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RESEARCH ARTICLE

Reconciling human and automated intelligence in the provision of occupant comfort

Raymond J. Cole[1*], Zosia Brown[2]

[1]School of Architecture and Landscape Architecture, University of British Columbia, Vancouver, BC, Canada
[2]Institute for Resources, Environment and Sustainability, University of British Columbia, AERL 4th Floor, 2202 Main Mall, Vancouver, BC, V6T 123 Canada

This article explores the relationship between increasing demands for personal control by building occupants and the changing role and expectations of the 'intelligent' building. It specifically examines the relationship between human and automated intelligence and how these are manifest in green buildings. Given that comfort expectations and technological prowess are culturally bound, the article contrasts the ways that 'intelligence' is evidenced in North American and Japanese green building assessment methods and green building practice. Conclusions reinforce the need to invest greater effort in understanding how buildings actually function and, more specifically, redefine design assumptions regarding the way that occupants engage with buildings and control strategies.

Keywords: automated intelligence; cultural difference; green building; human intelligence; occupant comfort; personal control

INTRODUCTION

Providing and maintaining an appropriate indoor environment with an economy of means has always been an implicit objective of architectural design. The definition of what conditions are deemed acceptable has a history of reassessment and refinement, as do the methods and technologies by which they can be achieved. Indeed it is difficult, if not impossible, to discuss the history or future of comfort provision in buildings without discussing the technological capability available to the design team to deliver it. Fraker and Prowler (1981), for example, argue that during the 20th century, the widespread deployment of energy-intensive mechanical systems that could be located remote from the spaces they served, liberated architects from many prior pragmatic concerns related to comfort provision. Technological innovation led to a shifting of design responsibility in comfort provision from architects to mechanical engineering consultants, and control responsibility from occupants to technology.

It is also impossible to discuss what constitutes appropriate comfort conditions simply in terms of human physiology – a host of cultural, psychological, behavioural and contextual factors shape a person's engagement and enjoyment of environmental conditions (Rybczynski, 1987; *Energy and Buildings*, 1992; Crowley, 2001). Yet, over a half-century of comfort research and comfort provision has been guided by the search

*Corresponding author. E-mail:raycole@arch.ubc.ca

earthscan

for a universally applicable set of optimum comfort conditions. The consequences of this extend well beyond the direct experience of building users, to the global standardization of comfort criteria and expectations and the erasing of cultural adaptations traditionally deployed in response to adverse climate conditions. See for example, Spain's abolished siesta (Crawford, 2005).

A central issue in the efficiency and effectiveness of buildings to provide occupant comfort is where 'intelligence' is assumed – either implicitly or explicitly. Clements-Croome (2004), Kell (2005), Wong et al. (2005) and others emphasize the multiplicity of definitions of an 'intelligent' building that have been offered over the past two decades, from the advocates of a purely technological framing to those that embrace aspects explicitly related to management practices and occupant health and well-being. The UK-based Intelligent Building Group defines an intelligent building as one that 'provides a sustainable, responsive, effective and supportive environment within which individuals and organizations can achieve their objectives' (ibgroup, 2007). In contrast, the American Intelligent Buildings Institute defines an intelligent building as 'one that provides a productive and cost-effective environment through optimization of its four basic components – structure, systems, services and management – and the interrelationships between them' (ibuilding, 2007). The differing emphases of these and other definitions communicates both technological capacity and culturally perceived needs in the design of buildings.

Three key issues central to all intelligent buildings, which will be further explored later in this article, are:

1. buildings embedded with technologies and control strategies designed to perform tasks more reliably and effectively than people
2. buildings, in and of themselves, cannot be 'sustainable' but can support sustainable patterns of living; similarly, as So et al. (2001) suggest, 'intelligent buildings are not intelligent by themselves, but they can furnish the occupants with more intelligence and enable them to work more efficiently'
3. knowing which aspects of building control to implement automatically, and the extent to which they should be pre-programmed versus accessible to the building operators or the individual occupant (Cohen et al., 1999).

Increasingly, research confirms the importance of having some level of direct control over the environmental conditions in the workplace as being paramount to occupant satisfaction (Heerwagen and Diamond, 1992. Baker, 1996; Leaman and Bordass, 1999). This article explores the relationship between increasing demands for personal control, and the changing role and expectations of intelligent buildings. It specifically examines the relationship between human and automated intelligence and how these are manifest in green buildings. Given that comfort expectation and technological prowess are culturally bound, the article contrasts the way that 'intelligence' is evidenced in North American and Japanese green building practice.

INTELLIGENT BUILDINGS

ATTRIBUTES OF INTELLIGENT BUILDINGS

Despite the widely different emphases placed on the notion and definition of an 'intelligent' building, it is possible to identify a set of key attributes. Kell (2005) identifies five complementary concepts of intelligent building that have evolved over the past 30 years. For the main part these reflect the changes in technological capability:

1. *Automated buildings:* Automated systems that improve the management, control of building services such as heating, ventilation and air-conditioning (HVAC), lighting, energy management, fire, security and access control.
2. *Informated buildings:* Integrated, centrally managed information and communications infrastructure and systems that enable buildings to continuously respond and adapt to changing conditions and perform more effectively.

3. *Intelligent space management:* Investing the building with the capability to respond easily and intelligently to rapid changes in the size and structure of organizations and work practices.
4. *Passive intelligence:* Perceptive design strategies – form, envelope, facades, fenestration, layout and thermal mass – to positively influence building environmental performance and thereby reducing or replacing unnecessary active systems.
5. *Organizational intelligence:* Strategic management plans that more closely integrate organizational need with building capability and potential. Available knowledge and skills are combined to manage its building services, information services, space management and building structures in an effective and integrated manner.

Kell (2005) emphasizes that a common factor in these concepts is a 'focus upon making better use of information to improve performance and increase value'. Within the context of this article, it is appropriate to make explicit a sixth concept – *occupant intelligence* – wherein the building explicitly enables its users to make appropriate adjustments in the environmental conditions in their workplace. More broadly, Himanen suggests that '[e]nd-user empowerment can be a driving force in the information and communications technology industry in [the] future and thus in the construction and real estate business of IBs' (Himanen, 2004, p26). As will be illustrated later, occupant intelligence can manifest differently in buildings designed to accommodate specific cultural norms.

DEMANDS ON INTELLIGENT BUILDINGS

Building intelligence has to fulfil a number of, at times competing, technical and human requirements (Cohen et al., 1999):

- Provide and maintain occupant comfort, health and well-being.
- Provide occupant and organizational safety and security.
- Provide and maintain operational efficiencies in energy use.
- Reconcile any conflicts between competing performance requirements and differences in perceived ideal conditions between occupants owing to age, sex, location, activity or plain personal preference.
- Improve performance, or compensate for the lack of features which building occupants value, like operable windows, control over noise and privacy, views out and natural light.

Effective building controls, whether local or central, manual or automatic, are central to this debate. On the one hand, the centralized, automated provision of comfort, health and well-being are often achieved at a high energy cost and can impede occupant productivity. On the other hand, local, manual control may enhance productivity, and reconcile differences between occupants in terms of perceived ideal conditions, but unless all occupants make appropriate and intelligent choices, efficiency, safety and security can be compromised. An implication for the intelligent building is, therefore, the extent to which controls are 'local' or 'global' in their consequence in terms of building performance (Beaven and Vincent, 2004).

GREEN BUILDINGS

The past decade or so has witnessed a maturing of concern and interest in environmental issues that is increasingly evidenced in building design and construction practice. Green design is not simply about attaining higher environmental performance standards or 'investing' in new values; it is also about rethinking design 'intelligence' and how it is placed in buildings. Indeed, many of the concepts described by Kell (2005) pertaining to intelligent buildings have inherent relevance in green design (see Table 1).

AUTOMATED, INFORMATED AND ORGANIZATIONAL INTELLIGENCE

Over their entire life cycle, green buildings are expected to use less energy and water, generate less greenhouse gases, use materials efficiently, and produce less waste. Efficient building operation can include the design and commissioning of automated systems to improve the management and control of building services (*automated* intelligence). Moreover, green features such as improved indoor air quality (IAQ) and thermal conditions, abundant natural light, elimination of materials that 'off-gas' harmful chemicals, views to the exterior and plentiful fresh air lend themselves to healthier interiors. Healthy indoor environments are linked to gains in productivity, decreased absenteeism, improved employee morale and increased occupant satisfaction (Fisk, 2000; Wargocki et al., 2000; Heschong et al., 2002). The maintenance of healthy environments through

TABLE 1 Intelligent building (IB) concepts, and green building concepts and strategies

IB concepts	Green building concepts	Green building strategies
Automated	• Efficient building operation	• Efficiency of services/equipment • Commissioning of systems • Mixed mode systems
Informated	• Provision of feedback on building performance; responsive systems	• Ongoing monitoring of energy and water use • Ongoing monitoring of CO_2 • Ongoing monitoring occupancy and use patterns • Daylight sensors • Solar tracking and responsive controls • Displays of building energy use
Intelligent space management	• Flexible, adaptive design	• Under-floor air distribution • Flexible electricity and telecommunications • Refined HVAC and electric lighting zones • Modularized, movable workstations and partitioning • Private and interaction space
Passive intelligence	• Passive environmental control	• Appropriate site selection • Appropriate orientation and massing • Integration of renewable energy technologies • Efficient building envelope • Thermal mass • Green material selection • Natural ventilation and daylighting
Organizational intelligence	• Multiple use buildings and spaces; effective operational management support	• Location of activities according to orientation/ core or perimeter • Efficient programming • Matching control complexity to management support
Occupant intelligence	• Personal control over ventilation, thermal comfort, natural light, noise and privacy	• Operable windows • Operable blinds • Task lighting • Private and interaction space • Manual override of automated systems

linking feedback on building performance with responsive systems, are concepts that share similar goals with *informated* intelligence.

Additionally, green buildings are often invested with the capability to serve multiple purposes over the course of a day and over the building lifetime, thus optimizing the use of the space and services. This can be considered *organizational* intelligence, in the sense that building capability and potential is integrated with organizational need.

PASSIVE INTELLIGENCE

Passive intelligence in green buildings can be characterized in a number of ways, from basic decisions regarding building form and materials, to solar or climate-actuated controls, e.g., the US-based Zomeworks Corporation's 'skylids' – pivoted and well-balanced louvres that are opened or closed depending on incident sunlight, to systems approaches, e.g., using heat dissipated from a photovoltaic (PV) array to enhance stack ventilation. In this latter example, the intelligence is clearly one of how technologies are integrated within an overall energy or building strategy rather than the technologies themselves.

Since many green buildings apply the 'passive intelligence' to improve building performance, this concept in particular serves to reassert the importance and role of architectural design decisions in the provision of comfort. Hartman (2006, p17) suggests that the 'history of the green building movement to date shows a subtle but persistent bias by architects away from the application of more advanced technologies in the comfort systems that serve buildings'. In North America, there has been a discernable pendulum swing over the past two decades from a fully mechanically controlled environment to one largely provided passively. This has been driven by the combination of perceived environmental and occupant–productivity benefits and a cultural antipathy to reliance upon the 'active intelligence' of building systems. More recently, there is a tendency to deploy mixed-mode approaches – raising the expectation of a greater and more effective synergistic relationship between simple, occupant-activated controls (*passive* intelligence) and advanced, automated technologies (*automated* intelligence). In all cases, the ways and extent that occupants are considered an integral part within the overall control system is critical.

INTELLIGENT SPACE MANAGEMENT AND OCCUPANT INTELLIGENCE

While space management has always been a key issue in organizational effectiveness, occupant intelligence has only recently been incorporated into the green building discussion. The flexible use of space is important from both the standpoint of rapidly changing organizations and work practices, and consequences of extreme weather and temperatures on indoor comfort conditions. While buildings in some areas may continue to need to be mechanically conditioned during the hottest times of the year, the need to reduce greenhouse gas emissions combined with rapidly rising electricity prices calls for the adoption of creative adaptive strategies (Roaf, 2006). Green building strategies that rely on both intelligent *space management* and *occupant* intelligence include: flexible, adaptive work environments; refined control zones and technologies that maximize occupants' access to adaptive opportunities, e.g., under-floor air distribution; and traditional 'intelligent' patterns of building use by local culturally adapted populations reintroduced into the workplace, e.g. seasonal dress codes, siestas, heat holidays.

USERS

Comfort provisioning and control have always been, and will remain, a critical performance requirement of buildings whether 'intelligent' or 'green' or both. The key issues of debate are the technical means by which it is attained, the extent to which system complexity matches management capacity, the degree of involvement of the occupant, and the integration of comfort with the full spectrum of other architectural requirements. Moreover, comfort is not just an outcome of the physical environment but as Brager and de Dear argue, '[i]t is our very attitudes about comfort – both on an individual and cultural scale – that influence our basic need for (or aversion to) mechanical heating and cooling' (Brager and de Dear, 2003).

Baker (2004) draws from a number of precedents to argue that variation in environmental conditions is essential, and yet the notion of an optimal temperature remains a current design aspiration wherein both spatial and temporal deviation away from this is seen as leading to a degradation in the quality of the environment. Although some degree of tolerance is acceptable, he suggests that 'close control remains the target of conventional services design' (p53). A parallel to this 'neutral' versus 'variable' indoor environment debate exists with regard to controls. Cohen et al. (1999), for example, argue that building occupants desire to 'either to be in control' of the conditions in their workplace or to be 'so well looked after that they never become uncomfortable'. Problems occur, they suggest, when they 'hit their crisis of discomfort' in those spaces with ineffective individual control and where management is non-responsive.

Building occupants' pleasure, comfort and productivity are closely linked with their real and perceived control over interior environmental conditions. When occupants have more perceived control over their indoor environment, as is common in naturally ventilated buildings with operable windows, they are more likely to tolerate less-than-ideal conditions (Humphreys and Nicol, 1998). While effective passive design strategies can regulate base comfort conditions within buildings, four key indoor environmental requirements typically require additional control, be it occupant or automated:

- *lighting:* blinds, screens and/or electric lighting switches/dimmers
- *thermal:* operable windows, solar controls and/or thermostat adjustment
- *ventilation:* operable windows and/or air supply vents
- *acoustic quality/privacy:* operable windows, enclosure and/ white noise.

Although not conclusive, there appear to be differences in the significance of control over the different environmental modalities and their influence on overall comfort. Cohen et al. (1999) argue that natural ventilation is firmly associated with manual control and that an operable window is 'a safety valve for the alleviation of discomfort' and the 'very act of opening a window by its nature makes an important psychological contribution to the perceived effectiveness of the ventilation'.

NECESSITY OF ACCOMMODATING HUMAN INTELLIGENCE

Cohen et al. (1999) examine how the buildings in the UK *Post-Occupancy Review of Buildings and their Engineering* (PROBE) research project are coping with emerging intelligent building technologies and the degree to which these influence energy performance and occupant satisfaction. A key observation from their studies is that '[n]otwithstanding all the implications of supposedly advanced automation, our experience is that the best intelligence in most buildings lies in the occupants themselves' and that the 'challenge for designers and manufacturers is then to support them with appropriate and understandable systems with readily-usable control interfaces, which give relevant and immediate feedback on performance'. In other words, buildings in and of themselves cannot be 'intelligent' but can support intelligent patterns of behaviour.

LIMITS OF OCCUPANTS' INTELLIGENCE

Placing responsibility for comfort conditioning in the hands of building occupants assumes that they will make appropriate and intelligent choices. A building occupant's pleasure, comfort and productivity are closely linked to their real and perceived control over interior environmental conditions (Heerwagen, 2000). Such knowledge has typically translated into guidelines that specify strategies and systems to provide users with adequate control, that are comprehensible, simple to manage and use and that provide quick responses to user-induced change.

However, simply *providing* operable windows, for example, is clearly insufficient in designing naturally conditioned buildings. The location, ergonomics and the extent of opening and their distribution profoundly affect performance and use. For example, in contrast to simple, generalized models of occupant behaviour assumed in design, Leaman (1999) presents a list of 'real' building user reactions and responses that indicate occupants tend to:

- act in response to random, external events
- take decisions to use switches or controls only after an event has prompted them to do so (rather than in advance of it)
- often wait for some time until taking action and typically when they reach a 'crisis of discomfort'
- over-compensate in their reactions for relatively minor annoyances
- operate the controls or systems that are most convenient to hand, rather than those that would logically be the most appropriate
- take the easiest and quickest option rather than the best for their immediate benefit
- consciously or otherwise, leave systems in their switched state, rather than altering them back again later, at least until another crisis of discomfort is reached.

COMPREHENSION OF AUTOMATED CONTROLS

It is widely known that building performance in use often differs markedly from that anticipated or predicted during design. This performance gap results not so much from the building design and technology itself, but rather from the differences between assumed and actual patterns of occupancy, the use of controls, and building operation and management. Based on a wealth of experience in evaluating actual building performance, Bordass and Leaman (1997), point to *overly complex* building systems as a major deterrent for efficient and effective building operation (see also Bordass et al., 1994). Their work suggests that high-tech buildings are relatively complex to operate, so dedicated management is essential if they are to achieve optimal performance. The findings speak to an underlying irony, in that well-designed technically sophisticated buildings are intended to reduce, and not add to, complexity. To enable occupants to solve operational problems, however, such systems must be readily accessible and comprehensible to building users and clearly accompanied by a willingness to use them. A key lesson is, therefore, that the environmental success of a building depends on matching technological and management sophistication.

The issues raised above may have more fundamental roots in the way that contemporary design conceptualizes and provides for the interactive process between users and building systems. The dominance of seemingly universal features of human need and 'viewing users as the passive beneficiaries of designers' decisions' (Shove, 1995, p165) provides little scope for alternatives and does little to encourage the need for understanding the culture of specific user groups.

CULTURAL CONTEXT

So et al. (2001), in developing a workable definition of intelligent buildings for Asia, provides a brief review of the different interpretations placed on intelligent building in North America and Europe. They argued that most existing definitions are 'either too vague to be useful guidance for detailed design [by placing] an unbalanced focus on technologies only, or do not fit the culture of Asia'. This last point highlights the importance of cultural context and expectation in the framing of discussions on intelligent buildings.

Subsequently, the Hong Kong-based Asian Institute of Intelligent Buildings (AIIB) introduced the *Intelligent Building Index* (IBI) as a means of providing a more complete and accurate characterization of intelligent buildings within the Asian context. The IBI Manual version 3.0 (AIIB, 2005) uses a series of indices based on the ten *quality environment modules:* green index, space index, comfort index, working efficiency index, culture index, high-tech image index, safety and structure index, management practice and security index, cost effectiveness index and health and sanitation index. Each index contains a list of elements – a total of 378 – that may be services, technologies or passive items that can subsequently be translated into an overall building score. AIIB thus defines an intelligent building as 'designed and constructed based on an appropriate selection of Quality Environment Modules to meet the User's Requirements by mapping with the appropriate building facilities to achieve a Long-Term Building Value'. The IBI can be contrasted with UK and US approaches referenced in the introduction, from the standpoint of emphasis, method and culturally perceived needs.

Similarly, priorities and practices in green building vary considerably worldwide. There is clearly no single correct approach to achieving improved environmental performance – the most often referenced distinction being between passive strategies (building form; materials etc.) and more sophisticated mechanical systems. There are two possible ways of distinguishing between cultural approaches to intelligent/green buildings:

- examining how and where 'intelligence' is embedded in the scope and content of building environmental assessment methods developed in different countries
- examining how and where 'intelligence' is the strategies deployed in leading-edge buildings within the respective countries.

INTELLIGENCE WITHIN BUILDING ENVIRONMENTAL ASSESSMENT METHODS

Green building practices have been institutionalized within building environmental assessment methods (Cole, 2005, 2006). In North America the US Green Building Council's *Leadership in Energy and Environmental Design* (LEED®), and the Japanese *Comprehensive Assessment System for Building Environmental Efficiency* (CASBEE):

- LEED® organizes performance criteria into five distinct categories: sustainable sites; water efficiency; energy and atmosphere; materials and resources; and indoor environmental quality. Building performance is summarized by an overall environmental rating of 'certified', 'silver', 'gold' or 'platinum' (USGBC, 2005).
- CASBEE explicitly distinguishes between the environmental loading (resource use and ecological impacts) and environmental quality and performance (indoor environmental quality and amenities), scoring them separately to determine the building environmental efficiency, i.e., the ratio of environmental quality and performance to environmental loading. Building performance is summarized by an overall environmental rating of 'C', 'B-', 'B+', 'A' or the highest 'S' (sustainable) (IBEC, 2003).

It was anticipated that North American green building practice would be characterized as typically favouring simple, passive approaches – natural ventilation, natural lighting – and giving greater responsibility and freedom to building occupants to make necessary changes. Japanese green building, by contrast, was anticipated to place greater faith in complex technologies, deploying sophisticated sensors and automated control systems to monitor and make changes.

Table 2 summarizes the emphasis given to building intelligence in energy and indoor environmental quality (IEQ) categories within LEED® and there counterparts in CASBEE, again organized under the intelligent building concepts. General distinctions between the two systems are:

- Both focus heavily on automated and informated intelligence.
- Both systems have 'some' emphasis on occupant intelligence.
- Both systems lack emphasis on organizational intelligence.
- LEED® uses informated intelligence for indoor quality whereas CASBEE uses informated intelligence for resource use.

TABLE 2 Green building performance credits in LEED® and CASBEE

	LEED®		CASBEE	
Intelligence	*Resource use*	*IEQ*	*Resource use*	*IEQ*
Automated	• Fundamental building system commissioning • Best practice commissioning • Optimize energy performance	• Fundamental building system commissioning • Best practice commissioning • Ventilation effectiveness	• Building thermal load • Efficiency in building service system • Reliability	• Room temperature control • Humidity control • Type of air conditioning
Informated	• Measurement and verification	• CO_2 monitoring • Temperature and humidity monitoring • Thermal comfort monitoring	• Efficient operation monitoring • Operational management system • Reliability	• CO_2 monitoring
Intelligent space management	• Durable building		• Reliability	• Zone control • Lighting controllability • Service ability: functionality and workability • Flexibility and adaptability
Passive intelligence	• Durable building • Optimize energy performance	• Low emitting materials • Chemical and pollutant source control • Daylight and views	• Service life of components • Noise, vibration and odour	• Sound insulation • Daylighting • Illuminance level • Pollution source control
Organizational intelligence	• Building reuse	• Daylight and views	• Reuse of existing building structure etc.	• Amenity: perceived spaciousness and access to view
Occupant intelligence		• Controllability of systems: thermal, ventilation and lighting • Innovative design credit: education outreach programme		• Anti-glare measures • Lighting controllability • Natural ventilation performance: operable windows • Amenity: space for refreshment

- CASBEE gives greater emphasis to space management.
- LEED® gives greater emphasis to passive intelligence for resource use, whereas CASBEE uses passive intelligence for indoor environmental quality.
- CASBEE recognizes acoustics as a quality issue, but there is no explicit reference to acoustics in LEED®.

INTELLIGENCE WITHIN CURRENT GREEN BUILDINGS

Table 3 summarizes the key design strategies of how user or automated controls are evidenced in three recent LEED® 'platinum' buildings in North America and three CASBEE 'sustainable' buildings in Japan to highlight cultural differences and interpretations. The strategies are organized under the intelligent building concepts.

North American 'platinum' projects:

- *Genzyme Centre,* Cambridge, MA. (Behnisch, Behnisch and Partner, 2003): A 12-storey 32,000m^2 corporate headquarters for a biotechnology company.
- *Alberici Corporate Headquarters,* Overland, MO. (Mackey Mitchell Associates, 2005): A 2-storey, 10,100m^2 corporate headquarters.
- *Banner Bank Building,* Boise, ID. (HDR Inc., 2006): An 11-storey, 17,700m^2 office building.

Japanese 'sustainable' projects:

- *Mabuchi Motor Corporation Headquarters,* Chiba. (Nihon Sekkie Inc., 2004): A 4-storey, 19,200m^2 corporate/administrative headquarters for a major manufacturing company.
- *Takanaka Corporation Headquarters,* Koutou-ku, Tokyo. (Takenaka Corporation, 2005): A 7-storey 29,750m^2 corporate headquarters for a major construction company.
- *The Kansai Electric Head Office,* Osaka. (Nikken Sekkei Ltd., 2005): A 41-storey, 106,500m^2 corporate headquarters for a major utility company.

Interestingly, the strategies evidenced in these six buildings are more similar than different, despite the anticipated generalized cultural differences with respect to technological sophistication alluded to earlier. This, perhaps, is more indicative of the fact that they are all relatively large, high-end projects.

The strategies evidenced in the case-study projects clearly extend beyond those explicit within the respective assessment systems. The three leading-edge North American green buildings:

- consistently provide operable windows as a perceived necessary requirement for occupant satisfaction
- place considerable emphasis on passive and organizational intelligence.

The three leading-edge Japanese green buildings:

- place emphasis on passive and organizational intelligence, but in a strategically different manner than in the North American projects
- consistently use sealed windows/separate perimeter air supply vents for natural ventilation and provide a measure of personal control at the workstation rather than at the building envelope.

DISCUSSION

This article has explored the relationship between 'intelligent' building and 'green' building from the standpoint of both passive and human intelligence and the relative emphasis placed on these in different cultural contexts. Using the characterization of intelligent building provided by Kell (2005), the article illustrates considerable overlap between 'intelligent' and 'green' building strategies.

INTELLIGENCE AND CONTROLS

While recognized as important, the extent that operational intelligence is placed in the hands of occupants in terms of offering personal control over one or more aspects of their immediate environment seems variously and inconsistently applied. The *provision* of operable windows

TABLE 3 Green building strategies emphasized in LEED® and CASBEE case-study buildings

	North American			Japan		
Intelligence	*Banner Bank*	*Genzyme Centre*	*Alberici Corporate Headquarters*	*Mabuchi Motor Corporation HQ*	*Takenaka Corporation HQ*	*Kansai Electric Head Office*
	11-storey, 17,700m^2 office building	12-storey, 32,000m^2 corporate headquarters	2-storey, 10,100m^2 corporate headquarters	4-storey, 19,200m^2 corporate headquarters	7-storey, 29,750m^2 corporate headquarters	41-storey, 106,500m^2 corporate headquarters
Automated	*Systems that improve the management and control of building services, such as HVAC, lighting, energy management, fire security and access control.*					
	• Building-wide lighting control system with automatic power-down function • Extensive building commissioning	• Steam power drives absorption chillers for summer cooling and exchanges for heat during winter • Efficient fans, motors and equipment • Integrated building management system controls 30,000 automation points • Extensive 3rd party building commissioning	• Mixed-mode ventilation • Efficient heating plant, cooling plant and cooling tower • High-efficiency fixtures, ballasts & lamps; dimming controls • Regulation and monitoring of light, variable-frequency drives, and operation of solar hot-water system • Clerestory windows open mechanically • Building commissioning and recommissioning	• Mixed mode ventilation: automated switching from mechanically to naturally conditioned • Ice thermal storage system • Automated lighting control • Automated blind system • Building energy management system • Building commissioning • Passive/active device for earthquake	• Mixed mode ventilation: automated switching from mechanically to naturally conditioned • Ice/water thermal storage system • High efficiency, low temperature water heating & cooling plant • Automated lighting control	• Mixed mode ventilation: automated switching from mechanically to naturally conditioned • District heating & cooling plant using river water as heating source • Low temperature water system to reduce pump & fan power • Automated lighting control with motion & daylighting sensors • Active device for earthquake
Informated	*Integrated, centrally managed information and communications infrastructure and systems that enable buildings to respond/adapt to changing conditions.*					
	• CO_2 monitoring • Room level occupancy monitoring linked to lighting control • Fluorescent fixtures self-adjust to daylight levels	• CO_2 monitoring • Overhead lighting dimmed by photo and occupancy sensors • Temperature and humidity monitoring • Solar-tracking mirrors deliver natural light	• IAQ monitoring, including CO_2 • Occupancy sensors • Tracking/measurement of atmospheric elements, rain, and wind speeds • Ongoing monitoring of energy and water use	• Roof mounted climate monitoring • Temperature and humidity monitoring • CO_2 monitoring • Building energy management system	• Roof mounted climate monitoring • Temperature and humidity monitoring • CO_2 monitoring • Solar-activated/ tracking heliostats enhance natural light in atrium	• Roof mounted climate monitoring • Temperature and humidity monitoring • CO_2 monitoring • Building energy management system

(**TABLE 3** *continued*)

	North American			Japan		
Intelligence	*Banner Bank*	*Genzyme Centre*	*Alberici Corporate Headquarters*	*Mabuchi Motor Corporation HQ*	*Takenaka Corporation HQ*	*Kansai Electric Head Office*
	• Building can globally power down all lights to assist local utility to meet power demands	• Motorized blinds adjust to sun's position, reflecting light into office space • Automated blind system eliminates light pollution at night • Fan coil units automatically shut off when windows or doors are opened for natural ventilation	• Control system interfaces with internal computer network to transfer data for analysis and storage		• Building energy management system • Access to BEMS through LAN for occupants & facilities managers • Displays of building energy use	• Development of 'e-BEMS' to enhance plan-do-check-act (PDCA) cycle
Intelligent space management	*Investing the building with the capability to respond easily and intelligently to rapid changes in the size and structure of organizations and work practices.*					
	• Under-floor air distribution & HVAC system delivers air throughout each office floor • Flexible electricity and telecommunications outlets • Modular wall systems allow tenants to reconfigure work areas	• Extensive shared spaces to facilitate collaboration	• Under-floor air distribution, displacement ventilation • Flexible departmental boundaries permitting changes in staff size and workloads while fostering interaction • Open-plan environment fosters teamwork and collaboration	• Under-floor air distribution • Modular & configurable workstations • Personal ventilation/air-conditioning supply integrated with under-floor air distribution • Open-plan environment fosters communication • Flexible electricity & telecommunications	• Modular workstations • Flexible electricity & telecommunications • Changing from enclosed elevators to open staircases	• Under-floor air distribution • Task air-conditioning with under-floor air distribution and air velocity control • 3-storey void space fosters communication • Flexible electricity & telecommunications

(**TABLE 3** *continued*)

	North American			Japan		
Intelligence	*Banner Bank*	*Genzyme Centre*	*Alberici Corporate Headquarters*	*Mabuchi Motor Corporation HQ*	*Takenaka Corporation HQ*	*Kansai Electric Head Office*
Passive intelligence	*Perceptive design strategies that positively influence building environmental performance thereby reducing or replacing unnecessary active systems.*					
	• Daylighting • Geothermal heat	• High-performance curtain wall glazing system blocks summer sun and captures winter solar gains • Central atrium acts as light shaft and return air duct • Natural light reflected deep into the building • Prismatic skylights • Reflective chandeliers • Rooftop photovoltaic arrays	• Major E-W orientation; south-facing 'saw-tooth' offices receive maximal daylight • An efficient building envelope results in lower energy usage • External sunscreens effectively block unwanted solar gain • Atria increase daylighting and induce ventilation as thermal flues • 65-kW wind turbine • Solar panels are used to preheat hot water	• Major E-W orientation • Daylighting from south and north facade • Central atrium; stack ventilation • Double skin in south facade; stack ventilation • Heating/cooling storage in building structure • Outdoor air cooling • Cool trench in underground pit • Green roof/garden	• Highly insulated envelope • Light court; daylighting • Solar heat collector ducts • Green roof	• Main office spaces face north orientation • Heating/cooling storage on building structure • Natural ventilation • Recessed windows; structural thermal mass
Organizational intelligence	*Strategic management of building services, information services, space management and building structures to more closely integrate organizational need with building capacity and potential.*					
		• 75% of workspaces natural light • 100% of regularly occupied spaces have views to outdoors • Extensive shared spaces to facilitate collaboration	• 90% of building occupants direct views to the outdoors • Open-plan environment fosters teamwork and collaboration • Multiple uses: open office environment, structured parking, training rooms, exercise facilities and dining facilities	• Central light-wells & atrium act as key communication devices	• Light courts act as communication device between worker and outdoors	• 3-storey void space fosters communication

(TABLE 3 *continued*)

Intelligence	North American			Japan		
	Banner Bank	*Genzyme Centre*	*Alberici Corporate Headquarters*	*Mabuchi Motor Corporation HQ*	*Takenaka Corporation HQ*	*Kansai Electric Head Office*
Occupant intelligence	*Explicitly enabling users to make appropriate adjustments in the environmental conditions of their workplace.*					
	• Lighting control from occupants' personal computers • Thermostats in each office • Tenant 'green' guidelines	• Task lights at each workstation • Operable windows • Operable blinds on internal glass walls • Local override of external louvred blinds • Individual temperature control using four-pipe fan coil system	• Task lights at each workstation • Operable windows • Thermal and ventilation, controlled manually through floor registers	• Personal control over ventilation/air-conditioning directly at workstation • Task lighting	• Task lights at each workstation	• Manual perimeter controls solar blinds • Ventilation controlled manually through floor registers • Task lighting

is widely held as a prerequisite for a North American green building irrespective of its type, size or complexity. However, it is less certain whether there is currently a culture of using operable windows as an effective environmental control measure.

The PROBE studies and others are increasingly showing how users engage with building controls and, more significantly, how this differs from current design practices. This represents a critically important issue regarding the ways that operational experience translates into future design knowledge. Hawkes (1996, p18) argues that 'one of the defining characteristics of architecture as a discipline is the complex interrelationship between theory and practice'. In architecture, he further suggests, 'there are circumstances in which practice may be informed by theory, but, equally there are others in which significant developments in the theory of the discipline follow the work of practitioners' (p19). There seems to be an opportunity for the shifting interaction between building users and environmental control systems to provide an informed context for emerging theories of environmental design.

NATURAL AND HUMAN INTELLIGENCE

A transition to an environmentally sustainable future will invariably parallel the rate and extent to which we model all human enterprise – including buildings, infrastructure and settlement patterns – on natural systems and processes (McDonough and Braungart, 2002). The emerging science of 'biomimicry' has already highlighted the potential for nature's wisdom to guide industrial production and for its operational principles to offer a source of both inspiration and direction for building design (Benyus, 2002; Beavan and Vincent, 2004). Ecological approaches are being used to guide the development of a new generation of energy-efficient integrated components of the future intelligent skin (Elkadi, 2000). Similarly, the notion of regenerative design seeks to embody intelligence in buildings by infusing them with the 'natural' ability to respond, adapt and change positively over long life spans.

Sustainability in the context of intelligent buildings is driving a fundamental rethinking of the relationship between human behaviour and needs, and building systems and processes and how they may co-evolve. Himanen (2004) explores the possible links between the 'essence of the intelligent building concepts – building intelligence – forms of human intelligence' and identifies several possible components:

- *building connectivity:* speaking and speech recognition, including music and linguistics; user-connectivity and either personal, organizational or automatic control
- *building self-recognition:* the building knows the state it is in; a kind of consciousness
- *spatiality:* a more conscious understanding of the spatial expression of the architecture structures, interior design
- *building kinaesthetics:* a sense of change, active structures, movable structures, furniture and equipment, adjustable technology or building services
- *building logic:* embedded sensors to monitor the occupant's daily activities, combinativity.

Current research in 'ambient intelligence' strives to augment physical spaces with computation, communication and digital content, to the point of actually transcending the limits of direct human perception (IET, 2007). 'Smart' or 'aware' environments are those which 'acquire and apply knowledge about the environment and its inhabitants in order to improve their experience in that environment' (Cook and Das, 2007). Spaces are embedded with pervasive devices that interact closely with occupants to help them achieve their tasks at hand, while simultaneously learning from their behaviour patterns and needs so that eventually the interaction becomes implicit. In other words, ambient intelligence can be considered a form of natural intelligence, where building environments are modelled off 'natural' human systems and processes.

In the context of furthering the notion of intelligent building, possible directions may emerge from an understanding of *human intelligence* and *nature's intelligence*. Researchers in the future may consider not only adjusting environments to fit individual preferences, but using the environment as 'a mechanism for influencing change in the individual' (Cook and Das, 2007).

COMMUNICATING INTELLIGENCE

Much of the current discussion of intelligence relates to direct, tangible attributes of buildings. David Orr's short essay on 'Architecture as pedagogy' offers clues to the fundamental ways that contemporary buildings communicate environmental responsibility. He suggests that the building in which he teaches communicates nothing whatsoever that reflects its locality, offers no clue about the origins of the materials used to build it, resonates with no part of our biology, evolutionary experience, or aesthetic sensibilities and reflects no understanding of ecology or ecological processes. In sum, he argues that it teaches that 'disconnectedness is normal' (Orr, 1999). This article has argued that from where intelligence is drawn and where intelligence is placed will require redefinition in the future of green buildings. The implication of Orr's position is that the manner in which this intelligence is expressed may be equally important in nurturing a more fundamental shift in building design to address the environmental agenda.

The evolution of information technology over the past two decades has provided building systems with an increasing capability to measure, evaluate, and respond to change. As Kell (2005) argues, the challenge of intelligent buildings is to make the best use of available information, with the understanding that 'which information, what performance, and how value is measured depend upon the viewpoint of the specific advocate'.

CONCLUSION

This article has reviewed key concepts in intelligent building that have evolved over the past 30 years, emphasizing where and how the intelligence is assumed. It has proposed a complementary concept, 'occupant intelligence', wherein the building explicitly enables its users to make appropriate adjustments in their environmental conditions in their workplace. Furthermore, the article raises the notion of competing demands on intelligent buildings, in particular the provision of comfort, health and well-being, while providing and maintaining operational efficiencies in energy use.

The concepts that collectively characterize an intelligent building are related to green buildings and green buildings design, illustrating considerable overlap between these two current trends in design and construction practice. Approaches to intelligent buildings vary considerably, and clearly there is no single correct approach to achieving improved environmental performance. This notion was explored through an examination of how and where intelligence is embedded in North American and Japanese building environmental assessment methods, and in leading-edge buildings within the respective countries. The results suggest that considerably less variation is evidenced in the strategies deployed in green building practices in the case studies than would be anticipated either culturally or from the scope and emphasis of the assessment methods.

Given an evolving context for building design and a broad range of potential stakeholders and interpretations, the relationship between occupant and automated control is a continuing and unfolding process – and one that warrants further exploration.

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