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THE NIST GREEN BUILDING PROGRAM

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Abstract

For over 2 decades, NIST has been involved in energy conservation programs. NIST's current programs broadly span the areas from waste minimization to air, soil, water, indoor air quality, ozone depletion, and global warming. The latest endeavor NIST is undertaking is the "Green Building Program" in which NIST is at the forefront of designing buildings using environmentally safe materials. NIST's program has two components. The laboratory-based activities involve NIST staff working directly with manufacturers and designers to develop technologies conducive to energy efficiency. The second component, demonstration buildings, includes environmentally safe buildings which are monuments to green technologies. These buildings not only demonstrate cost effectiveness and evaluate green technologies, they also identify new technologies needed to develop an effective green building.

Introduction

Green buildings are ones designed, constructed, operated, and demolished to have a minimum impact on the global, neighborhood, and internal environments. Green buildings have long been an interest at NIST and its predecessor organization, the National Bureau of Standards (NBS). Even before the Oil Embargo of 1973, NIST had developed the basic algorithms or calculation techniques for predicting energy transfer in buildings [1]. These techniques are used today in all major energy simulation programs such as DOE-II for designing energy conserving buildings.

After the oil embargo, NIST developed the very first draft of an energy conservation design standard for buildings that was the predecessor of ASHRAE Standard 90, now used in all building regulations across the United States [2].

NIST currently has an extensive group of programs in a wide variety of environmental technologies:

- waste minimization
- energy conservation
- air, soil, and water quality
- indoor air quality
- ozone depletion and global warming
- green building design

Advances in technology, key to stimulating the nation's economic growth, are critical to solving the nation's environmental issues. According to President William Clinton and Vice President Albert Gore in Technology for America's Economic Growth, A New Direction to Build Economic Strength [3],

> "Our most important measure of success will be our ability to make a difference in the lives of American people, to harness technology so that it improves the quality of their lives and the economic strength of our nation. We are moving in a new direction that recognizes the critical role technology must play in stimulating and sustaining the long-term economic growth that creates high-quality jobs and protects the environment."

As the only federal laboratory with the primary mission of helping U.S. industry strengthen its international competitiveness and as the nation's premier measurement laboratory, NIST is ideally poised to help U.S. industry to make the transition to "green" technologies.

Laboratory-Based Activities

The NIST Green Building Program has two main components: laboratory-based activities and a recently-begun demonstration phase. The laboratory-based activities have been designed to work directly with manufacturers and building designers to help develop technology for enhanced energy efficiency, improved indoor air quality, and replacements for chlorine-based refrigerants.

Improved Energy Efficiency - Thermal Insulation

NIST research on heat transfer through thermal insulation began in 1910 and in 1912 led to development of the first Guarded Hot Plate apparatus for precise measurement of heat transmission. This device and its successors have provided the basis for calibration of the measurement devices used by industry and regulatory authorities for determining the thermal resistance of insulation. Twenty-five millimeter thick calibration transfer standards were routinely supplied to industrial laboratories for calibration purposes prior to the 1970's. Concerns for energy efficiency after the 1973 Oil Embargo led to routine use of 150 to 450-mm low density insulation in U.S. buildings. In 1978-79, the Federal Trade Commission proposed requiring manufacturers to label their products for thermal resistance at a thickness representative of typical installation. Industry representatives, concerned for the accuracy of labeling, requested that the rule be deferred until their measurement devices could be calibrated with full thickness, low-density insulation calibration transfer standards.

In the late 1960's NIST staff formulated a radical new approach for accurately measuring heat transmission through thermal insulation, a circular line-source Guarded Hot Plate. At industry's and the Federal Trade Commission's request, NIST built a 1-m diameter version of the Guarded Hot Plate capable of full thickness measurements up to 380 mm to within 1 percent uncertainty and made calibration transfer standards available to industry.

In 1981, NIST completed the 1-m circular line-source Guarded Hot Plate that met design specifications. NIST subsequently developed two standard reference materials (SRM): a fibrous-glass blanket (SRM-1451) in 1985 and a fumed silica board (SRM-1449, 1459) in 1990. To date, approximately 60 SRMs have been sold and an additional 70 special calibrations have been completed for U.S. industry to support the accurate testing, production, and labeling of thermal insulation.

Advanced insulation products are now being developed and introduced into the U.S. market [4]. Examples of these products are aerogels, powder filled panels, and evacuated panels. These products offer extremely high insulating capabilities. For example, theoretical calculations reveal that an R-value approaching 100 may be achieved in a 25.4 mm thick evacuated panel.

Unfortunately, current test procedures for measuring thermal conductivity are only applicable to materials which are homogenous, have planar surfaces, and have relatively poor insulating capabilities compared to advanced insulation products. NIST is now developing appropriate measurement techniques to allow an accurate determination of the overall thermal conductance of advanced insulation systems.

A facility for the calorimetric testing of advanced insulation panels has been designed and fabricated. A Cooperative Research and Development Agreement (CRADA) is in place with a compact vacuum insulation manufacturer (Aladdin Industries). The new calorimeter will be tested using different insulation samples of known thermal conductivity. Each insulation sample will be evaluated over a range of mean temperatures and compared to measurements made on the NIST 1-m Guarded Hot Plate. These comparisons will be made to document the accuracy of the calorimeter when used to test homogenous materials. Once complete, the apparatus will be ready to determine the thermal conductivity of the evacuation insulation panels. Other measurement techniques, such as the use of infrared thermography, are also being investigated to determine the thermal conductivity of the evacuated insulation panels.

Large Building Automation Systems

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

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

For the past 7 years, NIST has worked cooperatively with the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) to develop BACnet, a communication protocol for Building Automation and Control networks. BACnet has been published as a draft ASHRAE standard and has completed its first public review. Several changes have been made to the draft standard as a result of the public review. A revised version of the standard was released in January, 1994 for additional public review. If this second review proceeds smoothly, it is expected that BACnet could be published as an ASHRAE standard in 1994.

The ASHRAE committee developing BACnet is known as the Standards Project Committee (SPC) 135P. The membership of SPC 135P represents a balance of interests between vendors, users, and general interest groups. The current membership of SPC 135P is shown in Table 1.

Table 1. Membership of SPC 135P

Voting Members	Interest Category
Andover Controls, Inc.	Producer
Cornell University	User
Engineering Economics	User
Gresham, Smith & Partners	User
Honeywell, Inc.	Producer
Johnson Controls, Inc.	Producer
The Kling Lindquist Partnership	General Interest
Landis & Gyr Powers, Inc.	Producer
National Institute of Standards & Technology	General Interest
PolarSoft	General Interest
Public Works of Canada	User
Siebe Environmental Systems	Producer
The Trane Company	Producer
Non-Voting Members	**Interest Category**
Delta Controls, Inc.	Producer
Energyline Corporation	Producer
IBM	User
RRH Associates	General Interest
Staefa Control Systems, Inc.	Producer

A ground swell of pressure from the user community motivated ASHRAE to form a committee to develop the BACnet standard. The pressure from the user community has increased since that time as expectations have been raised by publication of the draft standard. The largest landlord in the world, the United States Government, is also beginning to participate. The General Services Administration is planning to make conformance to BACnet a requirement for control systems purchased by civilian federal government agencies. The Department of Defense is also considering a requirement to use BACnet in military facilities. This kind of consumer interest has been a strong influence on manufacturers of building control systems.

The three largest control system manufacturers in the United States, Honeywell, Johnson Controls, and Landis & Gyr Powers have all publicly announced their intention to support BACnet in their products. At least 17 other manufacturers have also announced similar plans [5]. The Trane Company has announced that it will sell products which implement an early version of BACnet and provide a free upgrade to the final version of the standard.

NIST has just organized a consortium to conduct interoperability tests on BACnet implementations. All manufacturers who want to develop a BACnet implementation have been invited to join the consortium and test their implementations. So far, 13 companies have joined NIST consortium: American Auto-Matrix, Andover Controls, Delta Controls, Johnson Controls, Inc., Landis & Gyr Powers, PolarSoft, Siebe Environmental Controls, Snyder General, Staefa Control System, Inc., the Trane Company, Cornell University, Teletrol Systems, and Orion Analysis Corporation.

There is also international interest in the BACnet protocol. The European Community has formed a standards committee to adopt a standard protocol for Europe. BACnet is one of the leading candidates for adoption as a European standard.

The final answer on the success or failure of BACnet will not be known for some time but, for all of the above reasons, there are grounds for optimism.

Building Envelope Design Methods

NIST pioneered the development of a wide variety of diagnostic techniques for determining the integrity of building envelopes. They have covered tracer gas techniques for determining the air leakage into and out of buildings and the use of thermographic techniques for measuring the integrity of building envelopes [6-8]. Many have been incorporated into national and international standards.

NIST just completed a design guide for thermal integrity and airtightness of office building walls that incorporates a wide variety of recommendations developed as a result of using the diagnostic techniques in government office buildings [9]. Most recently, NIST has pioneered the development of analysis techniques for moisture migration and accumulation in building walls that destroy their thermal integrity. This has been implemented in the computer program MOIST [10]. MOIST predicts the combined transfer of heat and moisture in building envelopes. The program inputs hourly outdoor weather data and predicts the moisture content and temperature of the construction layers as a function of time of year. The algorithms of the program include moisture transfer by diffusion, convection, and capillary flows. The moisture transfer resistance offered by vapor retarders and paint layers are readily included in simulations [11, 12].

NIST is currently experimentally verifying MOIST by comparing a series of laboratory experiments. Twelve 1.2 m x 1.2 m test walls were installed in the NIST calibrated hot box. Each of the test walls was instrumented to measure the heat transfer rate at the inside surface and the surface moisture content of the construction layers. The exterior surfaces of the test walls were subsequently exposed to simulate steady and time-dependent winter outdoor conditions. The heat transfer rate and the moisture content of the construction layers were measured as a function of time and compared to corresponding values predicted by MOIST. The preliminary agreement between the measurements and computer predictions is good.

A MOIST user can investigate the effect of various parameters on moisture movement and accumulation within the building envelope. These parameters include climate, building materials, the use and placement of vapor retarders, and the relative placement of building materials. MOIST's capability to predict the moisture accumulation within each building material as a function of time allows the user to select the most appropriate building materials and construction for a given climate. This will insure that buildings do not exhibit moisture-related material degradation, thereby lengthening the service life of the materials.

Improved Indoor Air Quality

NIST has a major research program on building indoor air quality. Its goal is to develop measurement and testing procedures, technical data, and comprehensive computer models to assist building designers and operators to improve indoor air quality in buildings.

The program has two major elements. First, ventilation and building assessment protocols are being developed as tools for use by building operators and indoor air quality investigators. A large part of laboratory and field work has dealt with how air moves into and within large commercial buildings [13-19]. A unique feature of the work in two of the government buildings was the design and implementation of a "diagnostic center," centrally located instrumented facility in the building with the capability of automatically sampling air throughout the building [20].

The second major element of the program is development and application of multi-zone indoor air quality models that predict pollutant levels from sources introduced into buildings from outdoor air, and those generated inside from sources such as indoor combustion processes and furnishings. The modeling of contaminant dispersal has been accomplished by idealizing any building as a collection of well-mixed zones connected together by discrete flow paths. Element assembly techniques have been used where equations describing the discrete elements of the model are assembled into a set of equations approximating the behavior of the system as a whole. The modeling approach has been implemented into a computer program, CONTAM [21].

The CONTAM computer program has been applied to several test cases for the validation purposes. Comparisons between computed results and exact solutions for special cases of single and two-zone buildings and numerical solutions computed by other contaminants dispersal programs have shown excellent agreement. Comparisons between computed results and measured data have also been good. However, the amount of good measured data is limited.

Alternative Refrigerants

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are used as the working fluids in virtually all small and large-scale refrigeration and air-conditioning equipment. But, their chlorine is destroying the earth's stratospheric ozone layer. As a result, U.S. industry is replacing these chemicals as quickly as possible in response to national and international laws and agreements. Two independent, well-coordinated divisions within NIST, the Thermophysics and the Building Environment Divisions, have been focusing on the CFC problem since 1981.

NIST is providing the thermophysical properties and engineering data needed to identify promising alternatives, to retrofit existing equipment, and to design and optimize new equipment for the replacement fluids. The most promising replacements at this time are partially-fluorinated methane and ethane molecules with no chlorine and mixtures of such compounds. Fluorinated propanes, butanes, and ethers are also being investigated.

For the past 10 years, NIST has been involved in measuring selected thermophysical properties of the alternatives including vapor pressure, equation of state, heat capacity, speed of sound, thermal conductivity, and viscosity. NIST has developed models to predict the properties of pure fluids and mixtures, even when little or no data exist. Industrial cycle simulation codes and equipment design programs require such models in machine-readable form. Thus, NIST is providing computer packages for the CFC and HCFC alternatives and their mixtures. The most widely-distributed NIST-produced microcomputer-based predictive package to date is REFPROP [22], which can calculate the thermophysical properties of 38 pure refrigerants and all possible combinations of up to five component mixtures of these refrigerants.

For over 15 years, NIST has been developing the generic engineering data needed to assist refrigeration system designers in the selection of system configurations and hardware components. Many of the new refrigerants have a more complex molecular structure and higher molecular weight than the refrigerants being replaced. To assist the manufacturers, in general, NIST has incorporated the REFPROP data source into its machinery simulation codes and conducted thermodynamic cycle analyses to evaluate various alternative refrigerants and mixtures for the traditional refrigeration cycle with and without specific machinery modifications. The results of these analyses are then verified in a laboratory breadboard system.

In addition to the above generic studies, NIST is currently conducting about six proprietary laboratory studies with various manufacturers of refrigerants and equipment. The focus of these studies is on the specific adaptation of the most promising refrigerant alternatives and the determination of what hardware changes are necessary for energy performance optimization.

Demonstration Buildings

Beginning in 1993, Congress directed NIST to begin a national demonstration of green building technologies. Four building projects were selected in 1993 and an additional one was added in 1994. The purpose of these projects is to:

1. demonstrate the environmentally-safe technologies that are currently available and cost-effective to use in specific building applications,

2. evaluate the effectiveness of the technology once in place, and

3. in the course of designing the buildings or building additions, identify the technologies that need development to make an effective green building.

The buildings and their status will be described briefly.

Fish and Wildlife Refuge in Walnut Creek, Iowa

This green building will be the Visitor's Center to be built on this new 2800 hectare refuge. The design is currently 50% complete, and construction is scheduled to begin in August, 1994 with occupancy in April, 1996. Enermodal Engineering has done the assessment of green technologies to be incorporated into this building. Technologies include daylighting of large parts of exhibit area, the use of biofuels for space heating, the use of sustainable building materials, the integration of mechanical system with fire protection, water storage, and the generation of electricity from methane at the solid waste landfill. Susan Reilly of Enermodal Engineering has described the results of this predesign study in a separate paper in the conference proceedings.

New England Aquarium Expansion

The New England Aquarium in the Boston Harbor is being expanded with an 11,000 m^2 addition that will more than double the current facility. The project is currently in the pre-schematic design phase. An architecture engineering consulting firm has just been selected. Attention to date has been given to the nature of the expanded exhibits and exhibit areas prior to the design of the facility. It may be up to five years from today before the facility is completed.

NIST Advanced Technology Laboratories

NIST has just embarked on a major 10-year renovation program for the NIST campuses in Gaithersburg, MD and Boulder, CO. As part of that program, NIST will be designing and constructing new Advanced Technology Laboratories on both campuses. The architecture and engineering firm under contract to NIST is now developing the program documents and has been charged with developing a section of Green Buildings criteria to be used in guiding this project.

The Advanced Technology Laboratories are currently in the early schematic design phase. The laboratory building in Gaithersburg is planned to have a floor area of approximately 30,000 m^2. The one in Boulder, CO will be approximately half that size. The NIST green building staff is working closely with the architectual/engineering firm of Henningson, Durham, and Richardson, Inc. on these laboratory projects. The major challenge in a facility such as this will be to minimize the energy consumption with mechanical and electrical systems that must be designed first and foremost to provide exacting interior environmental conditions conducive for research work at molecular and atomic scales. For example, many of the laboratories require temperature variations at the research work station of less than 0.01 °C. This is expected to require abnormally large amounts of air circulation in the laboratory spaces.

The design of the Gaithersburg laboratory is expected to be completed in April, 1995 with construction completed in June, 1997 and occupancy in early 1999.

Montana State University, Economic Renewal and Technology Transfer

The grant has just been awarded and no definite plans have been made to date on the building to be built.

Columbia University, Geochemistry Building

This is to be a new 6000 m^2 facility on the campus of the Lamont-Dougherty Earth Observatory along the Hudson River just north of New York City. Comprehensive planning has been completed for this building by the Craxton Collaborative/Ehrenkrantz and Eckstut Architects [23]. Building construction is scheduled for early 1995 with occupancy in mid-1997.

The collection of technologies to be incorporated into this facility is impressive. They include fully daylighted laboratories, an absorption chiller plant, desiccant system for latent loads, air-to-air solar preheat for the air delivery system, fumed hood design for all the laboratories with occupancy sensors tied directly to a central energy management system, maximum use of recycled materials and detailed plans for commissioning of the building envelope. The building is estimated to result in 60-70% energy reduction compared to use of conventional technology in a similar building. The consultants are still examining the possibility of coupling of the building to the ground and using wind turbines for additional energy savings.

Summary

NIST's 20-year old energy conservation programs led the way to the new Green Building Program. With the commencement of the Green Building Program, NIST is emerging as the leader of designing buildings using environmentally safe materials. The two-phase program includes laboratory-based activities, as well as national demonstration projects. These buildings demonstrate green technologies, identify new technologies, and demonstrate the cost-effectiveness of using green materials for construction.

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