Testimony of
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At
National Institute of Building Sciences Hearing
on
Commercial Building Data Needs
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Introduction

Thank you for the opportunity to testify at this Hearing. I am testifying today as an independent consultant on indoor environmental quality and reside in Charlottesville, Virginia.[1] I am also an affiliated consultant with Wiss, Janney, Elstner Associates in Fairfax, Virginia, but am not representing them at this Hearing. Since 1960, I have been involved in servicing, designing, teaching, researching, diagnosing, and testifying on heating, ventilating, and air conditioning (HVAC) systems performance in commercial buildings.

The objectives of my testimony, today, are to:

1. Identify the prevalence of "Promises without Performance" and the need for an accurate database of building performance.

2. Describe limitations and weaknesses of the CBECS Database and why it should not be continued;

3. Present examples, in which I have personally been involved, on successes and failures in achieving expected energy use targets and other performance outcomes; and

4. Advocate that: 1) NIBS proceed to replace the statistical/inferential, energy-focused CBECS Database with a comprehensive, evidence-based, accurate database that is comprised of empirical data for all of the attributes of a High Performance Building, as defined in the Energy Independence and Security Act of 2007; and 2) the repository for this new database be the Whole Building Design Guide.

Credentials

During my 49 year professional career, I have focused on advancing the designs and operations of indoor environmental control systems to enhance the health, safety, and well-being of occupants, energy efficiently and cost-effectively.

My early professional practice (1962-68) was in designing and servicing automatic control systems for existing buildings and developing applications of laminar flow cleanroom technologies for health care and industrial processes. This work led to my recruitment into the Bioenvironmental Engineering Traineeship Program at Kansas State University, which was sponsored by the National Institutes of Health.

My research at KSU (1968-1974) focused on the interactions of physiological responses of humans and laboratory animals to thermal, lighting, and acoustic exposures. As Professor of Mechanical Engineering and Architecture at Iowa State University (1974-1983), I taught undergraduate and graduate courses in thermal, lighting, and acoustic principles and design, and established the Building Energy Utilization Laboratory and the Center for Advancement of Building Technologies. My research during that period focused on the relationships between indoor environmental control for occupant needs and building energy utilization.

As Senior Staff Scientist and Senior Engineering Manager at Honeywell, where I was responsible for scientific development of a multi-divisional and international program in indoor air quality (1983-1989), I focused on the development and application of scientific methodologies for diagnosing building performance that had discomforting and deleterious

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[1] My contact information is jewoods3@aol.com.

effects on occupants, which became known as "*Sick Building Syndrome*" (SBS) and "*Building Related Illness*" (BRI). Many of the cases we investigated resulted from over-aggressive energy conservation efforts. Results from a randomized national survey we conducted revealed that thermal and lighting exposures were *perceived* by employees in office environments to be significantly more important indoor environmental factors than were acoustic and indoor air quality exposures.

As Professor of Building Construction in the College of Architecture at Virginia Polytechnic Institute and State University (1989-1997), I was responsible for undergraduate and graduate instruction in mechanical and electrical systems and for research pertaining to human responses and control of indoor environments. During that time, I focused on research to improve the accuracy of building diagnostic procedures through adaptation of medical and other diagnostic paradigms.

Since I retired from Virginia Tech in 1997, I have focused on applying building diagnostic procedures for evaluating the interactions of human responses, indoor exposures, and building performance in terms of energy utilization (e.g., zero net energy mandates and goals) and protection during extraordinary conditions (e.g., resiliency) in federal buildings, other public buildings (e.g., schools and hospitals), and privately owned buildings.

This body of work has resulted in the publication of forty invited papers, fifty-five peer reviewed papers, fifty-one other articles and presentations, and six books that address the interactions between environmental control, system performance, and economic performance of buildings. This work has also resulted in five appearances before congressional committees, six testimonies at trial as an expert witness, and twenty-five depositions and administrative hearings that addressed the performance of buildings regarding their effects on health and safety.

ASHRAE

I became an Associate Member of ASHRAE in 1962 and a Full Member in 1967. I have served on Technical Committees since 1967, was elected an ASHRAE Fellow in 1992 and became a Life Member in 2005. I served as a Member of the Board of Directors from 1997 – 2000. My first involvement with ASHRAE Standards was as a Graduate Student at Kansas State University, where I helped prepare drafts of ASHRAE Standards 55-74: *Thermal Environmental Conditions for Human Occupancy*, and ASHRAE Standard 62-73: *Standards for Natural and Mechanical Ventilation*. As Chairman of the ASHRAE Technical Committee 9.2 (1972-1975), I became involved in the development of ASHRAE Standard 90-75: *Energy Conservation in New Building Design*. In 1978, I was appointed Chairman of the Committee that revised ASHRAE Standard 62-73 as ASHRAE Standard 62-1981: *Ventilation for Acceptable Indoor Air Quality*. In 1980-1981, I was appointed as Chairman of an *ASHRAE Presidential Ad Hoc Committee on Legionnaire's Disease* that prepared two seminal white papers on the sources, amplification sites, and energy and economic impacts of preventing future outbreaks of the disease in buildings. In October 2001, I was appointed as Chairman of an *ASHRAE Presidential Study Group and Ad Hoc Committee on Building Health and Safety Under Extraordinary Incidents* that prepared a white paper, which was accepted as a policy paper by the Board of Directors, and formed the basis of ASHRAE G29-2009: "*Guideline for Risk Management of Public Health and Safety in Buildings,*" of which I served as a member.

NIBS

I have participated on NIBS projects for nearly ten years. From July 2002 – June 2003, I was principal investigator of a project co-sponsored by GSA and ASHRAE to "*Develop and Implement a "Continuous Accountability" Protocol for Implementation of GSA/ PBS P-100.*" From July 2005 – June 2006, I was a team member that *provided physical security assessments for Department of Veteran Affairs Medical Centers*. From August 2004 – February 2007, I was a team member for the development of a "*Design Standard for Raised Floor Systems With and Without Underfloor Air Distribution," as a Supplement to the "PBS P100 Facility Standards for the Public Building Service*." From July 2007 – December 2008, I was a team member that provided *post-occupancy building performance evaluations* of four U.S. Courthouses for the GSA/PBS.   Since September 2008, I have been serving as a member of the Ad Hoc Subcommittee of the NIBS High Performance Building Council on the "*Development of requirements for providing higher performance of building operations in preparation and response to a disaster or catastrophic event than is presently provided by code*." Since May 2010, I have participated on a committee to develop plans for the *improved design for persons with low vision*; these improvements have strong implications for effective use of energy within buildings.

GSA/PBS

Since November 2003, I have been a participant in GSA/PBS's HVAC Quality Assurance Review Panels for new and renovation projects being designed. In November 2006, I was appointed as a Member of the GSA National Register of Peer Professionals. I have participated in more than fifty HVAC Quality Assurance reviews designs for U.S. Courthouses, Federal Office Buildings and Land Ports of Entry. I have also participated in drafting revisions to the 2005 and 2010 editions of PBS P100 Facility Standards for the Public Buildings Service.

U.S. DOE

From May 2000 – October 2001, I was a Member of the Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, Board of Energy and Environmental Systems, National Research Council (this study was sponsored by the U.S. Department of Energy). From November 2009 – November 2010, I was a participant in external review teams that were established by the U.S. DOE to evaluate more than seventy proposals submitted by universities, government laboratories, and corporations regarding research related to energy efficiency in buildings.

Promises and Performance

Fundamentally, buildings have a two-fold purpose: [2]

1. Provide shelter with safe, healthy, and secure conditions for its occupants; and

2. Facilitate the well-being, performance, and productivity of the occupants, owners and managers of the property.

To achieve and sustain this purpose, energy resources must be consumed to provide acceptable lighting and electrical power, heating and humidification, cooling, ventilation (including filtration and pressurization), and acoustic control.

Current issues regarding energy costs, energy security, and environmental impact (e.g., carbon footprint) are stimulating the promulgation of federal, state, and local public regulations and policies, as well as national standards and corporate policies. Frequently, these policies are proposed and implemented with only vague concepts of why or how to measure their impact on health, safety, security, or cost-effectiveness. Examples of such policies include: The American Recovery and Reinvestment Act of 2009; the Energy Policy Act of 2005; the Energy Independence and Security Act of 2007; the U.S. GSA/PBS *Facilities Standards for the Public Building Services* – P100-2010; ANSI/ASHRAE/IESNA 90.1-2010: *Energy Standard for Buildings Except Low-Rise Residential Buildings*; the AIA 2030 Challenge goals and policies; USGBC LEED® certifications; and the International Building Code. These policies focus on reducing building energy consumption from previous baselines.

Implementation of these policies has resulted in a significant marketing effort with promises and claims being made but not supported with documented evidence of actual building performance. One such example is given here, and others will be described later in this testimony.

The AIA 2030 Challenge

As stated in its website, [3] the AIA 2030 Challenge is for *"global architecture and building community to adopt the following targets:*

- *All new buildings, developments and major renovations shall be designed to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 60% below the regional average for the building type.*

- *The Fossil fuel reduction "standard" shall be increased to:*

  o *70% in 2015*

  o *80% in 2020*

  o *90% in 2025*

  o *Carbon neutral in 2030.*"

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[2] Woods, J.E. 2008. Expanding the Principles of Performance to Sustainable Buildings. *Real Estate Issues*, Vol. 33, No. 3, pp 37-46.

[3] See Case Studies at http://architecture2030.org/index.php.

> The AIA 2030 Challenge focuses exclusively on energy reductions; it does not address any other performance attributes.
>
> The availability of reliable "regional" databases, to which the energy "standards" in the 2030 Challenge have been referenced, has not been established.

A total of 144 case studies are posted on this website. Of these 65% were built before 2004, 40% had LEED® certifications with 17% at Platinum, *yet 61% did not provide energy consumption data that were measured or calculated*.

Of the 102 cases (i.e., 71% of the 144 cases) for which first costs were reported, 51% reported first costs between $100-199/SF,[4] and 38% reported first costs from $200/SF to more than $500/SF. *No further details of first costs and no information on life-cycle costs were provided.* Although expected pay-back periods were reported for a few cases, no documentation was provided to indicate if the pay-backs had been achieved.

Of the 56 cases (i.e., 39%) for which the annual Energy Utilization Intensity (kBtu/GSF)[5] values were reported, 75% claimed to consume less than 50 kBtu/GSF, *but most of these values were calculated and not verified as measured or metered values. No comparisons with "regional averages" were made*.

Of the 64 cases (i.e., 44%) that reported the use of renewable resources, 48% claimed offsets of annual energy consumption rates that exceeded 30% reduction in fossil fuel use, and 25% claimed 100% reductions in fossil fuel use. The latter set was reported to qualify as zero-net energy buildings. *Information to verify that these were actual measured reductions was not provided in these case studies.*

As shown in Fig. 1, the most frequently claimed or promised percentages of energy reductions for the 144 cases were between 20 and 79%, whether or not the EUIs had been reported. Moreover, the various baselines, to which these claims were referenced, were vaguely documented, if at all.

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[4] These data do not distinguish between SF and GSF (i.e., gross square feet). We have seen differences in these measures of more than 25%. It is critically important to be accurate in the description of these areas, and to distinguish between "gross," "net," "occupied," or "conditioned" floor area.

[5] The data were reported as EUI without dimensions. For this testimony, I have assumed the EUI is defined in accordance with the CBECS/EIA definition: Annual Energy Utilization Intensity in dimensions of kBtu/GSF.
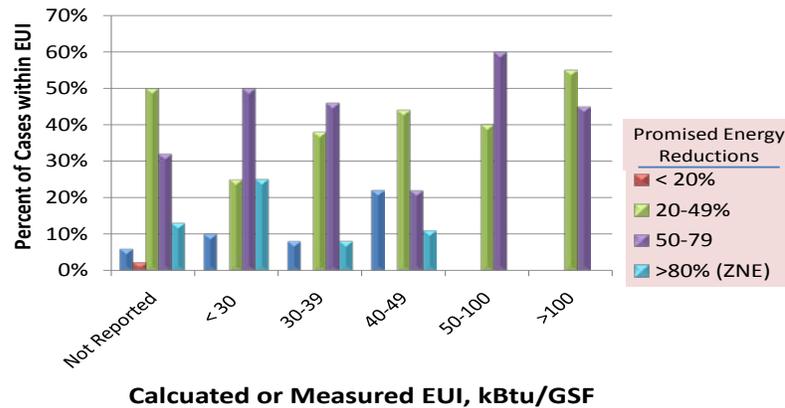
Figure 1. Promised energy reductions for reported EUI values.

Sixteen of the 144 cases were reported to be Zero-Net Energy Facilities. Of these, 12 did not report on measured or calculated EUIs, nine of the 16 claimed reductions of EUIs of more than 40% but without reference to baselines. The residual energy requirements were reported to have been provided by various combinations of photovoltaics, wind, hydroelectric and "earthen tubes." In seven cases, the offsets were reported as purchased "Green Power," some with leases of only two years. *Documentation of actual reductions was not provided for any of these cases.*

> For these case studies to be considered more than "promises," substantially more care and accountability are required to verify their actual "performances." As reported on the referenced AIA website, these case studies do not provide credible evidence that the "promises" in the 2030 Challenge are being fulfilled.

Accountability for Performance

If measurable improvements in energy utilization for safe, secure and healthy environments, acceptable occupant responses, and acceptable economic performance of buildings are to be realized, two basic objectives must be achieved:

> 1. *Establishment of credible and measureable criteria* for acceptable building performance, and corresponding implementation processes; and
>
> 2. *Establishment of a continuous accountability process*[6] for those who own, plan and design, construct, commission, and operate and maintain buildings.

Partially due to a lack of these credible and measurable criteria, the design profession has become increasingly compartmentalized and fundamentally risk-adverse.[7] Conversely, the

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[6] Woods, J. E. and Arora, S. 1991. Continuous Accountability for Acceptable Building Performance. *Proceedings of First International Symposium on Building Systems Automation- Integration*. University of Wisconsin. Madison, June 1991.

designs of building envelopes, lighting, and HVAC systems are becoming increasingly more complex, and the quality of construction work is changing.

These conditions demand that we develop a new paradigm for project delivery and for assurance of long-term performance.

Total Building Commissioning (C_x) and Building Envelope Commissioning (BEC_x) processes[8,9] have emerged as a result of this demand, in part because the design community has not assumed direct responsibility for the discrepancies between owner/developer expectations regarding accountability, the reality of how architecture and engineering are actually practiced today, and how buildings are actually delivered to the marketplace.

Although C_x and BEC_x processes assist in documenting building performance, they do no replace the need for *accountable persons* during the life-cycle of a building.

To assure continuous accountability, the accountable person must be:[10]

- E*xplicitly identified* for each phase in the building's life;

- E*mpowered* with authority to assure building performance; and

- E*ducated and trained* to assure adequate building performance and occupant well-being.

Furthermore, the criteria with which the accountable person evaluates the building performance must be consistent and measurable at each stage of the life-cycle of the building.

Analysis of the Commercial Building Energy Consumption Survey (CBECS) Database[11]

Basis of the CBECS Database

In recognition of the need for a national database on energy consumption in commercial buildings, the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE) developed and updated a database by collecting data and reporting on energy consumption, expenditures, and other energy-related topics in the major energy-consuming sectors of the U.S. economy, every three or four years from1979 to 2003.[12]

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[7] Lemieux, D.J. 2008. Trust, but Verify – Building Enclosure Commissioning in Sustainable Design. *Real Estate Issues*, Vol. 33, No. 3, pp 29-36.

[8] Ibid.

[9] See "Building Commissioning" at http://www.wbdg.org/project/buildingcomm.php.

[10] First presented by Woods, J. E. in 1994 at "Testimony at Public Hearing on OSHA Proposed Standard for Indoor Air Quality," before the Hon. John Vittore, Administrative Law Judge, Washington D.C., Sept. 23 1994.

[11] This analysis is derived from the study completed in 2009 by the National Center for Energy Management and Building Technologies for the U.S. Department of Energy: Scientific Outreach Program Pilot, Final Report 090717. Co-authors: James E. Woods, Richard Sweetser, and Davor Novosel. This report may be accessed at http://www.nemionline.org/site/content/reports/view/41.

[12] U.S. DOE/EIA. 1995. *Energy Consumption Series: Buildings and Energy in the 1980s*. DOE/EIA-0555(95)/1.

For this database, the EIA conducted separate surveys of the residential and commercial sectors: the Residential Energy Consumption Survey (RECS), and the Commercial Buildings Energy Consumption Survey (CBECS).

These data were also collected for publication in 2007, but because of data collection deficiencies and budget cuts, DOE announced that the 2007 CBECS data would not be published, and 2011 data from the RECS and CBECS would not be collected.[13,14]

The 1979-2003 surveys were conducted in two stages, a Household/Building Survey and an Energy Suppliers Survey:

(1) The Household/Building Characteristics Survey consisted of personal interviews with "knowledgeable" respondents at each sample household/building. An exception occurred in 1983, when the CBECS was conducted by Computer Assisted Telephone Interview (CATI). The interviews covered topics such as physical characteristics of the structure, occupancy patterns, major equipment, conservation practices, and the types and uses of energy in the facility. *Human response or occupant performance topics were not included in the interviews*.

(2) At the end of the interview, respondents were asked to provide the names and addresses of the companies that supplied energy to their household/building in the form of electricity, natural gas, fuel oil, or district heating and cooling (CBECS only), and to sign a form authorizing the EIA to collect billing information directly from these energy supply companies. A separate mail survey, the Energy Suppliers Survey, asked these energy suppliers to provide data on the amounts and costs of energy delivered to the household/building during the survey year.

For more than thirty years, the predominant building energy performance metric in the United States has been the "Energy Utilization Index" (EUI),[15,16] which is now also called the "Energy Utilization Intensity." Uncertainties in this metric have been known to exist since 1978.[17,18] *A variation of the EUI was used as the primary metric in the CBECS reports*. Whereas the EUI is a figure of merit for a specific building, the CBECS energy use data were normalized in groups of buildings as "Energy Intensity" (EI) or as "Gross Energy Intensity" (GEI) metrics.[19]

The terms EI and GEI, which were used interchangeably in the CBECS database, were defined as: *"Total consumption of a particular energy source(s) or fuel(s) by a group of*

[13] U.S. DOE/EIA. 2011. Press Announcement, 28 April, 2011, http://www.eia.gov/pressroom/releases/press362.cfm.

[14] U.S. DOE/EIA. 2011. Commercial Buildings Energy Consumption Survey, http://www.eia.gov/emeu/cbecs/.

[15] AIA Research Corporation. 1974. *Energy Conservation in Building Design*. American Institute of Architects, Washington, DC.

[16] Dubin F.S. and Long, C.G. 1978. *Energy Conservation Standards for Building Design, Construction and Operations*. McGraw-Hill, New York.

[17] Stroeh, H.H. and Woods, J.E. 1978. "Development of a Hospital Energy Management Index". *ASHRAE Trans*. 84 (Part 2): 68-76, 1978.

[18] Woods J.E. and Peterson P.W. 1978. "Development of a Building Energy Management Program for State Buildings in Iowa." Presented at the *Winter Annual Meeting of the American Society of Mechanical Engineers*, December, 1978.

[19] U.S. DOE/EIA. 1995. *Energy Consumption Series: Buildings and Energy in the 1980s*. DOE/EIA-0555(95)/1.

buildings, divided by the total floorspace of those buildings, including buildings and floorspace where the energy source or fuel is not used, i.e., the ratio of consumption to gross floorspace."[20]

The GEI provided for comparisons of normalized energy consumption rates between groups of buildings but only provided a "pooled value" as a statistical reference with which the EUI of a specific building could be compared. The pooled statistical data were further subdivided and modeled with computer programs (e.g., FEDS), by climate, size, age, functional use, and other parameters.[21, 22]

Historic Patterns of CBECS Database

Commercial Buildings Energy Consumption Surveys were completed for nonresidential buildings that were not primarily industrial or agricultural in 1979, 1983, 1986, 1989, 1992, 1995, 1999, and 2003. In 1986 and afterwards, commercial buildings less than 1,000 ft^2 floor area were excluded in the surveys. The number of commercial buildings for which both parts of the Survey were completed ranged from a high of 7,140 in 1983 to a low of 5,215 in 2003.[23]

During the period of 1979 – 2003, the estimated inventory of buildings represented by these surveys increased from just over 3 million to nearly 5 million buildings, an increase of approximately 2.4% per year. Therefore, the completed samples represented only 0.11 – 0.22% of the estimated total population of commercial buildings in the U.S. during the years sampled.

To adjust for the uncertainties due to the small sample sizes, the CBECS reports included "Relative Standard Errors" (RSE) for the various cells in the tables, which were a measure of the precision of a survey statistic. The RSE was defined as the "standard error of the survey estimate, expressed as a percent of the estimate."[24] To calculate the 95% Confidence Interval (CI) for the data shown in a particular cell, the CBECS Reports suggested that the RSE be multiplied by the factor 1.96.[25]

As shown in Figure 2, when the RSEs are applied to determine the 95% CIs for Office Buildings and for All Buildings, the 24-year average GEIs have remained statistically flat for the entire history of the CBECS data collection. Figure 2 also shows that the Lower Bands of the 95% CIs have always been at least 35% higher than the BEPS goal,[26] and that the 24-year average GEI values have consistently been nearly twice the BEPS goal with the average values for the subset of Office Buildings exceeding the average values for All Buildings (i.e., 104,600

[20] EIA glossary specific to the 1999 and 2003 Commercial Buildings Energy Consumption Surveys (CBECS). http://www.eia.doe.gov/emeu/cbecs/glossary_1.html.

[21] EIA. 2008. Estimation of Energy End-Use Consumption. http://www.eia.gov/emeu/cbecs/tech_end_use.

[22] EIA. 1995. Energy End-Use Intensities in Commercial Buildings, 1995 -- Overview/End-Use Estimation Methodology.

[23] Op. cit. 11.

[24] EIA glossary specific to the 1999 and 2003 Commercial Buildings Energy Consumption Surveys (CBECS). http://www.eia.doe.gov/emeu/cbecs/glossary_1.html

[25] See EIA website for 1995 survey information. http://www.eia.doe.gov/emeu/cbecs/stat_significance.html.

[26] Op. cit. 15 and 16.

Btu/GSF vs. 92,000 Btu/GSF). *This is another example of the discrepancies between the promises and the performance of commercial buildings.*
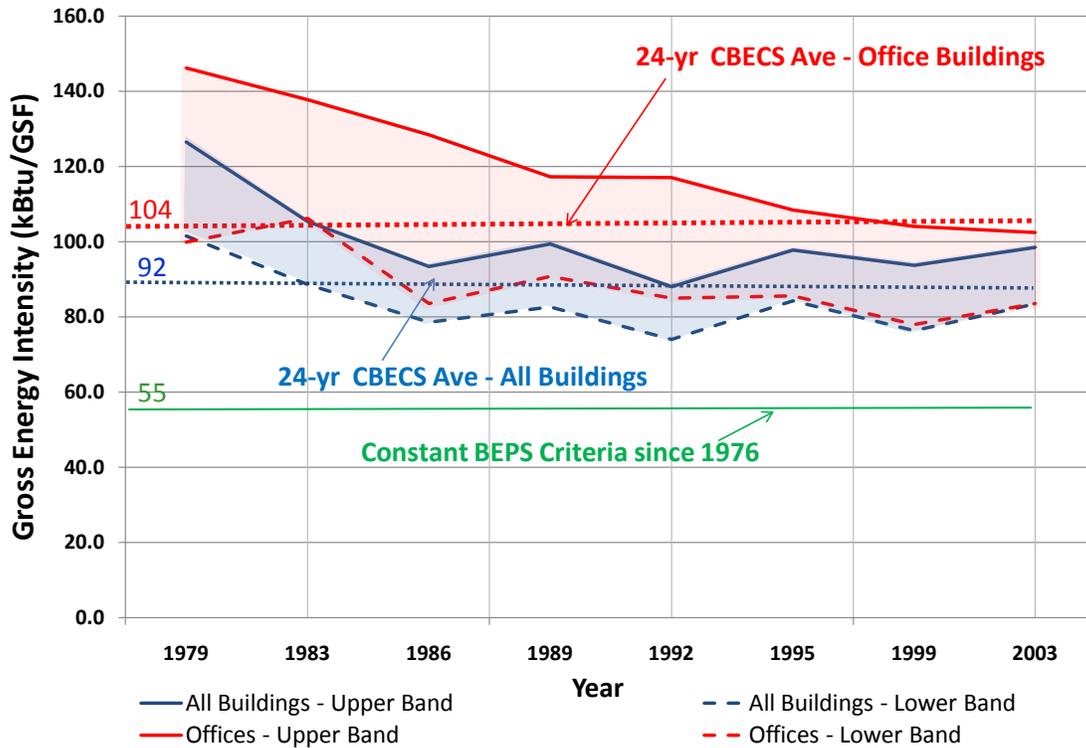

Figure 2 CBECS Data for All Buildings and Offices (1979-2003) with 95% Confidence Intervals.[27]

Based on these findings, the differences between the 24-year averages of the GEIs for Office Buildings (i.e., 104,600 Btu/GSF) and All Buildings (i.e., 92,000 Btu/GSF) are not statistically different within the 95% CIs. However, even with the imbedded uncertainties, these average values have served as a general reference with which comparisons of site-specific EUIs are to be made for compliance with EISA-2007.[28]

Additional Uncertainties in CBECS Database

In addition to the uncertainties due to the small samples sizes and different calculation procedures used during its 24-history, the CBECS database contains other uncertainties:

- The quantitative definitions of the boundaries of buildings (i.e., gross square footage of floor area, GSF) for GEI values is less precise than for EUIs, as GEI information is obtained by surveys rather than site-specific evaluations. These boundaries are even less precise when the buildings being surveyed are part of a campus, and results are pooled

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[27] Op. cit. 11.

[28] EISA. 2007. Title IV: Energy Savings in Buildings and Industry. *Energy Independence and Security Act of 2007.* Public Law 110-140, December 19, 2007.

over a "group of buildings" per the definition of GEI. *We have found errors in reported values of GSF up to 25%.*

- The periods of measurement for each energy resource are not uniform. Furthermore, normal occupancy periods and periods of extraordinary conditions (i.e., during and after natural, accidental, or intentional hazards) are not differentiated.

- The precision and accuracy (i.e., calibration) of the instrumentation and meters that were used to obtain the energy resource data are not known.

- The conversion factors to a common energy term in the GEI (e.g., Btu) are not uniform for all samples and for all years of the surveys.

- The gross floor areas in the groups of buildings were estimated based on personal interviews during the Building Characteristics Surveys. When the GSFs were not known, the interviewees were asked to estimate the sizes of the buildings within given ranges.

Other Needed Measures of Building Performance

Even with their uncertainties, building energy utilization metrics (e.g., EUI, GEI) provide some meaningful information regarding the normalized rate of consumption of energy resources during a defined period of time (e.g., kBtu/GSF/yr). *However, they provide no information regarding the <u>effectiveness</u> of the energy used to provide for the functional performance of buildings*.

> Management of building energy consumption is a necessary but not sufficient means to assure acceptable building performance.

EISA-2007[29] defines a high-performance building (HPB) as one that "integrates and optimizes on a life-cycle basis all major high-performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations." To integrate and optimize these attributes, objective measurement and control of them are required. To reduce uncertainties, these functional performance metrics must be quantitatively measurable, valid, repeatable and reliable, and referenceable to credible databases. These measures should be obtained through validated and standardized protocols for interviews, surveys, system diagnostics, and economic analyses.

Occupant Acceptability

> Essential measures for evaluating the achievement or sustainment of the fundamental purpose of a building include tenant or occupant acceptability of the indoor environment.

If the measured values comply with their criteria, occupant comfort is likely to be satisfactory, occupant performance is likely to be enhanced, the resultant productivity of the facility is likely to be improved, and the fundamental purpose of the building is likely to be sustained. Conversely, if these values fail to comply with their criteria, occupant health, safety, comfort, and performance are likely to be compromised, the resultant productivity of the facility is likely to degrade, and the fundamental purpose of the building is likely to be at risk.

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[29] Ibid.

Figure 3 provides a representation of the relationships among physical and human factors, which are forcing functions; cost and human response factors, which act as both forcing and response functions; and occupant performance and productivity factors, which are response functions.[30]
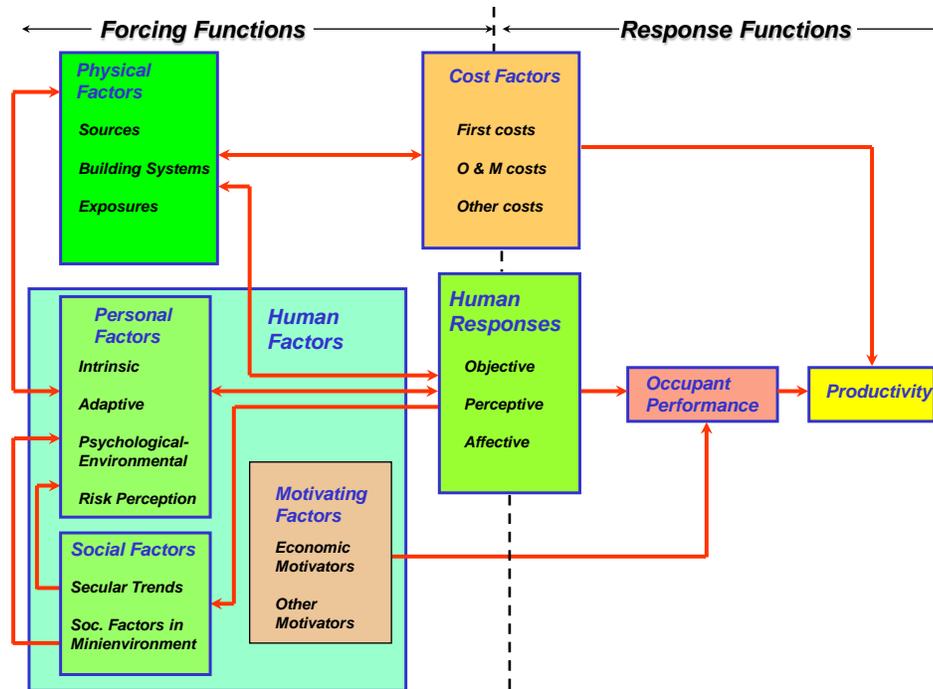

Figure 3. Relationships of forcing and response functions of occupants within buildings.[31]

Human Response, Occupant Performance and Productivity

A basic attribute of building performance is *human response*, which is influenced by both physical and human factors (see Fig. 3).

The perceptual and affective metrics of human response consist of four domains, two of these relate to Objects of Response (i.e., Environmental and Personal State), and two relate to Aspects of Response (i.e., Perceptual, and Affective or Judgmental).[32] As shown in Table 1, each cell of this 2 x 2 matrix defines a subset of human responses.

Table 1. Four Domains of Human Response.[33]

Objects of Response	Aspects of Response	
	Perceptual	Affective

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[30] Sensharma, N.P. and Woods, J.E. 1998. "An Extension of a Rational Model for Evaluation of Human Responses, Occupant Performance and Productivity." In: *Design, Construction, and Operations of Healthy Buildings: Solutions to Global and Regional Concerns*. D.J. Moschandreas, Editor. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Publisher, Atlanta, Ga., pp. 33-43.

[31] Ibid.

[32] Sensharma, N.P., Edwards, P.K., Woods, J.E., et al. 1993. Characterizing Human Response in Indoor Environmental Evaluations. *Proceedings of IAQ'93*, Philadelphia, pp. 107-113. ASHRAE, Atlanta.

[33] Ibid.

Environmental	• External Sensory Responses	• Acceptability • Preference
Personal State	• Internal Sensory Responses	• Comfort • Well Being

- The upper left cell defines perceptual responses to indoor environmental stressors that stimulate physiological (i.e., external sensory) receptors. These responses provide information regarding the indoor exposures. Examples of External Sensory Responses (ESR) are: the room is bright, the room is noisy, the room is hot, and the room is odorous. Research on these responses has provided the basis for environmental control criteria and metrics such as illumination levels, background noise levels, room temperatures and humidities, air movement, and ventilation rates.

- The lower left cell defines perceptual responses to internal stressors that stimulate other physiological receptors. These responses may or may not be related to ESRs. Responses in this domain include symptoms and discomfort complaints. Examples of Internal Sensory Responses (ISR) are: I am cold, I have a fever, I have a headache, I am dizzy, I cannot hear the speaker, I cannot read the book, and I smell chemicals. Criteria and metrics in this domain (e.g., percentage of occupants with certain symptoms or discomfort complaints) are usually appropriate for diagnosing "problem buildings" (e.g., SBS or BRI) and environmental security issues.

- The upper right cell defines affective or judgmental responses to the ESRs. Examples of these responses are: the environmental conditions in this room are acceptable, the glare in this room is unacceptable, the noise in this room is excessive, the thermal conditions in this room are satisfactory. *Most codes and standards are limited to defining metrics in this domain, which is appropriate for normal design conditions.*

- The lower right cell defines affective or judgmental responses to ISRs or to affective-environmental responses. Examples of these responses are: I am comfortable, I am satisfied, I am sick, I am safe. Criteria and metrics in this domain are usually appropriate for investigating occupant complaints or for assuring environmental safety and security, after the building is occupied.

For general evaluations in non-problematic buildings during normal intensities of physical and social forcing functions, *occupant acceptability* (i.e., environmental-affective domain) is a primary measure of human response.[34]

This measure can also be correlated with exposure attributes that vary for specific building functions. The measured values of occupant acceptability are also used as a basis for design criteria, building codes and design standards. For problematic buildings or other extraordinary conditions, attributes in the other human response domains (i.e., personal-perceptive domain, or personal-affective domain) may provide more sensitive information than occupant acceptability (i.e., environmental-affective domain), as measurable parameters and values can be selected that can minimize false negative errors.[35]

Measures of *occupant performance* are also essential in evaluating how well a building is achieving or sustaining its fundamental purpose.

Measures of occupant performance are distinct from measures of human response. While objective, perceptual and affective measures provide information on the *responses* of the occupants to the indoor environment, performance metrics provide information regarding the

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[34] Rohles, F. H., Jr., Woods, J. E., and Morey, P. R. 1989. "Indoor Environment Acceptability: The Development of a Rating Scale". *ASHRAE Trans* 95 (Part 1), pp. 23-27..

[35] Op. cit. 30

behavior of the occupants within the indoor environment.[36] *A fundamental difference between human response and occupant performance is the influence that motivation (e.g., monetary incentives, patriotism, fear and intimidation) has on the occupant* (see Fig. 3). A high level of motivation can result in increased occupant performance in spite of detrimental human responses. This conflict has been a contributing factor in cases of "Sick Building Syndrome" and "Building Related Illness."[37]

> Traditional measures of *productivity* are often confounded with measures of occupant performance.[38,39]

Whereas, occupant performance assesses functional action or behavior of the occupant in the indoor environment, productivity is a transformed economic metric of occupant performance and of other cost factors (see Fig. 3).

Uncertainties in Human Response, Occupant Performance, and Productivity Data

Several types of measures are needed to evaluate human response, occupant performance, and productivity. Some of these can be measured with more accuracy than others: 1) objective measures of human responses can be obtained with clinical procedures that have been tested for validity and reliability; 2) cost factors can be obtained with valid accounting procedures; and 3) some occupant performance measures can be obtained with independent, reliable and valid industrial engineering techniques (e.g., time and motion studies). *However, most of the human response and occupant performance data that are available from field studies and investigations are obtained by using survey and interview instruments that have not been pretested for reliability or validity.*

If the questions in survey and interview instruments for data acquisition on human response and occupant performance are pretested for validity and reliability (i.e., calibrated for precision and accuracy), the uncertainties of the survey and interview responses can be quantified in terms of standard deviations, standard errors, and confidence intervals.[40,41] Otherwise, the accuracies of these data are unknown.

Another source of uncertainty is the framing of the questions within the relevant human response domains that pertain to the objectives of a study. The number of variables and the uncertainties for evaluating human responses can be minimized by carefully selecting and constructing the questions within the appropriate domains. For example, questions for comparing occupant acceptability of the indoor environmental conditions with design criteria would focus on the environmental-affective domain, whereas questions for diagnosing occupant complaints would focus on the personal-perceptual and personal-affective domains.

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[36] Ibid.

[37] Building Research Board. 1987. *Policies and Procedures for Control of Indoor Air Quality*, National Research Council, Washington, D.C

[38] Sensharma, N.P., Woods, J.E., Goodwin, A.K. 1998. "Relationships between the Indoor Environment and Productivity: A Literature Review." *ASHRAE Trans*. Vol. 104, Part 1A, pp 686-701.

[39] Woods JE. 1989. Cost avoidance and productivity in owning and operating buildings. In: *Occupational Medicine: State of the Art Reviews* (JE Cone and MJ Hodgson, eds.), Philadelphia, PA, Hanley and Balfus, Vol 4, no. 4, pp. 753-770.

[40] Op. cit. 32.

[41] Op.cit. 34.

As productivity metrics are economic transformations of occupant performance metrics modified by cost factors, the uncertainties associated with productivity measures include the uncertainties in the occupant performance metrics, the uncertainties in the economic values attributed to the changes in occupant performance due to an intervention, and the uncertainties in the data compiled to determine the first costs of the intervention and the changes in operational and maintenance costs incurred during and after the intervention.

Figures of Merit: Acceptability Index Value

The effectiveness of the energy used to provide for the fundamental purpose of the building can be evaluated by establishing "Figures of Merit" (FOM)[42] that combine energy use and occupant response, or other empirical data, which are reflective of the time period and intensity of the forcing functions.

Such an FOM is the ratio of the EUI to the percentage of occupants whose average annual response is that the overall indoor environment in their workplaces is "acceptable." Another similar FOM is the ratio of the EUI to the percentage of occupants whose annual average response is that the temperature (or illumination level, acoustic level, or odor perception level) at their workplaces is acceptable. If the criterion value for EUI were 56,000 Btu/GSF and the criterion for annual average percentage of occupant acceptance were at least 80%, then an "Acceptability Index Value" (AIV) would be no higher than 700 (i.e., 56,000 Btu/GSF / 80 percent). For an AIV higher than 700, either the energy use is above the criterion or the occupant acceptance is below the criterion. A resolution to this issue would be to make physical changes to reduce energy consumption without comprising occupant acceptance, to make psycho-social changes that would improve acceptance without increasing energy consumption, or both.

Even greater sensitivities can be anticipated from other FOMs that are derived to evaluate the effectiveness of annual energy use per unit of annual average occupant performance or productivity metrics. However, it is anticipated that the uncertainties associated with the AIVs would be less than those associated with comparable FOMs that would include occupant performance or productivity attributes.

Therefore development of the overall AIV is a reasonable first step in improving the sensitivity of metrics for evaluating building performance.

Credible FOMs for evaluation of the effectiveness of the energy consumed in a building must be developed from empirical data sets that:

- Contain concurrent measures of building energy consumption and measures of acceptable human responses (i.e., response functions);

- Include information on the intensity and duration of the physical or social forcing functions imposed on the building as a system; and

- Address the uncertainties associated with these metrics.

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[42] Op. cit. 39.

Review of Data Sets

Five sets of empirical data that included office buildings were reviewed to determine if they qualified for use in developing the concept of the AIV; two qualified:

1. Two data sets from NCEMBT Reports.[43,44] In each of these sets, 10 buildings were evaluated. One set contained data from "normative buildings" with no known problems of health or safety. The other set contained "high performance" buildings that had received LEED® certificates and had no known health or safety problems. Site visits were made, information on building characteristics was obtained through a standardized data acquisition protocol, utility bills were obtained and analyzed to determine annual energy consumption, and human response and occupant performance data were obtained through a standardized survey questionnaire that was developed for these tasks. *Both of these sets of data qualified*.

2. The National Institute of Building Sciences (NIBS) reported on post-occupancy evaluations (POEs) of four US Federal Courthouses that were constructed, expanded, or modernized during the last 10 years.[45] Two of these were LEED® Gold: one new construction (NC), and one existing building (EB pilot). Concurrent data were acquired for energy consumption and for occupant responses, which were obtained by a standardized survey questionnaire, but different than the NCEMBT questionnaire. The occupant responses were primarily in the affective-environmental domain. These reports also include analyses of building system performance. *This set of data qualified*.

3. The DOE/EIA CBECS data set[46] of over 5,000 buildings *did not qualify* because occupant response data were not reported.

4. The US Environmental Protection Agency's Building Assessment Survey and Evaluation (BASE) data set[47] of 100 commercial buildings *did not qualify*, because energy consumption data were not reported.

5. The data in the New Building Institute (NBI) report on energy performance of buildings that had been LEED® certified for new construction projects[48] *did not qualify*. This report provided originally acquired energy consumption data from 121 LEED® certified commercial buildings, of which approximately 33% were office buildings.[49] This report

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[43] Stetzenbach, L.D., et al. 2008. Measurement and Verification of Building Performance Characteristics, National Center for Energy Management and Building Technologies, Alexandria, VA, Final Report NCEMBT-080201.

[44] Stetzenbach L.D., et al. 2008. Building Performance Characterization, Energy Usage, and Indoor Environmental Quality in High Performance Buildings, National Center for Energy Management and Building Technologies, Alexandria, VA, Final Report NCEMBT (Task 06-06).

[45] Kennett, E. 2009. *Post Occupancy Evaluations of GSA Federal Buildings*. Presented at US GSA HVAC Excellence Workshop, Albuquerque, NM, 5-7 May 2009. National Institute of Building Sciences, Washington, D.C. Presentation and individual POE Reports are available at ftp.wbdg.org.

[46] Energy Information Administration. 2009. Commercial Buildings Energy Consumption Survey (CBECS) Energy Uses and Cost Data (2003 data set). http://www.eia.doe.gov/emeu/cbecs/contents.html.

[47] U.S. EPA. 2003. *A Standardized EPA Protocol for Characterizing Indoor Air Quality in Large Office Buildings*. (PDF, 311, pp, 1.5 MB). Office of Research and Development and Office of Air and Radiation, U.S. EPA, Washington D.C.

[48] Turner, C., and Frankel, M. 2008. *Energy Performance of LEED® for New Construction Buildings*. The New Building Institute, Final Report, 4 March 2008, Vancouver, WA.

[49] This percentage was derived from Fig. 3 in footnote 48.

also briefly described occupant response data that were obtained by NBI through surveys of some occupants in 10 of the 121 buildings[50] in which average "comfort ratings" on a 5-point scale (i.e., affective-personal domain) were reported for acoustics, lighting, temperature, and air quality. *However, the energy consumption and occupant response data could not be transformed to AIVs as the report did not link the buildings from which the energy data were obtained to the buildings from which the occupancy response data were obtained.*

Selection of Buildings to Determine AIV

Buildings were selected from the NCEMBT and NIBS data sets based on the following set of criteria:

1. Energy consumption and occupancy response data were concurrent and contiguous.

2. Utility bills or energy consumption records were available and validated as reported, or by subsequent acquisition and validation.

3. The metered values in the utility records were defined as the boundary of the building.

4. Data on the gross square feet (GSF) of the building were validated as reported, or by subsequent acquisition and validation.

5. A statistically large number of questionnaires (i.e., ≥ 28) was returned from occupants in each building.

Of the 24 buildings in the two data sets, only seven were selected based on the five criteria. A summary of these buildings is shown in Table 2. Descriptions of these buildings were provided in the Appendix of the NCEMBT Report.[51]

Table 2. Summary of Selected Office Building Characteristics.[52]

Bldg ID	Const. Completion Date/ Location	LEED® Rating	No. Floors/GSF	System Type		EUI (Btu/GSF/yr)		Occupancy		Overall Accept-ance (%)
				Primary System	Supply Air Distribution	Reported	Verified	No.	Density (GSF/P)	
1-6	2004/ PA	Gold	4/ 189,599	Steam/ Packaged RTUs	VAV/UFAD	36,076	49,919	240	789	71

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[50] This number was derived from Fig. 27 in footnote 48.

[51] Op. cit. 11.

[52] Ibid.

1-8	2003/ CA	Gold	2/ 52,300	Hot/ chilled water AHUs	VAV/CAD	40,507	40,717	75	697	83
1-9	2004 MO/	Platinum	2/ 109,000	Steam/ Hot/ chilled water AHUs	CAV/UFAD	NA	61,171	170	641	61
6-3	2004/ NB	Gold	3/ 68,000	Hot/ chilled water AHUs	VAV/UFAD	NA	79,118	100	680	61
6-4	2005/ MO	Platinum	4/ 120,000	Hot/ chilled water AHUs	VAV/UFAD	40,506	45,716	300	400	61
FCH-1	2006/ OR	Gold	5/ 266,742	Hot/ chilled water AHUs	VAV/UFAD (50% of floor area)	30,500	53,386	180	1482	56
FCH-4	2003/ FL	Not Rated	15/ 491,698	Hot/ chilled water AHUs	VAV/CAD	54,347	54,347	NA	NA	91

Criteria for AIV Evaluation

Two goals were proposed for evaluation of the effectiveness of energy use in these buildings:

1. The annual Overall Acceptability Index Value (AIV), measured as EUI / % Overall Acceptance) should not exceed 700 (i.e., 56,000 Btu/GSF / 80% Overall Acceptance).

2. The annual Specific AIVs for thermal, IAQ, lighting, and acoustic attributes should not exceed 600 (i.e., 56,000 Btu/GSF / 90% Specific Attribute Acceptance).

A comparison of the overall and specific AIVs to the rational goals of 700 and 600, respectively, *provides a measure of the <u>effectiveness of energy use</u>*: if the measured values are less than the rational goals, the effectiveness of energy use can be considered to meet expectations; otherwise, the measured values indicate that either excessive energy is being used, systems are not performing adequately to provide for the expected environmental acceptability, or both.

Preliminary Findings

Significant variances existed in the means of all of the values and parameters calculated for the sets of the screened buildings. However, the uncertainties in the individual values and parameters were minimized through the screening, selection, and validation of these data sets. Therefore, it is likely that the variances observed in the means of these screened data sets (i.e., percent standard deviations greater than 10%) are indicative of the sensitivities of these AIVs in detecting the effectiveness of energy used to achieve the intended occupant responses in existing buildings. These mean values can also provide benchmarks for establishing goals and design criteria for new and existing buildings.

The specific AIVs identified additional sensitivities. In particular, two of the validated specific AIVs (i.e., "Temperature" and "Acoustics") indicated that even though the Overall Annual AIV might be close to the criteria (e.g., 700 Btu/GSF/yr/%OA), the specific AIVs may not be close to their goals.

Figure 4 illustrates the resultant AIVs for the three acceptability attributes (i.e., Overall, Temperature and Acoustics) that were determined by comparing the results of EUI and the acceptance responses in the selected buildings. As shown in this Figure, the Overall AIVs for three of the buildings (i.e., 1-6, 1-8, and FCH-4) were close to or within the overall goal of 700. However, with the exceptions of the Acoustics AIV for Building 1-6, and the Temperature AIV for Building 6-4, all of the Specific AIVs were larger than the corresponding Overall AIVs for the buildings. Only Building 1-8, had all three AIVs below the overall and specific goals and would qualify for further evaluation as a "high-performance building" according to the two-step process, as shown in Fig. 5. Conversely, four of the buildings, 1-9, 6-3, 6-4, and FCH-1 had AIVs that were substantially higher than the goals and are indicative of buildings in which improvements in system performance are likely to result in reduced energy use and increased occupant acceptability.
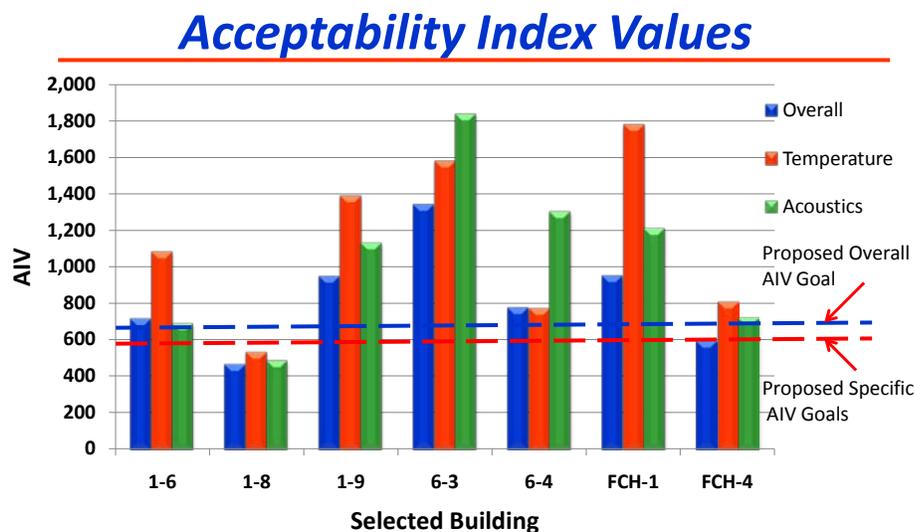

Figure 4. Overall and Specific Acceptability Index Values (AIV) for seven selected office buildings that had verified data for EUI and Environmental-Acceptability measures.[53]

These findings indicate that a two-step process, Fig. 5, may provide a highly sensitive method for evaluating the effectiveness of energy used in a building to achieve acceptable occupant responses and to qualify the building for further evaluation as a "high performance building":

1. If the Overall AIV meets the specified goal or evaluation criteria (e.g., less than or equal to 700), go to step 2. Otherwise, evaluate and adjust the building system performance to

[53] Ibid.

reduced energy consumption, increase human response, or both, to achieve compliance with the Overall AIV.

2. If the Specific AIVs meet the specified goals or evaluation criteria (e.g., less than or equal to 600), the building may be qualified as a "high-performance building." Otherwise, evaluate and adjust the building system performance to reduced energy consumption, increase human responses, or both, to achieve compliance with the specific AIVs.
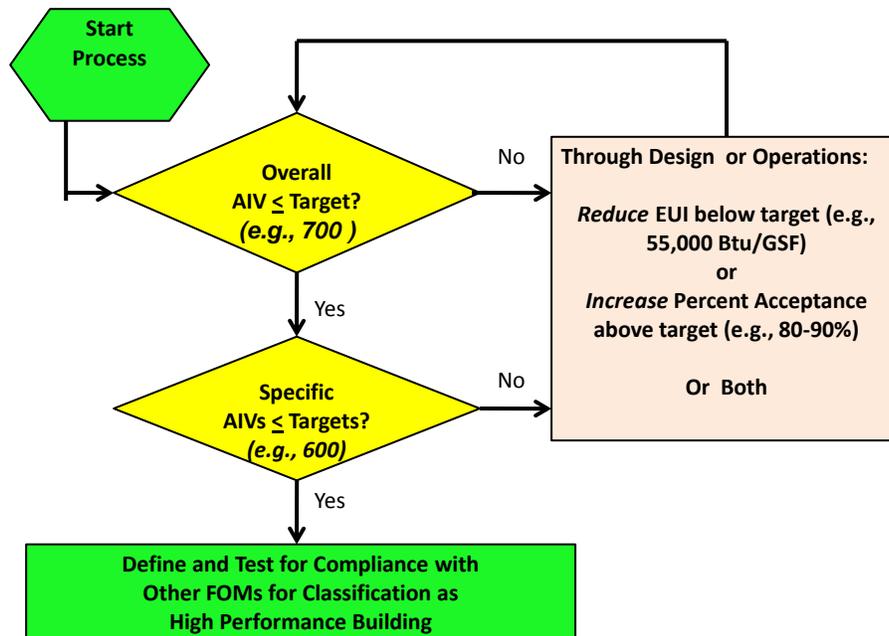

Figure 5. Two-step Process for evaluating the effectiveness of energy utilization and qualifying buildings as potential High-Performance Buildings.

Safety and Security

Safety and security are two of the primary attributes listed in the EISA-2007 definition of a High-Performance Building.[54]

Evidence-based data for these attributes are needed in the development of a comprehensive database. Of specific need is a repository of empirical data that address the interactions of these attributes with the energy and occupant response data during normal and extraordinary conditions.[55]

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[54] Op. cit. 28.

[55] ASHRAE. 2009. *Guideline 29-2009: Guideline for the Risk Management of Public Health and Safety in Buildings*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. Atlanta.

Concept of Residual Risk

Measures of safety and security effectiveness are needed for the life-cycle of the building, including periods of normal and extraordinary conditions. As shown in Fig. 6, the *concept of residual risk analysis*[56] may identify an approach to the development of FOMs that could be the basis for a comprehensive database.
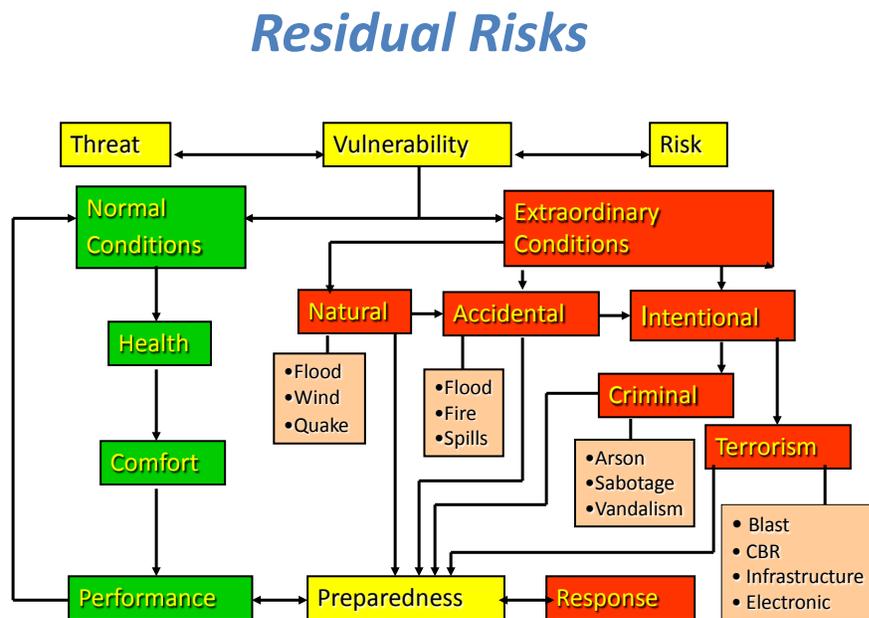
Residual Risks

Figure 6. Concept of Residual Risks that may be measured through Figures-of-Merit throughout the life-cycle of the building.[57]

Levels of Protection

Ongoing work by NIBS on the development of baseline and benchmark criteria for security and safety attributes has revealed a set of metrics that will likely be used in the design and operations of high-performance buildings to enhance assurance and accountability for safe and secure environments based on the level of risk established for a particular facility.[58]

A credible database of empirical data is needed with which to compare design predictions and to prepare for continuous operations.

Accessibility

Accessibility is another primary attribute listed in the EISA-2007 definition of a High-Performance Building. It is related to safety and security as provisions must be provided for occupants during both normal and extra-ordinary conditions.

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[56] Op. cit. 2.

[57] Ibid.

[58] These criteria are being developed through a NIBS project sponsored by the Department of Homeland Security.

Low Vision Population

In another ongoing project by NIBS, significant interactions between wayfinding, lighting, glare, and energy utilization have been identified that affect all occupants but especially those with "low vision."[59] Low vision is clinically defined, and affects approximately 10% of the total population in buildings. Pressures to reduce lighting power requirements in workspaces and transient areas are resulting in reduced lighting levels that are adversely affecting the health and safety of a significant percentage of occupants, and are likely also affecting their performance and the resultant productivity of the facility.

> Metrics and FOMs, which are in use today, are likely to change with advances in scientific knowledge and design applications.[60]
>
> *A credible database of empirical data is needed with which to compare design predictions, and evaluate occupant acceptance, occupant performance, and productivity (including the effective use of energy).*

Environmental Footprint

The environment is another primary attribute listed in the EISA-2007 definition of a High-Performance Building. The environmental footprint, which is a focus of current policy, is strongly related to the energy attribute during normal conditions.[61] This attribute is also be considered in the NIBS project on HPB, sponsored by DHS.[62]

Equivalent CO_2 Emissions (CO_2e)

Reduction of greenhouse gases (GHG) is currently the primary environmental footprint concern to designers and policy makers. The metric of choice in the building community is apparently the "equivalent emission rate of carbon dioxide gas (CO_2e) from combustion processes.[63] This metric, which is not measurable, is calculated by formula.[64]

> *A credible database of calculated CO_2e values from empirical building energy consumption data will be needed with which to compare design predictions, and to relate to occupant acceptance, occupant performance, and productivity (including the effective use of energy).*

Sustainability

Sustainability is another primary attribute listed in the EISA-2007 definition of a HPB. The sub-attribute of specific interest, currently, is renewable resources that do not produce GHG, as defined by EISA-2007:

"The term '*zero-net-energy commercial building*' means a commercial building that is designed, constructed, and operated to:

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[59] NIBS. 2011. *Proceedings of the Workshop on Improving Building Design for Persons with Low Vision,* 29-30 September 2010, http://files.nibs.org/; user name: lowvision; passcode: lowvision.
[60] Ibid.
[61] Op. cit. 28.
[62] Op. cit. 58.
[63] USEPA. 2011. Clean Energy: Calculations and References. http://www.epa.gov/cleanenergy/energy-resources/refs.html.
[64] Ibid.

(A) Require a <u>greatly</u> reduced quantity of energy to operate;

(B) Meet the balance of energy needs from sources of energy that <u>do not produce greenhouse gases</u>;

(C) Therefore, result in <u>no net emissions</u> of greenhouse gases; and

(D) Be <u>economically viable</u>."

By this definition, biofuels and other renewable resources that would be used for combustion processes are excluded for use in zero-net-energy commercial buildings.

> Metrics and FOMs that can quantify the production rate of non-GHG producing renewable resources will be needed.
>
> *A credible database of empirical data is needed with which to compare design predictions, and evaluate occupant acceptance, occupant performance, and productivity (including the effective use of non-renewable energy and investment).*

Cost Effectiveness

As indicated in the case studies for the AIA 2030 Challenge,[65] first costs were reported to have ranged from less than $100/SF to more than $500/SF. No life-cycle cost or risk-benefit analyses were reported. Although some cases did report on expected pay-back periods, no documentation was provided to indicate if the pay-back had been achieved.

> A credible database with verified first, operating and maintenance, and energy costs will be needed that pertain to the same periods during which the other performance metrics are obtained. These data should be verified to be valid for life-cycle analysis, risk-benefit analysis, or both.

Life-Cycle Cost Analysis

Section 401 of EISA-2007 defines a high-performance building (HPB) as one that "integrates and *optimizes* on a life-cycle basis <u>all</u> major high-performance attributes…"   It further defines life-cycle cost (LCC) as " a technique of economic evaluation that (A) sums, over a given study period, the costs of initial investment (less resale value), replacements, *operations (including energy use)* – [emphasis added] – , and maintenance and repair of an investment decision; and (B) is expressed (i) in present value terms, in the case of a study period equivalent to the longest useful life of the building, determined by taking into consideration the typical life of such a building in the area in which the building is to be located; or (ii) in annual value terms, in the case of any other study period."   *These definitions require the use of an LCC model that <u>optimizes</u> the cost-effectiveness of <u>all</u> of the HPB attributes being considered for a project.*

Conversely, the LCC analysis recommended in ASHRAE Standards 90.1-2004, 90.1-2010 and the 50% AEDG,[66,67] is intended for planning and design decisions that focus on predicted

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[65] Op. cit. 3.

[66] Thornton, B.A., Wang, W, Lane, M.D., Rosenberg, M.I., and Liu, B. 2009. *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings*, September, 2009, Pacific Northwest National Laboratory, PNNL 19004, U. S. Department of Energy, Washington, D.C.

[67] Thornton, B.A., Wang, W, Huang, Y., Lane, M.D., and Liu, B. 2010. *Technical Support Document: 50% Energy Savings Design Technology Packages for Small Office Buildings*, April, 2010, Pacific Northwest National Laboratory, PNNL 19341, U. S. Department of Energy, Washington, D.C.

energy savings from pre-selected "bundles" of opportunities, assuming that all other sub-attributes are constrained to minimal effects. Therefore, this type of energy-based LCC analysis, which is usually required for Federal Buildings,[68] is likely to be biased.

LCC analyses that optimize on increased levels of performance for the safety, security, and sustainability attributes and sub-attributes, including their interactions, are seldom conducted for public or private commercial building projects. Rather, the private sector more frequently relies on simple pay-back analyses.

> Energy-based LCC analyses provide systematic methods for comparing energy-related alternatives with different streams of costs *that provide the same benefits and risks* (i.e., constraints) over a defined period.
>
> *However, an LCC analysis without a risk-benefit analysis is incomplete and may be misleading, as it assumes no difference in costs of risks or values of benefits between options under consideration.*

Risk-Benefit Analysis

Risk-benefit methods utilize the results of the LCC to optimize alternatives, based on broad economic foundations.[69,70,71,72,73] These methods account for first costs, energy costs, and other maintenance and operating costs, in conjunction with the economic benefit and risk values for other attributes and sub-attributes.

> *Risk-benefit analyses that incorporate LCC provide comprehensive and accurate evaluations of alternatives to achieve compliance with the set of criteria for the attributes and sub-attributes that pertain to a project during the planning, design, and operational phases.*

Recommendations

Based on this testimony, I offer the following recommendations to develop and sustain a comprehensive, evidence-based, empirical, and accurate database for privately and publically owned commercial buildings in the United States:

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[68] GSA. 2010. *PBS P100-2010: Facilities Standards for the Public Building Service*. November 2010, U.S. General Services Administration, Washington, D.C.

[69] Op. cit. 55.

[70] FEMA. 2005. *Risk Assessment: A How-to Guide to Mitigate Potential Terrorist Attacks against Buildings*. Risk Management Series 452. Federal Emergency Management Administration. Department of Homeland Security, Washington, D.C.

[71] ASTM. 2010. *Standard Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems*. ASTM E964. ASTM, International, West Conshohocken, PA.

[72] ASTM. 2007. *Standard Practice for Measuring Cost Risk of Buildings and Building Systems*. ASTM E 1946. ASTM, International, West Conshohocken, PA.

[73] Chapman, R.E. 2003. *Applications of Life-Cycle Cost Analysis to Homeland Security Issues in Constructed Facilities: A Case Study*. NISTIR 7025, National Institute of Standards and Technology, Gaithersburg, MD.

1. Retire the CBECS Database

- The latest entries into this statistical/inferential database are nearly a decade old.

- The sampling rate has decreased during the 24 years of the existence of this database from 0.22 to 0.11% of the estimated population of commercial buildings in the U.S., resulting in large "Relative Standard Errors" (RSE).

- The protocols for sampling and analysis have been changed several times during the 24-year history, which has resulted in inconsistencies in the database.

- The database is limited to the energy attribute and is not amenable to acquisition or analysis of data pertaining to other performance attributes (e.g., safety, security, accessibility, occupant responses).

- The Figure of Merit (i.e., Gross Energy Intensity) is derived from computer simulations from blocks of data. The GEI results typically over-estimate empirically acquired values, which typically are based on a site-specific FOM (i.e., Energy Utilization Intensity, EUI).

- Uncertainties inherent with the CBECS database are large and do not provide the sensitivities that are now needed in analyzing the performance of new and existing buildings.

- Several other relatively large, energy-focused databases from the public and private sectors are becoming available *that provide empirical data*, including EUI (rather than EI or GEI).[74]

2. Create an Evidence-Based, Empirical, and Accurate Building Performance Database

Replace the CBECS database with a comprehensive, empirical, accurate, and transparent database including a rational set of FOMs that relate to the *interactions* among *all* of the Primary Attributes described in EISA-2007 and the Whole Building Design Guide: *energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations*.

Development of this rational-empirical database will require input from all affected stakeholders. This database should pertain to all of the major categories of commercial buildings including: office, educational, health care, institutional, and retail facilities. The buildings in this database should be categorized by demographic and climatic zones.

All input data should be empirically obtained from actual buildings during normal conditions and, as feasible, under actual or simulated extra-ordinary conditions. Neither computer-simulated data nor resultant analysis should be included in the database.

Sources for input data should include those from permanently installed sensors, monitors and samplers that interface with the Building Automation System (BAS) and undergo periodic calibration. When portable field-type instrumentation is used, including questionnaires,

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[74] Trehubenko, T. and Schmidt, D. 2011. *Multifamily Utility Usage Data: Issues and Opportunities*. Report published by Living Cities, a philanthropic collaborative of 22 of the world's largest foundations and financial institutions, 38 Chauncy Street, Suite 600, Boston MA, 02111, 16 June 2011, 67 pages.

documentation of its calibration or validation should be required. Economic data should be acquired from audited resources.

A standardized protocol for acquisition of a rational set of performance data should be developed and implemented with strong quality assurance/quality control (QA/QC) components. This protocol should include procedures for acquisition of a rational set of data for:

- All of the Primary Attributes and their major interactions;

- The corresponding building systems including: envelope, fire/life-safety, lighting, HVAC, architectural/accessibility, acoustic, IAQ, security, and BAS;

- A concomitant set of valid and reliable human response, occupant performance, and productivity FOMs; and

- A concomitant set of verifiable cost, risk, and benefit data.

The *accuracy* of this protocol should be determined before it is implemented. A minimum accuracy of 80% should be the goal. Standard methods of testing and evaluating protocol accuracy (i.e., minimizing false positive and false negative errors) are used in medical diagnostics, information technology, weather forecasting, manufacturing, and military operations.[75] This methodology is based on "signal detection theory" and addresses assessments of the both the validity and reliability of the protocol being tested and the expertise of the individuals using the protocol. *A major benefit of this methodology is the ability to compare protocols or to potentially improve a protocol compared to a baseline.* However, the use of accuracy for building diagnostics is a major gap.

Determination and publication of the accuracy of this protocol is likely to advance the credibility of the database and lead to a greater acceptance of accountability for system performance by those responsible for the planning and financing, design, construction, and operations of new and existing buildings.

This standardized protocol should be sufficiently robust to accommodate data acquisition in new and existing buildings throughout the U.S. This protocol may also be applicable for similar building types, internationally.

3. Implement the Database through the Whole Building Design Guide

The repository for this new database should be the Whole Building Design Guide (WBDG), which now provides comprehensive design and operational guidance to government agencies, private sector owners, developers and planners, financiers, realtors, designers, policy-makers, facilities managers, educators, and other stakeholders.

Based on previous experience, *NIBS should serve as the Clearinghouse*. Responsible and accountable parties should be authorized to acquire and submit data to the Clearinghouse for entry into the database, in accordance with the standardized protocol. This process would be similar to that being used today in the public health community.

Funding for implementing and sustaining the database through the WBDG should be considered on a long-term basis. Developing and implementing the database is expected to be of

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[75] Swets, J.A. 1988. Measuring the Accuracy of Diagnostic Systems. Science, Vol. 240, pp. 1285-1293.

the same magnitudes of delivery time (i.e., four years), and funding (i.e., estimated at $6 – 8 million and $8-12 million, respectively) for data acquisition in the 2007 and 2011 CBECS cycles,[76]

Implementing and sustaining the database on a continuous basis would likely be less costly than the repeated cycles of the CBECS program:

1. A draft of the protocol to be standardized should be developed through funding from both the public and private sectors. *Based on my experience in drafting protocols for validation*, delivery of the draft protocol is expected to take approximately one year with a ballpark cost estimate of $750,000 - $1,250,000.

2. A shell for the database should be developed through funding from both the public and private sectors. This shell must be specifically designed to accept the data acquired in accordance with the draft protocol. *Based on my experience with the NCEMBT database project*[77], delivery of the shell, including the computer hardware and software, is expected to be achieved simultaneously with Task 1, with a ballpark cost estimate of $500,000 - $700,000.

3. The draft protocol and shell should be pilot tested and evaluated for accuracy of the performance data to be entered and retrieved. Data would initially be acquired in approximately 30 buildings, with funding primarily from the owners of the public and private sector buildings. Accuracy testing and resultant revisions to the protocol would be funded by grants from the public and private sectors. *Based on my experience with the NCEMBT database project.*[78], delivery of the validated protocol and shell with an acceptable accuracy is expected to take two years after completion of Tasks 1 and 2, at a ballpark cost of $8,000,000 - $10,000,000.

4. Sustaining the database through the standardized protocol and shell would begin a long-term process of data acquisition, data entry, and data retrieval by the building community. Data acquisition and submission to the Clearinghouse, in accordance with the standardized protocol, would be funded for each building by resources from each building's owning and operating budget. Screening and entry of the data by staff would be funded through funds obtained by NIBS.

The supporting guidance in the WBDG, together with the development and sustainment of the new rational and accurate database, should enhance the value of the WBDG to the building community.

That developing and implementing an evidence-based, empirical, and accurate database for all the Primary Attributes and their interactions may take four or five years should not be discouraging. A paradigm shift will take time and effort. As stated in a quote attributed to Albert Einstein:

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[76] See website for Environmental Buildings News, 3 May 2011, http://www.buildinggreen.com/auth/article.cfm/2011/5/3/Key-CBECS-Energy-Data-Hit-Hard-by-Federal-EIA-Budget-Cuts/.

[77] Op. cit. 11.

[78] Ibid.

> "We can't solve problems by using the same kind of thinking we used when we created them."