Action at the Discrete Level

D. MICHELLE ADDINGTON
Harvard University

Often presented as a conflict, economic development and environmental policy are inherently products of industrial modernization. For many planners and economists, the developing countries present an intractable problem in regard to global environmental agendas. Sound economies correlate strongly with per capita energy use, and as such, an inevitable consequence of globalization will be that average energy use in developing countries will tend to rise toward the level of the United States, particularly as modernization brings energy intensive industry. Much of this has already been demonstrated in the case of China, where modernization has improved the standard of living, but at the expense of rapid increases in greenhouse gas emissions and air pollution due to the use of poor quality coal. For many environmental activists, however, the developing countries present a *tabula rasa* on which an idealized "green" development can be organically constructed and where vernacular strategies can be embraced and maintained. Neither the economic model nor the romantic model have been able to reconcile what one might call interstitial or non-industrial modernization, or as more commonly termed, "leap-frog" development.

For many in public policy, "leap-frogging" offers both a solution to the intractable problem and the *tabula rasa* for new development. Information technologies may enable developing countries to bypass industrialization, and the politics of newer economies tend to be friendlier toward frontier-science. The hope is that the combination of the two will yield the ability to put the best practices in place. Unresolved, however, is what indeed might be these best practices.

The term sustainability was coined in the 1980s to resolve the conflict between economic development and environmental protection. Nearly two decades later, many researchers are beginning to wonder if the term was only rhetorical:

> *The political impetus that carried the idea of sustainable development so far and so quickly in public forums has also increasingly distanced it from its scientific and technological base. As a result, even when the political will necessary for development has been present, the knowledge and know-how to make some headway often have not.*[1]

The following paper attempts to unravel the lineage of "green building" and energy conscious design as it occurred in the United States over the last three decades, and mine that lineage for a leap-frog strategy that would avoid the mis-steps that have so seriously compromised the global environment. While many would argue that the mis-steps were the result of inaction, and as such the correct strategies – or the best practices – exist but only need to be fully implemented, I am suggesting that our current environmental state may be the consequences of the strategies that were put in place.

THE ENERGY CONTEXT

The Arab oil embargo of 1973-1974 provoked the first scrutiny of the energy use by buildings and building systems since the beginning of the 20th century. The activities during and following the crisis were solution driven, energy was no longer abundant, and more importantly, no longer inexpensive. The new Department of Energy, spun off from the Atomic Energy Commission, assumed much of the responsibility for questioning the energy use and the necessity of these building systems. Early initiatives tackled many aspects of the problem from the purely technological – new control schemes, insulation, operating ranges – to the purely ideological – residents and building occupants were asked to do their part by turning back their thermostats, and the most committed assumed a Waldenesque lifestyle in which they shunned energy from the utilities. Schools of architecture were quick to join in, but shifted the subject of their investigations to those that found a natural home in the architecture academy. Vernacular revivals and passive solar design adhered to the anti-establishment ideology, while the high-tech approach presumed that the visual exposure of ducts and mechanical components would be enough to bring the technology to the forefront and encourage more judicious use. The initial success of the various approaches

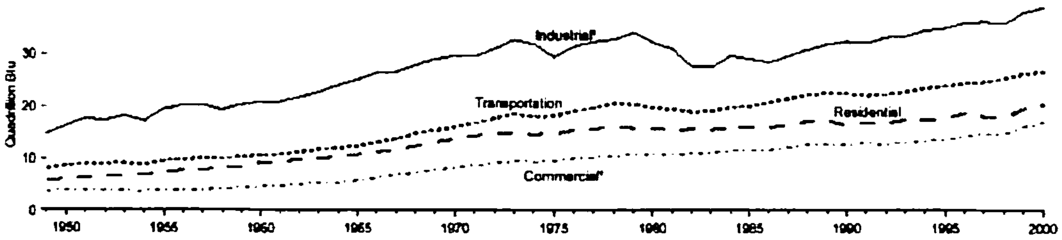

Fig. 1. From the Energy Information Agency "Annual Energy Review" September 2001.

seemed to be promising, particularly the new control schemes, as energy use began to dip almost immediately, only to later resume its pre-energy crisis rate of climb when energy became readily available again (see figure 1:note that energy used in the residential and commercial sectors is almost entirely due to buildings).

Many have blamed the return to "business-as-usual" energy use on a retrenchment of conservation efforts when availability was no longer threatened. Speed limits have almost returned to their pre-crisis levels, the installation of central air-conditioning in residences has nearly doubled since 1980, and sick building concerns have resulted in a backing off from the more efficient control schemes. This neglects, however, the many initiatives that have remained in place, the mandated improvements in equipment, the new building codes, and the expanded public awareness. Impetus continues to increase as concerns for the welfare of the global environment have replaced concerns about resource depletion and political instability. New initiatives are rapidly multiplying, from the Department of Energy's "Million Solar Roofs" campaign and "Energy Star®" labeling to LEED certification and sustainable master planning. Many architects and engineers have responded to the public's growing concern with the environment and are promoting buildings and design solutions that are "green." Manufacturers have been quick to join in, marketing their products as sustainable, environmentally friendly and/or low energy. Local and national governmental agencies have developed guidelines and checklists to ensure that these solutions and products are incorporated into the design and construction processes. The three legs necessary for initiatives to develop into standard practice are firmly in place: the public is aware enough to demand energy conservation and green buildings, designers and manufacturers are shifting their practice and production to meet these demands, and government is undergoing the necessary restructuring to facilitate the commitment to and longevity of "green" practices.

Nevertheless, the energy use by buildings continues to increase. In December 2000, the Energy Information Agency (EIA) projected that growth rates for energy demand in the commercial and residential sectors, in which buildings are the most significant energy consumers, will be 25% higher for the period from 1999 to 2020 than from 1984 to 1998.[2] Two years earlier, the Department of Energy released results surveying energy use by commercial buildings, documenting that newer buildings, even though they generally reported having more energy-efficient features, used more electricity than old buildings. The problem is not so much that energy conservation initiatives are flawed, but rather they are focusing on marginal improvements in efficiencies rather than on substantial reductions in consumption. For example, newer buildings tend to be larger than existing buildings, with more square footage per occupant and per function. To further exacerbate energy use, additional space in a building increases the energy use of the ambient systems – lighting and HVAC – by as much as the square of the added floor space. Additional data from the EIA report in December 2000 projects that although the number of households is expected to increase by 1% a year, the residential energy demand will increase by 1.9%, while an increase in commercial floor space of 1.3% will produce a 2% increase in electricity use. Energy reductions wrought by efficiency improvements are quickly subsumed and surpassed by the energy demands to support the additional space. While proponents of many of the initiatives have argued that energy intensity (energy per GDP) has been reduced and as such, the initiatives have had an impact, we still cannot overlook that the total energy use of buildings continues to climb at a disturbing rate (see figure 2 for trends in electricity).

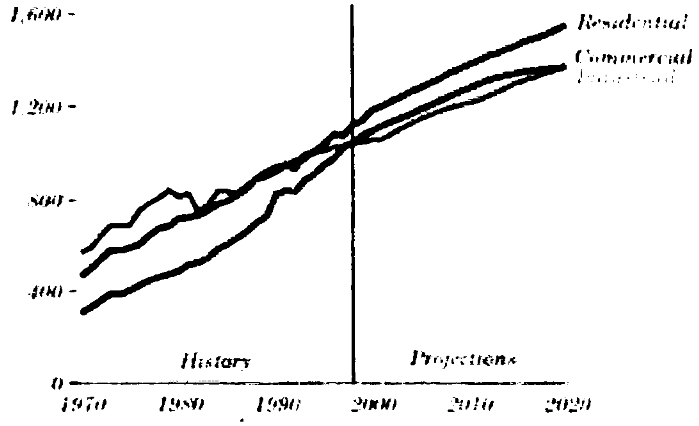

Fig. 2. Annual electricity sales (US) by sector in billion kilowatt-hours from Energy Information Administration, Annual Energy Review 1999, DOE/EIA-0384(99).

It is this rise, of course, that is of concern for the global environment, particularly with regard to greenhouse gas emissions. The Department of Energy's Budget request for FY2000 reported that "energy use in buildings is responsible for 35% of the Nation's carbon dioxide emissions, 48 percent of the sulfur dioxide emissions, (and) 23 percent of the nitrogen emissions . . . (with) emissions expected to increase by more than 25 percent between now and 2010."[3] Although many have lamented the United States' backing away from the Kyoto Protocol, one could perhaps assume that the federal government was all too aware of just how far away the projected emissions are from the earlier goals.

In September 2000, the Boston Globe highlighted a signature energy-efficient home, not much different that those that have been showcased for the last several years.[4] It had many of the features associated with the genre – geothermal system, radiant flooring, copious daylight – as well as 10 tons of cellulose insulation that had been partially funded from the local electric company's program to promote energy-efficiency. The house does indeed use less energy per square foot than does the typical home in the region, but as it is a 5500 square ft home with only one adult and one child residing within, the total impact on greenhouse gas emissions is much more detrimental than it would have been if they stayed in their previous home. Size does matter.

The self-evident conclusion would seem to be the constraint of building size. Notwithstanding the difficulty of implementing and enforcing such a measure, it would have no impact on the existing building stock. Furthermore, the increasing size of buildings is not just a trend in the United States; in China, residential space more than doubled over a five-year period. Instead we should be thinking small about a completely different aspect of the building – its ambient systems (primarily HVAC and lighting). With the exception of specific building types that serve processes or equipment (for example, laboratories), most buildings employ ambient systems for the comfort and. performance of the human occupants. Nevertheless, these systems are designed on the scale of the building, not at the scale of its functions, and certainly not at the discrete scale of occupants. Instead of following the current trend of increasing the integration of building systems, we should be looking to decouple and discretionalize ambient systems. Most importantly, rather than prescribing solutions to improve efficiency, we can and should return to a more fundamental understanding of how we use energy in a building for environmental control.

SEEING SMALL

Electric lighting alone can be responsible for as much as 50% of a commercial building's electricity use, and is estimated to be responsible for 20 to 25% of the nation's electricity use. One of the widest-spread energy conservation strategies involves the replacement of incandescent lamps with compact fluorescent lamps. With efficiencies approximately four times greater than incandescents, fluorescents have shed their "polyester" image and often are central to the front-line strategy in new energy-efficiency initiatives. It would certainly seem to make sense: relamping requires little infrastructural work and the capital costs are significantly lower than for major equipment overhauls. As such, with the dramatic increase in efficiency, relamping is a relatively painless and seemingly effective way to "pick the low-hanging fruit." The production of light from electricity, however, is an "uphill" energy conversion, and thus a process in which the maximum achievable efficiency, constrained by thermodynamic law, is quite low. If one examines total energy conversion efficiency – from coal mine to lamp – then both fluorescents and incandescents operate at net efficiencies below 5%. Almost all of the discussion regarding lighting efficacy has used stage efficiencies (in this case: the energy conversion within the luminaire) rather than cumulative or total efficiencies. As a result, eliminating one incandescent lamp has the approximately the same impact on reducing greenhouse gas emission as replacing twenty incandescent lamps with fluorescent lamps. The majority of efforts to curtail the energy use by lighting have focused on efficiency, rather than consumption, even insofar as improvements toward the theoretical limit are producing marginally smaller returns. Efficiency becomes more important further upstream in the process, whereas consumption is more important downstream.[5]

Little questioned in many of these efforts are the quantity and quality of light in a space. Lighting, like HVAC systems, has been treated as an ambient system: we light space rather than things. Ambient lighting systems are designed to provide standard lighting levels on horizontal surfaces. Many of the standards determining the ideal illumination levels date from the 1950s when ambient illumination had become the norm after the spread of fluorescent lighting. Indeed, sales manuals from fluorescent companies were heavily responsible for the later light standards: the early fluorescents offered no advantages over incandescents, so the primary marketing strategy was to convince consumers that they needed more light than what could be provided with incandescents.

Much of the knowledge, however, of how the eye responds to light was not developed until quite recently. Among the most important developments is that the eye has several complex mechanisms for seeing, all based on relative contrasts, such that the minimum necessary light level – the threshold – for visual performance is up to 100 times less than previously assumed.[6] The contrast ratio, which is the relative luminance between adjacent surfaces in the field of view, determines how well we see.[7] The absolute levels that standards are typically based on are almost meaningless above the threshold. If we could begin to think about lighting at the small scale – what the eye sees – and not the large scale – the building space – we could drop lighting levels quite dramatically while enhancing the visual

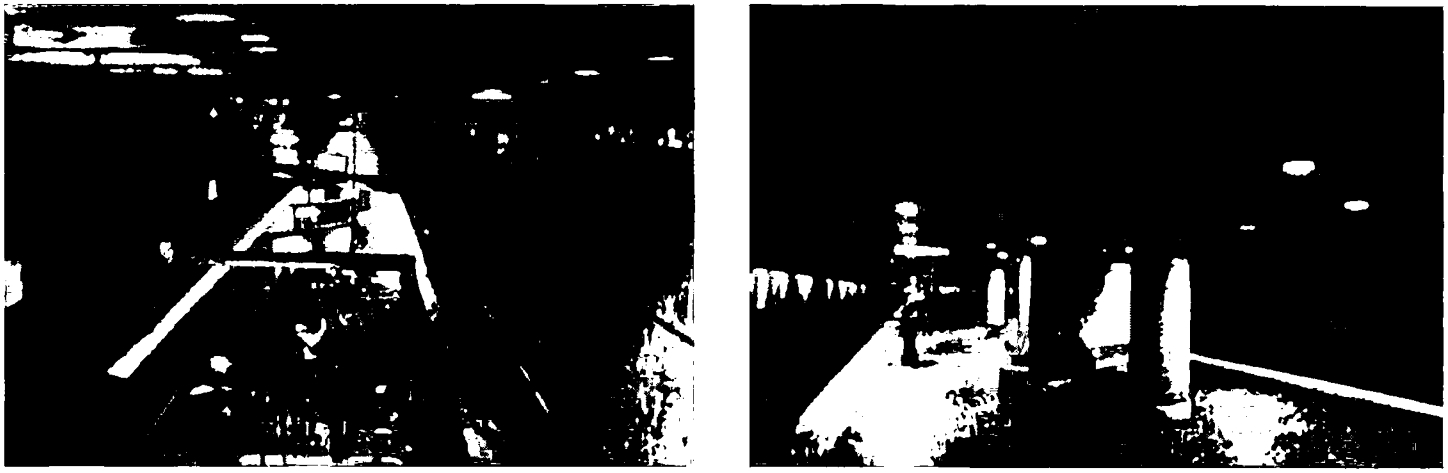

Fig. 3. Photos of existing lighting conditions at Davis Square T-stop.

experience. As the eye responds to stimuli logarithmically, a reduction of light levels by up to a factor of ten would not be noticeably different if contrast ratios are controlled. Energy consumption, however, would drop dramatically. A tenfold reduction in light consumption would produce a corresponding tenfold reduction in lighting energy use, but its real impact would be much greater. If we considered the reduction in terms of delivered energy – that is from coal mine to lamp – then the total energy reduction would be closer to one-hundredfold.

Such an approach would have been impractical even a few years ago. Building interiors are so variable and occupants are so often unpredictable that it would be quite difficult, if not impossible, to design a lighting system that maintained acceptable performance. Today, however, we are beginning to have the tools and technologies to light discretely at the small scale. The sensor industry has undergone explosive growth due in part to the development of MEMS (micro-electro-mechanical systems) and sensors are not only rapidly dropping in price, they no longer require the infrastructure needed to support earlier monitoring systems. Occupancy sensors are routinely used to shut down light systems when no one is present, but a much greater potential would be to incorporate luminance and position sensors to manage the transient lighting levels in discrete locations as the sun and people move within a space. Simulation tools for energy and light analysis have already begun to simplify the lighting design process, allowing the designer to optimize the relationship between daylighting and artificial lighting as well as determine the most suitable building materials and luminaire positions. Indeed, any building owner equipped with a lighting simulation could simply reconsider the color of paint in order to reduce the light necessary for maintaining appropriate contrast ratios. Furthermore, many of the new technologies such as fiber optics and LEDs that had previously been unsuitable for lighting at high levels or in large spaces can be incorporated as we transition to discrete lighting. These new technologies bring many benefits for energy reduction: they allow for direct control of contrast, they reduce lighting losses due to the position and distance of the lamp, and

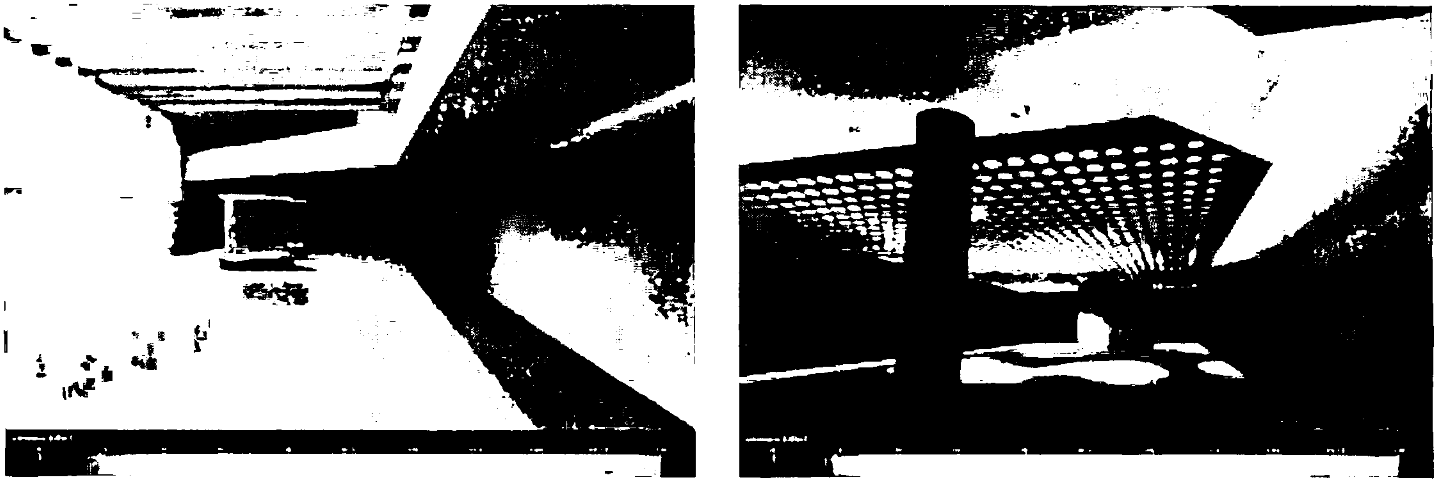

Fig. 4. Lightscape analyses of proposed modifications.

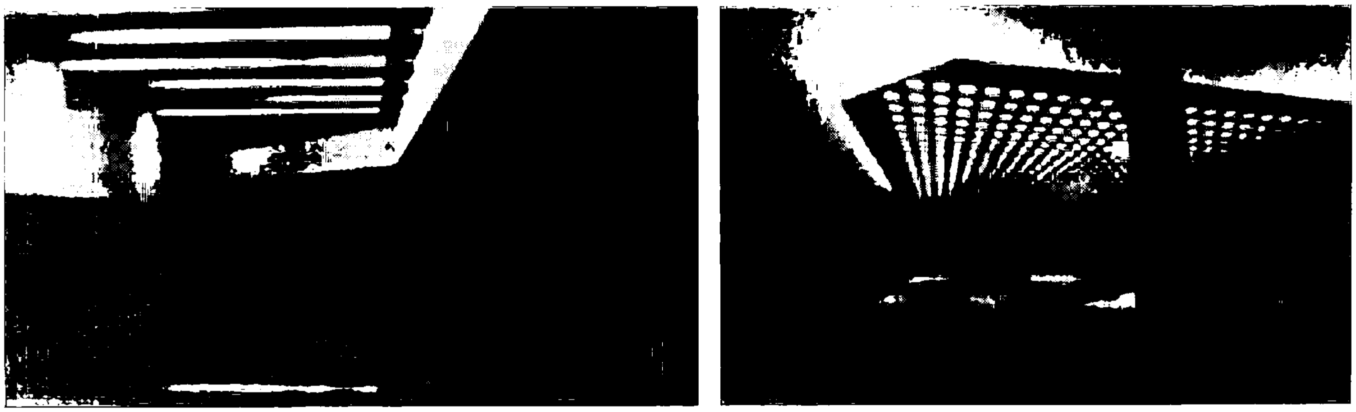

Fig. 5. Renderings of proposed modifications to T-stop.

they also significantly reduce heat generation in a building, thereby reducing cooling costs as well.

MAKING SMALL

The reduction of light levels, however, requires no new technologies. One has only to visit the typical small museum to discover just how bright low levels can be. Very few collections will agree to lend any of their work, regardless of whether the work is in oil (less sensitive to light) or in water color (highly sensitive to light) unless the exhibiting museum agrees that the work will not receive more than 5 footcandles (fc) of illuminance. Standards for office lighting generally call for 30 fc or more, factories can require more than 1000 fc. Exhibit designers carefully control wall color and textures, not as much for aesthetic or curatorial requirements, but to manage the contrast ratio so that the work can be legible regardless of the medium.

Rather than blanketing spaces with ambient light, a thoughtful heterogeneity could improve the visual aesthetics and performance of the space, while reducing the energy used by lighting by a factor of ten. This type of reduction is free – no investment, no infrastructural modifications, no need for new construction – and it is divisible (implemental at any scale).

The lack of technological complexity renders this approach suspect, but one must recognize that the science behind this approach is quite sophisticated as far as building systems go. Only rarely during the last century as ambient building systems were being disseminated has there been any questioning as to the purpose of these systems. Only recently have we understood the neurological behavior of the eye. The simplicity of the approach is belied by its counter-intuitive actions. Few would agree, unless part of a demonstration, that darkening interior surfaces will improve the ability to see, or that flooding spaces with daylight, particularly in offices, will increase the need for artificial light. This is simple to do, but not so simple to imagine.

STUDENT EXPERIMENTS

During Fall semester, 2001, advanced students at Harvard University Graduate School of Design had the opportunity to participate in a seminar titled "Energy and Environment Implications for Buildings: The Discrete System." Working with psychology researchers, theater lighting designers and art museum curators, the students re-addressed several different lighting scenarios from the standpoint of contrast ratio. Given the charge that the conditions for lighting must improve while the energy use dropped by at least one-half, the students analyzed existing conditions and developed new lighting designs. All scenarios were tested through Lightscape® simulations and, in some cases, the students were able to implement their suggestions and test them empirically. The objective of the course was to demonstrate that design at the scale of the phenomenon of interest, and not at the scale of the building, yields higher performance with greater design freedom.

PROJECT ONE: REDESIGN OF DAVIS SQUARE T-STATION LIGHTING NANCY CUTLER AND JODY SHAW

The students selected this subway stop for two reasons: the lighting quality was poor contributing to security concerns, yet the lighting quantity was quite high leading to high energy costs. They took light level readings at several locations and at several times, they found the specifications on all of the existing luminiares, they recorded all of the materials and finish conditions, and they developed AUTOCAD and Lightscape® models of the station. The photos of the existing conditions are shown in figure 3. They proposed three different types of modifications: (1) equalization of the ambient lighting to remove spots of high glare and eliminate dark areas throughout the station, (2) selective covering of the platform that is activated by train motion to bring visual variety and communicate clearly the train arrival/departure zone, and (3) bench lighting to promote security yet maintain a degree of facial privacy. The Lightscape® analysis of the first two scenarios are shown in figure 4 with the design renderings shown in figure 5.

NOTES

[1] National Research Council, Board of Sustainable Development, *Our Common Journey*, 1999

[2] Energy Information Administration, *Annual Energy Review 1999*, DOE/EIA-0384(99)

[3] From Department of Energy FY 2000 Congressional Budget Request, Energy Efficiency and Renewable Energy, Energy Conservation, Building Technology, State and Community Sector

[4] Cited from Eric Goldsheider, "Under the Big Top," *Boston Globe Magazine*, September 17, 2000. The house is located in Western Massachusetts.

[5] A ½% increase in the chiller efficiency for a typical building would likely produce substantially larger reductions in total energy than would a full relamping of the building.

[6] The threshold for distinguishable seeing, which means full color, texture and form recognition, is approximately 0.3 footcandles. This level is well documented in the literature.

[7] Contrast ratio can be calculated in several ways, but the most accurate for general uses is considered to be the Burr, Ross and Malone contrast: $[L1 - L2] / L1$ where $L1$ is the maximum luminance and $L2$ is the minimum luminance.