FOCUS ON GREEN BUILDING

Expanding the Principles of Performance to Sustainable Buildings

BY JAMES E. WOODS, PH.D., P.E.

A major issue is evolving with regard to the meaning and implications of the term "building performance." To some, this expression means a promise to design buildings that will function in accordance with "green" or "high-performance-green" ratings. Others aspire to operate safe, secure and healthy buildings. And most owners expect their buildings to yield attractive rates of return on investment. Yet the criteria with which to measure and evaluate actual building performance are seldom defined in objective and measurable terms. The intent of this article is to explore this issue by reviewing the concepts and principles of building performance, the functional status of the existing building stock, and the risks and opportunities associated with accountability for the performance of these buildings.

THE IMPORTANCE OF BUILDING PERFORMANCE

Fundamentally, buildings have a two-fold purpose: 1) to provide safe, healthy and secure conditions for occupants; and 2) to facilitate the well-being and productivity of the occupants, owners and managers of the property. If buildings are designed, constructed and operated for this purpose, the natural consequences are effective use of energy, environmental and financial resources. Conversely, if promises and policies are made to minimize energy consumption and environmental impact without achieving the two-fold purpose, then safety, health, security, and economic risks are likely to increase.

To credibly account for how well a building is achieving its two-fold purpose at any time during its useful life, objective methods for measuring and evaluating building performance are required. Based on principles of control theory and the assumption that a building functions as a system:

> *Building performance* can be defined as a set of *measured responses* of the building, as a system, to anticipated and actual *forcing functions.*[1]

In this definition:

- *Measured responses* are data that are obtained in terms of valid parameters and values of human responses (e.g., perceptions and judgments), occupant exposures (e.g., environmental stressors that affect human responses), system performance (e.g., measurable factors that affect occupant exposures), energy consumption and economic performance (e.g., consequences of system performance and occupant behavior).[2]
- *Forcing functions* are quantitatively determined physical and social forces that perturb the building

About the Author

James E. Woods, Ph.D., P.E., *Fellow ASHRAE, is executive director of The Building Diagnostics Research Institute, Inc., in Chevy Chase, Maryland. In 1997 he retired as the William E. Jamerson Professor of Building Construction at Virginia Polytechnic Institute and State University. Woods has served as a consultant to design engineering and architectural firms, utility companies, state energy agencies, the U.S. General Services Administration, and many other private and public agencies.*

system and the measured responses during both normal and extraordinary conditions.[3] Sources of physical forces include climate (outdoor temperature and humidity conditions), wind, rain and snow loads (hurricanes, tornados, blizzards), earthquakes, fires, floods, chemical and biological releases, and blasts. Sources of social forces include aesthetics, economic and other motivations of occupants, tenants and owners, secular trends (e.g., policies on smoking, green practices), and threats (e.g., job security, reliability of utilities, criminal intent, terrorist activities).

This definition of building performance does not presume a predetermined quality of performance. However, some other definitions have been promulgated that promise a certain quality of performance (e.g., green, high, net-zero energy, sustainable), but have not defined the constellation of forcing functions or the set of responses in measurable terms that can be used to evaluate and account for the actual building performance under normal or extraordinary conditions, which may be caused by natural, accidental or intentional hazards.[4] Such a qualitative definition has recently been proposed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE):[5]

> A *high-performance green* building is defined as "a building designed, constructed and capable of being operated in a manner which *increases environmental performance* and *economic value* over time, *safeguards the health of occupants*, and *enhances satisfaction and productivity of workers* through *integration* of *environmentally-preferred building materials*, and *water-efficient* and *energy-efficient systems*." (Emphasis added)

In this ASHRAE definition, the physical or social forcing functions for normal and extraordinary conditions (e.g., weather conditions and anticipated hazards) are not identified, but the italicized terms promise improvements (i.e., increases, safeguards, enhancements) of response functions and processes that may not be quantitatively measurable.

A comparison of these definitions indicates that risks are inherent in promising building performance that cannot be objectively measured and evaluated for compliance with established criteria (e.g., building codes and standards, contract requirements, owner and tenant policies). Some of the risks associated with the unfulfilled promises of achieving high-performance green buildings during the design process have been discussed by Butters.[6] Similar risks are also expected as a result of unfulfilled promises made to justify modifications, renovations, or changes in operations within existing buildings.

FUNDAMENTAL CONCEPTS AND PRINCIPLES OF ENVIRONMENTAL CONTROL

To achieve and sustain the fundamental purpose of buildings, environmental control must be provided to meet the following objectives:

1. Prevent adverse health and safety effects during normal and extraordinary or emergency operational conditions;[7]
2. Provide for desired conditions of human response, occupant exposure, and productivity.[8]

In general, the quality of control required to achieve the second objective also provides the means and methods required to achieve the first objective.

TWO PRIMARY PRINCIPLES

To meet these objectives, simultaneous control is required for at least four indoor environmental parameters (i.e., thermal, lighting, acoustics and indoor air quality [IAQ]). The priority of the site-specific control strategies and the range of values of the selected control parameters should be based on two primary principles: 1) the Maslow Hierarchy of Needs (physiological, safety and security, belonging, esteem and self-actualization);[9] and 2) the definition of Health as defined in the Constitution of the World Health Organization (WHO): "A state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity."[10] From the perspective of building design and operations, these two principles are synergistic:

- The WHO definition of Health emphasizes that control to prevent illness is necessary but is not sufficient to provide for occupant well-being;
- The Maslow Hierarchy of Needs emphasizes that control to provide for occupant well-being must include the higher order needs of belonging, esteem and self-actualization.

SUSTAINABLE DESIGN

As shown in Table 1, a set of three objectives and six principles has now been incorporated into another concept of building performance: "sustainable design."

Table 1

Objectives and Principles of Sustainable Design from the Whole Building Design Guide[11]

OBJECTIVES	PRINCIPLES
1. Avoid resource depletion of energy, water and raw materials. 2. Prevent environmental degradation caused by facilities and infrastructure throughout their life cycles. 3. Create built environments that are livable, comfortable, safe and productive.	1. Optimize site potential. 2. Optimize energy use. 3. Protect and conserve water. 4. Use environmentally preferred products. 5. Enhance indoor environmental quality (IEQ). 6. Optimize operations and maintenance procedures.

These objectives and principles, which promise both outdoor and indoor environmental control, are similar to ASHRAE's definition of high-performance green buildings. They promise a certain quality of performance *through design* without defining the constellation of forcing functions or a set of responses in measurable terms that can be used to evaluate the actual building performance under normal or extraordinary conditions. Moreover, these objectives and principles appear to invert the control priority established by the Maslow Hierarchy of Needs and to exacerbate the risks in promising sustainable building performance. As typically advocated, these objectives and principles tend to focus first on minimizing the impact of building performance on climate change and depletion of natural resources, then on controlling for the health, safety and well-being of the building occupants. Taken to its logical extreme, this apparent inversion would require that buildings not be built or operated. Conversely, if buildings are to function, they must provide for occupant health, safety and well-being; and the physical laws of nature require the use of energy, other natural and human resources, and the necessary discharge of waste products. Therefore, integration of the objectives and principles of sustainable design should focus primarily on developing and using quantitative measures to assure compliance with the Maslow Hierarchy of Needs.

RISK MANAGEMENT

A critically important lesson has been learned during the last two decades. Buildings must be *resilient*: they must perform under normal forcing functions during their entire useful lives, and be prepared to effectively respond during and after the occurrence of extraordinary forcing functions caused by relatively short periods of natural disasters, accidental incidents and intentional events.[12]

The strategies for resilient control during the normal and extraordinary periods should be evaluated and updated through periodic risk assessments of the specific site, which identify the threats (i.e., forcing functions), the vulnerabilities or weaknesses in the building system (i.e., measured responses), and risks that can result. As an example of resilient control, consider the required performance of a building with a critical need to continue its operations during an extraordinary weather event. It must have adequate emergency and redundant electrical power generating equipment (e.g., diesel generators), HVAC capacity, and flexibility of control to provide for occupant health and safety; and it must reliably power the critical operations during the event in addition to re-establishing normal operations rapidly after the event. A flow diagram of this resiliency is shown in Figure 1.

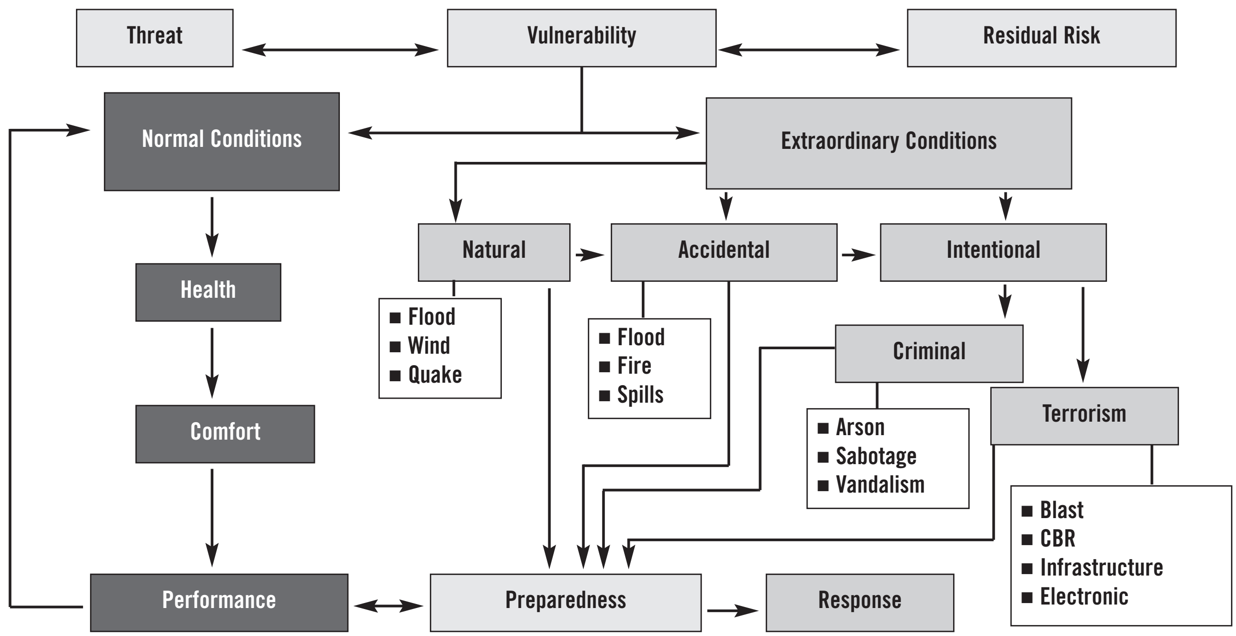
A building is subject to vulnerabilities under normal as well as under extraordinary conditions which may be markedly different. An energy efficient system during normal conditions may prove to have very high vulnerabilities to intentional acts or vice versa. No building can avoid a level of residual risk which remains no matter what the desire to eliminate all risk. Rather, this residual risk needs to be managed. In fact, the resiliency of a building is its capacity to minimize this residual risk so that it can quickly return to its proper functional reason for being.

The concepts of residual risk and resiliency incorporate the Maslow Hierarchy of Needs and the WHO definition of Health while extending the concept of sustainability beyond that shown in Table 1.

- During normal conditions, a set of forcing functions occurs on a regular basis, and control of the measured responses should be sustained within the ranges of expected values for the intended performance of the building.
- During extraordinary conditions, an expanded set of forcing functions occurs for short periods of time (i.e.,

Figure 1

Residual Risks



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threats) that result from natural disasters, accidents and malicious events.

- If the building performance is assured during normal conditions, its preparedness for safe and secure performance during and after extraordinary conditions is likely to be enhanced and the residual risk is likely to be diminished.
- If preparedness of the building performance before, during and after natural disasters (e.g., floods, quakes, fires, winds) is assured to be in compliance with codes and standards for new and existing buildings, the physical means and methods employed are also likely to diminish the risks associated with accidental, criminal or terrorist incidents.
    - If preparedness of the building performance before, during and after accidental incidents (e.g., internal floods, fires, spills) is assured to be in compliance with standards and policies, the physical and social means and methods employed are also likely to diminish the risks associated with criminal incidents.
    - If preparedness of the building performance before, during and after criminal incidents (e.g., arson, sabotage, vandalism) is assured to be in compliance with standards and policies, the physical and social means and methods employed are also likely to diminish the risks associated with terrorist incidents (e.g., blasts, chemical or biological releases, infrastructure attacks, electronic interferences).

BUILDING PERFORMANCE

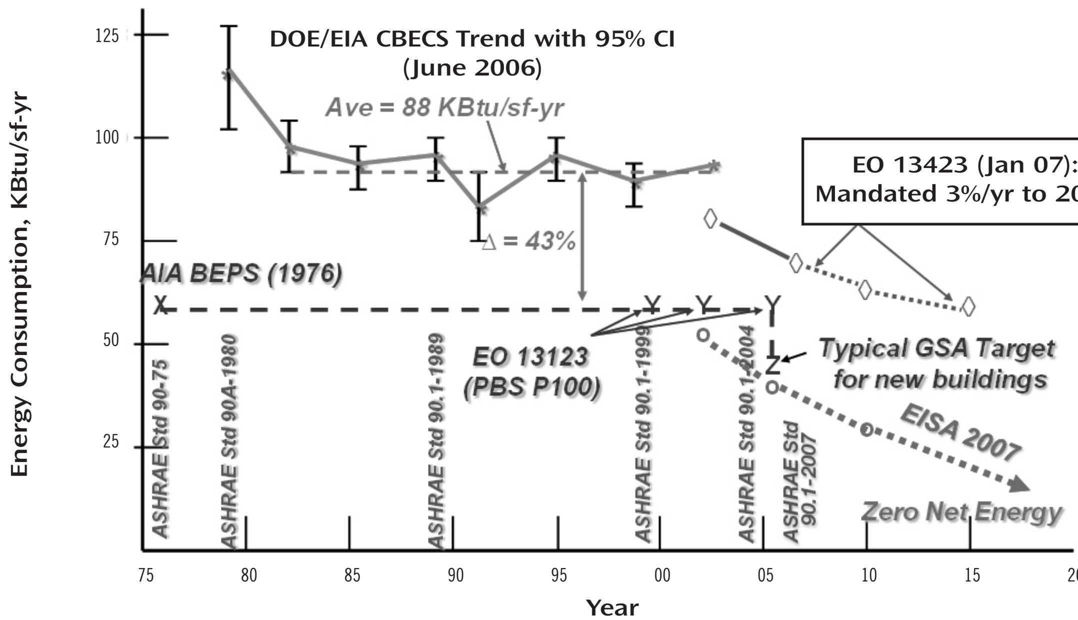
Under this more comprehensive definition of measurable building performance, an owner needs to assess what attributes of the building affect the primary business function. If an important function of the building is for it to be occupied by employees, workers or visitors, the owner should consider how to minimize the residual risk and maximize the resiliency of such a building. Therefore, both the physical and social factors of a building must be addressed to properly fulfill the building's function. In other, rarer cases, either the physical or the social factors will dominate.

ENERGY UTILIZATION

Energy utilization is a consequence of both physical and

Figure 2

Energy Trends and Predictions



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social factors. When considering energy utilization we should keep this in mind, especially when dealing with policy formulation. According to the Energy Information Agency of the U.S. Department of Energy,[13] approximately 4.7 million commercial and 107 million residential buildings now exist in the U.S. and replacement rate for this building stock has been 2–4 percent per year for the last 20 years. If this rate continues, more than 80 percent of the buildings that will exist in 2030 have already been built. Therefore, the new "energy efficiency" and environmental laws, codes and standards promulgated by government and advocacy groups for new building designs are not likely to have the national and global effects on building inventories that have been promised. Some of the reasons for this dilemma were described by Bezdek[14] at the REI Forum in February 2008 as the Jevons Paradox: "The more efficient we become in using a given resource, the more we consume of that resource."

An example is shown in Figure 2: an analysis of thirty years of Commercial Building Energy Survey (CBECS) data published by the Energy Information Agency of the U.S. Department of Energy (DOE/EIA) revealed that the average Energy Utilization Index (EUI), which is a widely used index for commercial buildings in the U.S., has been statistically flat at 88 kBtu/sf-yr within a 95 percent confidence interval (CI) for the last 25 years.

This average value consistently has been 43 percent higher than the energy goals that have been set since 1975-1976 for new building design by the American Society of Heating Refrigerating, and Air-Conditioning Engineers (ASHRAE Standard 90-75, 90A-1980, 90.1-1999, 90.1-2004, 90.1-2007). These are labeled in Figure 2 along the x-axis by date of standard released. ASHRAE has for many years been advocating for decreased use of energy per its standards but this seems to have had little impact on the 88 kBtu/sf-yr seen in the CBECS data.

The American Institute of Architects has also spent much time trying to attack this problem by participating in the creation and promulgation of various standards to decrease energy consumption for private buildings (Building Performance Standards, BEPS 1976, with a target of 55 kBtu/sf-yr shown in Figure 2), and public buildings (the Facilities Standards for the Public Building Service, U.S. General Services Administration (PBS P 100-2000, 2003 and 2005 setting the same goal of 55 kBtu/sf-yr). Of particular note:

- The Presidential Executive Order 13423, issued in January 2007, now requires, as an unfunded mandate, that the consumption rates of energy and water be reduced by 3 and 2 percent per year, respectively, in each Agency's inventory of buildings until 2015 (upper right quadrant of Figure 2).
- The Energy Independence and Security Act of 2007 (EISA 2007, the decreasingly sloping curve in the right bottom quadrant of Figure 2) now requires 50 percent reductions in energy consumption by 2020 in new building design, compared to those determined by ASHRAE Standard 90.1-2004, and "net-zero" energy consumption by 2030, where "net-zero" energy consumption means that renewable resources must provide at least as much energy as is consumed by the building.

When all these hopeful standards and regulations are superimposed, it is clear that the 88 kBtu/sq-ft average will be exceedingly difficult to change. These results indicate the difficulty that has been experienced in achieving a national impact on energy reduction in buildings. Even more, it indicates the often wishful thinking in much public policy behind the regulatory or legislative enactments. Advocacy decoupled from the actual performance data may increasingly lead to a gap of credibility for public expenditures and subsidies. This would be a very unwelcome outcome.

Moreover, this example does not include trends in building performance with regard to other measured responses such as occupant health, safety and well-being, indoor exposures or system performance.

INDOOR ENVIRONMENTAL QUALITY

Not only has the measured energy utilization in buildings failed to meet the expected goals, but the environmental quality within these buildings has not met expectations. Providing indoor environmental quality (IEQ) is a primary requirement of building performance. IEQ is dependent on both physical and social factors.

Since the important concept of "continuous degradation" of the building stock was introduced in 1988,[15] the percentages of commercial buildings with less than acceptable indoor environmental quality have been reported to exceed 30 percent in both the private and public sectors. In the 1990s, the U.S. General Accountability Office (USGAO) reported that 58 percent of the approximately 100,000 K-12 schools in the U.S. had at least one unsatisfactory environmental condition and 13 percent had more than five unsatisfactory environmental conditions. In 2003, the USGAO added Federal Real Property to their "high risk" category due to poor quality of health and safety conditions.

The 2006 CBECS data also reveal some other attributes of interest:

- Approximately 11 percent of the commercial building stock is government owned, so approximately 89 percent of the commercial building stock is in the private sector.
- The sizes of the commercial buildings in the database ranged from less than 1,000 square feet to more than 2,000,000 square feet:
    - 50 percent of the commercial buildings are smaller than 5,000 square feet;
    - Approximately 75 percent of the commercial buildings are smaller than 10,000 square feet;
    - Fewer than 5 percent of the commercial buildings are larger than 50,000 square feet.
- The employee population is inversely proportional to the number and size of the buildings:
    - Half of all employees occupy the 5 percent of the buildings larger than 50,000 square feet;
    - One quarter of all employees occupy the 75 percent of the buildings smaller than 10,000 square feet.

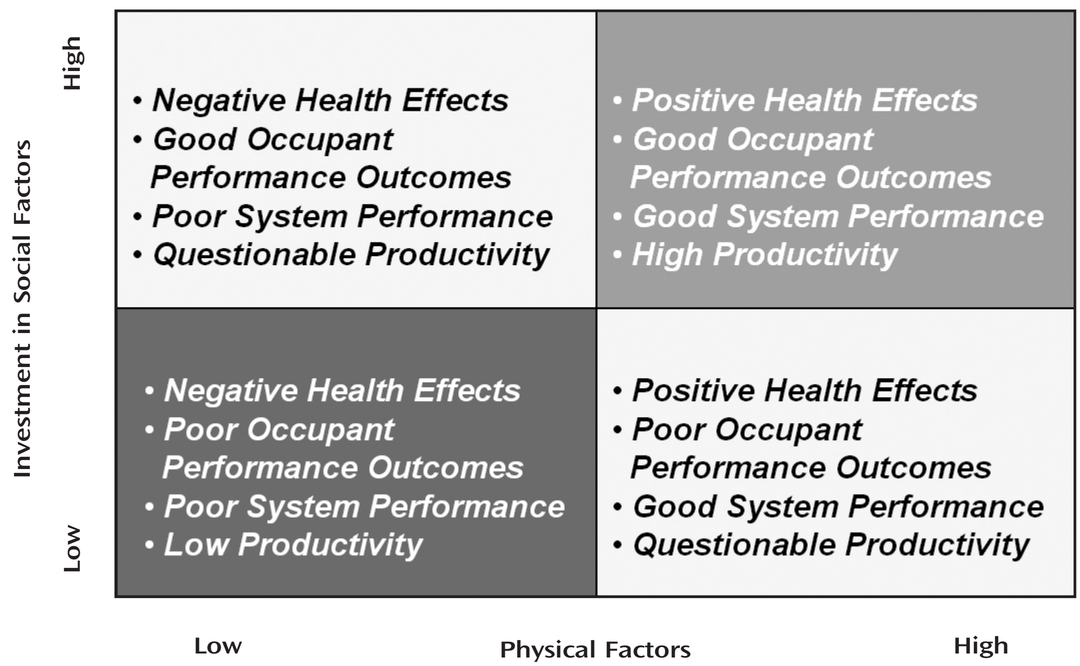
BALANCING THE FACTORS

From a building performance perspective, the data in the examples above present two important questions: First, how important are the physical factors compared to the social and motivational factors in delivering the functionality as set by the primary business goals? Second, how much should be invested in the control of the physical versus the motivational and social factors given the context of the given functional desires? It may be much more important for an owner to do what is necessary to increase his or her productivity than to worry about the energy expenditure if increased productivity has the greater impact on profitability. In the latter example, the owner would want to invest more in credible and measur-

Figure 3

Expected Outcomes

Example of a risk and investment management dilemma that must be solved periodically throughout the life of the building.



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able methods to deal with productivity issues related to the building rather than decreases in energy consumption.

An example of the risk management and investment dilemma that must be resolved periodically throughout the lifetime of the building is shown in Figure 3. If little or much is invested in both the physical and the motivating factors (the lower left and upper right quadrants of Figure 3), the outcomes are obvious. However, if the investment must be limited and non-uniformly distributed among the choices, which set of measurable factors incur the highest risks (i.e., high motivation and low physical performance; or low motivation and high physical performance)?

This dilemma can be illustrated as follows: If a school superintendent has a limited budget of $1,000,000 to invest in the improvement of student performance in a 250,000-square-foot high school of 2,000 students, how much of the investment should be directed to the replacement of three highly talented and motivated teachers who are retiring, and how much should be directed to mold remediation and repair of water leaks in the roof?

- Dilemma 1: Insufficient funding is available to accomplish both objectives, but to accomplish neither is not an option.
- Dilemma 2: If the mold is remediated and the roof leaks fixed but all of the talented and motivated replacement teachers are not hired, the health risks will be reduced but the risks of diminished learning outcomes will be increased.
- Dilemma 3: If the teachers are hired but the mold remediation and roof repairs are not completed, the learning outcomes will not be impaired but the health risks will be increased.
- Dilemma 4: When considering the total impact on the investment, which is more important: to reduce the risk of increased life-time health impairment or to reduce the risk of life-time deficiencies from the

learning outcomes?

To resolve such dilemmas, credible sets of forcing functions and response functions must be objectively defined and quantitatively measured.

RISK AND ACCOUNTABILITY

Risks associated with the unintended consequences and unfulfilled promises of building performance have been the focus in this article. The primary causes of these risks may be lack of measured performance data and the means and methods to collect them. Once credible data become available to the real estate industry, those being held accountable for building performance during both normal and extraordinary conditions will be able to verify that the buildings are quantitatively performing in accordance with the appropriate criteria, which may not yet be developed.

Accountability for the performance of a building is not a new issue, but it has become a nebulous function during design, construction and operations of buildings. It is certainly not a term that is easily found in contracts for these services. A major issue is: for what are the designer, contractor, owner and tenant accountable?

- Designers, contractors and building operators are not currently prepared to evaluate health consequences of their decisions, although professional licensure requires this knowledge to protect the health and safety of the general public.
- Codes and standards seldom address "health" issues, and prescriptive formats of these documents are not consistent with evaluation of health consequences.
- Occupant health may be explicitly excluded from these contracts.
- Occupant health is generally avoided in project documentation.
- Insurance policies often have exclusion clauses on indoor environmental issues and health consequences, or they are very expensive.

As health, safety, security and sustainability have all been integrated into the lexicon of building performance, accountability is likely to be required for each of these factors during each phase of the building's life. As shown in Figure 4, accountability for building performance should be considered as a cycle.[16]

This cycle outlines a protocol that can be used to assure the performance of a building and its systems from planning and design through construction and operations. This protocol focuses on the interception of continuous degradation through building diagnostics, and defines the concept of "continuous accountability:"

1. Through the process of building diagnostics, the rate of degradation in building performance (e.g., occupant complaints, exposure deficiencies, system imbalances and vulnerabilities, energy and economic deficiencies) can be detected and intercepted to protect occupants and assets.
2. Cost-effective interventions can then be identified, designed and implemented for normal conditions, and emergency responses can be implemented for extraordinary incidents.
3. The interventions go through a process of building commissioning to assure proper installation and operation using building diagnostics procedures, to assure that the healthy building status has been regained.
4. An "accountable person" provides the continuity to assure the success of this process.

For this cycle to be effective, the accountable person must be:[17]

- *explicitly identified* for each phase in the building's life;
- *empowered* with authority to assure building performance; and
- *educated and trained* to assure adequate building performance and occupant well-being.

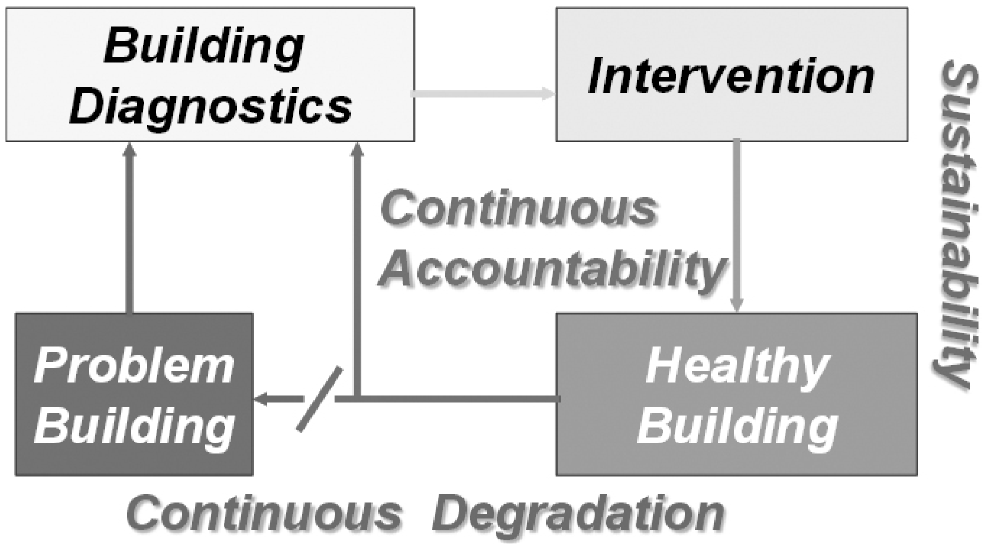
CONCLUSIONS

Building performance is a set of facts and not just promises. If the promises are achieved and verified through measurement, beneficial consequences will result and risks will be managed. However, if the promises are not achieved, adverse consequences are likely to lead to increased risks to the occupants and tenants, building owners, designers and contractors; and to the larger interests of national security and climate change.

A primary means to assure intended building performance is through the process of "continuous accountability." This process is something very common in successful businesses. Only by measuring and verifying the outcomes of particular resource investment strategies over appropriate time periods can a company monitor

Figure 4

Concept of Continuous Accountability



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and improve performance. One might even say this is the only way to determine on a periodic basis the "health of the business." The building diagnostics approach simply transfers this thinking about a healthy business and applies it to the company's inventory of building(s).

The bottom line is that verifiable assurance of the promised building performance allows the owner to determine if he or she made a good investment. ■

ENDNOTES

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