ASHRAE'S NEW PERFORMANCE MEASUREMENT PROTOCOLS FOR COMMERCIAL BUILDINGS

Jeff S. Haberl, Texas A&M University
Hywel Davies, CIBSE
Brendan Owens, USGBC
Bruce Hunn, ASHRAE

ABSTRACT

ASHRAE[1], CIBSE[2] and USGBC[3] are developing a standardized, consistent set of protocols to facilitate the comparison of the measured performance of buildings, especially those claimed to be green, sustainable, and/or high performance. Such protocols are needed because claims of high performance cannot be credible without such standardized protocols being applied consistently in the U.S. as well as internationally. The protocols will identify what is to be measured, how it is to be measured (instrumentation and spatial resolution), and how often it is to be measured. They will address both the use and reporting of the measured data, as well as appropriate benchmarks for each of the following characteristics: Energy Use (site, and source), Indoor Environmental Quality (IEQ)-Thermal Comfort, IEQ-Indoor Air Quality, IEQ-Lighting/Daylighting Quality, IEQ-Acoustics and Water Use.

The primary users of the protocols document will be building owners and facility managers, rating and labeling system developers, government officials, as well as architects and design engineers. To date, a scoping document has been developed, an extensive literature review has been performed (available on ASHRAE's web site), and a committee formed to write the protocols, which are intended for publication in January 2009.

INTRODUCTION

In the spring of 2005 the USGBC approached ASHRAE to inquire about the development of Performance Measurement Protocols for LEED[4] buildings. In response to this inquiry ASHRAE, CIBSE and USGBC formed a working group to develop a scoping study to perform a preliminary survey of the relevant documents and develop recommendations to ASHRAE Technology Council regarding how to proceed. In January 2006 the scoping study was completed (Haberl et al. 2006). It identified the need to provide guidance regarding the measurement and reporting of the performance of new and existing commercial buildings. The scoping study proposed a short-term and long-term effort to accomplish this. In the short-term it was proposed that a consensus ASHRAE protocol be developed for rapid dissemination in an ASHRAE Special Publication.

Over the long-term, an ASHRAE Standard or Guideline was recommended by the Committee that would be based on existing ASHRAE Standards, Guidelines and other relevant documents that would provide a consistent method of measuring, expressing and comparing the energy use, water use, and indoor environment of buildings. These documents would be immediately useful to other organizations, including the USGBC, CIBSE, AIA[5], IES[6], USEPA[7], USDOE[8], GSA[9], the US Military, IEA[10], the European Union, and other organizations interested in sustainable design and performance.

In August 2007, ASHRAE joined with USGBC and CIBSE to complete an extensive literature survey, which surveyed over 400 documents that were analyzed and, with the help of expert interviews, were ranked according to their relevance to the protocols (McNeill et al. 2007). Based on the survey of the literature, a committee of industry experts was assembled to write the protocols, or procedures for the performance measurement of commercial buildings, including: energy use, indoor environmental quality (IEQ: thermal comfort, indoor air quality - IAQ, lighting, acoustics), and water use (ASHRAE 2008).

---

[1] ASHRAE is the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta, Georgia.
[2] CIBSE is the Chartered Institution of Building Services Engineers, London, England.
[3] USGBC is the United States Green Building Council, Washington, D.C.
[4] LEED is the Leadership in Energy and Environmental Design green building rating system of the USGBC.

[5] AIA is the American Institute of Architects.
[6] IES is the Illuminating Engineering Society.
[7] USEPA is the United States Environmental Protection Agency.
[8] USDOE is the United States Department of Energy.
[9] GSA is the federal government's General Services Administration.
[10] IEA is the International Energy Agency.

The resultant protocols are intended to provide procedures for the performance measurement of commercial buildings, including: energy use, indoor environmental quality (i.e., thermal comfort, Indoor Air Quality (IAQ), lighting, acoustics), and water use. The protocols are meant for the determination of the performance of an individual building or facility. The energy protocols apply to all forms of energy, including: electricity, gas, oil, district heating/cooling, and renewables. The IEQ protocols apply to thermal comfort, indoor air quality, lighting, and acoustics. The water protocols apply to individual facilities or meters. Cost and resource information will also be discussed in each section, as appropriate. The protocols are not intended to provide: sampling methodologies used in large-scale demand-side management programs; metering standards, or major industrial loads.

The primary users of the protocols document will be building owners and facility managers, rating and labeling system developers, government officials, as well as architects and design engineers. The contents of the protocols will be written for these professionals, however it must be written to be understandable by owners, government officials and decision makers, and others with little technical background. Additional users include energy researchers interested in whole building performance.

PERFORMANCE MEASUREMENT PROTOCOLS

Based in part on the experience gained from the scoping document and the literature search, it was decided to form a committee of recognized experts to generate the material for the protocol. Table 1 contains a listing of the committee members that were chosen to help with the protocols. For each of the topical areas one or more experts were chosen to generate the chapter that pertained to that material. Overall reviewers and representatives of various entities were also added to the committee to obtain an industry-wide consensus.

Table 1: Performance Measurement Protocols Committee Members.

Jeff Haberl	Chair, Energy	Texas A & M University
Hywel Davies	Vice-Chair, Energy	CIBSE, UK
Bruce Hunn	Staff Liaison	ASHRAE
Lilas Pratt	Staff	ASHRAE
Brendan Owens	USGBC Liaison	USGBC
Klaus Sommer	EU Representative	Cologne Univ. of Applied Sciences
Karen Butler	EPA/Energy Star	EPA Energy Star Program
Mark Frankel	USGBC/NBI Rep.	New Buildings Institute
Mike MacDonald	Energy	Oak Ridge National Laboratory
Fred Bauman	IEQ/Thermal Comfort	Univ. of California, Berkeley
Gail Brager	IEQ/Thermal Comfort	Univ. of California, Berkeley
Ed Arens	IEQ/Thermal Comfort	Univ. of California, Berkeley
Barry Bridges	IEQ/IAQ	Sebesta Blomberg & Associates
Dave Marciniak	IEQ/IAQ	GSA
Fergus Nicol	IEQ/IAQ	Brookes College, Oxford
Richard Heinisch	IEQ/Lighting	Lithonia Lighting
Harvey Bryan	IEQ/Lighting	Arizona State Univ.
Curt Eichelberger	IEQ/Acoustics	Johnson Controls
Jim Bochat	Water/NEEB Rep.	Commissioning Concepts
Fred Goldner	Water	Energy Mgmt. & Research Assc.
John Swaffield	Water	Consultant, UK

The layout of the document was then developed to include one chapter for each of the relevant measurement areas (i.e., energy, IEQ-thermal comfort, IAQ, lighting, acoustics, and water) as well as an introduction, summary, references and supporting appendices. Within each chapter authors were asked to provide an introduction, three levels of measurement methods (i.e., basic, intermediate and advanced), a discussion of the relevant benchmarks, other useful material and references. In the sections that follow each of the chapters is discussed, including a brief discussion of the three levels of measurement.

Chapter 1: Energy (Authors: MacDonald, Haberl).

In Chapter 1 the protocols for measuring the building's energy use are presented. These protocols begin with a collection of facility information and whole-building, annual energy use using ASHRAE Standard 105-2007 for the Level 1: basic method, with suggested benchmarks such as the USEPA Energy Star Portfolio Manager for buildings with similar functions in similar climates. Table 2 is an example of the type of information asked for in Form 1 of Standard 105. For Level 2, the protocols require that Level 1 information be gathered and that a monthly index be created for the whole-building analysis. These monthly data can then be compared to similar buildings in similar climates, or normalized for weather conditions using ASHRAE's Inverse Model Toolkit (Haberl et al. 2003; Kissock et al. 2003).

Figure 1 provides an example of a temperature-dependent, four-parameter model applied to the ASHRAE headquarters building in Atlanta, Georgia using monthly utility billing data. In Level 3: advanced methods, the user is required to obtain all the information in Level 1 and then apply the appropriate performance model from either a whole-building daily model, component or sub-system model, or calibrated simulation, using many of the methods described in ASHRAE Guideline 14-2002. For Level 3, depending upon the model chosen, the benchmarks would be either similar equipment, similar buildings or possibly

Table 2: ASHRAE Standard 105-2007 Form 1.

BUILDING TYPE [3] (Percent of Gross Floor Area)

Office
- ____ Owner Occupied
- ____ Leased—1–5 Tenants
- ____ Leased—5+ Tenants
- ____ Bank/Financial
- ____ Courthouse
- ____ Other—Define ________

Hotel/Motel
- ____ Motel (No Food)
- ____ Hotel
- ____ Hotel/Convention
- ____ Other—Define ________

Apartment
- ____ General Occupancy
- ____ Seniors Only
- ____ Dorm/Fraternity/Sorority
- ____ Other—Define ________

Education
- ____ Primary
- ____ Pre-School/Daycare
- ____ Secondary
- ____ College/University
- ____ Other—Define ________

Food Services
- ____ Restaurant—Full Service
- ____ Fast Food
- ____ Take Out
- ____ Lounge
- ____ Other—Define ________

Auto Services
- ____ Service/Repair
- ____ Sales
- ____ Other—Define ________

Public Order
- ____ Jail/Penitentiary
- ____ Fire/Police Station

Health Care
- ____ Nursing Home/Assisted Living
- ____ Psychiatric
- ____ Clinic/Outpatient
- ____ Active Treatment Hospital
- ____ Other—Define ________

Retail
- ____ Dry-Cleaning/Laundromat
- ____ Supermarket/Food Market
- ____ General Merchandise
- ____ Shopping Mall without Tenant Loads
- ____ Shopping Mall without Tenant Lighting Loads
- ____ Shopping Mall
- ____ Specialty Shop
- ____ Bakery
- ____ Other—Define ________

Assembly
- ____ Theatre
- ____ Library
- ____ Convention Center
- ____ Museum/Gallery
- ____ Church/Synagogue
- ____ Arena/Gym
- ____ Arena/Rink
- ____ Nightclub
- ____ Other—Define ________

Other
- ____ Laboratory
- ____ Warehouse
- ____ Warehouse—Refrigerated
- ____ Recreation/Athletic Facility
- ____ Post Office/Center
- ____ Transport Terminal
- ____ Multi-Use Complex
- ____ Other—Define ________

1 See Section 3 for definition of gross floor area.
2 THE MEDIAN YEAR for construction of at least 51% of the conditioned space.
3 BUILDING TYPE: determine building type and then enter the percent of gross floor area for each sub-area or sub-type, dividing common areas between major sub-areas or sub-types.

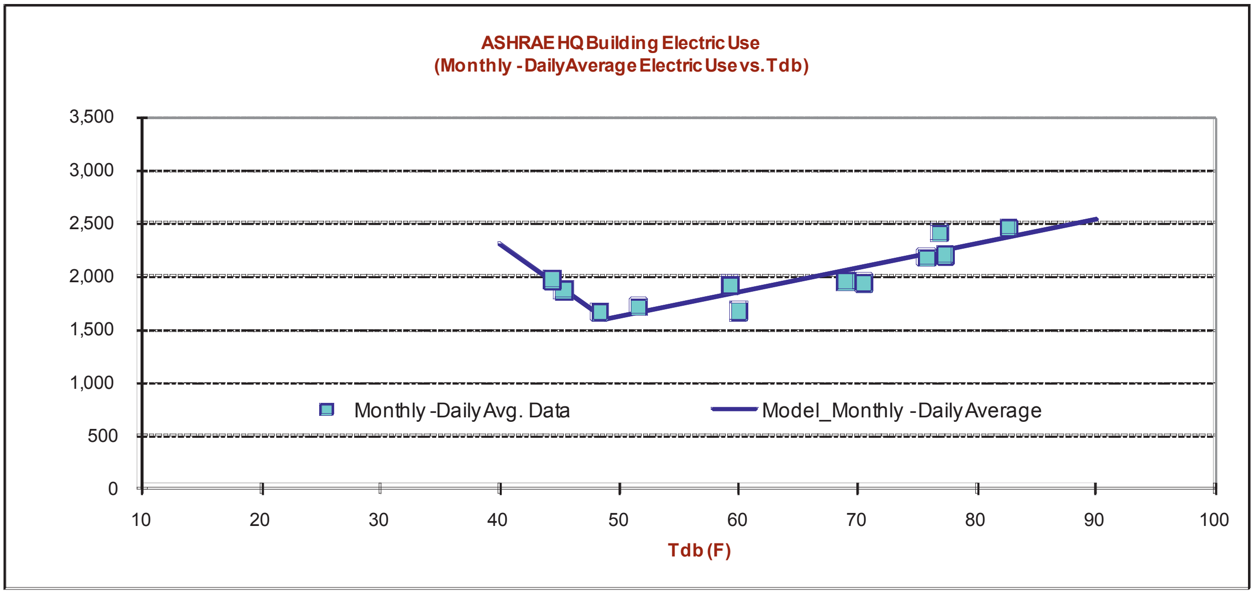

Figure 1: ASHRAE Headquarters Building Whole Building Electric Energy Use (Monthly), Versus Monthly Average Temperature (F), Including the Inverse Model Toolkit Four-Parameter (4-P) Model.

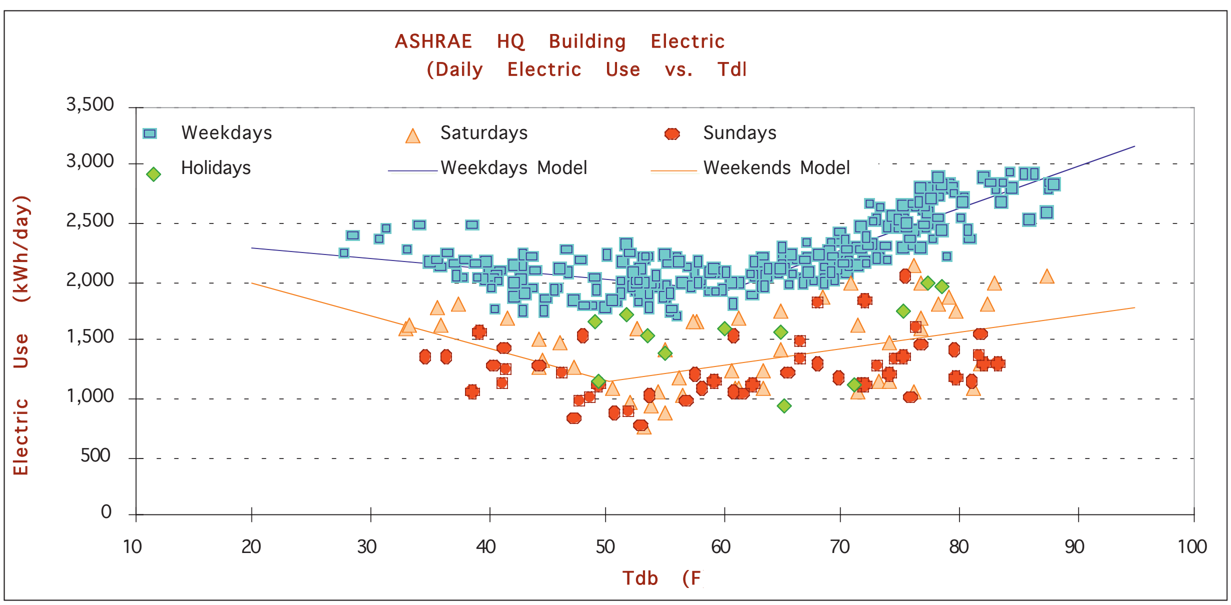

Figure 2: ASHRAE Headquarters Building Whole Building Electric Energy Use (Daily) for Weekdays, and Versus Average Daily Temperature (F), Including the Inverse Model Toolkit Four-Parameter (4-P) Model.

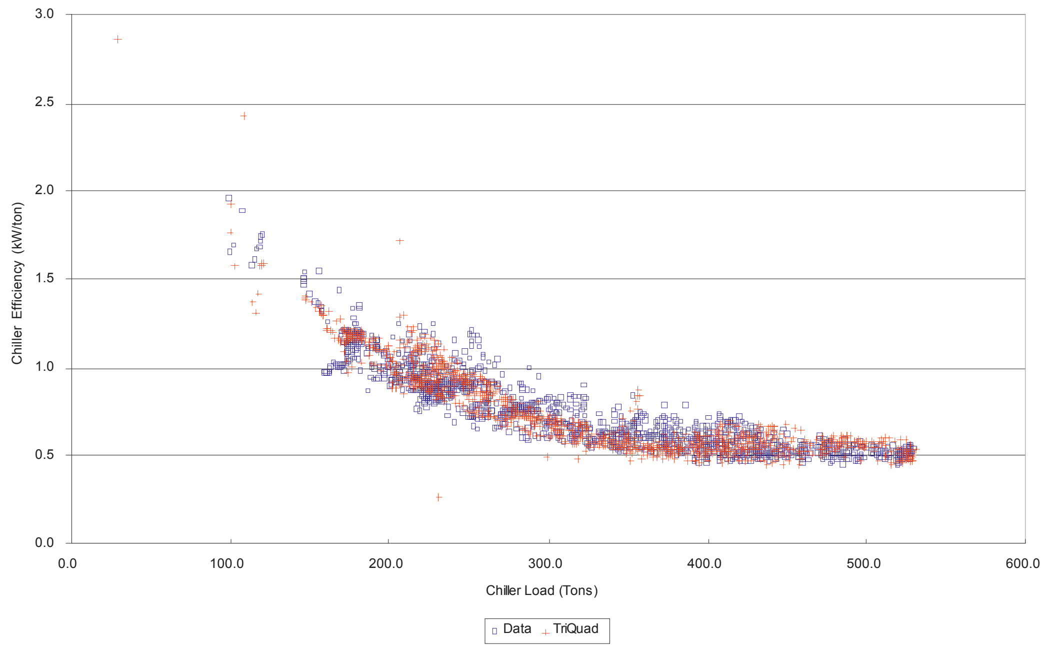

Figure 3: Example chiller analysis. Chiller performance plot of chiller efficiency (kW/ton) versus the chiller cooling load. In this figure a tri-quadratic chiller model (R^2 = 83.7%) is shown.

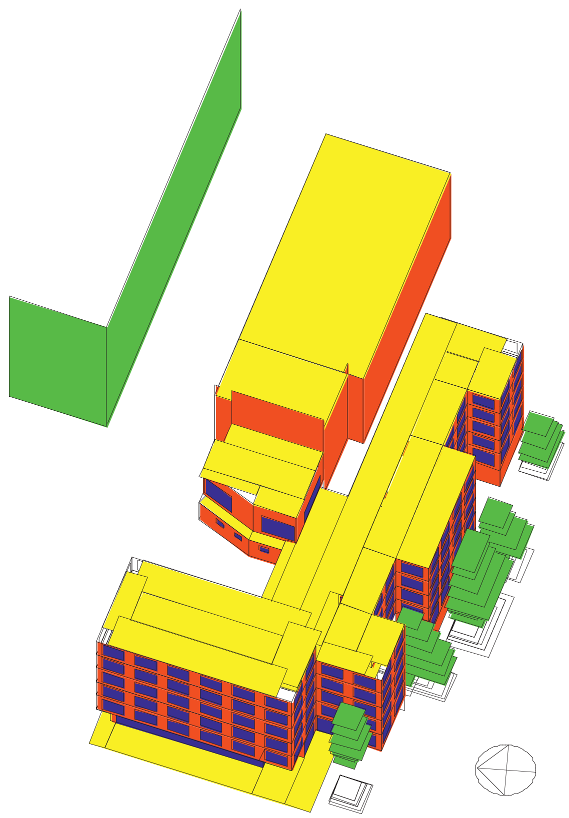

Figure 4: Example Architectural Rendering of the Robert E. Johnson Building, Austin, Texas.

simulated data from design standards.
Figure 2 provides an example of a Level 3, whole-building analysis applied to the daily electricity use of the ASHRAE headquarters buildings for the same period as Figure 3 provides an example chiller analysis that shows measured data (kW/ton) and a performance model constructed with a tri-quadratic chiller model. Figure 4 provides an example of an architectural rendering of the computer simulation input file, which is used to verify the appropriate positioning and placement of surfaces, shading, etc., during the calibration of the simulation program.

Chapter 2: Thermal Comfort (Authors: Bauman, Brager, Arens).

In Chapter 2 protocols are presented for the measurement of thermal comfort, which rely to a large extent on the published work of the Center for the Built Environment at the University of California at Berkeley (CBE), and the Lawrence Berkeley National Laboratory (LBNL). In Level 1 information about the thermal comfort of a buildings relies on operator or occupant surveys and spot measurements (T_{db}, RH, MRT, V_{air}), that can then be compared to benchmarks such as those published by the CBE. In Level 2, in addition to Level 1 information, the user performs “right now” surveys near to the occupant using 1-5 minute data logger measurements to document temporal comfort conditions (T_{db}, RH, MRT, V_{air}) and uses ASHRAE Standard 55 or the results of ASHRAE Research Project 887 as benchmarks. In Level 3, in addition to the information in Level 1, the user performs continuous 1-5 minute data logger measurements at multiple heights to document temporal comfort conditions (T_{db}, RH, MRT, V_{air}) and uses ASHRAE Standard 55, Predicted Mean Vote (PMV), for comparison of asymmetric measurements. Figure 5 provides an example of a desktop thermal comfort measurement station, and

Figure 6 shows a three position thermal comfort portable measurement cart for making Level 3 measurements.

Chapter 3: Indoor Air Quality (Bridges, Marciniak)

In Chapter 3, protocols for measuring indoor air quality are presented. In Level 1, it is recommended that Energy Management Control Systems (EMCS) trend logs, or hand-held meters be used to capture either spot measurements or continuous measurements (Tdb, RH, CO2, CO, TVOC, HCHO, Petroleum Distillates, Bio samples) and compared to published references such as ASHRAE Standard 62.1, the US EPA’s NAAQS[11] standards, or in some instances compared against ambient outdoor conditions. In Level 2, information from Level 1 measurements can be supplemented with localized observations and data loggers measurements (Tdb, RH, CO2, CO, TVOC, HCHO, Petroleum Distillates, Bio samples), and compared to published references such as ASHRAE Standard 62.1, the US EPA’s NAAQS standards,

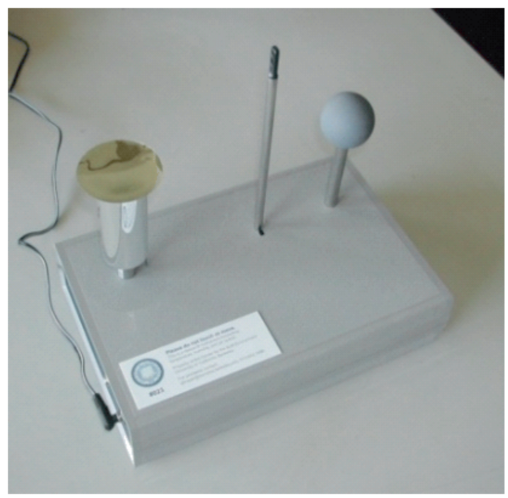

Figure 5: Desktop Thermal Comfort Monitoring Device

[11] NAAQS is the USEPA’s National Ambient Air Quality Standard.

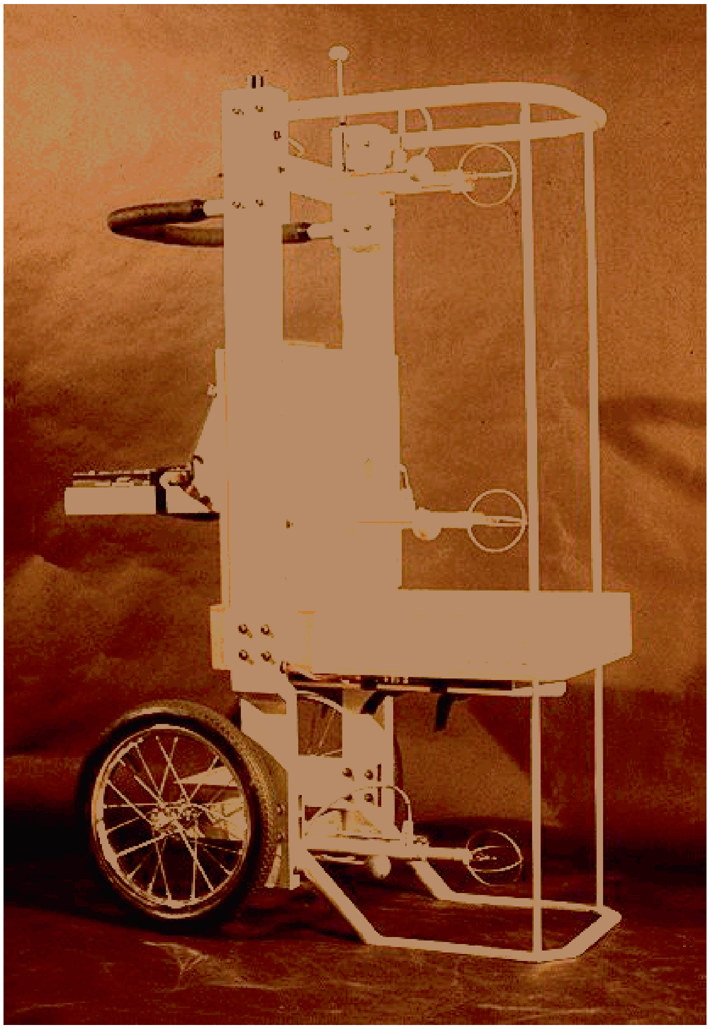

Figure 6: Instrumented, chair-like cart measuring at three levels specified by ASHRAE Standard 55.

or in some instances compared against ambient outdoor conditions. In Level 3, information in Level 2 is supplemented with continuous data loggers measurements (Tdb, RH, CO2, CO, TVOC, HCHO, Petroleum Distillates, Bio samples) would be taken and compared to published references such as ASHRAE Standard 62.1, the US EPA's NAAQS standards, or in some instances compared against ambient outdoor conditions.

Chapter 4: Lighting/Daylighting (Authors: Richard Heinisch)

In Chapter 4 protocols are presented for the performance measurement of lighting and daylighting, which rely heavily on standards published by the IES. In the Level 1, basic method, occupant surveys and spot illuminance or luminance measurements are made and compared to published illumination levels in the IES Standards. In the Level 2, information from Level 1 is combined with glare predictions using lighting software and compared with IES Standards. In Level 3, Level 2 information is supplemented with calibrated HDR[12] photographs to allow for glare predictions using specialized software. Comparisons are then made to published standards by the IES. Figure 7 provides an example

[12] HDR is High Dynamic Range.

of commercial illuminance and luminance meters.

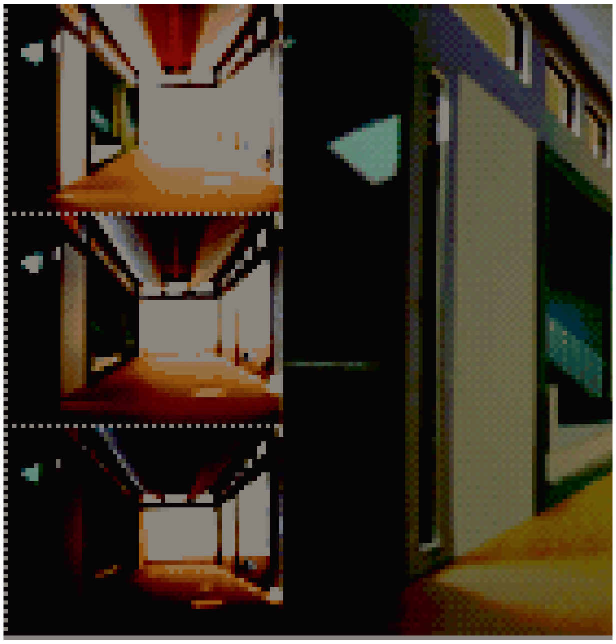

Figure 8 shows an example of photograph of a lighting model compared with a simulated image using Radiance software.

Chapter 5: Acoustics (Curt Eichelberger).

In Chapter 5 protocols are provided for the performance measurement of indoor acoustics. In Level 1, basic method, indoor and outdoor dBA spot measurements are recommended, which are then compared to the appropriate Room Criteria (RC), Noise Criteria (NC) for the space being measured. In Level 2, Level 1 measurements are taken and supplemented with octave band surveys, including Reverbation Time and compared to the appropriate Room Criteria (RC), Noise Criteria (NC), and Reverberation Time (RT) for the space being measured. In Level 3, Level 2 measurements are supplemented with evaluations for speech or communication scales and compared to the appropriate RC, NC, or Speech Interference Levels (SIL) for the space. In Figure 9 a frequency response curve is shown for dBA, dBB and dBC curves. Figure 10 shows a cumulative spectral decay plot that would be used for spectral RT measurements.

Chapter 6: Potable Water (Authors: Bochat, Goldner)

In Chapter 6 protocols are presented for potable water measurements. In a similar fashion as Chapter 1, Level 1 in this chapter also uses information gathered as part of the facility information in Standard 105 and uses a monthly index. The benchmark proposed for Level 1 would then be a comparison to national database water use information such as Energy Star or USGBC information. Level 2 would consist of Level 1 information plus sub-metering of specific water using loads such as landscape watering or cooling towers. In a similar fashion as Level 1, the benchmark for Level 2 would be a comparison to a national database. Level 3 would consist of Level 2 information and hourly metering from data loggers or EMCS data, and may include wastewater metering. The benchmark for Level 3 would also be a comparison to a national database.

Figure 7: Commercial Illuminance Meters: (left) portable illuminance meter with integrating sphere, (middle) laboratory grade system that includes a photometer, radiometer and fiber-optic power meter, (right) multifunction portable illuminance meter with detachable receptor head.

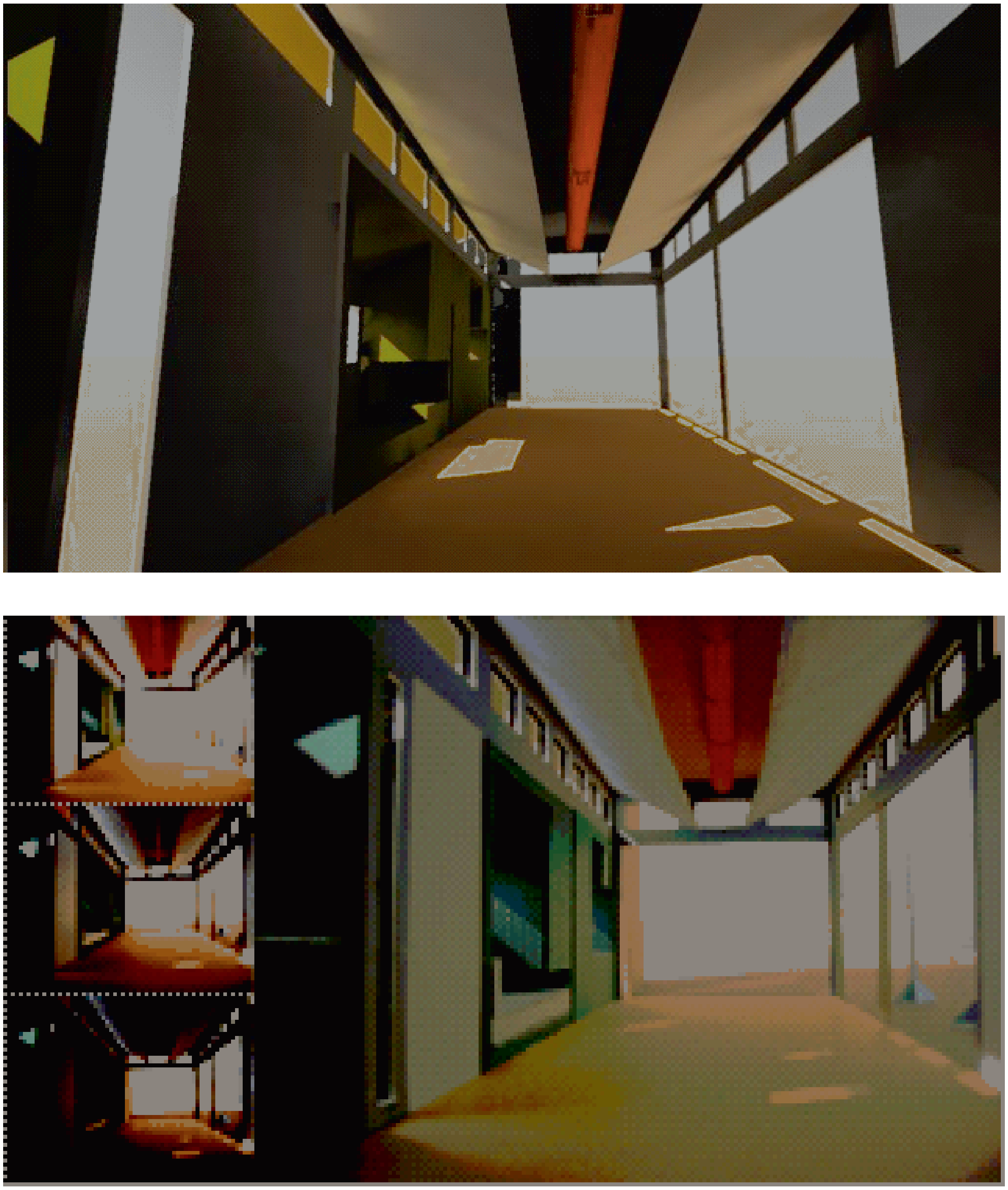

Figure 8: Example Calibrated Lighting Model. (upper) image rendered by radiance software, (lower) photograph taken of scale model (Ramirez 2008).

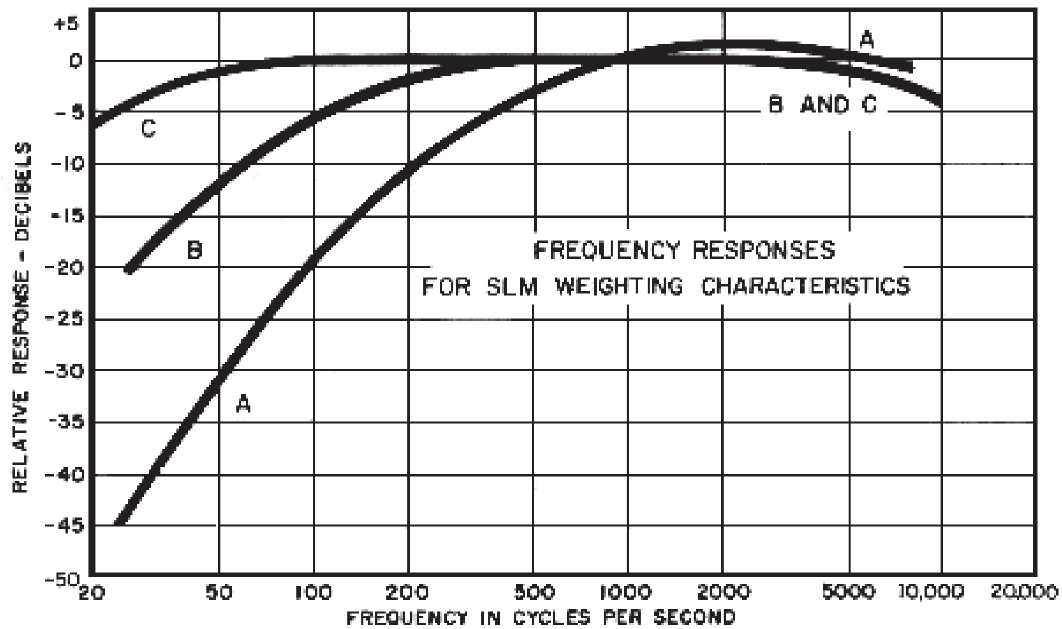

Figure 9: Example Frequency Response Curves for dbA, dbB and dbC curves.

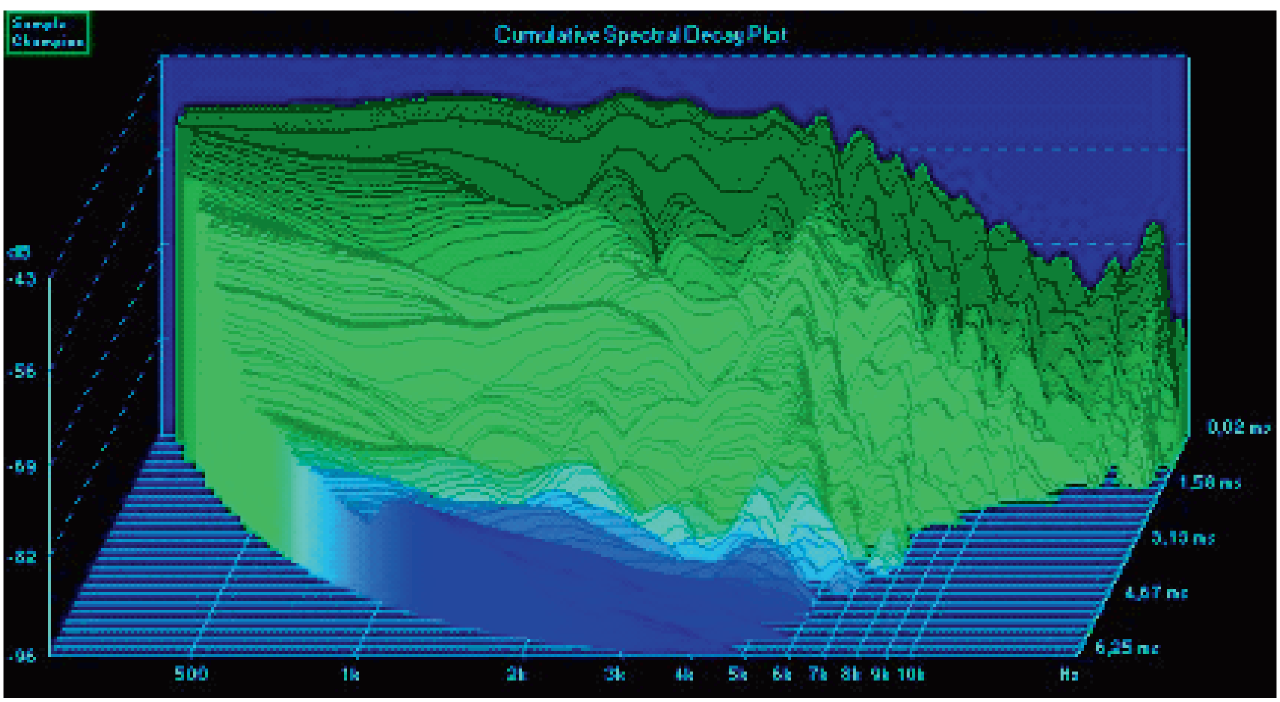

Figure 10: Example Acoustic Spectral Decay Plot.

SUMMARY

In summary, ASHRAE, CIBSE and USGBC are developing a standardized, consistent set of protocols to facilitate the comparison of the measured performance of buildings, especially those claimed to be green, sustainable, and/or high performance. The protocols will identify what is to be measured, how it is to be measured, and how often it is to be measured. They will address both use and reporting of the measured data, as well as appropriate benchmarks for each of the following characteristics: Energy Use (site, and source), IEQ-Thermal Comfort, IEQ-Indoor Air Quality, IEQ-Lighting/Daylighting Quality, IEQ-Acoustics and Water Use. Final publication for the protocols is scheduled for the fall 2008.

ACKNOWLEDGEMENTS

REFERENCES

ASHRAE 2008. *Performance Measurement Protocols for Commercial Buildings Scoping Document*. Atlanta: American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc. (January).

Haberl, J., Case, M., Kettler, G., Hunn, B., and B. Owens. 2006. *Scoping Study: Protocols for Measuring and Reporting the On-site Performance of Buildings Except Low-rise Residential Buildings*. Atlanta: American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc. (January).

Haberl, J., Claridge, D., and K. Kissock. 2003. Inverse Model Toolkit (1050RP): Application and Testing. *ASHRAE Transactions-Research* 109(2):435-448.

Kissock, K., Haberl, J., and D. Claridge. 2003. Inverse Model Toolkit (1050RP): Numerical Algorithms for Best-Fit Variable-Base Degree-Day and Change-Point Models. *ASHRAE Transactions-Research* 109(2):425-434.

McNeill, J., Zhai, J., Tan, G., and M. Stetz. 2007. *Protocols for Measuring and Reporting the On-site Performance of Buildings Except Low-Rise Residential Buildings: Final Report.* ASHRAE Research Project, Atlanta: American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc. (August).

Ramirez, E. 2008. *Engineering Design, Construction, Operation and Analysis of the 2007 Texas A&M University Solar Decathlon House*. Final Examination Report, College Station: Texas A&M University, Mechanical Engineering Department.