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Centennial *The History and Promise of Environmental Control*

The Super-Efficient Passive Building Frontier

By Amory Lovins

I would like to look ahead to the next century and to suggest that what this century has been preparing us for is not just a linear view of progress, but a cyclic view of progress in which we rediscover much forgotten wisdom. I think in the next century of mechanical design pressures on capital and energy costs, environmental performance, and operability will rapidly shift designs from active to passive, from formulaic to uniquely optimized, and from complex to simple.

I am going to suggest that integrated whole-building design can yield superior comfort with about three to thirty times less mechanical energy and often with lower capital costs, but that achieving this poses fundamental challenges to professional education and practice and to compensation structure.

The United States has already misallocated something like two hundred million tons of cooling capacity and 200 peak gigawatts of power supply to run it, at a total marginal cost approaching $1 trillion, through failure to optimize the buildings that that capacity was installed in. We need to do better.

How can we apply and integrate proven methods that build on millennia of design wisdom? As an example, I would like to talk about a house that has been occupied for the past year in Davis, California. It was done as part of the Pacific Gas and Electric ACT^2 experiment. It is an ordinary-looking tract house of 1,672 ft^2 (155 m^2) that is compliant with the strictest energy code in the country (1993 Title 24). The design temperature is 105°F (41°C), the peak about 113°F (45°C).

About the Author
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PG&E's Davis ACT^2 house included energy savings designs that saved $4,000 on construction costs and reduced energy use by 15% annually.

The Super-Efficient Passive Building Frontier

A design team at Davis Energy Group was first able to eliminate 7 meters of superfluous perimeter by improving the floor plan. In addition, they put the windows in the right place and designed an engineered wall made of an oriented strandwood product that is a kind of synthetic hardwood. In this way they saved three-quarters of the wood, doubled the insulating value to a true R-27, improved strength, airtightness, durability, stability and speed of construction, and saved $2,000.

Altogether their design changes saved on the order of 15% of the original energy use and $4,000 of construction costs. On the interior the designers did a lot of little things to the appliances, lights, glazings, and hot water system, thereby raising the total savings to about 60% of original energy use. Along the way they got rid of the furnace, using instead a hydronic back-up to a radiant slab coil fed by the 94%-efficient gas water heater that they were paying for anyway.

In other words, by getting about twice as much insulation in the shell and much better glazings, they found they did not need the furnace any more. But they still had left a third of the original 3-1/2 ton cooling capacity and were up to their cost-effectiveness limit. What to do? Well, they had thoughtfully reserved a special "potential cooling elimination package" into which they had put all other measures considered but rejected because they did not save enough *energy* to pay for themselves—yet they also saved cooling load. When seven such measures were added to the design, they more than eliminated the remaining air conditioning needs. They therefore achieved even larger savings at lower capital cost because they saved $1,500 on air conditioning and ductwork.

The result, therefore, of putting in these supposedly non-cost-effective measures was to give bigger and cheaper total savings. In fact, the design basis was 80% savings on space and water heating, space cooling, refrigeration, and lighting, and it appears it is probably working at least that well. In a mature market, construction cost would be about $1,800 below normal and present-valued maintenance cost $1,600 below normal.

The Davis house shows in a hot climate, and Rocky Mountain Institute's 99% passive-solar banana farm in an 8700-degree day-Fahrenheit climate showed in 1983, that *big savings can be cheaper than small savings* if you combine the right ingredients in the right way. We are often seeing this phenomenon in hot and cold climates, big and small buildings, and in new and even retrofit buildings. We are also seeing it in many other technical systems: motor and lighting systems, hot water systems, computer design, cars, and almost everywhere else we look.

The magical economics come from single expenditures with multiple benefits. For example, superwindows have ten main benefits. They do not just save HVAC energy. They also provide such superior *radiant* comfort that they save a lot of energy indirectly through relaxed thermostat setpoints. They also let you downsize, simplify or even eliminate mechanical equipment.

HVAC simplification and the reduction of loads in commercial buildings create many important indirect benefits. You may, for example, go from big rectangular ducts to small round ducts, saving 70% of the metal and more on labor, reducing plenum height, getting more stories per unit height, and saving structural loads and plan areas no longer taken up by those big duct sections and wiring closets and mechanical rooms. You can rent out the space next to the mechanical rooms because the equipment becomes very quiet. Altogether, these kinds of indirect savings that pyramid through all aspects of the design may save more capital cost than the reduction in mechanical capacity.

In a cold climate, just superwindows' ability to eliminate perimeter zone heating in a commercial building more than pays their marginal cost, making other benefits free. You save not only the capital cost, but also some floor space and flexibility in reconfiguring the space in perimeter offices.

In addition there is better UV control from superwindows, better noise suppression and reduced maintenance costs. You facilitate the entry and control of daylighting to displace both lighting and cooling energy and capacity, separating light from unwanted heat with near-perfection. You end up creating such superior visual, thermal and acoustic comfort from an integrated design that recent case-studies show you may well get labor productivity benefits of 6 to 16%. These benefits could be worth an order of magnitude more than the entire energy bill.

This example suggests that if we properly count multiple benefits and take credit for those that are real and measurable in rigorous engineering-economic terms, we will very often find that the way to make a building inexpensive to construct is to make the windows expensive. This is not the usual value engineering approach of squeezing pennies out of each component separately, but it is investing our money in a highly integrated fashion to put more in some places so we can put a lot less in others.

Let me give a few examples of how this can happen. To create comfort, there are many things we can do to expand the comfort envelope: for example, better mean radiant temperature and less asymmetry in it, or air movement, or ventilative chairs. Then there is load reduction. That is remarkably powerful if we combine systematic reduction of internal gains like lights and plug loads with reduction of external gains through insulation, superwindows, shell albedo, mass, shading and orientation. Just making the building the right shape and pointing it in the right direction is often good for about a one-third saving in energy use.

It is not unusual in office design to be able to go from 250 or 350 ft^2 (32 m^2) per ton up to 800 ft^2 or 1,000 ft^2 (74 m^2 to 92 m^2) and in state-of-the-art designs, 1,200 ft^2 (111 m^2) per ton. Obviously, downsizing the mechanicals at $3,000 per whole-system ton is good business and, in fact, it will often facilitate the use of passive and alternative cooling. Passive may be ground coupling, ventilative, radiative. Alternative may be desiccant, absorption, evaporative, and combinations of them. Then you can cut any remaining mechanical refrigerative system to 0.6 kW/ton or less including all auxiliaries from supply fan through cooling tower (An indirect-evap-plus variable-speed recip system was recently designed at 0.14 kW/ton.); then do better controls; and then perhaps storage. Thus you gradually nibble away at the original energy use with a chain of successive savings until almost nothing is left.

Let us consider a 200,000 ft^2 (18 850 m^2), twenty-year-old curtainwall office building with dark glazing units that are starting to fail from old age. Normally you would just replace what is there with more just like it. It turns out at almost the same cost you can save three-quarters of the energy with the retrofit. How do you do that? You reglaze it with superwindows that are twice as good at letting in light as heat, admit six times as much light, and insulate four times as well as the old dark units, yet cost almost the same. You flood the space with deep daylighting, glare-free and

nicely distributed. You also put in very efficient lighting and plug loads (totaling 0.5 W/ft^2 as used) and you thereby reduce the design cooling load from 750 tons to under 200 tons.

Now, ordinarily you would have renovated the 750 tons for maybe $800 a ton, that's $600,000. Instead, you can rebuild 200 tons to get not 1.9 but 0.5 system kilowatts per ton. So it is almost four times as efficient, and may cost 2-1/2 times as much per ton, but you have almost four times fewer tons. You save $200,000 on the mechanical retrofit, and that is what pays for the lighting and glass retrofit. Calculated payback: minus 5 to plus 9 months. There are over 100,000 big, old curtainwall buildings out there that many of you can retrofit in this fashion.

The general strategy, then, for commercial retrofit is to rigorously avoid internal heat gains and have an exemplary envelope with tuned superwindows and deep daylighting. Some load reductions you can do only in new buildings, but many you can do in retrofit. Then you have smaller and much better mechanicals to the extent they are still required, and superefficient drivesystems and controls. You typically end up with site energy around 10,000-20,000 site BTU/ft^2–y—80–90% savings—but construction costs go *down* by several percent.

Such good design needs better compensation structure. If design professionals of any kind are compensated for what they spend, not for what they save, they have a perverse incentive that rewards inefficiency and penalizes efficiency.

I think it is important for design professionals, as for other parties in the real estate process to be rewarded for energy efficiency: for example, to be allowed to keep as extra compensation a percentage of whatever life-cycle costs they save. That could double or triple a conventional fee. It is a fair reward for the extra work. It certainly gets people's attention. And it would help, I think, to reintegrate the design process and to substitute true engineering optimization for rules of thumb.

The sort of world engineers will face in the next hundred years will require us all to do much more with much less. I am grateful for this opportunity to offer a few perhaps provocative insights into how this is starting to happen and how it can return us again to the existential joys of real engineering. ■