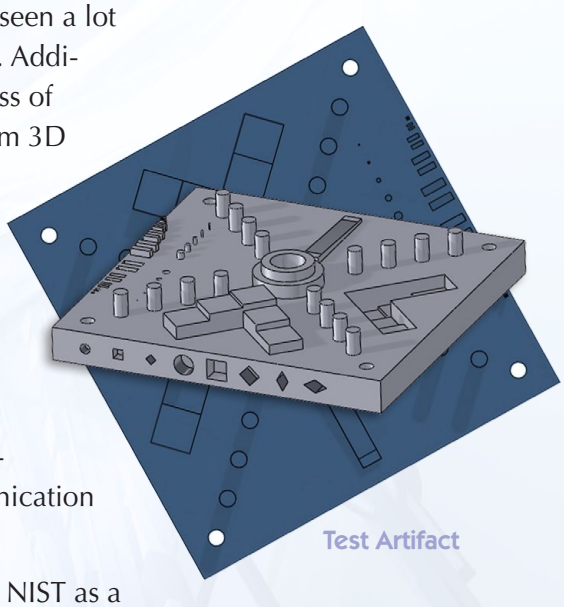
engineering laboratory

Newsletter • Fall 2012

What's inside

NIST National Institute of Standards and Technology U.S. Department of Commerce

The Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST) is wrapping up another fantastic fiscal year and I would like to take this opportunity to share with you one of the areas where we have seen a lot of progress – additive manufacturing. Additive Manufacturing (AM) is the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. The technology is a key enabler for agile manufacturing providing fast response to changes in customer demand and efficient and local production of specialized products directly from electronic communication of designs and design changes.



Test Artifact

In the recent past, EL has established NIST as a major influence and recognized technical contributor in the emerging field of additive manufacturing (AM) for U.S. manufacturers by

1. bringing online new capabilities (metal-based AM research platform),
2. delivering measurement science results (test artifact for performance evaluation of AM systems, measurement methods for characterizing metal powders used in AM, process models for direct metal laser sintering additive process), and
3. leading and contributing to other organizations (leading the strategic planning efforts for ASTM F42, contributing significantly to the interagency technical advisory board for the NNMI pilot on additive manufacturing)

Additive manufacturing is poised to be one of the drivers of continued U.S. manufacturing competitiveness and I am excited to see the Engineering Laboratory play a critical role in this development.

Please visit our website for more information on ongoing activities in the Laboratory: www.nist.gov/el/

Sincerely,

Dr. S. Shyam Sunder

Director, NIST Engineering Laboratory

Home Sweet Lab: Computerized House to Generate as Much Energy as it Uses

NIST Unveils Net-Zero Energy Residential Test Facility to Improve Testing of Energy-Efficient Technologies

In a ribbon-cutting ceremony on September 12th, the U.S. Commerce Department's National Institute of Standards and Technology (NIST) unveiled a new laboratory designed to demonstrate that a typical-looking suburban home for a family of four can generate as much energy as it uses in a year. Following an initial year-long experiment, the facility will be used to improve test methods for energy-efficient technologies and develop cost-effective design standards for energy-efficient homes that could reduce overall energy consumption and harmful pollution, and save families money on their monthly utility bills.

The unique facility looks and behaves like an actual house, and has been built to U.S. Green Building Council LEED Platinum standards—the highest standard for sustainable structures. The two-story, four-bedroom, three-bath Net-Zero Energy Residential Test Facility incorporates energy-efficient construction and appliances, as well as energy-generating technologies such as solar water heating and solar photovoltaic systems.

"Results from this lab will show if net-zero home design and technologies are ready for a neighborhood near you," said Under Secretary of Commerce for Standards and Technology and NIST Director Patrick Gallagher. "It will also allow development of new design standards and test methods for emerging energy-efficient technologies and, we hope, speed their adoption."

Funded by the American Recovery and Reinvestment Act of 2009, which included green technologies among its priorities, the facility was built almost entirely with U.S.-made materials and equipment. Through its Building America effort, the Department of Energy (DOE) provided architectural design, training and management support for this project. Deputy Assistant Secretary for Energy Efficiency Kathleen Hogan represented DOE during the ribbon-cutting.

For the first year of its operation, the lab will be used to demonstrate net-zero energy usage. NIST researchers will use computer software and mechanical controls to simulate the activities of a family of four living in an energy-efficient home. No actual humans will be allowed to enter the house during this time so that researchers can monitor how the house performs, but lights will turn on and off at specified times, hot water and appliances will run—and small devices will emit heat and humidity just as people would.

A solar photovoltaic system will generate electricity to power lights and appliances when weather permits, and excess energy will be sent back to the local utility grid by means of a smart electric meter. The house will draw energy from the grid on days it cannot generate enough on its own, but over the course of a year it will produce enough to make up for that purchased energy, for a net-zero energy usage.

During the ceremony, Rick Fedrizzi, president, CEO and founding chairman of the U.S. Green Building Council, announced that the Net-Zero Energy Residential Test Facility has earned a LEED Platinum rating.

NIST researchers plan to make data from the net-zero experiment available online so that researchers and the public can follow its progress. Visit http://www.nist.gov/el/nzertf/ for images, video and more details on the new laboratory.

New NIST Strategic Roadmap Aims to Reduce the Nation's Preventable Fire Burden by a Third

The United States already has one of the highest direct fire loss rates among developed nations, and progress in reducing this tremendous burden is slowing.

Fires claim more than 3,000 lives a year, injure more than 90,000 firefighters and civilians, and impose costs and losses totaling more than $300 billion—equivalent to about 2 percent of the nation's gross domestic product.

Fire researchers at the National Institute of Standards and Technology (NIST) believe that the devastating annual toll can be significantly reduced over the next two decades. Even better, they have a plan that prioritizes and details the research and other work needed to enable that goal.

Crafted with input from fire service organizations, standards and building-code developers, equipment manufacturers, insurers and others, NIST's newly issued "strategic roadmap"* lays out a clear technological course for reducing the risk of fire in buildings and communities. It calls for tackling the nation's fire problem on three fronts:

- Reducing fire hazards in buildings,
- Advancing firefighter technologies, and
- Reducing the risk of fire in communities bordering forests and "wildlands."

The new roadmap is NIST's most comprehensive effort to establish fire-risk reduction goals for its programs since the influential America Burning report was published in the mid-1970s.

In response to that report, Congress established a center for fire research at NIST. The report's recommendations served as goals for attacking the nation's fire problem. Over the last several decades, research-enabled advances have paid off with improvements in fire safety and related benefits.

For example, results of fire research have led to standards for children's sleepwear, automatic sprinklers, reduced-ignition-propensity cigarettes, modernized building codes, and computer models that can predict the behavior of fire, smoke and toxic products.Since the early 1980s, the number of fires has been cut by more than half and the fire-caused civilian deaths and injuries have been reduced by nearly half.

Controlled experiment at NIST's National Fire Research Laboratory yields data that inform approaches to preventing and fighting fires at the wildland-urban interface. Credit: NIST

"The nation has made major progress in improving fire safety over the last few decades due to the combined and concerted efforts of many organizations," says Shyam Sunder, director of NIST's Engineering Laboratory. "But fire losses are still too high, and there are new and potentially costly threats to fire safety that are emerging in communities across the country. At the same time, advances

*Fire Research Division, Engineering Laboratory, Reducing the Risk of Fire in Buildings and Communities: A Strategic Roadmap to Guide and Prioritize Research, NIST Special Publication 1130, April 2012.

in materials, computing and other technologies present opportunities to launch a new wave of improvements in fire protection and safety."

Reflecting NIST's unique technical support role, the new roadmap sets targets for new measurement capabilities that underpin innovation in fire-risk-reducing technologies and best practices. These advanced capabilities are required to overcome technical hurdles that stand in the way of nascent or current technologies with the potential to deliver a wide range of fire safety benefits. These range from earlier fire detection and fire-safety improvements in the design and construction of buildings and communities, to better firefighting equipment and tactics, to more effective approaches to preventing and responding to "wildland-urban interface" fires, a rapidly growing national fire problem.

The new NIST roadmap sets short, medium and long-term goals—from fewer than three years to more than eight—for eliminating these gaps and accomplishing the overall objective of reducing the nation's fire burden by a third. The publication is available at www.nist.gov/manuscript-publication-search.cfm?pub_id=909653.

Live Fire Tests with FDNY Will Guide Improvements in Fire Department Tactics

In the name of science, but with aim of saving lives, preventing injuries and reducing property losses, members of the New York City Fire Department (FDNY) spent much of the first two weeks in July setting fire to 20 abandoned townhouses on Governors Island, about a kilometer from the southern tip of Manhattan.

In a series of "live burn" experiments, conducted in collaboration with the National Institute of Standards and Technology (NIST) and Underwriters Laboratories (UL), New York firefighters challenged the conventional wisdom on, and tested new tactics for, controlling fires and rescuing occupants inside burning homes.

"We studied these fires from start to finish," explains NIST fire protection engineer Dan Madrzykowski , who led the NIST research contingent at Governors Island. "We turned these row houses into laboratories for real-life experiments that will provide guidance for improving fire-fighting tactics."

An abandoned Coast Guard barracks built in the 1980s served as the proving ground for so-called positive pressure techniques and other potentially useful ventilation-control and exterior fire suppression methods. The row houses were among structures scheduled for demolition as part of efforts to transform the former Coast Guard regional headquarters into a park and for other civic uses. The townhouses—wood-framed with brick exteriors—were supplied with the same package of sofas, chairs, beds, and other furnishings for the experiments. Each townhouse also was outfitted with about 100 sensors to measure temperatures, heat flows, concentrations of toxic gases and other variables. Cameras were installed inside each row house, as well as in front and back, to monitor and record conditions.

The primary motivation for the live burn experiments are the changing dynamics of fires. The contents of American homes have changed significantly in the past few years. Plastics and other synthetic materials have replaced the natural materials that once made up the bulk of furniture items. In addition, modern living spaces tend to be more open, less compartmentalized.

As a result, interior house fires tend to burn faster and hotter today. The average time to flashover—the extremely perilous phenomenon that occurs when heat builds up in a burning structure's contents and components to the point that they burst into flames simultaneously—has dropped dramatically since the 1980s.

The experiments evaluated individual and combinations of methods for strategically ventilating and isolating fires to prevent flashover—or at least delay it. In contrast, kicking a door

open or breaking a window without knowledge of conditions inside could create a portal for air that can literally fan the flames.

"Fire consumes all the oxygen in a building, and when we ventilate the building, oxygen-induced flashover can occur," explains Robert Maynes, FDNY deputy assistant chief. "That impacts the safety of our fire-fighters."

Information gathered and lessons learned during Governors Island tests will be shared with fire departments throughout the nation. In addition, NIST will use the data to improve the accuracy and improve the capabilities of its widely used fire modeling software.

"These on-the-ground fire tests—in collaboration with FDNY and Underwriters Laboratories—provide a great opportunity for NIST to gather data at full-scale. The data will strengthen the scientific underpinnings of modern fire-fighting tactics and technologies, improve their effectiveness, enhance fire fighter safety, and lead to better building codes and standards," said Shyam Sunder, the director of NIST's Engineering Laboratory.

The New York City Fire Department, NIST and Underwriters Laboratories set fire to 20 abandoned townhouses on Governors Island, New York, in a series of experiments to test the conventional wisdom on, and new tactics for, controlling fires and rescuing occupants inside burning homes. Credit: FDNY Photo

EL Leads Effort to Publish New ISO Standard for Testing the Geometric Accuracy of Machine Tools

EL researcher Alkan Donmez led extensive efforts to revise and release a new international standard for testing the geometric accuracy of machine tools. The new version of ISO 230-1 "Geometric accuracy of machine tools operating under no-load or quasi-static conditions" was published by the International Organization for Standardization (ISO) in March 2012.

This standard defines performance parameters and test procedures to specify and validate the geometric accuracy of machine tools, as well as tests that allow machine tool builders to align and test components during assembly of the machines. In addition, the standard provides the technical foundation for other ISO standards that define performance specifications and validation methods for specific machine tool configurations. The principles and test procedures embodied in the previous version of the ISO 230-1 standard prescribed tests to check the functional surfaces of machine tools (based on metrology principles developed by German professor G. Schlesinger in the 1920s).

The previous version did not address the relative motion between the cutting tool and the workpiece, which is the most important function of a machine tool. As such, significant differences existed between the ISO and ANSI/ASME standards on this subject. Working with international colleagues and the U.S. ASME B5/TC52 committee on machine tool performance testing, Dr. Donmez led the revision of this standard through several stages of the draft standard. These revisions addressed hundreds of comments, incorporated advances in metrology concepts and machine tool technologies, simplified the structure of this fundamental standard, and harmonized the ISO standard with the corresponding U.S. ANSI/ASME standard. Harmonization of U.S. and ISO machine tool standards is of great importance to U.S. manufacturers and members of ASME B5/TC52 since 1) foreign vendors of machine tools and machine tool testing equipment typically comply with ISO standards, 2) U.S. machine tool users with international operations prefer to work with a single set of standards, and 3) other key manufacturing countries have replaced their national standards in favor of ISO standards.

Credit: Earl Zubkoff

Novel Clay-based Coating May Point the Way to New Generation of Green Flame Retardants

In searching for better flame retardants for home furnishings—a large source of fuel in house fires—National Institute of Standards and Technology (NIST) researchers defied the conventional wisdom and literally hit a wall, one made of clay.

It wasn't a dead end, but rather a surprising result that may lead to a new generation of nonhalogenated, sustainable flame retardant technology for polyurethane foam. The thick, fast-forming coating that the NIST team created has a uniformly high concentration of flame-inhibiting clay particles, and it adheres strongly to the Swiss cheese-like surface of polyurethane foam, which is used in furniture cushions, carpet padding, children's car seats, and other items.

"In effect, we can build the equivalent of a flame-retarding clay wall on the foam in a way that has no adverse impact on the foam manufacturing process," explains NIST fire researcher Rick Davis. "Our clay-based coatings perform at least as well as commercial retardant approaches, and we think there's room for improvement. We hope this new approach provides industry with practical alternative flame retardants."

Davis and his NIST colleagues describe the new coating and the process they used to make it in the journal ACS Macro Letters.*

To date, researchers have built up coatings by stacking thin layers in pairs that are held together by basic electrical attraction. With no clay present, just a pure polymer, a thick coating is formed rapidly, but it isn't a fire retardant. With clay in every other layer, either the coating is too thin or the clay content is too low to be an effective fire retardant.

The NIST team tried something you would expect not to work: trilayers consisting of a positively charged bottom topped by two negatively charged layers. Under most circumstances, the two negative layers would repulse each other, but it turns out that hydrogen bonds formed between the two negative layers and overcame this repulsive force.

The resulting trilayer yields a unique result: a thick, fast-forming, and high concentration clay coating on polyurethane foam. This nanocomposite coating is 10 times thicker, contains 6 times more clay, and achieves this using at least 5 times fewer total layers than the traditional bilayer coatings.

"The eight trilayer system thoroughly coated all internal and external surfaces of the porous polyurethane foam, creating a clay brick wall barrier that reduced foam flammability by as much as 17 percent of the peak heat release rate," the team reported. Only a few hundred nanometers thick, the final coating is transparent and the foam still has the same softness, support and feel.

Compared with amounts of current flame retardant applied to polyurethane foam, only half as much of the new clay-based coating was required to achieve comparable levels of performance.

Using a testing device called a cone calorimeter, NIST researchers measure the heat-release rate and other flammability properties of materials. Above, untreated polyurethane foam catches fire from a nearby heat source. Below, foam treated with a novel clay-filled coating did not ignite when exposed to the same heat source. Instead, a fast-growing protective layer called char forms on the surface. Credit: NIST

* Y.S. Kim, R. Harris and R. Davis. Innovative approach to rapid growth of highly clay-filled coatings on porous polyurethane foam. ACS Macro Letters, 2012, 1, 820–824. .

NIST Measurement Advance Could Speed Innovation in Solar Devices

A new versatile measurement system devised by researchers at the National Institute of Standards and Technology (NIST) accurately and quickly measures the electric power output of solar energy devices, capabilities useful to researchers and manufacturers working to develop and make next-generation solar energy cells.

Innovative devices that convert sunlight to electric power more efficiently and cost effectively than the current generation of solar cell technology are the objects of a global pursuit—means to reducing fossil-fuel consumption and to securing pole position in the competition for fast-growing international markets for clean energy sources.

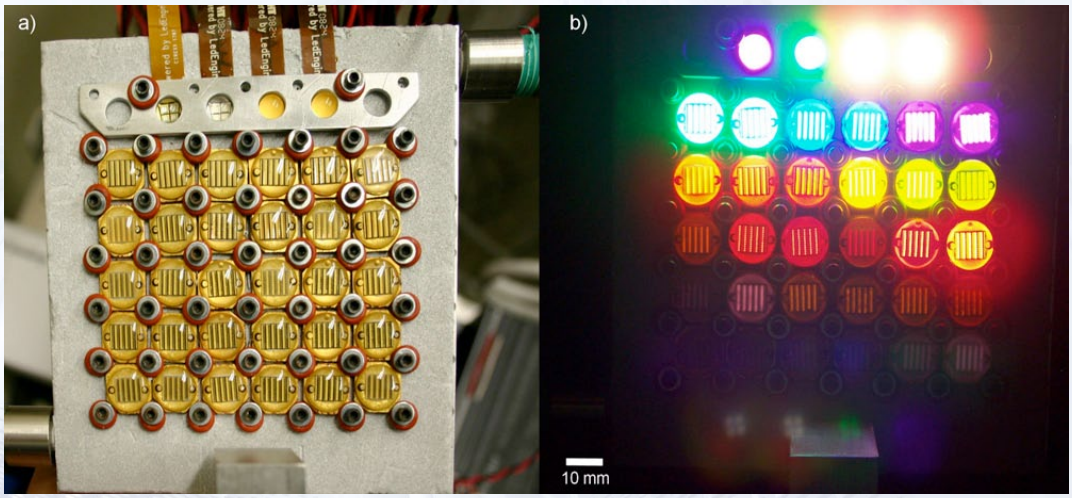
As reported in the journal Applied Optics,* the NIST team has combined 32 LEDs—each generating light from different segments of the solar spectrum—and other off-the-shelf equipment with their custom-made technologies to build a system that measures the wavelength-dependent quantum efficiency of solar devices over a relatively large area.

Anticipated advantages over current approaches—most of which use incandescent lamps or xenon arc and other types of discharge lamps—are greater speed and ease of operation, more uniform illumination, and a service life that is about 10 times longer.

The new NIST system for measuring spectral response easily accommodates two unique but complementary methods for determining how much electric current a solar, or photovoltaic (PV), device generates when hit by a standard amount of sunlight. Both methods are straightforward, and they use the same hardware setup.

With either method, the automated system produces measurements more rapidly than current instruments used to simulate solar radiation and characterize how efficiently a device converts light energy to electric energy.

One method, which activates the LED lights sequentially, is less subject to interference than the other technique, and yields a spectral response measurement in about 6 minutes. With the other method, all 32 LEDs are activated simultaneously, but each generates pulses of light at a different rate. The solar response of a PV device over the entire LED-blended spectrum can be determined in about 4 seconds.



Sections of the new NIST measurement system's LED plate are shown. A water-coolant system on the back (a) keeps the operating temperature constant. Collectively, the different-colored LEDs (b) generate light in wavelengths covering much of the solar spectrum. LEDs in the second row from the bottom emit most of their radiation in the near infrared region and appear very faint to the human eye. Light from the last row of LEDs is completely invisible. Credit: NIST

* B. H. Hamadani, J. Roller, B. Dougherty and H. W. Yoon. Versatile Light-Emitting-Diode-based Spectral Response Measurement System for Photovoltaic Device Characterization. Applied Optics Vol. 51, No. 19, July 1, 2102.

**Foundations for Innovation: Photovoltaic Technologies for the 21st Century (Report of the Steering Committee for Advancing Solar Photovoltaic Technologies). Available at: http://events.energetics.com/NISTGrandChallenges2010/index.html.

Though more susceptible to interference, the faster method has potential for in-line manufacturing tests for ensuring quality, the researchers write.

The new system represents a major stride toward a technical goal set by a group of solar energy experts convened by NIST in late 2010.** "To accelerate all types of PV development and lower costs through more accurate assessment of performance," these experts set the goal to achieve spectral response measurements in fewer than 10 minutes.

While the new system beats the time requirement, the NIST team must push their technology further to match related targets that are part of the goal. Their to-do list includes matching or exceeding the energy intensity of the sun, broadening the LED-synthesized spectrum to include the infrared portion of the sun's output, and consistently achieving measurement results with uncertainties of less than 1 percent.

With their work to date, however, the NIST researchers have demonstrated that LEDs are now "technologically viable" for use in solar simulators and for characterizing PV and other photoelectric devices, says NIST physicist Behrang Hamadani.

Nationwide Adoption of NIST-Developed Test Predicted to Cut Death Toll Due to Cigarette-Caused Fires

In 2003, New York became the first state requiring cigarettes sold within its borders to pass a fire safety standard based on a test developed by the National Institute of Standards and Technology (NIST) to reduce the risk of igniting upholstered furniture and bedding, a major cause of residential fires.

Last year, when Wyoming enacted a law similar to New York's, a milestone with lifesaving consequences was achieved: all 50 states had made the Standard Test Method for Measuring the Ignition Strength of Cigarettes (ASTM E2187) a regulatory requirement.

A new study* projects that, with nationwide adoption, deaths due to fires ignited by cigarettes or other tobacco products will drop 30 percent below the total number of such fatalities in 2003, the last full year before the ASTM E2187 was first implemented in a state. The projected decrease translates into about 200 lives saved annually.

People age 50 and older may benefit the most from the state regulations, according to the National Fire Protection Association study. This age group constitutes only 31 percent of the U.S. population, but accounts for 77 percent of deaths due to residential fires caused by smoking materials.

A NIST team, sponsored by the New York State Office of Fire Prevention and Control and led by senior research scientist Richard Gann, studied how cigarettes ignite home furnishings and then developed the test method on which the fire-safety standard is based. In 2002, the private-sector standards organization ASTM International formally adopted the test as the recommended method for measuring the capability of a cigarette to continue burning and ignite bedding, upholstered furniture and related items. Gann now chairs the ASTM International Task Group that regularly reviews the standard with the aim of identifying potential improvement in light of recent research and market developments.

The path that led to the standard and its subsequent adoption across the United States spans 28 years, beginning when Congress passed the Cigarette Safety Act of 1984. The law mandated a thorough analysis of the feasibility of developing cigarettes with a reduced propensity to ignite furnishings. A technical committee led by Gann determined that a number of already-patented cigarette design features reduced the risk of ignition.

The committee also recommended developing a valid and reliable measurement method to determine that a cigarette is less prone to ignite a fire.

* J.R. Hall, Jr., "The Smoking-Material Problem," National Fire Protection Association, March 2012. Download PDF: http://www.nfpa.org/assets/files/PDF/OS.Smoking.pdf.

Congress endorsed this recommendation in the Fire Safe Cigarette Act of 1990. Gann and his team developed two test approaches, but they eventually decided to promote their "cigarette extinction method" as a proposed standard.

Over the next decade, the NIST team subjected the test method to an extensive series of trials that involved testing laboratories throughout the United States and around the world. Results confirmed the test's validity and eventually quieted the objections of critics. Momentum in the states picked up in 2006 with the formation of the Coalition for Fire-Safe Cigarettes, a national alliance of fire service organizations, consumer groups, disabled rights advocates, public health practitioners, and others. The coalition advocated for industry and state adoption of ASTM E2187.

Gann welcomes the progress achieved over the last decade, but says there's more work to be done. "While U.S. deaths from cigarette-initiated fires are projected to be reduced by 30 percent, cigarettes will continue to be the largest cause of U.S. fire deaths," he notes.

Examples of results of the Standard Test Method for Measuring the Ignition Strength of Cigarettes (ASTM E2187) are shown. Non-filter (top) and filter (left) cigarettes "failed," having burned the full length in the test. The cigarette that extinguished before burning its full length (right) passed. The test calls for performing 40 such determinations for each cigarette and reporting the number of full-length burns. Cigarettes are positioned on the standard ASTM E2187 test substrate. Credit: NIST

Benefits of the standard are being reaped internationally. Canada, Australia and Finland already have adopted ASTM E2187. The International Organization for Standardization (ISO) has approved a version of the ASTM standard, as prepared by a committee chaired by Gann. This standard (ISO 12863) has been adopted by the European Union.

Staff Awards

Dan Madrzykowski, Nelson Bryner, Kelly Opert and Adam Barowy

Recipients of the International Association of Arson Investigators 2012 Outstanding Accomplishment Award

For research activities in the fight against arson

William Healy, Tania Ullah, and John Roller

Recipients of the ASHRAE Technical Paper Award

For their paper entitled: "Input-Output Approach to Predicting the Energy Efficiency of Residential Water Heaters – Testing of Gas Tankless and Electric Storage Water Heaters"

Sudarsan Rachuri

Computer Scientist

Elected 2012 American Society of Mechanical Engineers Fellow

For his significant contributions in information and semantic modeling of product life cycle management and the application of measurement science for sustainable manufacturing

Object Management Group Recognizes NIST EL Contributions

The Object Management Group recognized NIST EL for its technical contributions to OMG standards development. U.S. manufacturers and engineering application providers use OMG standards and modeling languages to integrate their engineering information systems

Fred Proctor

American Society of Mechanical Engineers 2012 Distinguished Service Award

For his distinguished service as Chair of the CIE division of ASME

Mahesh Mani

American Society of Mechanical Engineers 2012 Service Award

For his sustained contributions to the CIE division newsletter

Steven Emmerich

ASHRAE Environmental Health Award, 2012

In recognition of excellence in volunteer service focused on environmental health issues

Harrison Skye

Homer Addams Award, ASHRAE

For outstanding Ph.D. research at the University of Wisconsin – Madison on selecting optimal blends of refrigerants for use in a cryosurgical probe system

Piotr A. Domanski

Wilbur T. Pentzer Leadership and Achievement Award, USNC IIR

For outstanding contribution to the growth and well-being of the International Institute of Refrigeration and the US National Committee

Recent Publications

- Science-Based Metrics For Product Sustainability Assessment
- Theory Building: An Examination of the Pre-evacuation Period of the 2001 WTC Disaster"
- Evacuation of People with Disabilities on Stairs
- More Thoughts on Defaults
- Technology Readiness Levels for Randomized Bin Picking, Performance Metrics for Intelligent Systems (PerMIS)
- Overview of the Structural Design of World Trade Center
- Modeling Methodologies and Simulation for Dynamical Systems
- Service Life Prediction for Sealants
- A high-bandwidth electromagnetic MEMS motion stage for scanning applications
- Characterizing Sustainability for Manufacturing Performance Assessment
- An overview of sustainability indicators and metrics for discrete part manufacturing
- Performance Evaluation of Consumer-Grade 3D Sensors for Static 6DOF Pose Estimation Systems
- Web-enabled Real-time Quality Feedback for Factory Systems using MTConnect
- Design and Fabrication of a Three-DoF MEMS Stage Based on Nested Structures
- Accelerated Weathering of Firefighter Protective Clothing Containing Melamine Fiber Blends
- Model Based Enterprise / Technical Data Package Summit Report
- Properties of Metal Powders for Additive Manufacturing: A Review of the State of the Art of Metal Powder Property Testing
- Application of Internal Curing for Mixtures Containing High Volumes of Fly Ash
- Increasing the Service Life of Bridge Decks by Incorporating Phase Change Materials (PCMs) to Reduce Freeze/Thaw Cycles
- Using Viscosity Modifiers to Reduce Effective Diffusivity in Mortars
- The Date-Time Vocabulary
- An Integrated Data Model for Quality Information Exchange in Manufacturing Systems
- Information Required for Dimensional Measurement
- Firebrand Generation Data Obtained from a Full Scale Structure Burn

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