels for equal clarity. This work dealt with four levels of visibility--1) detection, e.g., seeing an object; 2) recognition, seeing that the object is a ball; 3) identification, seeing that the ball is a baseball; and 4) degree of identification, seeing that the baseball is an official American League baseball. The promise of these investigations is greater visibility and reduced use of energy for illumination.

Color



The NBS history in colorimetry goes back to the Bureau's earliest days and has yielded, among other contributions, the Inter-Society Color Council NBS color designation system. The colorimetry program was placed in the Institute for Applied Technology in 1969, and the following year much of this program was located in the Applied Acoustics and Illumination Section of the Building Research Division. Later the program was made part of the Sensory Environment Section in the Center's Building Environment Division.

The color scientists' work included color coding for safety, the objective being the development of precisely defined colors with explicit safety meanings. This work was carried on by Kenneth L. Kelly and Gerald L. Howett, both of whom had had a long association with the NBS colorimetry program and the late Dr. Deane B. Judd, the Bureau's world-renowned color authority. Another color scientist, Gary Yonemura, turned his attention to light and more accurate simulations of illumination requirements for image clarity.

Lead Paint

It is estimated that as many as a half million American children could have excessive lead levels traceable to lead in air, water, food, and dust (318). A major source of lead poisoning may be painted surfaces. In addition to the natural tendencies of small children to chew and teethe on nonfood items, some children attempt to seek out and ingest lead paint (729). Dried, peeling paint on walls, woodwork, and other accessible surfaces represents a health hazard to these children (730), especially when the paint contains lead compounds. High body burdens of lead result in severe neurological damage, including mental retardation, and, in some cases, death.

HUD was directed by the Lead-Based Paint Poisoning Prevention Act of 1972 to conduct a research and demonstration program that would determine the nature and extent of lead paint poisoning, and to evaluate methods for the detection of this hazard and its elimination from housing. HUD requested NBS' scientific and technical support. In response, NBS organized a multidisciplinary lead paint team headed by Harvey Berger and composed of chemists, engineers, mathematicians, systems analysts, housing technologists, and others (323).

To determine the magnitude of the lead paint problem, NBS developed a mathematical model for estimating the incidence of lead poisoning in 241 metropolitan areas (733). Following a pre-test in Washington, D.C., a procedure including survey plans, techniques, and analytical methodologies was developed for carrying out a major-city statistical survey of housing for lead paint hazards (456).

Chemical methods used in laboratory and field to detect lead in paint were evaluated (742). Portable x-ray fluorescence lead detectors were exhaustively evaluated and characterized (442), and new guidelines for their use by housing authorities were prepared. A Lead-Based Paint Standard Reference Material was developed for use by laboratory chemists in calibrating and standardizing lead paint analysis procedures (200).

A testing and evaluation program was conducted to determine potential usefulness of hazard elimination methods which were identified as a result of a comprehensive survey of industry (325, 335). Pilot demonstrations of hazard abatement techniques were carried out in Washington, D.C's housing in anticipation of a large-scale hazard abatement demonstration program (443, 458).

As HUD's research needs and objectives became more clearly defined, the responsibilities of the Lead Paint Project, under the leadership of Harvey W. Berger, expanded into several area. These included a technical evaluation of HUD's development contracts for improved lead detection devices and innovative abatement methods, technical evaluation of HUD's Experimental Hazard Abatement Program involving 250 dwellings distributed among a number of major cities, and analysis of housing and lead poisoning incidence data derived from a major-city survey. The Lead Paint Project team also was asked to participate in further efforts to identify and evaluate innovative abatement methods and to develop an information dissemination program on lead poisoning.

CHAPTER 8

REACHING THE APPLICATION POINTS

The mission of the Center for Building Technology includes the diffusion as well as the generation of technology. One of the Center's more significant diffusion activities is its traditional participation in the formulation of voluntary standards.

Standards Participation

The contributions to the committees, A40 Plumbing Code and A112 Standardization of Plumbing Materials and Equipment, operating under American National Standards Institute (ANSI) procedures, are typical of how technical information is carried to points of application through standards participation. These contributions have included recommended technical bases and updated design criteria for establishing storm loads or flow capacities, for limiting the lengths and sizes of piping system components, and for the design of reduced-size venting.

Building research personnel hold approximately 300 memberships on standards-generating bodies, occupying chairmanships or other offices on many of these. Taking note of this extensive and critical role in standards work, building research management in 1973 established a Standards Management Council to effect a coordinated program in standards generation.

A standard is usually prepared under a consensus procedure that accommodates the investment and trade interests affected by it. Participating Bureau personnel, on the other hand, have no vested interest and are thus free to represent the general or public interest. Their work in upgrading standards ultimately upgrades the system of building regulation since codes are essentially reference documents based on citations of existing standards and materials specifications.

Working with Other Agencies

Federal builders and building operators have all the headaches of their counterparts in the private sector. Theirs are real, on-line problems. Accordingly, research addressed to the solution of these problems produces results that tend to win ready acceptance at the Federal level and rapid diffusion in the building community through demonstrated performance.

Frequently NBS and collaborating agencies explicitly set out to effect a "demonstration"--as in the case of the previously-discussed performance specification for office buildings for the Public Buildings Service (PBS). Another PBS demonstration was planned for a Federal office building, the design of which would incorporate a host of energy-saving techniques and devices with the object of reducing the building's energy consumption by one-third of what was considered normal for an office building of its size.

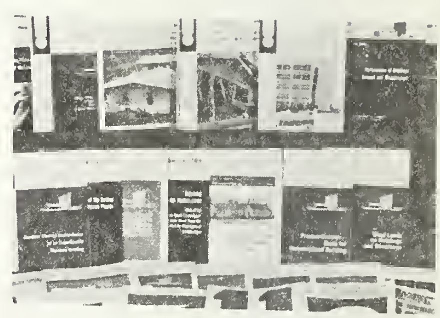
Assistance in developing Federal procurement specification procedures benefits the agency in question and the Federal government generally through the family of federal specifications produced by the General Services Administration. Further benefits accrue to the public through adoption of improved practices in voluntary standards and from producers making improved products available to the general public.

Information Dissemination

Publications are a key part of the technology transfer program. More than 100 publications are prepared each year by the research staff.

While most of these publications are addressed to technical and professional audiences, consumer brochures also are produced. Two brochures, "7 Ways to Reduce Fuel Consumption in Household Heating...through Energy Conservation," and "11 Ways to Reduce Energy Consumption and Increase Comfort in Household Cooling," had a distribution of more than one million.

The brochures have been the basis of television "spot" messages and have been cited by a number of popular publications. These booklets were prepared in 1971-72 under the leadership of James L. Haecker, Chief of the Scientific and Professional Liaison Section, in collaboration with the Sensory Environment Branch. They were developed from historical knowledge at NBS and were in wide circulation by the time the Middle East oil embargo struck the nation in 1973.



Interaction with the Building Community

Both formal and informal relations were maintained with the building community. The formal research associate program carried out in cooperation with industry brings about a cross-fertilization between NBS building research laboratories and those of the private sector. Guest worker arrangements were maintained with a number of building product manufacturers, universities, and professional and trade organizations. The findings resulting from such joint programs are disseminated to the building community.

Building research personnel hold memberships in over 70 professional organizations, and research alumni have carried measurement techniques and knowledge acquired at NBS to industry, the professions, and the academic community. George Washington University offered a course in the performance approach to building that was taught by a team of three former building researchers at NBS.

NBS in 1973 established an architect-in-residence program with the American Institute of Architects. The program each year brings to the Bureau a practicing architect for the purposes of sharing building knowledge, strengthening the architectural community's relationship with NBS building research, and sharpening the direction of research to better serve design practitioners.

Guest workers are brought to the NBS building research activity under various arrangements, including the Intergovernmental Personnel Act, and under such titles as Senior Research Fellow, Post Doctoral Research Associate, Presidential Intern, and United Nations Guest Worker. With such programs as these the Structures Section, for example, is rarely without one or two guest workers.

Foreign Activities

While acknowledging the regional or national uniqueness of building problems found around the world, building research management noted the presence of "large areas of common interest." Management felt that these areas "should be discovered, discussed, and divided among interested nations in such a way that solutions can be found efficiently and without duplication of effort." William R. Herron was named to head a program in international coordination.

A report summarizing the 1972 international activities of the Center listed four cooperative programs, 10 exchange (of professional visits and literature) programs, and three special projects (457).

The cooperative programs included that conducted with the Centre Scientifique et Technique du Batiment (CSTB). This program embraced projects in environmental engineering, materials durability, wind loads on structures, fire research, building acoustics, building evaluation mechanisms, plumbing, and building economics.

The complementary program established with the United Kingdom's Building Research Establishment in 1971 set as its initial goal an exchange of documents and visits and made provision for extension of the program to include long term exchanges of professionals and joint research projects. And the US/Japan Panel on Wind and Seismic Effects, a cooperative program conducted with the Japanese Public Works Research Institute, Ministry of Construction, exchanges information, specialists, technical data, and research equipment.

Other exchanges of building information and professional visits were conducted with building research units in Australia, Canada, Denmark, Ghana, India, Japan, New Zealand, Norway, South Africa and Sweden.

NBS Special Foreign Currency Program projects were conducted with India, Israel, Pakistan, Poland, the United Arab Republic and in 1972 numbered 10. These projects were made possible by an excess of foreign currencies which accumulated as a result of the conduct of U.S. government business abroad. Project criteria under this program include requirements that projects "benefit both the U.S. and the participating countries" and that they be "within the main stream of NBS interests."

Additionally, as previously indicated, the Center supported the U.S. Agency for International Development efforts to make low-cost housing in developing countries more resistant to windstorms and earthquakes. As a special project the Center furnished assistance to Nicaraguan authorities following the December 23, 1972, Managua earthquake.

The 1972 report also noted Center membership and participation in such international organizations as the Reunion Internationale des Laboratoires d'Essais et de Reserches sur les Materiaux et les Materiaux (RILEM) and the Conseil International du Batiment pour la Recherche l'Etude et la Documentation (CIB). The efforts of the Center in its foreign/international activities dealt with the transfer as well as the generation of technology and resulted in a number of translations of French reports for the American building community.

A major publication was Industrialized Building in the Soviet Union (202), the result of a visitation conducted under the US/USSR Exchanges Agreement which in 1969 brought a Soviet delegation to the United States and sent a team of U.S. building community leaders to the USSR. David Watstein, former Chief of the Structures Section and at the time Structural Research Manager of the Structural Clay Products Institute, was instrumental in making arrangements for the visit and served as interpreter for the American team which was especially interested in Soviet inovations in building products and processes.

CHAPTER 9

CONSERVATION OF ENERGY

By the mid-1970s the word energy held profound lifestyle and pocketbook implications. Energy conservation was becoming a pervasive concern. Buildings, responsible for a third of the nation's energy consumption, figured prominently in conservation efforts, and conservation became a principal concern of building research at NBS.

The research interest in energy at NBS rested on a tradition of energy-related measurements and investigation. This longstanding interest provided a foundation for anticipation of the domestic energy shortage by the Building Research Division as early as 1970. The research program in energy conservation was initiated by Paul R. Achenbach and was augmented by the timely arrival of Dr. Charles Berg, who came to the Bureau from the Massachusetts Institute of Technology in 1971. As the program grew in size and involved additional NBS organizational units, it was placed under the leadership of Dr. Jack E. Snell.

Energy developments unfolded at NBS from laboratory, field, and analytical studies. Among them were the following:

Thermal Load Determination

Dr. Tamami Kusuda in the late 1960s began to develop, under the sponsorship of the Department of Housing and Urban Development, a computer program to help architects and engineers predict the thermal performance of a building. Important enough at the time, this work was to balloon in significance in the context of energy shortages and rapidly escalating energy prices.

The program was named the National Bureau of Standards Load Determination (NBSLD) program (477). In the use of NBSLD, it is necessary to input outdoor weather conditions, design details of the building, and the planned schedule for operating the building. Algorithms of NBSLD operate on these data and predict the heating and cooling load.

Loads are predicted on a dynamic or time-varying basis, taking into consideration, for example, lag induced by the thermal storage and transmission characteristics of the building's mass. Attention to dynamics contributes to the proper sizing of heating and cooling equipment; steady-state calculation techniques can lead to oversizing and thus to operating inefficiencies that waste energy.

NBSLD's distinctiveness among thermal load calculation programs lies in its philosophical approach. Instead of taking the building envisaged as an unalterable given upon which to simply determine the kinds and quantity of heating/cooling equipment, NBSLD invites manipulation of the building design scheme toward the goal of greater energy efficiency. It can be taken so far as to profile the hour-to-hour indoor temperatures that would prevail without mechanical heating or cooling.

Such profiles can point to energy-saving opportunities. Where summer weather is moderate, for example, they may suggest the possibility of avoiding mechanical cooling by adjusting one or several variables in the design. Long, moderate spring and fall seasons also may offer natural ventilation opportunities even where winters are cold and summers are hot.

The ability of NBSLD to predict the thermal performance of two full-scale buildings was determined experimentally in the Center's threestory environmental laboratory (145). The first building, of heavy masonry materials, was designed for very little air leakage. The heat transfer characteristics of the building were studied under cyclic "outdoor" air temperature conditions in the laboratory. This was done first without any room heat being added, and later with the indoor air heated and the temperature under thermostatic control.

Several tests were made for each type of operating condition, but with different insulating conditions of the exterior walls and with varying fenestration arrangements. The difference between the predicted and observed values of indoor temperature did not exceed one half of one degree Celsius in all the tests performed. The difference between the measured and predicted maximum heating load was less than 8 percent.

The masonry building was intentionally designed for experimental simplicity. A second, lightweight building was considerably more complex to model and was used to extend the NBSLD validation exercise (157). This was a full-scale house composed of three "box" modules of insulated frame construction. The modules were joined inside the environmental laboratory forming the house. The four-bedroom house had a floor area of about 112 m^2 (approximately 1200 ft^2) and was factory-equipped with a warm-air furnace and air-conditioner. It was fully furnished for the tests, and all heat release functions for a family of six were simulated.

A summation of curves plotted for predicted and observed energy consumption indicated a disparity of only 5 to 10 percent for a 24-hour test. NBSLD predicted peak heating and cooling energy requirements within 8 percent.

The laboratory studies of the two buildings revealed the ability of the NBSLD computer program to accurately determine varying heat transmission rates in buildings of different heat capacity under changing outdoor conditions and with typical patterns of indoor heat release.

NBSLD is being continually updated and improved with respect to its basic heat transfer data, mathematical procedures, and input/output handling. The precision of the program is approximately 5 percent.

Some of the unique applications of NBSLD are to:

- Determine the effect of interior partition walls or floor-ceiling sandwich structures on the heat storage characteristics of a room
- Evaluate intentionally undersized heating and cooling equipment, permitting room temperature and humidity deviations from a design set-point in order to determine whether indoor conditions remained within acceptable limits
- Evaluate an indoor thermal environment of various zones during the intermediate season, such as spring and autumn, when the heating or cooling requirements for some zones may not be in phase with that of the building as a whole
- Calculate solar energy for heating and cooling buildings
- Design heating and cooling systems and equipment on the basis of intermittent operation, such as shutdown of air-conditioning facilities when the building is not in use
- Effectively plan a ventilation schedule to minimize the heating load during the winter season.

Because of its unique features and reliability, NBSLD has been gaining gradual acceptance by many who are actually pursuing an energy conservation objective through building design. Moreover, the algorithms employed in NBSLD have been adopted by the American Society of Heating, Refrigerating and Air-Conditioning Engineers as a recommended procedure for computerized energy calculations.[28]

Indoor Air Quality

The high cost of energy raised questions which suddenly acquired new pertinence. What is a reasonable contaminant burden for a building environment? What, if any, health hazards should be risked? And what, if any, comfort sacrifice should be accepted? These questions were prompted by the energy predicament, energy conservation suggesting the use of greater amounts of recirculated air and less fresh air.

Center researchers in their investigations of this subject measured the airborne particulates contributed by cigarette smoking, cooking, cleaning, and aerosol spraying. These measurements contributed to the hard data necessary for ventilation practices appropriate for a time of uncertain energy supplies and escalated energy costs.

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[28] ASHRAE Special Publication, "Procedures for Determining Heating and Cooling Loads for Computerized Energy Calculation," 1975.

Air infiltration may be the prime factor behind 10 to 50 percent of the heating and cooling load. Infiltration is determined experimentally by measuring the decay of a tracer gas distributed through the building. The decay rate makes possible a calculation of the infiltration rate.

Dr. Charles Hunt developed a procedure which uses sulfur hexafluoride (SF_6) as the tracer gas and adopts a commercially available leak detector which can measure minute amounts of the gas (157, 842, 843). So sensitive is the detector that a volume of SF_6 no greater than that of ping-pong ball is enough to measure the rate of infiltration in a 500 m^3 (18,000 ft^3) house.

The correlation of the infiltration rate with weather conditions, e.g., temperature and wind, requires repetitive measurements over as wide a range of conditions as possible. Thus a semi-automated version of the procedure has been developed. From a number of locations within a building an apparatus collects the necessary concentration-versus-time data for infiltration measurements.

As with the work in air quality, the infiltration investigations are aimed at producing a quantified understanding of a wide range of infiltration combinations. One general observation made in the course of early measurements, however, is that cracks around windows represent only a small part of the total leakage path in a house.

Office Building Demonstration

In May of 1972, the General Services Administration (GSA) joined with NBS in sponsoring an Energy Conservation Roundtable for the purpose of gathering from participants--30 designers, engineers, executives, and government officials--techniques for conserving energy in buildings.

While the conference only scratched the surface of conservation possibilities, it produced agreement that much could be done to reduce energy consumption in buildings. GSA announced to the conference its intention to test that premise by having an energy-conserving building designed and constructed.

GSA said it would construct the building in Manchester, N.H., and that it would demonstrate to the building community various conservation strategies. The building's size, shape, climate orientation, thermal transmission characteristics, the performance of the mechanical and electrical systems, and the use of supplementary solar apparatus were factors considered in the design.

The Center used the NBSLD program to calculate the annual energy requirements (171). Design options for energy conservation were introduced sequentially into the program to reach a recommended design. This design, predicted a

53 percent energy saving over a conventional office building.

The building, completed late in 1976, will be the subject of field measurements pertaining to the use of a gas engine to drive an air-conditioning compressor and a generator for emergency power in case of power failure, and the integration of a solar collector into the mechanical system to further reduce fuel and electricity consumption for domestic water heating and absorption air-conditioning. The Center designed and prepared the purchase specifications for the instrumentation and data acquisition system. Among the concerns of the demonstration at Manchester are occupant thermal comfort and illumination requirements.

Total Energy

Another full-scale field study, this one carried out under HUD's sponsorship, was undertaken at an Operation Breakthrough complex in Jersey City, N.J. The complex consists of four buildings containing 485 apartments for 1250 residents, a 4,650 m^2 (50,000 ft^2) office building, an elementary school, a swimming pool--and a total energy system. The on-site total energy utility furnishes all electricity, hot water for space heating and domestic use, and chilled water for air-conditioning. It also collects solid waste by a pneumatic system and compacts it for removal from the site.

Essentially, total energy takes the combustion energy normally lost to the environment in electrical generation, putting this energy to work in space heating and cooling. The Center prepared the performance specification for the total energy system's design, operation, and maintenance. In work sponsored by HUD, the Center designed and installed a system of 300 digital channels and six analog channels to collect performance information on the total energy plant (497). The system records information on the electricity generated, fuel burned, heating and air-conditioning performance, costs, and system maintainability and reliability. The system also records voltage and frequency transients whenever an electrical malfunction occurs in the plant. An NBS minicomputer facilitates analysis of the data.

Early Solar Work

Solar energy work conducted in 1970 was connected with the NBSLD prediction program. From incident solar radiation data gathered over the cloudy/clear day spectrum, comprehensive solar radiation routines were developed for NBSLD.

About the same time, total hemispherical radiation, diffuse sky radiation, and ultraviolet data were collected in a study of the effect of various types of ground cover on earth temperatures to depths of 9 meters (30 feet). This work showed that ground temperatures in summer can be as much as 15°C (27°F) higher under an unpainted paved surface than under a grass-covered surface.

Begun in the late 1950s, the underground studies were undertaken in connection with fall-out shelter environments and heat distribution systems. The findings of this work are of obvious importance to campuses, shopping centers, and to any building complex, city, or even region where thermal energy is produced in a central plant (directly or as a byproduct of power generation) and delivered through a distribution network.

Insulation

The early energy work in building technology at NBS dealt largely with thermal insulation. A 1971 projection by the Bureau showed important savings potential in the use of insulation. Based on a projected increase in the nation's housing stock from 60 million units to 100 million units over a 25-year period, and assuming modest thermal performance improvements over present construction, the projection showed potential cost savings of from $100 billion to $500 billion, depending on the annual rate of energy price increases. (Increases of 2, 4, 6, 8, and 10 percent were calculated in the projections.)

Symposia

The Thermal Engineering Section of the Building Environment Division, in addition to developing computer programs for its own research purposes, e.g., NBSLD, through symposia helped to advance the use of computers in environmental analysis, the start of which was sluggish compared with the rate of use in structural engineering, for example: The "First Symposium on the Use of Computers for Environmental Engineering Related to Buildings," jointly sponsored with the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and Automated Procedures for Engineering Consultants, Inc., drew 500 architects and engineers to Gaithersburg, November 30-December 2, 1971. The published proceedings of this symposium, which included 59 papers from 12 countries, became a landmark in the use of computers in environmental engineering (139).

The second symposium on the same subject was held in Paris in June, 1974. The proceedings were accepted for publication by the Comite Scientifique et Technique de L'industrie du Chauffage, de la Ventilation et du Conditionement D'Air.

Mean Radiant Temperature

The telling measurements for comfort are those which center on the occupant of the building. It is generally accepted that the primary variables governing comfort are temperature, relative humidity, air velocity, mean radiant temperature, the metabolic rate of the occupant, and the clothing worn.

The mean radiant temperature (MRT) is defined by ASHRAE as the temperature of a uniform black enclosure in which a solid body or occupant would exchange the same amount of radiant heat as in the existing non-uniform environment. A globe thermometer is commonly used to measure MRT because it integrates the effects from all directions into a single reading. But it does not evaluate the asymmetrical aspects of the environment.

NBS designed a scanning radiometer which measures the surface temperature in any direction or measures and records a 360 profile by automatically rotating the instrument a full turn. The radiometer is being used to study the pattern of mean radiant temperature before and after thermal improvements. Such studies provide greater insight into the intricacies of thermal comfort (831).

Modular Boilers

The potential for increased efficiency in substituting several small boilers for one large boiler was investigated in the laboratory under a range of heating loads. Large boilers make the match with fractional loads by intermittent operation or cycling. Experience indicates that any central heating device suffers a decrease in operating efficiency as the percentage of running time decreases.

In the modular arrangement, the small boilers or modules are sequentially fired to match the heat output in the load. The efficiencies of various combinations of the boilers, with several variations in the control systems, were measured and the results plotted to give efficiency versus load curves. While four of the five combinations set up for the measurements showed no greater efficiency with the modular configuration, one combination did produce higher efficiencies for all loads below about 70 percent of the maximum heating load.

The improved efficiency amounted to 7 to 8 percent at 25 percent of full heating load. This combination consisted of four small boilers with primary pumping in which water was circulated through all four boilers, with pilot lights turned off in modules not in use at a given load, and with secondary valving allowing water to flow through only the boilers that were operating.

Solar Test Methods

In late 1973 Dr. James Hill undertook the development of standard test methods for solar collectors and thermal storage systems. The National Science Foundation (NSF), which had a research program addressed to solar collectors and heat storage systems, engaged the Center to help fill a need revealed by this program-the standardization of test procedure as a basis of comparison for both prototype and commercial hardware in the solar field. Draft standards were transmitted to NSF and ASHRAE (484).

During the course of developing test procedures, the Center was asked to perform an evaluation of the instrumentation and planned use of a transportable solar heating and cooling research laboratory built for NSF by the Honeywell Corporation. The laboratory consists of an equipment van and mobile home linked together and heated and cooled by a solar system. Transducers measuring the critical parameters of insulation, temperature, and fluid flow rate were calibrated and specific recommendations were made to ensure that significant data would be taken by the portable laboratory.

Solar Retrofit

The factory-built house used in the experimental validation of the NBSLD in 1972 and 1973 was exploited further in a solar retrofit project. The procedure followed in the validation exercise exposed the house to various environmental influences while maintaining an interior temperature of 24°C (75°F). The hourly heating and cooling input energies were measured and compared with predicted values.

Thus actual in-use data were assembled; these data, as it turned out, formed a conventional energy base against which to evaluate the performance of the house when solar equipped.

The house was retrofitted with 45 m^2 (485 ft^2) of flat-plate collectors having water/ethylene glycol as the transfer fluid, fluid storage facilities, and an absorption air-conditioning unit integrated into the house's existing forced air system. The performance of this system during typical summer and winter operation was to be compared with that of the gas-fired furnace and electric air-conditioner as recorded in the earlier measurements. Some 15 different solar energy systems can be simulated as a basis for developing methods of measurement and criteria for solar energy system performance.

Utility Integration

The Center under the leadership of Clinton W. Phillips furnished both technical and programmatic support to HUD's Modular Integrated Utility System (MIUS) program, a program with implications not only for energy but for the environment and human settlement patterns as well.

MIUS, like total energy, generates electric power at the site of its consumption and captures much of the heat energy this process normally loses to the environment (about 65 percent) for use in heating or cooling buildings and in providing domestic hot water. But MIUS goes further, encompassing potable water services, the treatment of liquid waste and the use of the resultant effluent as a cooling agent in utility or industrial processes. MIUS also reduces and exploits solid wastes by extracting their energy content through burning.

Insulating Glass

Factory-sealed, double-glazed insulating window units are intended to provide a permanently sealed air space between two or more panes. The air must be held at a moisture content or frost point so low that no moisture will condense between the panes. This is essential because condensation over a long period may leave a cloudy film on inaccessible glass surfaces.

Double-glazed insulating glass units have relatively high thermal resistance which reduce heat loss in winter and heat gain in summer. But because of their high first cost, there is great need for standard test methods to evaluate the quality, service life, and durability of sealed insulating glass units.

A "Seminar on the Durability of Insulating Glass," held at the Bureau in 1968 under the sponsorship of NBS and the American Society for Testing and Materials (ASTM), produced the idea for a project to develop an insulating glass test method (120). ASTM sponsored a Research Associate at NBS and Dr. Mahn Hee Hahn, the Research Associate, developed a dew-frost-point measuring apparatus that controls the temperature within a half-degree Celsius and can measure the repeatable dew-frost-point within a half-degree Celsius.

Heat Pump Evaluation

A project to evaluate the performance of heat pumps was initiated in 1973. This project was aimed at determining the potential energy savings that might result from the employment of more innovative heat pump systems. Basically the heat pump works like a refrigerator or air-conditioner, transferring the heat from one space to another, except that in the heating cycle, the heat is transferred to the interior of the building, and in the cooling cycle, the heat is expelled from the building.

Usually operated by electricity, the heat pump can deliver two or more times the heat energy produced by resistance heating, the most common form of electric heating. A heat pump may reduce electric heating bills by 30 to 50 percent or more, depending on the climate.

Center engineers set out to develop a laboratory test procedure that would simulate field conditions and thus yield realistic the actual efficiency values. By studying heat pumps under both laboratory and field conditions, the Center documented the actual part-load performance of the present-day electric heat pump. This information facilitates estimates of expected seasonal performance of heat pumps in various climates, and it provides a basis for decisionmaking in energy conservation.

Besides laboratory, analytical, and field studies, the energy research program at NBS dealt with the economics of energy conservation and with the implementation of energy conserving technology.

The long era of relatively cheap energy produced buildings, heating and cooling equipment, and control systems that emphasized low first costs. When energy prices rose sharply, builders, financiers, and government policy makers were not prepared to identify the cost-effective levels for many of the known techniques for improving the energy efficiency of buildings, mechanical and electrical equipment, and industrial processes. This area of the Center research program was directed toward better economic guidance in improving the energy performance of buildings and equipment. It was also intended to assure lending institutions and owners alike that energy conservation makes financial sense.

In one project, for example, an economist reasoned that the huge increase in energy prices and the unevenness in prices between electricity, fuel oil, and natural gas were bound to impact the question of what constitutes adequate insulation. He found the situation so drastically altered that a Washington, D.C., homeowner's heating bill suddenly read as if his house had been whisked to Minnesota. To be sure, he needed more insulation. The question was--under radically changed prices--how much more?

In cooperation with the Federal Energy Administration, CBT economist, Stephen R. Petersen conducted a study which showed homeowners just how much insulation to install in order to get the maximum return on their investment. The study dealt with such variables as climate, energy prices, and the cost of the thermal improvements, and came up with answers sensitive to these variables. While 230-300 mm (9-12 in) of insulation for attics in oil-burning houses generated the greatest savings in heating and cooling in all but the mildest climates, the study found that 150-230 mm (6-9 in) of attic insulation was economical for gas heated houses in most climates, and that 300 mm (12 in) or more was recommended for houses which are both heated and cooled electrically (163, 601).

In short, thermal improvements that reflect the variation in fuel prices, and the cost of the improvements themselves, yield greater benefits than recommendations taking into account climate alone.

CHAPTER 10

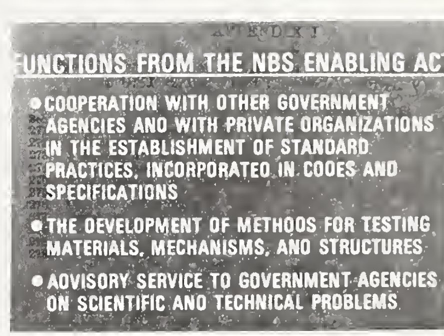
A MATURING CENTER FOR BUILDING TECHNOLOGY

Increasingly, buildings were being perceived less as structures and more as conditioned spaces for people and their activities--a shift in perspective due in part to the energy problem, and due in part to the increased concern bestowed upon the building user. The energy efficiency of buildings was becoming as common a notion as the gasoline efficiency of automobiles.

All building issues, whether energy-connected or not, were enlivened by this fresh perception. Furthermore, virtually all issues ran the risk of being overridden in the name of energy efficiency--all were subject to trade-off in the interest of energy.

Rational trading off cannot be done, however, without a sense, if not a measurement, of the value of that which is being sacrificed. Reducing a house's volume may be an excellent way to reduce its energy needs, but at the same time, it is a step that compels examination of the value of the spatial sacrifice--functionally, psychologically, esthetically, etc.

Energy was just one of the concerns to catch the attention of the nation and to find expression in national legislation. Other issues spawned legislation, too, and many of the measures that were adopted held express or implied meaning for building researchers at the Bureau who conduct their activities, basically, in the context of two laws. One, Public Law 177, established the Bureau in 1901, and the other, Public Law 619, was enacted in 1950, elaborates upon Bureau functions. These functions included testing materials and structures; cooperating with others in establishing standard practices, specifications, and codes; and determining the properties of building materials and structural elements.



While responsibilities stemming from founding legislation remained central, additional demands--legislated and otherwise--were placed on the Bureau and its building researchers. An ability to identify what needed to be measured and to make the measurements, the Bureau's close connection with the standards world, and its third-party objectivity were among the factors that made NBS an attractive resource. Additionally, the Bureau was credited with having the requisite competence to address some of the acute technical problems facing the nation. By 1974 the Bureau's focus had shifted, announced NBS Director Richard Roberts, from measurement standards to "new national concerns," e.g., pollution, safety, personal security, energy, and consumer protection.

A dozen or so separate pieces of legislation adopted from 1965 to 1974 gave Congressional assignments to NBS. Some of the measures placed explicit responsibilities on NBS building researchers while others appeared to be likely generators of Bureau research.

The research implications of the Housing Act of 1968 were discussed earlier. The Occupational Safety and Health Act of 1970 was to result in Center involvement in research aimed at understanding and reducing or ameliorating accidents at places of employment including building construction sites. The Consumer Product Safety Act of 1972 directed the Consumer Product Safety Commission to use the Bureau to "perform research, develop test methods, and provide technical assistance." The language of the Noise Control Act of 1972 also specifically called for the use of NBS services.

Legislation called on HUD to consult with NBS in prescribing energy conservation and solar energy standards (Housing and Community Development Act of 1974) and set forth numerous responsibilities for the Bureau in solar enegry development (Solar Heating and Cooling Demonstration Act of 1974). Other mandates included the Fire Prevention and Control Act of 1974, the Federal Non-Nuclear Energy Research and Development Act of 1974, and later the Energy Policy and Conservation Act and the Metric Conversion Act.

Not all of the research impetus came from legislation. Forces were also afoot outside the legislative chambers. For example, the concern over energy in 1972 moved the National Conference of States on Building Codes and Standards (NCBCS) to request a report on the Bureau's energy-related activities. This was furnished and the following year a joint NBS-NCSBCS workshop was held. Two significant developments resulted from the workshop.

One was a publication, Technical Options for Energy Conservation in Buildings, which contains the workshop papers of Center staff and which was to become a much-sought-after guide to energy conservation techniques (330). The other was NCSBCS' request that NBS develop an energy conservation standard for new buildings. Work on the conservation standard was begun immediately. On November 11-12, 1973, a workshop was held to assess the approach being taken with the standard, receive technical comment, and identify areas requiring further work. Attending were some 250 persons from 31 States, several foreign countries, and all sectors of the building community. This was but one of several steps taken to obtain feedback from the building community.

On February 27, 1974, the draft document, NBSIR-74-452 Design Evaluation Criteria for Energy Conservation in New Buildings (462), was presented to NCSBCS. The document was transmitted to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) which had offered to process it as an ASHRAE standard and as a consensus standard under procedures of the American National Standards Institute (ANSI).

The consensus process brought into play a mix of special and general interests. While some of the requirements of the NBS document were omitted or relaxed, the standard[29] to emerge did retain the format and philosophy of the NBS document.

Both the ASHRAE and NBS documents can be characterized as "component performance standards" in that their requirements are cast in performance language and promote the aggregation of energy-efficient components or subsystems in the design of a building. Both documents provide alternatives for innovative design and for trade-offs between different energy conservation options.

By the mid-1970s the Center was confronted by emphatic research challenges, particularly over the need for resource conservation in building technology. Heading the management team charged with shaping a response to these challenges was Dr. Richard N. Wright, successor to Dr. James R. Wright who in early 1974 left the Center to become Deputy Director of the Institute for Applied Technology.

Key team members were Harry Thompson, Center Deputy Director, and the Chiefs of the Center's principal organizational units: Gene Rowland, Building Standards and Codes Services; James Gross, Housing Technology; Samuel Kramer, Federal Building Technology; Dr. Edward O. Pfrang, Structures, Materials, and Safety; Paul R. Achenbach, Building Environment; and Porter Driscoll, Technical Evaluation and Application.

Heading the Sections were Dr. Robert A. Crist, Structures; Dr. Geoffrey J.C. Frohnsdorff, Materials and Composites; James O. Bryson, Building Safety; Frank J. Powell, Thermal Engineering Systems; Dr. Arthur I. Rubin, Sensory Environment; Dr. Lawrence S. Galowin, Building Service Systems; Dr. Robert Wehrli, Architectural Research; Dr. Harold E. Marshall, Building Economics; and Roger A. Rensberger, Scientific and Professional Liaison.

The research facilities within the Center, or available to the Center, were impressive. Structural research apparatus included testing machines with capacities of up to 2,700,000 N (600,000 pounds) in compression and 900,000 N (200,000 pounds) in tension, a three-story bay laboratory with a tie-down floor capable of testing full-size building systems, and systems providing as many as 200 channels for collecting data suitable for automated processing. Facilities available for environmental engineering include seven environmental chambers in a range of features and sizes, the largest capable of subjecting a full-size, two-story house to a temperature range of -45° to 66°C (-50 to 150°F) and a relative humidity range of 15 to 85 percent.

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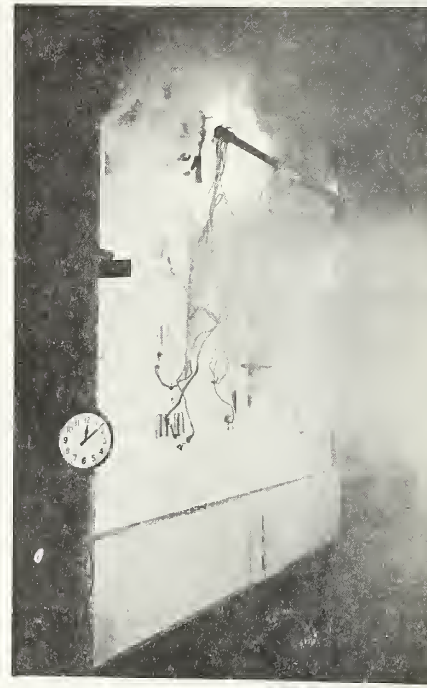
[29] ASHRAE Standard 90-75, Energy Conservation in New Building Design, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (1975).

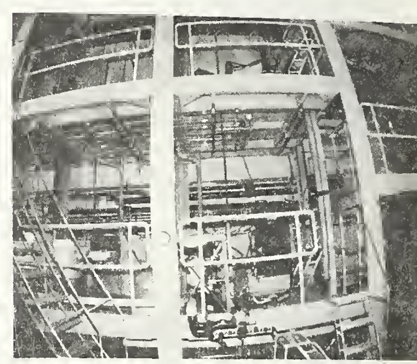
The early 1970s witnessed the construction of a new fire research facility to replace the large-scale testing laboratory at the Bureau's former site in Washington, D.C. The new laboratory, a facility of the Center for Fire Research, permits a wide range of full-scale testing. It is considered one of the most sophisticated facilities of its kind.

The fire laboratory contains a multi-purpose fire endurance furnace which measures the fire endurance of floors, walls and columns. It also includes a full-scale corridor where researchers can simulate a fire in a room adjoining the corridor and determine the contribution of the corridor walls, floor, and ceiling to fire and smoke spread in a building. Fire growth in fully-furnished rooms as well as the fire behavior of individual pieces of furniture can also be observed and quantified. In all, the information gained through the tests provides the technical base for better fire standards and fire-safe design.



A plumbing laboratory features a five-story test tower where plumbing configurations ranging from those of ranch houses to apartment complexes are simulated. It also includes two tools that have boosted capabilities in plumbing research-electronic instrumentation and a high-speed minicomputer.

With plumbing research tools such as these it is possible to pre-program the control of experiments and to visually display significant action at critical points in systems under test. An instantaneous picture of the dynamics of a plumbing process is offered. Computer print-outs, e.g., graphs or tabulations, can be obtained as a test is being run.



For the first time, key dynamic performance parameters could be measured for correlation with traditional static or steady-state design criteria. This capability provides the basis for greater precision in the design of traditional plumbing systems and for an acceptable evaluation methodology for innovative systems. Among the many dynamics that can now be measured are pressures, velocities, and massflow or volume-discharge rates of air and water, water levels, temperatures, strains and stresses, accumulated weights, and linear or rotational movements.

Finally, in tandem with the network of outdoor exposure sites, building researchers' efforts in materials technology benefit from accelerated weathering laboratories.

The Center also draws support from others. It has linkages with a host of agencies and organizations with which it collaborates in the development of standards and in the general advancement of building technology. As part of the Bureau, the Center is a laboratory within a laboratory. In the larger laboratory--the Bureau--are units with which the Center has particular opportunities for technical cooperation. These units (pre 1978 NBS reorganization) include:

--The Analytical Chemistry Division and the Metallurgy Division in NBS' Institute for Materials Research, and in the Institute for Basic Standards, the Applied Mathematics Division, the Mechanics Division, and the Applied Acoustics Section. Acoustic facilities at NBS include an anechoic (echo-free) chamber for use in the calibration of microphones and accoustical instruments and in experimentation requiring a noise-free environment, and a reverberation chamber used in measuring the sound absorption of architectural materials and the sound power output of machinery and equipment.

--The Center for Consumer Product Technology in the Institute for Applied Technology. The Institute for Applied Technology is also home for the Center for Fire Research.

--And the Institute for Computer Sciences and Technology with its Computer Services, Information Technology, Systems and Software, and Computer Systems Engineering Divisions.

The richness of the Center for Building Technology's own technical program, its research facilities, its collaborative relationships with other organizations, and its location within the National Bureau of Standards, all heighten the prospects of successfully meeting the challenges of building research in the final quarter of the 20th century. What may have equipped the Center more than anything else, though, was its philosophic and programmatic approach to building research. This approach had grown more responsive to the full range of building community needs.

John Eberhard laid the foundation for the widened approach, and on this foundation James Wright and colleagues erected a new research structure. Lending guidance and counsel along the way was William Allen, formerly of the Building Research Station, British Research Establishment, and at present chairman of the London architectural firm of Bickerdike Allen Bramble.

The research unit in building technology had grown; in terms of one index, the number of research personnel, it was two and one-half times the building research force of the mid 1960s. More importantly, it had registered a notable gain in breadth.

The emphasis Center management placed on the performance approach to building mandated the inclusion of new research disciplines and directions. This emphasis had more than theoretical roots . Indeed the late 1960s and early 1970s were distinguished for having challenged NBS building researchers to test performance theories in the real world of building. The challenges were met in the development of the PBS performance specification for office buildings and the criteria for HUD's Operation Breakthrough, both major ventures in the application of the performance concept.

The new structure of building research sought greater involvement with other Federal agencies having responsibilities in building technology. It also pursued greater cooperation with the building community and a stronger program for disseminating research findings.

In short, the building research activity at NBS had undergone significant growth. Moreover, it had grown up in the sense of having acquired the attributes necessary for mature, responsible service to the complex building enterprise, and to the complex interrelationship between building users and the built environment as well.

Dr. Richard N. Wright, who left the University of Illinois where he was a professor in the Department of Civil Engineering, to be at the helm of the Bureau's program in building technology, was no stranger to the Center. He had served as Chief of the Building Research Division's Structures Section (1971-72) and as Center Deputy Director--Technical (1972-73).

Richard Wright called on the broadened Center staff to renew its commitment to excellence, demonstrating "expertise in all sciences, esthetic sensibilities, political awareness, common sense--and a dedication to the public benefit."

So changed, NBS building research professionals looked to a future certain to present new research challenges. They faced what lay ahead with the reinforcing legacy of a research program that, in its recent years, dared to grapple with the broad issues of the built environment.

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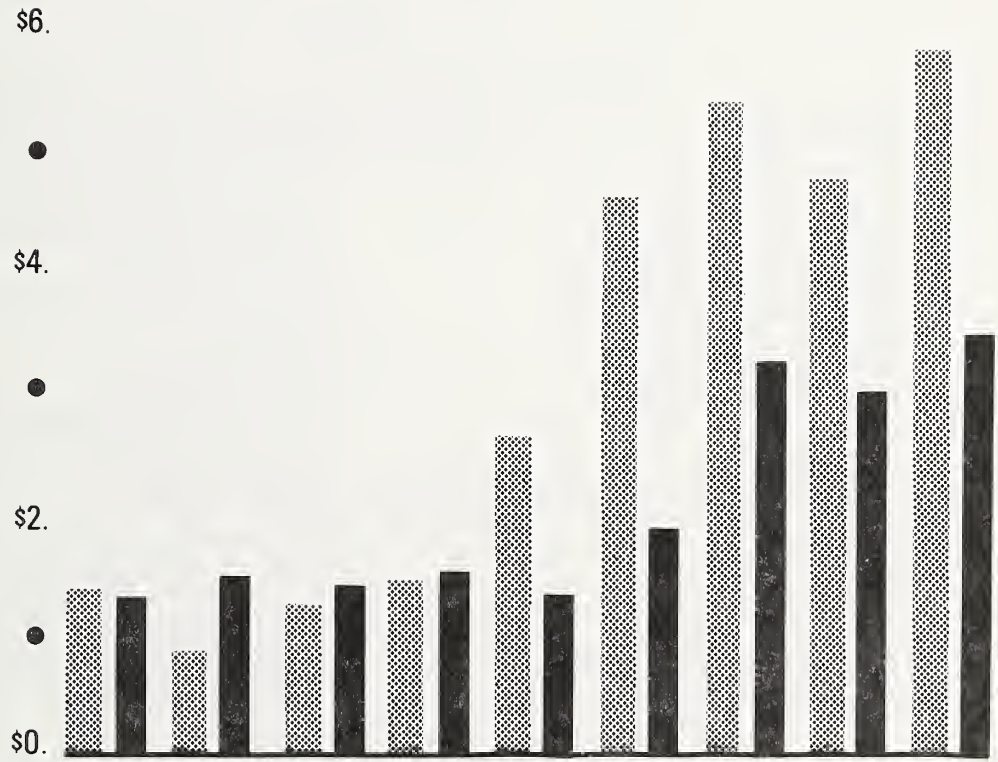
SUPPLEMENTS

STAFFING/FUNDING 1966-74

	1966	1967	1968	1969	1970	1971	1972	1973	1974
STAFFING:	105	98	115	159	201	225	208	207	231

FUNDING:
Millions



	1966	1967	1968	1969	1970	1971	1972	1973	1974
Sponsored Res.	1.3	.9	1.2	1.5	2.7	4.9	5.4	4.9	5.8
Allocated Funds	1.2	1.5	1.4	1.6	1.3	1.9	3.2	2.9	3.4
TOTALS $	2.5	2.4	2.6	3.1	4.0	6.8	8.6	7.8	9.2

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- Architect - Psychologist
- Architect - Sociologist
- Architectural Engineer
- Behavioral Psychologist
- Ceramic Engineer
- Chemical Engineer
- Chemist
- Civil Engineer
- Code Analyst
- Economist
- Electrical Engineer
- Electronics Engineer
- Fire Prevention Engineer
- General Engineer
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- Industrial Engineer
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- Metallurgist
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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report details the progress of building research at the Center for Building Technology from the year 1968 to 1974. Starting with the backlog of needed research in building techniques, components, and materials that faced researchers in the 60's, this history covers the evolution of the performance concept for building specifications, cooperation with states and codes-generating organizations, and specific technical accomplishments. The report continues with discussions of programs involving the building community, research on the needs of the building users, and technology transfer. A special chapter is devoted to energy conservation in buildings and how CBT's test methods and other programs - including solar - were pressed into this vital national struggle.

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