Shades of green technologies: identification of significant parameters affecting the performance of green technologies in buildings

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Abstract: This study developed essential parameters to be employed as tools for supporting decisions regarding the implementation of green technologies (GT) in buildings. This was done by identifying the most significant parameters that affect the performance of GT in buildings, primarily from the perspective of facility managers as well as the present and future facility users, public and the environment. They include cost, user needs, simplicity, integration and availability of service and maintenance. These parameters were further mapped into measurable equivalents that may prove useful in the development of a model for performance indexing of GT. The developed model may further be used to predict the resulting grades or 'shades of green technologies' (SGT). The specific objective of the present paper is to present the most important benefits to people and the environment following the application of GT. One may argue that not only 'green' but any building technology should satisfy some basic qualitative and quantitative criteria in order to be considered viable for a building construction project. The phrase 'shades of green technologies' is offered here to reflect the potential for 'scaling' or grading of 'green' in building construction projects.

Keywords: green technologies; GT; environmental policy; renewable technologies; building performance; energy saving; optimisation; technology integration.

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1 Introduction

"Man makes tools because he is rational" – Hegel

Buildings are dynamic and complex entities with specific needs similar to those of the living organisms that they usually house (Makarechi, 2006). Green technologies (GT) are defined as those practices that focus on sustainable as well as environmentally responsible construction technologies. They are intended to improve both the sustainability and the environmental performance aspects with a promise of an overall improvement to the building's performance in areas such as energy consumption and operation cost. It is assumed that any improvement to the performance of a building tends not to compromise a comfortable, healthy and suitable environment for its occupants. The issues of health and comfort are sometimes addressed by the implementation of automatic monitoring and control systems that will monitor the vital signs of a building and will feedback a measure of vital signs to a logic system. The logic system compares the received information with the desired levels or 'set points' commonly defined by the users and will adjust the performance levels accordingly. It is therefore important to consider the role and to emphasise the existence of such control measures in all building technologies while including them as much as possible in the use of GT.

Current energy codes, standards and practices such as ASHRAE 90.1 (2004), Energy-Star (2005) and LEED that stands for leadership in energy and environmental design certification (US Green Building Council, 2005) are methods designed to provide generic instructions or prescriptions that are usually tailored into proper steps for improvement of each specific construction project's performance. The idea is to measure the performance of vital systems and compare them with pre-determined recommended ranges in order to initiate improvements, measure the impact of the employed improvements and apply corrections as needed. The specified targets for buildings are sometimes called the prescribed minimum acceptable standards or code levels. Some target levels of GT have been introduced by the building industry as voluntary enhancements towards sustainable practice. The LEED certification is one of the most popular programs in the USA to the extent that it has the reputation of the measure of good practice for construction. For example a 'silver' certified building by LEED may be desired by an owner who wants to reflect his relatively high level of commitment to the environment and desires to be known as a responsible construction practitioner in the public eye. It is quite likely that such owner would not specify the details of how the silver rating should be achieved in order to provide a certain level of freedom to the designers and constructors. Typical owners would not dictate the steps and sequences that need to be followed by the constructors to accomplish this task. Examples include increasing the insulation of building skin, reducing wasteful levels of lighting and improving air conditioning and heating system efficiencies. These actions will increase the LEED rating and they are all interactive because each has certain impacts on others. For example, reduction of lighting will reduce the building cooling needs while increasing its mechanical heating requirements. It is evident that these steps are part of a complex system and it is extremely difficult to quantify the impact of their interactions. It is also well established that the outcome of different steps are not additive and the product of sum is smaller than the sum of products of individual steps (ASHRAE, 2005). This leads us to state that similar LEED ratings for identical buildings may result in different building performances based on how the ratings were accumulated and accomplished.

Life cycle cost analysis incorporates unique circumstances of each project and it is possible that after accumulation of a certain number of LEED points, any additional increase in the amount of 'greening' will no longer prove cost effective or offer significant improvements to the building's overall performance.

Given the focus of this study which has been the ultimate performance of buildings, it is worth noting that a performance-based approach to building construction has been favoured by some construction delivery methods. Turn key or design-build approach may have advantages over design-bid-build in certain cases. Many such cases have been documented in academic research (Kashiwagi, 2005). Kashiwagi (2005) has recorded evidence of superior performance on several case studies where the contractors had been chosen based on their past performance and not on their prices alone. It has been shown that specified minimum levels of performance by the designers and owners in a competitive bidding environment will automatically set the maximum performance expectation for the selected constructors and the resulting level of performance may not always provide the best outcome that an owner can obtain at a similar cost (Makarechi, 2005a).

Satisfying the client's requirements such as obtaining LEED's silver rating without detailed instructions or specifications on how to accomplish such desired results will sometimes promote creativity and a determination by the contractors to push beyond and above the limits dictated by the codes and standards. On the other hand, creativity of poor performers can be quite detrimental to the final building's performance. The question before us is to identify the most significant factors that should be monitored in order to ensure the desired outcome of a given task or project. This is a valid question for all building systems and for the implementation of all building technologies, despite the focus of this paper which is on GT.

The currently available analytical tools for building performance require detailed and cumbersome numerical simulations while offering few scientific or practical solutions for evaluating the ultimate building systems' performances (Makarechi, 2005a). Whenever building modelling tools such as Energy Plus (Crawley et al., 2001), Power DOE (Hirsch, 1998) or eQuest (DOE, 2005) are employed to assess energy or operating cost performance, choices for GT may be selected as a set of options chosen from a menu of possibilities. One common misconception is that green practices always provide a better, if not optimum, performance when chosen for a project. Another misconception is the correlation between the level of a building's built-in intelligence and its performance. Here is a definition of building intelligence based on information from a presentation sponsored by the Continental Automated Buildings Association (CABA) notes (Katz, 2005):

> "Intelligent Building is a building which has the inherent ability, through the design of its infrastructure and systems, to respond to the changing needs of its tenants/occupants and building owner/investor group quickly, safely and cost effectively."

The above definition needs to be expanded to include the natural environment and the public outside of the conventional 'tenants/occupants' of a project. Two years later, Katz (2007) showed the very important link between the building's intelligence and the controls needed to meet the intent and requirements of LEED. However, although it may have been implied, these studies failed to conclude that unconstrained improvements to the building's intelligence and controls or greening do not necessarily continue to improve its performance.

2 Problem statement

Buildings are major energy consumers and imposers of environmental impacts in a world that is currently facing energy and environmental crisis. The implementation of GT is expected to result in more effective and efficient building operations; effective in terms of providing more comfortable and productive environments and efficient in terms of energy use, environmental impact and cost of operations. The question to ponder is: 'What are the parameters or indicators that can be employed to make informed decisions about the implementation of such building technologies as GT?'.

Facility managers, owners and tenants acknowledge the benefits of implementing GT and their long-term global effects. However, they cannot ignore the constant need to reduce the costs associated with operating their buildings, hence, the performance aspects of any implemented technology will be critical in their decision making strategies. Commercial facility managers, in particular, should be motivated to incorporate additional levels of GT in order to increase the appeal of their buildings to today's more sophisticated tenants as well as the general public as they compete for efficiency as well as attracting future tenants while they are aiming for optimum operating costs. Many governmental projects mandate a minimum level of greening. The challenge facing the project designers is the absence of essential and established tools for predicting the performance aspects of green building technologies. This paper makes an attempt towards answering this need.

As an example, one designer may suggest that spaces on the same floor and exposure of a commercial office building should share thermostats in order to save on the initial and maintenance costs of control systems. It is an established fact that adding more thermostats requires additional controls and will increase the cost of environmental systems. On the other hand, operating a heating, ventilation and air conditioning (HVAC) system for a large number of rooms from a combined thermostat may not be an energy-efficient solution because of the varied occupancy and use in different rooms. Some of the rooms that are thermally identical may or may not even be occupied at the same time. One can ask if an unoccupied space needs to be heated or cooled at all. However, there is no established protocol for identifying how many thermostats, sensors or monitors would provide the best performance for a given project. Therefore, we face the question of how to predict and quantify a building's overall performance in relationship with the decisions regarding the extent of its use of GT.

3 Literature review

As noted in the above problem statement, the building performance resulting from the implementation of GT can be the basis for selecting to incorporate such technologies. GT may include the responsible practices of using clean (non-fossil fuel) energies which reduce the negative health and environmental impacts. The use of active and passive methods to harness wind, water and solar energies are examples of renewable GT (RGT). Katz (2007) presented a direct relationship between GT and building automation systems (BAS). This route is explored for identification of the significant parameters that apply to GT because of the existence of a rich body of research for identification of significant building automation parameters that affect the building performance.

Katzel (1998) defined BAS as a "collection of equipment from sensor to software, blended together to achieve a seamless flow of data and control actions." Specific components may include end devices, controllers and networks from which data are transferred and an information path to front-end operator interfaces. The system installed in a new construction often receives only cursory attention due to the overwhelming volume of tasks required at start-up. Although every BAS is capable of help in intelligent decision making, significant savings may be lost unless appropriate collection mechanisms are established to gather data and sufficient time is spent to analyse them.

Katzel (1998) also promoted systems integration and flexibility and advised plant engineers and facility managers to audit facility performance, establish data collection mechanisms and analyse reports. He also promoted a standard protocol that allows a BAS to exchange information simply and economically, avoiding complicated proprietary or third-party gateways.

While promoting flexibility and simplicity, Prasad (1998) discussed controlled and regulated automation that will ultimately lead to inter-operability and higher productivity at lower cost. In the context of human-machine systems, Wei et al. (1998) demonstrated that high levels of automation may have adverse effects and do not necessarily result in increased benefits. He quantified the level of automation by the ratio of existing automation at a given time to full automation.

Similarly, in a study of human factors and cognitive neuroscience, Parasuraman (2000) investigated the influence of automation and computer technology on attention, memory and vigilance of human operators and concluded that too much automation will produce detrimental effects. Similar results have been reported by Lee and See (2004).

Heath (2001) documented benefits of two-way communications for monitoring and control using the internet. He highlighted integration of HVAC with lighting, security and building management systems.

Johnson (2001) focused on the networking and integration of building systems and specifically, on the application of wireless technology in building security controls.

CABA (2002), a professional organisation dedicated to BAS issues and initiatives, started efforts in the early 2000 to promote the development of building intelligence quotient (BIQ). Intelligent buildings are those equipped with BAS and the higher the level of automation, the more intelligence is associated with the building.

Hirsch (1998) developed simulation algorithms for integrated building systems and Rogers (2004) proposed control architecture with a focus on the building as a power plant and its energy use. Bowen (2005) discussed expected energy savings by the incorporation of simulation techniques in intelligent buildings among the efforts to make buildings more manageable. He affirmed that building monitoring and control schemes that include HVAC, power production, lighting, elevators, safety and security can be complex and should involve computer simulations associated with building control systems that are updated by sensor feedback and performance data. Sensors are commonly used to monitor parameters by mechanical, magnetic, electromagnetic, thermal, optical, chemical, biological, or acoustic means. The assembly of sensors employed in intelligent buildings is increasingly accessed via wireless networks. Bowen (2005) expressed concerns about the deployment of an excessive number of sensors and collection of too much data rather than narrowing in on key performance measures. She is also quoted saying “I honestly think the idea of having everything networked together misses the point” and “you can do a hell of a lot with a few discrete things” (Bowen, 2005).

Wei et al. (1998) noted that building environments represent some of the most difficult problems in fluid dynamics. He also stated that “there’s a concern that the technology is coming in before we have the sophistication to know how best to deploy it”.

Research by Hansen (2005) focused on building systems and divided it into four areas of applications, hardware, communications and oversight. His work promoted automated commissioning and diagnostic technologies for building systems and equipment to help improve building operation by automatically and continuously detecting performance problems and maintenance requirements and bringing them to the attention of building operators.

Sinclair (2005) declared that a renaissance type revival is happening in the world of building systems interconnectivity and Zimmer (2005) highlighted the evolution and convergence of communication life safety automation (CLA).

Bashi (2006) explained simple fuzzy logic modelling for BAS while Ehrlich (2006) discussed intelligent building construction and operation issues including building management tools and tenant portals and Hartman (2006) illustrated the potential energy savings of a network-integrated system.

Makarechi (2005b) conducted a survey of 29 experts with industrial and academic backgrounds, each one with over 15 years of combined experience in building systems, building controls, facility commissioning and facility operations. This research was based on independent survey of a group of 13 experts in phase 1 (Makarechi, 2005b) and continued with seven members of the first group in phase 2 (Makarechi, 2006). The survey identified significant parameters that affect building performance in selected building control technologies.

4 Assumptions

The following assumptions will help this research by concentrating on GT performance aspects rather than design issues and by simplifying the quantification of complex parameters such as user needs. The selected terminology is in agreement with those recommended by ASHRAE (2005):

1. All building equipment and controls are properly sized, commissioned and calibrated and all devices and components are properly selected for their applications. Furthermore, all building systems and associated devices are assumed to meet the needs and limitations of application for which they are used.
2. Growth in user needs will prompt proportional expansion of building systems, which means an increase in the number of control points.
3. All building technologies including GT are provided with the required controls within cost effective norms in building construction.

5 Economics

Facility owners, engineers and managers are training their staff for the evolution of building technologies and systems towards internet-based systems (Allen, 2003). Economical analysis of alternative networking methods has been done to show viability of a global approach to building systems (Avaya, 2003). The concept of real-time building management services or global optimisation systems was implemented by Cumali and Sezgen (1979) and further discussed by Makarechi (2005a). Cumali and Sezgen (1979) installed sensors in PG&E office buildings in downtown San Francisco and used a central personal computer to collect and analyse the data gathered from various buildings' systems such as HVAC, lighting and security. The experimental set-up was also capable of connecting with national weather service forecast office of the SF Bay Area by modem. This assembly provided a feed-forward positioning for pumps, fans, air and water systems serving the buildings for smooth and energy efficient operation that met the building demands with minimum overshooting and waste. Today, building systems can integrate and operate multiple projects via the internet while providing remote monitoring, updating and manipulation of their operations.

It has been demonstrated through 40-year life cycle cost studies by Katz (2005) that building operating costs account for about 50% of its total lifetime costs. Improving the performance of building technologies and systems is expected to lower building operating costs.

6 Methodology: identification of significant parameters

As noted in the background studies, Katz (2007) indicated that GT and BAS technologies are governed by similar decision support parameters. Makarechi (2005b and 2006) utilised a Delphi style survey of industry experts (Linstone and Turoff, 2002) and identified the following basic list of significant aspects that affect the performance of BAS:

1. maintenance cost
2. integration of systems capabilities
3. simplicity of systems operation and training
4. accuracy of sensors and operation of actuators in control systems
5. flexibility
6. alarms and warning devices
7. occupant comfort levels
8. local service and maintenance capability and availability
9. ease of data gathering
10. first cost
11. reliability
12. on-demand service response
13. system self-learning capabilities
14. automated systems upgrade capabilities
15. life-cycle assessment (LCA)
16. waiting time for parts.

A review of the above list reveals that a different classification may be possible by placing several items in one group, as follows:

1. items 1, 10 and 15 as part of ‘cost’
2. items 4, 5, 6, 7 and 11 as part of ‘user needs’
3. items 3 and 9 as part of ‘simplicity’
4. items 2 and 13 as part of ‘integration’
5. items 8, 12, 14 and 16 as part of ‘availability of service and maintenance’.

Consequently, the following, much smaller list is generated:

- cost [life cycle cost (LCC)]
- user needs
- simplicity (of learning and operating)

- integration (or the level of openness to share information with other systems)
- availability (of service maintenance for technologies used in the building).

It is not surprising that each of the identified parameters is a complex indicator that encompasses several items. For example, the parameter labelled 'cost' includes the initial cost of GT systems, the maintenance and operating cost as well as periodical replacement and upgrading costs. For a given period and financing interest rates, the total net present value of the above costs will represent the GT's LCC. This cost, normalised for a representative unit of area such as 100 square meters of a typical office building, may be used as the parameter labelled 'cost'.

The second parameter represents a classification labelled 'user needs' which includes items such as accuracy, flexibility, alarms, comfort and reliability. Each one of these items in turn represents a complex aspect of the GT performance. User needs should also be normalised and represented by a quantifiable representative variable.

The third parameter is labelled 'simplicity' and represents categories such as operational ease and training requirements as well as the ease of data gathering. It should be noted that even the appearance of complexity of technologies can be detrimental to their implementation. Currently, much of the building potentials remain underutilised due to the shortage of trained and experienced specialists and the required funding.

The fourth parameter covers issues related to 'integration' which signifies the number of systems that share data for their operation. This parameter is also a measure of interconnectivity of building systems to improve their co-operations.

The fifth parameter deals with 'availability of service and maintenance' covering items such as the availability of repair service and replacement parts and possibility of on-demand services. It addresses issues such as the desire for minimising the downtime of building facilities.

For the five significant parameters of cost (C), user needs (U), simplicity (S), integration (I) and availability (A) of service and maintenance, the challenge is related to their quantification. All parameters, except the 'user needs' and 'simplicity', are easily quantifiable and they are normalised based on the unit area of typical construction projects. For 'user needs' and 'simplicity', representative quantifiable parameters should be defined. Assuming that the more incorporated are the user needs, the more complex will be the building systems, the number of potential GT measures for a project or 'P' may replace both 'U' and 'S' because more needs by the users will require more measures, thus making the system more complex.

'Availability of service and maintenance' (A) may be represented by the number of available vendors that provide timely services to the incorporated systems and it is readily quantifiable. In the case of a proprietary building system, 'A' will be low (1) meaning that only a specific manufacturer and its authorised service vendors may provide products and services, while in the case of systems with multiple vendors available to interchange parts using a common communication protocols, 'A' can be higher. The number of available vendors for some projects may be as high as ten in the vicinity of the project location, thus creating a competitive environment which will lead to a reduction in cost and the required service time, while improving the quality of the provided services. Therefore, the expected GT performance is directly proportional to the value of 'A'.

The parameter identified as the level of 'integration' (I) indicates the number of building systems that communicate with each other by sharing information. In the case of integration of HVAC and lighting, 'I' may be designated as the number two which may increase to three if security system is also integrated with HVAC and lighting.

The general form of the model for shades of green technology or SGT may therefore be expressed as a function of the significant parameters defined as follows:

SGT = function of (C, U, S, I, A)

where:

SGT an index with a positive value with an upper and lower limit as a function of C, U, S, I and A.

C cost

U user needs

S simplicity

I integration

A availability of service and maintenance.

C, U, S, I and A are non-zero positive integers, each with a minimum value of one.

7 Evaluation of significant parameters

7.1 Cost (C)

All aspects of 'cost' including initial cost, operating cost, life cycle cost and replacement cost may be represented with this parameter. It should be noted that for the purpose of modelling and in order to have a manageable working range, cost per unit area (square meter) or $\$/m^2$ may represent this parameter in the modelling. For the purpose of cost modelling in a scale of 1 through 5, 1 shall represent a low-unit cost (for example $\$2/m^2$) and 5 shall represent a high-unit cost (for example $\$5/m^2$).

7.2 User needs (U)

'User needs' define the requirements for human comfort as well as the needs of a process like manufacturing, special archives and computer rooms. The criteria for the storage environment of products and preservation of life and certain data processing facilities or manufacturing environments are also represented by U. According to the expert survey (Makarechi, 2006) this parameter may be measured by the historical number of annual complaints per unit area for similar projects. For the purpose of modelling in a scale of 1 through 5, 1 may represent low satisfaction of user needs (for example, 10 annual complaints/m^2) and 5 shall represent high satisfaction of user needs (for example, 1 annual complaint/m^2).

7.3 Simplicity (S)

The experts surveyed by Makarechi (2006) provided a consensus that the annual number of hours of BAS training of the facility management personnel is a suitable indicator of the measure of simplicity. For the purpose of modelling in a scale of 1 through 5, 1 may represent a low level of simplicity (for example, 10 annual training man-hours/m^2) and 5 shall represent a high level of simplicity (for example, 1 annual training man-hour/m^2).

7.4 Integration (I)

The number of building technologies that share information to trigger a central controlling decision and to coordinate their operation is measured by 'I'. As explained before, the level of integration in a scale of 1 through 5 used for the purpose of modelling may be as low as one or as high as the number of systems that share common communication protocols and signals for coordinating their status for monitoring and control of their operations and services. The survey by Makarechi (2006) revealed that three, representing HVAC, lighting and security, would be a suitable average and five will represent a high level of integration of building technologies.

7.5 Availability of service and maintenance (A)

The specifications of construction industry demand a minimum of three suppliers for products and services. The automation industry, however, has been traditionally a closed environment in the sense that once the products of a specific manufacturer were selected for a project, other vendors would not be able to provide parts or services to that project without imposing major changes on the system. This exclusive right would create an environment without competition, causing unnecessary inflations to both the cost and time of services. In order to correct this situation, some clients freeze the unit prices for a specified period during the bid process.

According to the present study, the overall performance of a GT system would significantly improve if the number of vendors that are allowed to service the system is increased. For the purpose of modelling in a scale of 1 through 5, 1 shall represent a low level of service availability (for example, one service vendor for the GT project) and 5 may represent a high level of service and maintenance availability.

As discussed, all five significant parameters may be defined by a positive scale of 1 through 5. Having identified the controlling parameters, the next step will be to define a model to evaluate a building's GT performance as parts of the objectives of future research.

8 Conclusions

The primary contribution of this paper is the identification of a set of parameters rendered significant to the performance of GT. The quantification of the level of GT's performance in a building (SGT) will be through defining linear or nonlinear models built on these significant parameters.

Five significant parameters were identified in this study as the major contributors to the evaluation of the GT performance in buildings. They include: cost, user needs, simplicity, integration, and availability of service and maintenance. The results suggest that quantitative models may be developed based on the identified parameters to evaluate a building's GT performance or SGT in buildings as discussed in the 'evaluation of significant parameters' section.

Future studies are predicted to investigate various modelling techniques for linear or non-linear relationships between the identified parameters, leading to the development of models that can estimate the performance expectations of the applied GT.

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