Achieving Building Sustainability through Innovation:
An American Perspective

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Introduction

Among the technical challenges for building professionals in achieving sustainability in today's increasingly complex and cost constrained working environment are a greater appreciation and knowledge of related environmental impacts (e.g. greenhouse gases), their associated societal costs and uncertainties[1] along with a need to establish achievable benchmarks for demonstrating improved building performance across the whole range of building types and occupancies that our HVAC&R industry impacts. Sounds like a tall order –well it is.

To better understand the term "sustainability" naturally I turned to my trusty desk edition of Webster's II New Revised Dictionary. Sustainability per se becomes in effect one or more of the following: "the ability to holdup, support, maintain, supply with nourishment, support the spirit, courage or resolution of, corroborate, withstand and endure". What then is building sustainability? To grasp its full meaning, I turned next to ASHRAE's recently adopted policy statement supporting "building sustainability" defined as a means to provide a safe, healthy, comfortable indoor environment while simultaneously limiting the impact on the Earth's natural resources.

ASHRAE has also pledged to use its position as the technical society recognized as the global leader in HVAC&R technologies and applications, to develop and disseminate technical information, standards, educational programs and research on issues of social importance, to promote building sustainability. ASHRAE plans to do this by integrating building sustainability principles, effective practices and emerging concepts into all its appropriate standards, guidelines, Handbook chapters and Society publications, actively participating with internationally recognized building sustainability groups where deemed appropriate, and by promoting and providing educational materials on building sustainability to its members and society at large through the ASHRAE Learning Institute and at grassroots college student chapter activities.

The goal of newly formed ASHRAE Technical Committee (T.C.) 2.8, Building Environmental Impacts and Sustainability, which held its first meeting at ASHRAE's 2003 Winter Meeting in Chicago, is to give added emphasis to finding ways to reduce the impact of buildings on the environment. Impacts include biological and mineral resource depletion; environmental impacts of energy production, conversion, delivery and use; availability of future energy resources; pollution of air, water, and soil; and encroachment on sensitive habitats and ecosystems.

T.C. 2.8 also intends to work to provide information on energy resources and the various impacts of development and use of those resources hopefully to be incorporated into the ASHRAE Handbook. The committee also intends to continue working on the ASHRAE GreenGuide, which will provide practical information for owners, consulting engineers and others on the design and operation of environmentally friendly buildings.

So then, to capture the essential "spirit" of building sustainability, one can liken the process to the "Red Queen's Race," named after the character created by Lewis Carroll of achieving it in *Through the Looking Glass*. Alice, the young heroine, comes across the Red Queen, who insists that they run faster and faster. After running for some time, Alice complains: "Well in our country, you'd generally get somewhere else – if you ran very fast for a long time, as we've been doing." "A slow sort of country!" said the Queen. Now here, you see, it takes all the running you can do to keep in the same place."

Yet, too often for HVAC&R professionals, the impulse to seek "design perfection" can take one in the wrong direction if that entails mimicking our most recent trouble free project. For want of a better name, I chose to call this the "low load" package solution. The Red Queen would never accept that and neither must we. Perhaps our most important strength is our ability to innovate, and in the process to create methods and processes leading to improved sustainable buildings that can serve as next year's benchmarks to beat.

Mistakes and failure are the inevitable consequences of taking risks. One measure of genuine risk-taking is the amount of failure generated. That is why IBM's Thomas Watson Sr. once said, "If you want to increase the probability of success, double your failure rate." Great U.S. innovators from Thomas Edison on down have operated on the same principle. They understand that failure and success are intimately connected, inter-dependent, and sometimes indistinguishable. One has always led to the other. Finally, as Ambrose Bierce noted almost a century ago, accountability is "the mother of caution." In a climate of fear, we become increasingly risk-averse. Taking some risks, however, is precisely what is not needed, perhaps now more than ever if we are to surpass last year's "status quo".

Defining the Challenge

Is risk the only avenue to innovation? Not necessarily. Yet the demand for innovation in our current fast-paced, globalized and technologized economy remains ever constant. We need innovation in both HVAC&R product and design process if we are to maintain our respective economies to achieve full and meaningful employment for all our citizens, while encouraging our HVAC&R colleagues in the emerging nations to reach similar goals where possible.

Accordingly, building MEP services engineers, constructors and operators must better relate as team players in the decision making process thereby becoming more actively engaged with building owners, ideally commencing at initial project conceptualization, and extending into design development after interactive models are put through optimization studies, both cost and environmental impacts, tradeoffs, etc. This is then followed by a professionally managed construction process including commissioning, hands-on-training of building operators in whose hands, in the final analysis, will a building's actual and planned sustainable performance ultimately depend.

Interestingly enough, ASME's Environmental Engineering Division also recently endorsed the "Dialogue on the Engineers Role in Sustainable Development – Johannesburg and Beyond," a declaration by the U.S. engineering community on sustainability. This statement, initiated by the National Academy of Engineering, U.S. State Department, American Association of Engineering Societies, and the American Institute of Chemical Engineers, serves as the engineering community's statement to the World Summit on Sustainable Development. The statement was also in affiliation with the American Society of Civil Engineers, Engineers International Roundtable, and the World Federation of Engineering Organizations-Committee on Sustainable Technology.

The Dialogue states, "Creating a sustainable world that provides a safe, secure, healthy life for all peoples is a priority for the U.S. engineering community. It is evident that U.S. engineering must increase its focus on sharing and disseminating information, knowledge and technology that provides access to minerals, materials, energy, water, food and public health while addressing basic human needs. Engineers must deliver solutions that are technically viable, commercially feasible and, environmentally and socially sustainable.

Greenhouse Gas Emissions Reductions

The Voluntary Reporting of Greenhouse Gases Program, required by Section 1605(b) of the U.S. Energy Policy Act of 1992, is part of U.S. Government's efforts to develop innovative, low-cost, and nonregulatory approaches to limit emissions of greenhouse gases. Greenhouse gases, which include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), absorb infrared energy and prevent it from leaving the atmosphere[2].

A total of 228 U.S. companies and other entities reported to the Energy Information Administration's (EIA) Voluntary Reporting of Greenhouse Gases Program that they had undertaken 1,705 projects to reduce or sequester greenhouse gases in 2001.

The electric power sector, with 103 companies reporting, has continued to provide the largest number of participants to the program. Reporters included nearly all of the largest electricity generating utilities. The companies reported projects such as improved plant efficiencies, cogeneration, use of non-fossil fuels such as nuclear and renewable fuels, and demand-side management programs that reduce power use by their customers. Other projects cover many different approaches to reducing or offsetting emissions, including activities such as methane recovery projects at landfills, urban forestry, and worldwide tree planting projects.

The number of participants from outside the electric power sector (125 reporters) was ten times the number reported for 1994, the first year of the Program. These companies now comprise more than half (55 percent) of the reporters to the program and include firms engaged in automobile manufacturing, petroleum production and refining, coal mining, food processing, and the chemical industry. Also reporting on projects were alternative energy providers, agriculture and forestry organizations, and organizations in other sectors (government, commercial and residential).

Expressed as a percentage of estimated total U.S. greenhouse gas emissions in 2001, reported direct emission reductions represented 3.2 percent of total U.S. greenhouse gas emissions, while reported indirect reductions were 1.0 percent, unspecified reductions corresponded to 0.2 percent, and carbon sequestration represented 0.1 percent. Direct reductions are emission reductions from sources owned or leased by the reporting entity, while indirect reductions are emission reductions from sources not owned or leased by the reporting entity but that occur as a result of the entity's activities.

Reported emission reductions included 222 million metric tons of carbon dioxide equivalent (MMTC02e) in direct emissions reductions, 71 MMTC02e in indirect emission reductions, and 8 million metric tons of reductions from carbon sequestration. In addition, 15 million metric tons of reductions were reported under the EIA 1605EZ form, which does not specify whether reported reductions are direct reductions or indirect reductions. Relative to 2000 levels, direct emission reductions increased by 5.2 percent, indirect reductions grew by 14.4 percent and unspecified reductions expanded by 20.9 percent, while carbon sequestration fell by 11.7 percent. Figure 1 following illustrates the growth in reported reductions since the Program's inception in 1994.

Sustainability Benefits from Research

By sponsoring[3] significant research programs, ASHRAE continues to publish the results of useful field studies that impact upon its practitioner members in meaningful ways. For example, take the results of two such research projects; namely RP-822 and RP-1055. They were both undertaken at the Institute of Environmental Research at Kansas State University. Their goal was to seek field data guidance in identifying actual patterns of equipment heat gains for common applications in office buildings, laboratories and hospitals. What they found was quite interesting. Whereas the field data test results in laboratories and hospitals were too diverse for generalization, the very opposite was true for office building occupancies. What they found was:

1. Office equipment energy intensity had been decreasing through 2002.
2. Office equipment energy intensity would be increasing slowly from 2002 through 2010.
3. There was a disparity between heat gains taken from equipment nameplates provided by manufacturers and measured heat gains both with and without diversity considerations.
4. Assuming no diversity, approximately 50% of listed nameplate heat gain values were confirmed by field measurements taken over time.
5. Actual heat gains (with diversity accounted for) amounted to approximately 21% of manufactured listed nameplate heat gain values.

Accordingly, we now realize that we need to better communicate this information to manufacturers who appear to be overstating equipment heat gains. Such misinformation results in significant over-sizing of HVAC&R system equipment, distribution ductwork and piping with the resulting waste of both material and energy cost further impacting building owner profitability and resulting in excessive generation of greenhouse gases.

Building Sustainability Benchmarks

With buildings now responsible for a third of the worlds energy use, our HVAC&R industry needs to establish comparable energy use and greenhouse emissions equivalents incorporating benchmark values of representative energy budgets for various occupancy types, in BTU/ft^2 (or m^2) year as determined from a statistical weighting of climatically normalized average values provided from monitored and reported operating data as equivalent greenhouse emission quantities in a similar format to that illustrated in Figure 1. How is that achievable you will ask?

Sustainability in our HVAC&R building industry has in recent years become the “poster boy” for a range of initiatives aimed at the more efficient use of energy for heating, cooling and powering our MEP building services.

Collateral benefits of improved HVAC&R design methods can include lower emission rates of harmful pollutants entering our atmosphere, thereby improving air quality while reducing potentials for climate change. Similar concerns parallel to these above become the “driver” for improved worldwide automotive standards for increasing company average fleet efficiency (or CAFE) standards achieved by the design of more efficient and hybrid gas/electric engines, lower vehicle weight through material substitution as well as lower cost recycling potentials that such lighter weight material substitutions also afford.

It is also likely that the construction industry may someday find itself embracing the benefits of construction material substitution[4] should the cost of energy rise to the point where the energy cost to fabricate and assemble on-site various building exterior and interior materials, along with the cost to operate construction equipment during the construction process result in fundamental changes to the building design and construction process encouraging recycling and more efficient on-site assembly and/or construction methods, including a greater reliance on prefabrication.

Being more actively and personally involved in HVAC&R work that will make this a better world remains a challenge in these uncertain times. Failure to achieve building sustainability in our complex society can only add to an “inevitable increase in entropy”, which thermodynamics has taught us can only lead to greater “chaos”. Building sustainability is not an option; it is a mandate for continued innovation and a constant challenge for our HVAC&R industry in the years ahead.

Use of Advanced Inverse Models

Improvements to the performance of along with significant reductions in the first cost of commercially available HVAC sensors, controllers and, networking hardware have contributed to the development of smart building features e.g. optimal supervising control, continuous performance control, real time, utility pricing and automated diagnostics.

As an example of advancing the best use of available building materials, HVAC&R designers need to take advantage of a building’s inherent thermal massing effect. To do this one must first accurately predict transient cooling and heating building requirements and/or total building energy consumption. Using inverse models that are “trained” through better use of on-site data is one exciting new possibility along the road begun by ASHRAE some years ago under the generalized heading of “Total Building Design”. Where then do we start?

Well, the 2001 ASHRAE Handbook, for example, separates modeling into two basic categories; namely, forward or inverse modeling. Forward system modeling illustrated in Figure 2, commences with a physical description of a building e.g. construction materials, geometry, physical location, microclimatic data, type of HVAC system proposed, etc. as typically employed by HVAC system designers.

Inverse system models of the type illustrated in Figure 3, on the other hand, are derived[5] from empirical behavior and are generally expressed in terms of one or more driving forces and a set of empirical parameters.

Hybrid or gray box models proposed by Braun, et al. employ transfer functions where parameters are constrained to satisfy a simple physical representation of energy flows in a building including a methodology for training parameters of the constrained model by which initial values of and limits on physical parameters are estimated from a rough building description as illustrated in Figure 4.

Better estimates[6] are then obtained using search and non-linear regression algorithms while incorporating site-specific control strategies as illustrated in Figure 5. Algorithms used to identify optimal parameters by means of Braun’s proposed system tool are illustrated in Figure 6.

Finally, Braun reported finding that only 2 weeks of accumulated on-site data were sufficient to train an inverse model to accurately predict transient heating or cooling requirements following extensively testing his above described inverse modeling and parameter training methods for different buildings and locations using data generated from use of a detailed (forward model) simulation program along with data obtained from a field test site located near Chicago, Illinois.

Subsequently, Braun reported assessing load shifting and peak shaving potentials through the control of building thermal mass for a 1.4 million s.f. building employing 4 nominal 900 ton chillers using similar robust inverse models resulting in less than a five percent (5%) difference in utility cost prediction as illustrated in Figure 7.

Conclusions

Braun’s conclusions of the latter major office building field test follow in Figure 8 and demonstrate the need to better calibrate our models. Using inverse modeling of our buildings for reasons summarized in Figure 9, versus the widespread use of our more conventional forward modeling approaches would suggest that if we are to achieve lower building energy usage, improve the selection of building materials, reduce harmful emissions and predict with greater accuracy. Through continued HVAC&R research, including field studies in actual buildings, more accurate predictions of the probable cost of operating our buildings is achievable resulting in greater client profitability and other related societal benefits in the coming years as indicated in Figure 10.

References

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