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Sustainable Development of Buildings and Environment

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Abstract

One of the current challenges is how to develop smart and sustainable buildings, so they use a minimum of nonrenewable energy, produce a minimum of pollution, and a minimum cost of energy, while increasing the comfort, health, and safety of the people who live and work in them. This paper introduces an integrated approach to achieve a successful sustainable development of buildings and environment. The integrated design approach includes sustainable site design, building design including passive solar design (day lighting, building envelope, and renewable energy), building systems and indoor environmental quality, materials and specifications, construction process, and building operations and maintenance. This integrated approach can benefit designers, builders, building owner, planning authorities. National and local programs should encourage sustainable development of buildings and environment by applying this integrated approach in demonstration buildings across the country in order to provide tangible examples of what sustainable development of buildings can accomplish in terms of comfort, aesthetics, energy and resource efficiency.

1. Introduction

As the world's population continues to expand, implementation of resource-efficient measures in all areas of human activity is imperative. The built environment is one clear example of the impact of human activity on resources. Buildings have a significant impact on the environment, accounting for one-sixth of the world's freshwater withdrawals, one-quarter of its wood harvest, and two-fifths of its material and energy flows (Rodman and Lenssen, 1995).

Sustainable development is the challenge of meeting growing human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and natural resources for future life and development. This concept recognizes that meeting long-term human needs will be impossible unless the earth's natural physical, chemical, and biological systems are conserved (US GB, 1996). Sustainable development is a strategy through which communities seek economic development approaches that also benefit the local environment and quality of life. Sustainable development allows economic progress and environmental quality to be compatible goals. Sustainable development strategies save money, improve the profits of local businesses, and make the community much more livable.

Currently, buildings are a major source of the pollution that causes urban air quality problems, and the pollutants that contribute to climate change. They account for 49 percent of sulfur dioxide emissions, 25 percent of nitrous oxide emissions, and 10 percent of particulate emissions, all of which damage urban air

quality. Buildings produce 35 percent of carbon dioxide emissions (US GB, 1996). Traditional building practices often overlook the interrelationships between a building, its components, its surroundings, and its occupants. Typical buildings consume more of natural resources than necessary, negatively impact the environment, and generate a large amount of waste. There are many opportunities to make buildings cleaner. Sustainable building practices offer an opportunity to create environmentally-sound and resource-efficient buildings by using an integrated approach to design. Sustainable buildings promote resource conservation, including energy efficiency, renewable energy, and water conservation features; consider environmental impacts and waste minimization; create a healthy and comfortable environment; reduce operation and maintenance costs; and address issues such as historical preservation, access to public transportation and other community infrastructure systems. The entire life cycle of the building and its components is considered, as well as the economic and environmental impact and performance.

2. Sustainable development of buildings

Sustainable development of buildings requires a change in the way the building industry and building owners approach the design, construction, and operation of structures. This leads public and private sectors of the building industry towards a new value in its work; that is environmental performance. The industry's growing sustainability ethic is based on the principles of resource efficiency, health, and productivity. Successful sustainable design requires an integrated approach as shown in Figure 1. Realization of these principles involves an integrated, multidisciplinary approach; one in which a building project and its components are viewed on a full life-cycle basis. This "cradle-to-cradle" approach, known as "green" or "sustainable" building, considers a building's total economic and environmental impact and performance, from material extraction and product manufacture to product transportation, building design and construction, operations and maintenance, and building reuse or disposal. This paper focuses on introducing guidelines for site design and building design that might help in achieving sustainable development of buildings and environment. Ultimately, adoption of sustainable building practices will lead to a shift in the building industry, with sustainability thoroughly embedded in its practice, products, standards, codes, and regulations.

An environmentally responsive design process adds the elements of integrated building design, design and construction team collaboration, and the development of environmental design guidelines. These new elements should be incorporated into the project from the very beginning and carried throughout the project phases to the final occupancy of the building. Conventional buildings often fail to consider the interrelationships among building site, design elements, energy and resource constraints, building systems, and building function. Sustainable buildings, through an integrated design approach, take into consideration the effect these factors have on one another. Climate and building orientation, design factors such as day-lighting opportunities, building envelope and system choices, as well as economic guidelines and occupant activities, are all factors that need to be considered in an integrated approach.

Sustainable building systems and operational practices are dependent on building site, solar access and light penetration, architectural design, and product specification. Sustainable buildings should take all of these factors into consideration on an integrated basis. This is a circular and multi-dimensional approach. Sustainable development concepts (applied to the design, construction, and operation of buildings), can enhance both the economic well-being and environmental health of communities around the world. A building's life spans its planning; its design, construction and operation; and its ultimate reuse or demolition. Often, the entity responsible for design, construction, and initial financing of a building is different from those operating the building, meeting its operational expenses, and paying employees' salaries and benefits. However, the decisions made at the first phase of building design and construction can significantly affect the costs and efficiencies of later phases.

Studies have shown that sustainable building measures taken during construction or renovation can result in significant building operational savings, as well as increases in employee productivity. Therefore, building related costs are best revealed and understood when they are analyzed over the life span of a building. Life-cycle cost analysis (an increasingly accepted analytical method that calculates costs over the "useful" or anticipated life of an asset), reveals that low up-front expenditures, though easier to finance at building inception, can result in much higher costs over the life of a building or system. Choosing space-

conditioning systems with the lowest first cost, for example, may prove to be a poor life-cycle decision, when energy operation costs over the useful years of the systems are factored into the analysis (Gottfried, 1996).

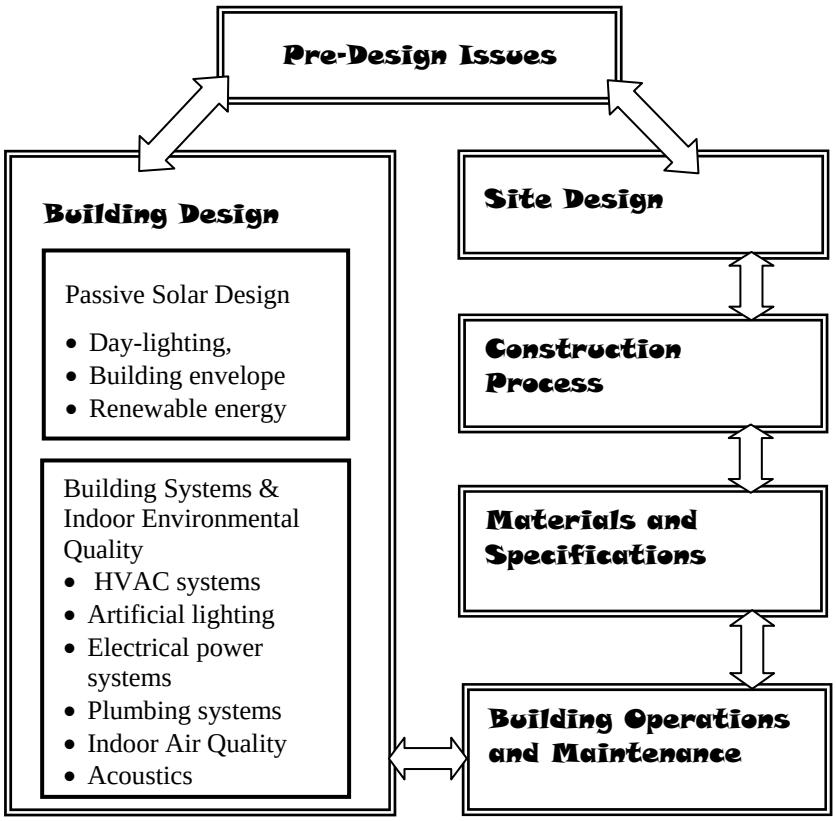

Figure 1. An integrated approach for achieving a sustainable development of buildings.

3. Sustainable Site Design

Sustainable site planning and design do not impose building design on the site. Rather, they identify the ecological characteristics of the site, determine whether it is appropriate for its proposed use, and design ways to integrate the building with the site. The intent is to lessen the environmental impact of human activity, while using natural characteristics of the site to enhance human comfort and health, and potentially provide a significant portion of the building's energy requirement. Preservation of site resources and conservation of energy and materials in construction and building operations are important results of good site design.

Site planning assesses a particular landscape to determine its appropriate use, then maps the areas most suitable for accommodating specific activities associated with that use. The process is based upon the premise that any landscape setting can be analyzed and studied as a series of interconnected geological, hydrological, topographic, ecological, climatological, and cultural features and systems. An ideal site plan is one in which the arrangement of roads, buildings, and associated uses is developed using site data and information from the larger macro-environment, including existing historical and cultural patterns of the community. Selecting a building site begins the process of calculating the degree of resource use and the degree of disturbance of existing natural systems that will be required to support a building's development. The most environmentally sound development is one that disturbs as little of the existing site as possible. Therefore, sites suitable for commercial building should ideally be located within or adjacent to existing commercial environments. Building projects also require connections to mass transit, vehicular infrastructure,

and utility and telecommunication networks. Sound site planning and building design should consider locating building-support services in common corridors, or building site to take advantage of existing service networks. This consolidation can minimize site disruption and facilitate building repair and inspection. Some of the guidelines that can assist in achieving sustainable site design are introduced in Table 1.

Table 1. Some guidelines that can assist in achieving sustainable site design.

Infrastructure	**Utility Corridors**	• Minimize road length, building footprint, and the actual ground area required for intended improvements. • Avoid pumped sewer systems because of ongoing power consumption. • Aggregate utility corridors when feasible. • Where possible, common site utility corridors should be consolidated along previously disturbed areas or along new road or walk construction, both to minimize unnecessary clearing and trenching and to ensure ease of access for ongoing repairs.
	Transportation	• Use existing vehicular transportation networks to minimize the need for new infrastructure. • Consider increased use of telecommuting strategies. • Telecommuting and teleconferencing can reduce commute. • Plan for adequate telecommunications infrastructure and access in building design. • Consolidate service, pedestrian, and automobile paths. • To minimize pavement costs, improve efficiency, and centralize runoff, the pattern of roads, walkways, and parking should be compact.
	Building and Site Orientation	• Orient building to take advantage of solar energy for passive and active solar systems. • If solar collectors systems are proposed, orientation should allow maximum access to sunlight. • Landscaped areas, open spaces, and parking should be aggregated to provide the least solar shadow for southern orientations of the building project and adjoining buildings. • Provide a building-entrance orientation that maximizes safety and ease of access.
	Landscaping	• Vegetation can be used to provide shade, transpiration and wind protection. • Design access roads, landscaping, and ancillary structures to channel wind toward main buildings for cooling, or away from them to reduce heat loss. • Modulation of tree-canopy heights and inclusion of water fountains and other built structures can fine-tune an exterior site by accelerating or decelerating site winds.

4. Sustainability of Building Design

The integrated approach introduced in this paper considers a building as a complete system, with the building site, form, envelope, systems, and contents simultaneously interacting together and fitting their setting in nature. The resulting building will perform as a resource-efficient and cost-effective system designed to enhance occupants' productivity and health. Sustainability of building design includes passive solar design and building systems and indoor air quality as detailed in the following sub-sections.

4.1 Passive Solar Design

Passive solar design is a broad term used to encompass a wide range of strategies and options resulting in

energy-efficient building design and increased occupant comfort. The concept emphasizes architectural design approaches that minimize building energy consumption by integrating conventional energy-efficient devices, such as mechanical and electrical pumps, fans, lighting fixtures, and other equipment, with passive design elements, such as an efficient envelope, appropriate amounts of fenestration, increased day-lighting design, and thermal mass. Many passive buildings are compatible with active components such as solar hot water systems. Passive solar design balances all aspects of the energy use in a building: lighting, cooling, heating, and ventilation. It achieves this by combining, in a single concept, the use of renewable resources and conventional, energy-efficient strategies. The basic idea of passive solar design is to allow daylight, heat, and airflow into a building only when beneficial. The objectives are to control the entrance of sunlight and air flows into the building at appropriate times and to store and distribute the heat and cool air so it is available when needed. Many passive solar design options can be achieved at little or no additional cost. Others are economically viable over a building's life-cycle (PSIC & NREL, 1996).

Passive building design starts with consideration of building site and day-lighting opportunities and the building envelope; then building systems are considered. Almost every element of a passive solar design serves more than one purpose. Landscaping can be aesthetic while also providing critical shading or direct air flow. Window shades are both a shading device and part of the interior design scheme. Masonry floors store heat and also provide a durable walking surface. Sunlight bounced around a room provides a bright space and task light. Critical design areas of passive solar design include the following:

- Thermal protection provides appropriate levels of insulation and minimal air leakage.
- Windows transmit heat, light, and air between interior space and the outside environment.
- Day-lighting reduces lighting, cooling energy use and creates a better working environment, leading to increased comfort and productivity.
- Passive solar heating allows heat to enter the building during the winter months and rejects it during the summer months through the use of appropriate amount and type of south-facing glazing and properly designed shading devices.
- Energy-efficient lighting utilizes efficient lamps, ballasts, controls, and luminaries coordinated with daylight and color of interior space to provide the requisite level of light.
- Internal heat-gain control minimizes heat gain generated by lights, people, and equipment through the use of day-lighting, thermal mass, efficient equipment selection, and venting.
- Passive cooling with natural ventilation incorporates controlled air exchanges through natural or mechanical means, and helps to increase energy performance of buildings in most locations.
- Energy-efficient HVAC system reduces system load by integrating above-listed design strategies and using measures such as efficient motors, heat pumps, variable speed drives, and sophisticated building controls.

4.1.1 Day-lighting

Day-lighting is the practice of bringing light into a building interior and distributing it in a way that provides more desirable and better-quality illumination than artificial light sources. This reduces the need for electrical light sources, thus cutting down on electricity use and its associated costs and pollution. Studies substantiate that day-lighting creates healthier and more stimulating work environments than artificial lighting systems and can increase productivity. Day-lighting significantly reduces energy consumption and operating costs. Energy used for lighting in buildings can account for 40 to 50 percent of total energy consumption. Properly designed and implemented day-lighting strategies can save 50 to 80 percent of lighting energy. Some of the general day-lighting principles that can help in achieving sustainability include (Abraham, 1996):

- Avoid direct sunlight on critical tasks and excessive brightness.
  When a critical task is performed in direct sunlight, the light can cause unacceptable contrast ratios, disability glare, or veiled reflection. In this situation, the work surface or computer screen reflects the light source so that it is difficult to see the intended task. The recommended maximum background-to-task ratio is 10 to one; the recommended maximum light source-to-background ratio is 40 to one.

- Bring the daylight in at a high location.
  The four basic types of daylight apertures are windows, skylights, roof monitors, and clerestories as shown in Figure 2. Skylights, roof monitors, and clerestories tend to be more effective than windows because their high location in a building affords penetration of light into the building core. Windows, unless fitted with light shelves or Venetian blinds, can sometimes cause unacceptable brightness levels and excessive contrast ratios of background to foreground, thereby creating visual problems.

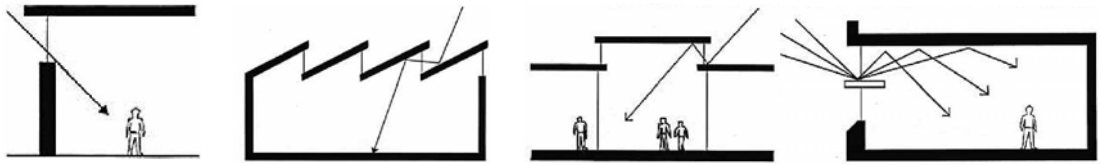

Figure 2. Effective types of daylight apertures.

- Filter the daylight.
  Trees, plants, draperies, screens, translucent shades, and light-scattering glazing diffuse and distribute light while reducing its intensity.

- Bounce daylight off of surrounding surfaces.
  Light shelves, louvers, blinds, and vertical baffles reflect and distribute light throughout a building interior. In general, the larger and softer the light source, the better the visual quality, the less the resulting eye strain, and the easier it is to function and perform a given task. When the light is non-directional (reflected from countless surfaces) shadows are avoided or eliminated and visual quality is improved.

- Integrate daylight with other building systems and strategies.
  The most effective day-lighting solutions work in concert with and not against other building systems or design strategies, for example, HVAC systems, including natural ventilation, passive solar heating and cooling, acoustic control systems, electrical lighting systems incorporating occupancy sensors, photocells and dimmable electronic ballasts, and building energy management systems

4.1.2 Building Envelope

The building envelope consists of structural materials and finishes that enclose space, separating inside from outside. This includes walls, windows, doors, roofs, and floor surfaces. The envelope must balance requirements for ventilation and daylight while providing thermal and moisture protection appropriate to the climatic conditions of the site. Envelope design is a major factor in determining the amount of energy a building will use in its operation. The overall environmental life-cycle impacts and energy costs associated with the production and transportation of different envelope materials vary greatly (Burke, 1996). Some guidelines that may help in achieving sustainable building envelope are shown in Table 2.

4.1.3 Renewable Energy

Integration of passive solar heating, cooling, and thermal storage features, along with day-lighting, into a building can yield considerable energy benefits and added occupant comfort. Incorporation of these items into the building design can lead to substantial reduction in the load requirements for building heating and cooling mechanical systems. The passive solar measures and mechanical systems need to be evaluated on an interactive basis during the design process, since an increase in one can lead to a decrease in the other. Thermal mass in a passive solar building is intended to meet two needs. It should be designed to quickly absorb solar heat for use over the diurnal cycle and to avoid overheating. Active solar collector systems take

advantage of the sun to provide energy for domestic water heating, pool heating, ventilation air preheat, and space heating. Active solar systems should be integrated with a building's design and systems only after passive solar and energy-conserving strategies are considered.

Table 2. Some guidelines that may help in achieving sustainable building envelope.

Climate Considerations:	• Assess the local climate to determine appropriate envelope materials and building designs. • Assess the site's solar geometry. Solar gain on roofs, walls, and the building interior through window openings can be either a benefit or a hindrance to heating, cooling, and occupant comfort. A thorough understanding of solar geometry specific to the site is crucial to proper envelope design.
Building Shape and Orientation	• Choose the most compact building footprint and shape that work with requirements for day-lighting, solar heating and cooling, and function. The greater the amount of building skin in relation to the volume of space enclosed, the more the building is influenced by heat exchanges at the skin. Excluding consideration of window openings and glazing choices, if two building designs under consideration enclose the same volume, the one with the more compact plan will have greater thermal efficiency. • Site and orient the building so as to minimize the effects of wind turbulence upon the envelope. The shape and orientation of the building shell has an impact upon wind turbulence and opportunities for infiltration through the envelope. However, an orientation that minimizes winter wind may also limit opportunities to make use of cooling breezes in summer.
Doors, Windows, and Openings	• Size and position doors, windows, and vents in the envelope based on careful consideration of day-lighting, heating, and ventilating strategies. The form, size, and location of openings may vary depending on how they affect the building envelope. High windows for day-lighting are preferable because, if properly designed, they bring light deeper into the interior and eliminate glare. • Shade openings in the envelope during hot weather to reduce the penetration of direct sunlight to the interior of the building. • Select the proper glazing for windows, where appropriate. Glazing uses metallic layers of coating or tints to either absorb or reflect specific wavelengths in the solar spectrum. More advanced windows use glazing that is altered with changing conditions, such as windows with tinting that increases under direct sunlight and decreases as light levels are reduced.
Thermal Efficiency	• Build walls, roofs, and floors of adequate thermal resistance to provide human comfort and energy efficiency. • Consider the reflectivity of the building envelope. • Specify construction materials and details that reduce heat transfer. • Incorporate solar controls on the building exterior to reduce heat gain.
Building Grounds	• Coordinate building strategy with landscaping decisions. • Reduce paved areas to lessen heat buildup around the building that will add to the load on the building envelope.

4.2 Buildings Systems and Indoor Environmental Quality

Designing and installing environmentally sound and energy-efficient systems have a long-term impact on the cost-effective operations of a building and on the productivity of building occupants.

4.2.1 Heating, ventilating, and air-conditioning (HVAC) systems

The amount of energy used annually by heating, ventilating, and air-conditioning (HVAC) systems typically ranges from 40 to 60 percent of the overall energy consumption in a building, depending on the building's design, the use of renewable energy strategies, climate, the building's function, and its condition. HVAC systems also affect the health and comfort of building occupants (Bisel, 1996). These systems serve an essential function and are identified as problem areas more often than other occupancy issues. The goal of environmentally sound HVAC system design is to meet occupant needs through the most efficient and environmentally positive means at the lowest initial and life-cycle costs. Solutions that have evolved provide environmental comfort while accounting for climatic conditions, use of space, and building technology. These sustainable system designs take into consideration factors such as solar orientation, floor-plate depth, thermal mass, insulation, selection of architectural materials, placement and type of doors and windows, and natural ventilation. Energy efficiency and indoor air quality (IAQ) can be closely linked through integrated design strategies for ventilation systems.

4.2.2 Artificial lighting

Artificial lighting constitutes 20 to 30 percent of all energy use in a commercial building. Reductions in energy use can be achieved with natural day-lighting, advanced lighting technology, and efficient lighting design. Artificial light has been generally overused in most buildings. Some building codes mandate a maximum lighting power density of 1.5 to 2.5 watts per square foot. Nevertheless, a lighting power density of 0.65 to 1.2 watts per square foot can be achieved while still providing a fully functional, well-lit space (Bisel, 1996). With additional improvements from control systems that reduce usage during periods of non-occupancy, the use of day-lighting, and light-level maintenance and tuning control, energy savings of more than 50 percent are possible. Because reduced lighting generates less heat, HVAC cooling requirements are lowered as well.

4.2.3 Electrical Power Systems

Office technology, including telecommunication devices, personal computers, networks, copiers, printers, and other equipment that has revolutionized the workplace in the past two decades, together with appliances such as refrigerators and dishwashers, makes up the fastest-growing energy load within a building. The consumption of energy to run these devices can be comparable to that of a building's mechanical or lighting systems. Local area networks (LANs) and peer-to-peer computing create significant energy loads within a building because they create a demand for 24-hour operation. LAN rooms, telephone closets, and even some general office areas need to maintain 24-hour "computer-room" cooling and humidity requirements year-round, further increasing energy demands and costs.

4.2.4 Plumbing Systems

Water use in buildings has two environmental impacts: the direct use of water, a limited resource; and the expenditure of energy used in water pumping, purification, treatment, and heating. The overall amount of energy used to pump, treat, and heat water can approach 10 percent of a utility company's output. The primary areas where improvement is possible are: more efficient water generation and end-use devices, reduced storage losses in hot water equipment, reduced piping and pumping losses, and reduction in hot-water temperatures to provide the minimum acceptable temperature for intended use.

4.2.5 Indoor Air Quality (IAQ)

The quality of indoor air results from the interaction of many complex factors including construction materials, building envelope, furnishings, equipment, ventilation systems, maintenance, occupants, and electrical and magnetic fields each contributing different effects. The ways in which these factors contribute to IAQ may be as follows (Bernheim, 1996):

- Construction materials, furnishings, and equipment may emit odor, particles, and volatile organic compounds (VOCs), and adsorb and desorb VOCs. Individual VOCs from a specific material may combine with VOCs from other materials to form new chemicals.
- The building envelope controls the infiltration of outside air and moisture, and may include operable or inoperable windows.
- Acoustical materials in heating, ventilating, and air-conditioning (HVAC) systems may contribute to indoor air pollution in the same way as construction materials, mentioned above. Ventilation systems also control the distribution, quantity, temperature, and humidity of air.
- Lack of maintenance allows dirt, dust, mold, odors, and particles to increase. The use of high-VOC cleaning agents pollutes air.
- The number of occupants and the amount of equipment contribute to indoor air pollution. People and pets are major sources of microorganisms and airborne allergens in indoor environments. Occupant activities also can pollute the air.

4.2.6 Acoustics

Acoustics have a significant impact upon the overall indoor environmental quality of modern buildings and the amount of noise emission or pollution discharged to the outdoors. The levels of background noise, privacy, and separation between particular types of spaces have important implications for the work environment of building occupants. Surface finishes are also important in the acoustic environment and can influence the character of the space as significantly as color or shape. Selecting the correct balance between hard, acoustically reflective materials and soft, absorptive ones facilitates the projection of speech to intended areas and prevents echoes or the excessive buildup of unwanted sound in other areas. Outdoor sound emissions must also be considered. In manufacturing areas, the operation of equipment that exceeds ambient noise levels can affect adjacent residential areas. The criteria for noise emission to the external environment are based on existing environmental conditions. In rural areas, for instance, background noise levels during the quietest periods of the day or night may drop to 35 or 40 dB(A). dB(A) is a measure that represents a single-figure decibel weighted to the A-scale, which simulates the response of the human ear to different sound frequencies. In urban areas, the level is unlikely to drop below 50 to 55 dB(A) at night and 60 to 65 dB(A) during the day (Longman, 1996). If the jurisdictional authority has not prescribed a limit on noise emissions, the designer should establish a level consistent with existing ambient noise levels at property lines or neighboring buildings.

5. Discussion

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. As such it requires the promotion of values that encourage consumption standards that are within the bounds of the ecologically possible and to which all could reasonably aspire. Sustainable construction means that the principles of sustainable development are applied to the comprehensive construction cycle from the extraction and beneficiation of raw materials, through the planning, design and construction of buildings and infrastructure, until their final deconstruction and management of the resultant waste. It is a holistic process aiming to restore and maintain harmony between the natural and built environments, while creating settlements that affirm human dignity and encourage economic equity (du Plessis, 2002).

The sustainable building movement has started to gain momentum. Each year yields additional demonstration projects; dozens of new efficient and healthy technologies; and expanded research, standards, codes, and regulations. These include rating systems to evaluate a building's environmental performance, certification programs for sustainable building products, and the adoption of sustainable building standards and practices by recognized standard-setting organizations. The availability of increasingly sophisticated computer software programs also fosters the growth of sustainable building practices by making it easier to identify and evaluate options for a building project. Other new trends and emerging concepts affecting the building industry include performance-based contracts, remanufacturing and product leasing, telecommuting and "virtual offices," and efforts to mitigate natural-disaster losses through improved building practices.

Promotion and implementation of sustainable building practices within a community can generate new economic development opportunities. These opportunities can take a variety of forms, including new business development to meet the demand for sustainable products and services; resource-efficiency improvement programs that enable existing businesses to lower operating costs; development of environmentally oriented business districts; and job training related to new sustainable businesses and products.

In the event up-front costs are higher for high performance sustainable buildings, they can be recovered. Integrated design lowers ongoing operating costs. Better buildings equate to better employee productivity. New technologies enhance health and well being. Healthier buildings can reduce liability. Tenants' costs can be significantly reduced. Property value will increase.

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