ENERGY-EFFICIENT BUILDINGS: INSTITUTIONAL BARRIERS AND OPPORTUNITIES

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E X E C U T I V E S U M M A R Y

Buildings are rarely built to use energy efficiently, despite the sizeable costs that inefficient designs impose on building owners, occupants, and the utility companies that serve them. The reasons for this massive market failure have to do with the institutional framework within which buildings are financed, designed, constructed, and operated: many of the roughly two dozen actors who play a role in this process have perverse incentives that reward inefficient practice. Fragmented and commoditized design, false price signals, and substitution of obsolete rules-of-thumb for true engineering optimization have yielded buildings that cost more to build, are less comfortable, and use more energy than they should. In the United States alone, the unnecessary expenditures made over the past several decades on space conditioning equipment and the electricity supply infrastructure to run it total hundreds of billions of dollars. Investments in design education, leasing reform, elimination of perverse incentives for designers and engineers, and support of building commissioning and operation offer tightly focused, high-leverage opportunities to achieve important benefits relatively quickly. In response to these opportunities, a "second generation" of utility DSM programs is already beginning to emerge, incorporating novel approaches such as direct incentives for building designers. At the same time, the ability to build and operate buildings that incorporate the best energy design features is becoming an increasingly important competitive factor for building owners and developers.

1. INTRODUCTION

E SOURCE's detailed technical assessment of electricity use for space cooling and air handling identified large and untapped opportunities for electricity savings in buildings.[1] Well over half of the energy used to cool and ventilate buildings in countries like the United States can be saved by improvements that typically repay their cost within a few years. This opportunity is especially important for electric utilities, since space cooling represents 44 percent of U.S. noncoincident peak load. Previous analyses have found comparable potential savings in lighting, drivepower, office equipment and other end-uses.

To a theoretical economist, these are astounding statements: it is inconceivable that in a market economy, such large and profitable savings would remain untapped. But to a practitioner who knows how buildings are created and run, it is not only conceivable but obvious. This *Strategic Issues Paper* explores why such a massive market failure has occurred, and what to do about it.

Buildings use roughly a third of the energy and five-eighths of the electricity in the United States, and similar or larger fractions in many other countries. Buildings are cooled, ventilated, lit, and equipped in abysmally inefficient ways not because anyone was venal or stupid, but because they all faithfully did their jobs, responding to the incentives they saw. The market in efficient building services is so strikingly imperfect that the whole structure of incentives is best described as "spherically senseless" (it makes no sense no matter which way around you look at it).[2]

Changing the design—the structure, reward system, information flows, decisional processes, technical and social work systems, and strategy—of the system that creates and runs buildings can correct these market failures. First, however, we must understand what the failures are and how they arise at each stage of the building process. As the U.S. Congress Office of Technology Assessment remarked when introducing the results of ethnographic interviews on energy efficiency in U.S. buildings,

> Energy use in buildings is determined by decisions about equipment selection and operation, and these decisions are made to satisfy a number of needs and constraints. Implementing greater energy efficiency in buildings will require policies that influence these decisions; these policies will be most effective if they are based on a clear understanding of how and why decisions about equipment selection and operation are made. . . . The focus [here] is on how these decisions are made, as distinct from how they should be made.[3]

This *Strategic Issues Paper* reflects E SOURCE's understanding of problems and potential solutions related to the institutional context of buildings, gained from our own experience advising on dozens of building projects in many countries over the past decade, our review of the professional and trade literature, and interviews with more than fifty[4] design professionals and analysts of the design process in the U.S. and abroad, reflecting their collective experience in thousands of projects. We believe it reveals the essential features of the key issues, and is consistent with, but more complete than, the findings of the most nearly comparable formal study based on ethnographic interview techniques.[5] It is often framed in terms specific to space conditioning, but the same diagnoses and prescriptions apply with only minor variations to lighting, appliances, drivesystems, and other kinds of energy use in buildings as well.

As will become clear, not only does each player in the building business have perverse incentives, but there are a couple of dozen main kinds of players, and each tends to talk to and understand the work of only the few other kinds with whom they most directly interact. The resulting fragmentation, to a remarkable degree, isolates functionally the various actors already isolated by idiom, concerns, culture, and institutional setting. This fragmentation, in turn, sets at cross-purposes many interests that can be served only if aligned and coordinated. The virtual absence from previous literature of any comparable attempt at synthesizing the entire building process and the features that make it dysfunctional (at least from the viewpoint of energy efficiency) is itself an indication of how excessively narrow and overspecialized the study of these problems has become. To be sure, solutions must come in many small and particular pieces, not just a few big ones. But we cannot understand how those pieces fit together until we look at the whole complicated process synoptically. Here is one attempt at such an overview.

2. WHY BUILDING ENERGY SYSTEMS ARE INEFFICIENT

2.1 PROJECT ORIGIN AND FINANCING

Real-estate developers and investors, who are frequently in the position of making large financial commitments on a speculative basis, typically want fast, cheap buildings: as cheap, that is, as the aesthetic character, comfort, and functionality demanded by a local market will permit. More precisely, these parties seek to maximize the net present value of a building's net income during the holding period and of potential resale value. Energy seldom enters this equation except as one of many relatively minor operating costs. Although owners and tenants have consistent long-term financial interests in energy efficiency—it increases profits for both—the value of marginal investments to improve efficiency is almost never considered up front. Potential future energy savings, where they *are* evaluated, are often discounted at implicit real interest rates on the order of 30–60% per year—an order of magnitude higher than the typical real cost of capital for commercial construction (~4–6% per year).[6]

Subject to getting the kind of building they want, developers and owner-investors focus almost exclusively on minimizing capital cost per unit of net marketable floorspace. Particularly since the late 1960s, when nonrecourse financing started to decouple the development process from tradeoffs between capital and operating costs, lifecycle cost has become a comparative abstraction. The developer, who controls design choices, will probably neither own the building in the long run nor pay its operating costs, and hence no longer expects to retain a long-term interest in the project's actual, as opposed to its projected, financial performance.

U.S. tax rules for commercial buildings exacerbate this bias. Capital costs must be depreciated over more than 30 years, whereas operating costs can be fully deducted from taxable income or passed through directly to tenants.[7] Although intricate and constantly shifting tax rules can complicate this comparison, it appears that tax effects range from neutral to unfavorable for most energy-saving investments. In the U.S., twelve states charge sales tax on residential energy-saving devices but not on residential fuels and electricity, while only one, Rhode Island, does the opposite.[8]

While many developers may go as far as installing compact fluorescent lobby lights, VAV air handling, or an energy management system, most do not appreciate that such incremental changes fall far short of the profound and fundamental changes possible with integrated design. Mechanical design and the factors that affect it are low on commercial developers' agendas and, usually, in their knowledge and competence; they want to be sure that the mechanicals will create comfort, not that they will reduce operating cost. Indeed, operating cost is considered scantily if at all: it is generally ignored by speculative builders whose aim is immediate resale, and heavily discounted even by owner-occupiers. The possibility of lower *capital* cost for carefully designed heating and cooling systems is usually unfamiliar and implausible to them, and is obscured by reliance on rule-of-thumb estimates of how much mechanical systems "should" cost.[9]

DEVELOPERS AND INVESTORS TYPICALLY WANT FAST, CHEAP BUILDINGS.

Real-estate financing, especially for large commercial projects, often involves very large and complex organizations. Loan officers and architectural and engineering reviewers are often subject to pressures from commission-driven loan producers and equity dealmakers to process loan requests rapidly by making their reviews cursory and affirmative. An experienced developer, or advisory mortgage banker, "may reject innovative design in order not to create an excuse for the reviewing engineer to hold things up with the same kind of 'it doesn't conform to standard practice, therefore it won't work' mentality that code officials and others show. Time is money. Feasibility can founder if interest rates rise ahead of rents. Delay can kill a project if permits or financing commitments expire; it also increases the risk of missing rentals as competing projects come to market. Even without the time pressure of design-build or fast-track construction, innovation is discouraged."[10]

This "checker" mentality, natural in people under time pressure and rewarded only for preventing mistakes but not for improving performance, is an important obstacle, because these reviewers have neither time nor inclination to study unusual designs. The key financial players—brokers, mortgage bankers, and investment advisors—are likely to get bonuses based on the value of deals closed, not on the long-term financial performance of the properties financed. This encourages both large-scale projects and those likely to be approved quickly with no questions asked.

Confirming the developer's priorities, commercial appraisers tend to know even less about energy systems. Few appraisers have any background in or give significant weight to energy efficiency, whether superficial or fundamental: their emphasis is on markets, aesthetics, and location, not on nonstandard operating costs that they believe the market doesn't recognize or on new technologies they barely understand. Lacking the kind of building-certification rating systems emerging in Britain and Canada[11], they may also lack a foundation for evaluating designers' projections of performance, let alone market response to resulting improvements in economics or amenity. In principle, they could overcome these obstacles simply by using the income method of appraisal and capitalizing energy savings that flow to Net Operating Income, but few bother. The competitive value of energy-efficient commercial buildings, therefore, is seldom reflected in their market value or in financiers' perceptions of their risk/reward ratio, nor does it appear to be part of any current due-diligence process in commercial lending. Nor, further, do securities rating agencies seem to consider it when assessing the financial strength of institutions with large real-estate portfolios.

COMMERCIAL LENDERS OFTEN INHIBIT ENERGY-SAVING BUILDING RETROFITS.

Commercial lenders with these handicaps do not merely finance inefficient buildings; often they also inhibit energy-saving retrofits of existing buildings whose financial nonperformance puts them under the lenders' control under workout agreements (the current position of much third-party-owned U.S. commercial real estate). Such lenders are often strongly averse to what they see as a new investment burden that they do not directly relate to occupancy, retention, and net operating income, even where it can create value for lenders so submerged that their asset value is less than their loan balance. They may also fear criticism from government examiners, the Controller of the Currency, the Resolution Trust Corporation, or others for investing more money in real estate, even to help rescue it. Thus, they resist what could in fact be a tool for gaining net worth, tenants, and cashflow (see §3.3). The value of energy retrofits in markedly improving the financial performance of some poorly-performing projects now deeply underwater does not appear yet to have been impressed upon the regulators of financial institutions: they too may consider their resistance to such investments a sign of prudence rather than of short-sightedness.

Likewise, in the residential market, few developers, appraisers, or builders believe efficiency sells:

> For example, if a builder invests $1,000 in insulation, then most of this investment will be invisible to the prospective purchaser—but the additional cost of the insulation will be extremely visible, in the form of a higher priced house. From the builder's perspective, it may make more sense not to invest the $1,000 and thereby reduce the house price, or alternately to invest the $1,000 in a feature that is more visible to the prospective buyer (*e.g.,* landscaping or more expensive doors).
>
> Builders often market homes as a "base" home, and then offer a series of upgrades. An upgrade might consist of more expensive bathroom fixtures, wood floors, or a finished basement. Energy efficiency upgrades, however, are rarely offered, as some builders fear that offering such an upgrade will give consumers the impression that their base house is not energy efficient. . . . A director of marketing for a large home building firm interviewed by OTA indicated that many home-buyers think of energy efficiency as a yes/no feature, similar to a garage or central air conditioning, *i.e.*, the home either has it or doesn't have it.

> Interviews with larger homebuilding firms . . . revealed a considerable knowledge and understanding of energy efficient technologies and construction methods. The decisions of these firms to adopt or not adopt innovative energy efficient technologies were not based on ignorance or lack of information but on their perceptions of the economic interests of their company. The director of architecture at one large home building firm, for example, had previously taught passive solar design at an architecture school. However, he did not consider solar orientation when designing a new subdivision, because to do so would apparently reduce by 15 percent the number of homes he could fit into the subdivision, which would in turn reduce the firm's revenues. . . . [12]

Moreover, in 1990 61% of new U.S. single-family houses were built for the speculative market, 36% for a specific owner, and 3% for rental, so nearly two-thirds lacked any direct input of the occupants' preferences.[13] Of total 1989 U.S. houses built, 15% were manufactured (mobile) units, 6% modular (*i.e.*, 95% factory-built), 36% panelized (with major components factory-built), 38% used preassembled roof and floor trusses, and only 5% were stick-built entirely onsite.[14] Hence, choices about both the shell and the mechanical equipment are made almost entirely *at the factory*, according to first cost, reliability, familiarity, and convenience—all as seen by the manufacturer.[15]

About one-third of single-family U.S. households are estimated to perform an energy-related retrofit or repair each year.[16] Yet even in retrofits, the firms involved often shun the perceived risk of new, unproven, or possibly unsatisfactory technology. Participants in a workshop of retrofit contractors estimated that "90% of homeowners do not want to pay extra for energy efficiency."[17] Whether that is true or not, if it's what contractors believe, it determines how they'll behave. To be sure, residential owner-builders have a tax incentive opposite to that of commercial developers—the homeowner is better off with a bigger mortgage (whose interest is tax-deductible) and lower energy costs (which are not)—but owner-builders are rare, so the spec-builder culture and incentives prevail.

2.2 Design process and method

Even the best building designs are often gravely disabled before they are born. For multibuilding and especially multiuse developments, a project architect, landscape designer, or site planner may specify location, footprint, height, orientation, and relationship to existing shading before the building architect is even hired, let alone asked for input. The energy consequences may or may not be remediable afterwards. Even then, the building architect may specify form, relief patterns, exterior materials, and fenestration with or without much thought to energy. Most U.S. buildings of the past few decades, says architect William McDonough, are "monuments to the designer's ignorance of where the sun is." Just proper choice of architectural form, envelope, and orientation can often save upwards of a third of the building's energy at no extra cost—44% in one recent California design.[18]

The commercial project's architect seldom knows much about mechanical equipment or its interactions with other building systems. The architect wants a happy client, and knows this depends on speed, low capital cost, no novelty, attractive outward aesthetics, and undeniably ample provision for occupants' comfort. The architect therefore delegates mechanical design to consulting mechanical engineers or design-build firms. The consulting engineers in turn are often not responsible for, and may not even know about, the cooling loads generated by other design elements (lighting, daylighting, glazings, other shell components, plug loads), usually chosen by someone else and often by a different design firm. In fact, when a commercial building meant for lease to the general public ("competitive space") is designed, those critical loads are often *not yet known*, because they will be chosen later as part of tenant finish and tenant equipment procurement *after* the building is constructed, subdivided, and leased. Rather than trying to influence prospective tenants' efficiency so that the whole building will work better and cost less, the mechanical designer simply invokes a safety margin so large that it is virtually certain to cover whatever equipment the tenants might choose to install.

NOBODY EVER GOT FIRED
FOR MAKING A
MECHANICAL SYSTEM TOO BIG.

Safety margins and sizing

Being unfamiliar with and often unable to influence the cooling loads, the mechanical designer is likely to guess high or "round up" when in doubt: nobody ever got fired for making a mechanical system or its components too big. Various parties involved in the design process—each wishing to avoid blame or liability—sometimes round up equipment sizes at separate stages of review and approval, piling safety margin on safety margin. Three roundings-up, each by one-third, yields sizing 2.4 times the original size. This is a common result in the commercial sector, where oversizing by tenfold is not unheard of. All the incentives of risk and reward propel this result. One leading practitioner of energy-efficient design has suggested that:

> If building services engineers were to design tables, they would be of titanium and have six legs, two are spare, just in case; if they were to design cars, these bullet-proof vehicles would have eight wheels (one spare each, just in case) with twin engines, twin steering wheels, and twin seat belts.[19]

To be sure, there is a proper place for safety margins, but they are often misused. Many project engineers are civil engineers or architects whose notion of proper safety margins is conditioned by their structural experience with steel and concrete. These products have highly variable strength, depending on workmanship at the site, so both codes and prudence typically require safety factors of two to three times. Safety margins of 50–100% in the HVAC context are wholly inappropriate. Concrete and steel are passive; you pay for them once, and the marginal cost of the extra materials is relatively low. But you pay for oversized HVAC equipment heavily and *perpetually* through increased costs of three kinds: energy (due to often severe part-load penalties), maintenance (for which contractors typically quote by the chiller ton, air handling cfm, etc.), and ultimate replacement-in-kind.[20]

SAFETY MARGINS OF
50 TO 100 PERCENT ARE
WHOLLY INAPPROPRIATE
FOR HVAC SYSTEMS.

Few designers perform dynamic thermal simulations, even though they cost only 0.1–0.5% of project cost for most commercial office space.[21] This in itself causes major oversizing of cooling equipment, often by twofold, since worst-case static load calculations ignore the ability of the building's thermal mass to "ride through" peak thermal loads without ever "seeing" the design conditions. Moreover, better understanding of what actually makes people comfortable is likely to afford designers greater freedom in designing indoor conditions than the conventional engineering paradigm implies.[22]

Interactions between designers and manufacturers

Designers must inevitably work with equipment suppliers and manufacturers on an ongoing basis. Under the best of circumstances, this relationship may facilitate the introduction of new and better products, and allow practitioners to optimally use available equipment. In practice, however, the relationship often falls short of this ideal. Busy designers in some parts of the world leave the sizing of HVAC equipment to the manufacturers—a clear conflict of interest. Very low design fees in cutthroat markets encourage this unfortunate practice. Moreover, the dominance of chiller manufacturers' own software for doing thermal load calculations and related design analyses may encourage more subtle manipulation of the results than simply buying unnecessarily large capacity. Such analyses often recommend types or size ranges of chillers in which that manufacturer happens to be particularly strong.

For chillers, the most costly and critical component of conventional HVAC systems, the best models are not in the catalogs: a designer must know, and take the trouble, to custom-design an unlisted combination of impeller, gears, heat exchangers, etc. Worse, the designer is generally "flying blind" in these choices, because the manufacturers consider the "compressor map" to be proprietary, and do not release the computer codes needed to optimize the half-dozen major and several minor variables[23] when specifying each machine for a particular application.

Schedule pressures and design innovation

The best designs often require an investment of time for learning new methods, or for seeking out whole-system solutions. Tightly scheduled, "just-in-time" design, on the other hand, assumes that design is a linear science rather than a systemic art, and often precludes whole-system solutions. Moreover, the narrow focus required for rapid design reduces the psychological sense of freedom necessary for innovation.

JUST-IN-TIME DESIGN
ASSUMES THAT
DESIGN IS A LINEAR SCIENCE
RATHER THAN A SYSTEMIC ART.

Changing established practice may also carry the implication that past practice was inferior. Designers often resist change because of a subliminal fear of embarrassment at not having changed earlier, and conceal ignorance of innovations by pretending familiarity with them and telling the client they won't work. In the cost- and comfort-conscious space-conditioning business, some designers worry that if they now achieve big energy savings, someone may ask why they didn't do so long ago. This concern often underlies what may look like simply a stubborn resistance to innovation. Overcoming it requires a cultural environment that takes a "no-fault" attitude to rewarding continuous improvement. Only then will designers unhesitatingly tell a client, "Yes, I'm glad you asked about that new approach—I've heard there's an exciting new technology that's just become available, but I haven't used it before, so let me go find out more about the details and how we might apply it to this project."

2.3 THE DIS-INTEGRATION OF DESIGN

A well-integrated and interdisciplinary effort by a design team is often the key to producing buildings that achieve exceptional energy efficiency and aesthetic comfort. Yet in most cases, even with a relatively well-ordered design team, it is rare to find anyone taking responsibility for the entire interactive system. The delegation of assignments to specialists weakens the essential linkages between different tasks. Some parts of the system are optimized or sized at the expense of others and of the overall result, but the tradeoffs are seldom made explicit.

Instead, each successive designer's product is tossed over the wall to the next designer, as if the effort were not a team play but a relay race. This is not surprising: most architects, for example, don't even *meet* a practicing mechanical engineer until after they have graduated, and none of the several dozen design specialists gets any appreciable training, let alone experience, in how best to collaborate with the rest.

Even when these specialists do meet and wish to communicate, they may not be able to, because each of the approximately two dozen categories of actors described in this chapter has different incentives, outlook, and technical language. **Table 1** provides a summary of the many different performance measures these parties apply to a building project.

Table 1
"The Tower of Babel"
Technical Specialization and Disparate Vocabularies

Specialist	Performance Measures/Objectives
Developers	dollars per square foot or meter
Investors	risk/reward ratios; return on investment
Asset managers	net operating income
Lender's counsel	due diligence; liability
Electrical engineers	watts per square foot
Lighting engineers	footcandles or lux
Mechanical engineers	square feet per ton; kilowatts per ton
Estimators	tables and modification factors
Contractors	budget and schedule
Construction workers	signoff
Construction managers	critical path and specifications/drawing adherence
Building inspectors	code-section compliance
Commissioning agents	punchlist items
Indoor air quality experts	concentrations and exposures
Leasing brokers	deals
Appraisers	comparables
Building managers	occupancy
Building operators	simple payback
Maintenance staff	complaints
Suppliers	sales and margins
Tenancy managers	gross effective occupancy costs
Space planners	square feet per person
Occupants	comfort
Utility DSM program designers	dollars per avoided peak kilowatt; cents per saved kilowatt-hour
Utility measurement and evaluation staff	process and impact data

Architects may not be fluent in any of the quantitative languages familiar to financiers and engineers, because most of them use the other brain hemisphere altogether: they're visual. So is the interior designer, whose choices of furniture, finishes, etc. can profoundly if unwittingly affect such factors as light distribution (hence cooling loads), airflow, and indoor air quality. And so, often, are two more categories: the designers and manufacturers of the furniture, furnishings, and finishes. Finally, the utility demand-side management program designers and field staff who try to encourage efficient design tend to speak their own arcane lingo, laced with obscure references to "site (or source) Btu per square foot-year," "benefit/cost ratio," and "free riders." Even without invoking the charmingly parochial units of measure used in many countries, most of all the United States, it doesn't take much of a mixture of ESI footcandles, cubic feet per minute per square foot, parts per billion, Internal Rate of Return, occupancy costs, and adjusted basis points to produce utterly comprehensive incomprehension.

No lexicons exist to translate between these languages. There is no Rosetta Stone. Hardly any interpreters can communicate smoothly in more than a half-dozen of these diverse tongues. To be sure, a few hardy and curious wayfarers may notice that utility economists' levelization formula looks like a level-payment annuity calculation, or that watts per square foot can be related to dollars per square foot and ultimately even to net operating income; but such adventures are rare. Only the first rough attempts to translate energy experts' efficiency metrics into developers' economic metrics have yet been made.[24] Indeed, few energy experts even realize that the same buildings that they think of as physical structures with energy flowing through them are viewed by their owners and managers as financial structures with money flowing through them—a paradigm difference offering only the most tenuous common ground.

UTILITIES SEE BUILDINGS AS PHYSICAL STRUCTURES WITH ENERGY FLOWING THROUGH THEM; DEVELOPERS SEE THEM AS FINANCIAL STRUCTURES WITH MONEY FLOWING THROUGH THEM.

Speaking to each of these constituencies' concerns and in its own language is a formidable challenge. Yet there is no alternative, because failing to inform and involve any of these roughly two dozen actors can be a show-stopper, requiring you later to retrofit a new building or even a building still under construction. Although this is often done, it is far less lucrative than doing it right the first time. If you can't afford to do it right the first time, how come you can afford to do it twice?

Interdisciplinary teamwork

Increasingly, the realization that truly integrated design can yield projects that are both ecologically and economically green is attracting unusual constellations of integrative designers and holistic clients. When this conjunction creates true teamwork, the results can be extraordinary. For example, Nederlandsche Middenstandsbank's 50,000-m^2 (538,000-ft^2) headquarters, built south of Amsterdam during 1983–87, was to be "an organic building that would integrate art, natural materials, sunlight, green plants, energy conservation, low noise levels, and water." These goals were achieved with 92% lower energy use than the previous headquarters, hardly any extra capital cost (~$1.27/ft^2 in 1991 $ and a ~0–3-month payback), decreased absenteeism, exceptional praise by employees and customers, and dramatic improvement in public image and growth in market share.[25] But this required three years' intensive collaboration by a team including not only the usual design professionals but also artists, workers, landscapers, and builders, all *encouraged* to intervene outside their disciplines.

Unfortunately, this approach is rare, and many designers would find it uncomfortable or even threatening. Over the last several decades, architects have been forced by scale, complexity, schedule, skill, and compensation to slice and dice the design process until none of its connective tissue remains. The shell and the core of the building may even be designed by different firms, as if all that mattered about the shell were how it looked. Synergism and elegantly frugal solutions are lost. In their frustration, many architects have lately been seeking out clients and projects that can give them back the great gift of becoming architects again. Still, conventional practice offers few such opportunities.

Who conducts the orchestra?

Even in conventionally hierarchical projects, the architect rarely "conducts the orchestra" to capture synergisms between building systems and architectural elements. Consider, for example, the complexity of trying to capture energy savings' architectural advantages. These indirect benefits often include:

- shallower ceiling plena because reduced cooling loads require smaller mechanical equipment and smaller ducts,
- further plenum-height savings from the small round ducts permitted by cold air distribution or desiccant dehumidification, thus saving ~70% of the duct metal[26] and most of its installation labor,
- ability to add one or more new stories to buildings with height restrictions or simply to build more stories within the same budget,
- ability to rent space adjacent to fan and chiller rooms that were previously too noisy,
- major improvements in acoustics in other occupied space,
- markedly increased space efficiency (both plan and volumetric) from smaller ducts, wiring closets, and mechanical rooms,
- greatly reduced reconfiguration costs (and ancillary benefits from avoiding drop ceilings, using indirect lighting, etc.) if underfloor air distribution is used—a natural partner with evaporative cooling, and the basis for superior displacement ventilation even with refrigerative cooling systems,
- more flexible orientation and improved perimeter radiant comfort, hence better space planning, via superwindows, and
- less structure to support reduced mass.

These and other indirect effects can bring enormous economic benefits: *e.g.*, efficient lighting and office equipment (say, designing for 0.5 W/ft^2 instead of 8) and colder chilled water may reduce plenum depth and hence story-to-story height by 8–10" (20–25 cm) or even by a 1–2' step, saving building skin at, say, \$80/ft^2; then the skin and duct savings, combined with increased net rentable space and other indirect effects, can yield total net dollar savings "well into seven figures" in a 1.8-million-ft^2 project.[27] Together, these indirect benefits of energy efficiency often double, or more, the directly calculated savings in energy and maintenance costs. Yet few practitioners have a sufficiently integrated view of whole-system design to take full credit for such benefits, let alone perform whole-system optimization that exploits them.

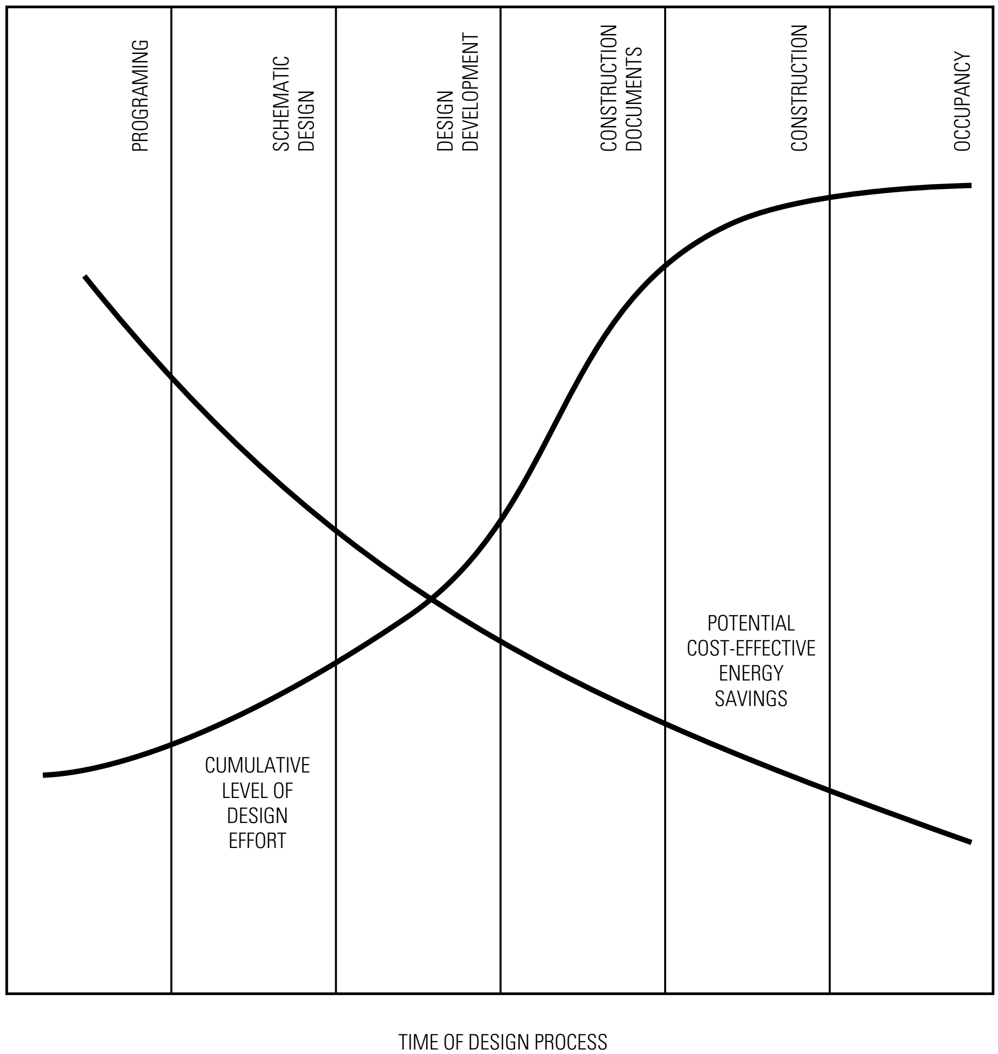
2.4 DESIGN SEQUENCE

Mechanical designers are usually among the last to do design work for a given building: they are presented with building form and envelope, lighting, plug loads, etc. as givens, not as variables to be co-optimized with their own options. Especially in fast-track projects, they are often presented with something even worse: a laid-out, nearly finished building design that is a kind of preordained three-dimensional maze into which mechanical systems are to be shoehorned as an afterthought, wherever they fit. This often yields the worst possible layout, with long and circuitous runs of ducts and pipes that maximize friction and hence fan and

MECHANICAL ENGINEERS ARE RARELY CONSULTED AT THE CONCEPTUAL DESIGN STAGE, WHEN THE OPPORTUNITIES FOR ENERGY SAVINGS ARE LARGEST.

pump energy, and with poor or no access for cleaning and maintenance. At the earliest stages of the design process—preconceptual and conceptual—when the mechanical designers could achieve the biggest savings with the least effort and expense, they are seldom consulted. At each stage of the design process, from preconceptual to conceptual to schematic to design development to construction documents (working drawings and specifications) and beyond, the difficulty and expense of making basic changes that affect energy use rise steeply, the effectiveness of interventions falls steeply, and the opportunities to save capital cost by eliminating or downsizing mechanical systems recede (**Figure 1**). Yet mechanical design is normally scheduled as if the opposite were true—as if only afterthoughts mattered.

Figure 1
Energy-Savings Opportunities and the Design Sequence



Source: ENSAR Group; E SOURCE.

2.5 DESIGN INCENTIVES

Only a small fraction of practicing designers can be considered skilled and experienced in integrating modern energy-efficiency options into buildings. Most designers—especially mechanical engineers—are given neither budget nor time to learn or to innovate. Most have few useful and up-to-date opportunities for continuing education. Despite much good work by the professional associations, much of the ongoing education in the profession is dominated by equipment manufacturers, who also write and provide many of the most widely used design tools. Continuing education tends to concern the "crisis of the year" (indoor air quality, CFCs) or the currently fashionable technology (energy management systems, thermal energy storage), not how to integrate into design continuing advances made on a broad front, much of it outside the normal province of mechanical design.

Architectural fee structures and schedules neither support nor reward much coordinating and analytic effort. The architect is already too busy trying to coordinate contributions by as many as 25 specialists on the design team—a task which is already "exceeding the ability of any one person or firm."[28] In the many cases where the consulting engineers are retained directly by the owner, rather than as subcontractors to the architect, design coordination may not take place at all, or if it does, may be short-changed because the architect is not compensated for leading it.

Even if properly compensated, most architects lack the time and knowledge to check the engineers' work for maximal energy efficiency. More likely to be checked is whether ducts fit the structural layout, equipment fits the spaces reserved for it, and sometimes, for indoor air quality, that air intakes are not located over garage doors or trash bins (a surprisingly common and often-litigated error). What is inside the black boxes specified by the engineers is seldom of much interest to the architect.

DESIGNERS' CONCERNS ABOUT LIABILITY ARE MOST EASILY MET BY OVERSIZING EQUIPMENT.

Moreover, designers' concerns about potential liability are most easily and safely met by over-sizing equipment at the client's expense: the designers will pay neither capital nor operating costs, but know they could be sued or lose clients if occupants are uncomfortable.[29] Liability litigation leads to defensive design and institutionalized conformity: the usual legal test is whether the designer's judgment was reasonable "within the norms established by the judgments and practices of other qualified professionals."[30] If the test is conformity to ordinary peer practice, then departing from the lowest common denominator invites an added responsibility to assume the burden of proving that such divergence was justified. The designers know, too, that if they do anything unusual, their superiors or colleagues will want to change it back to the safe and familiar. Nobody wants hassles with code officials; that delays approvals and irritates clients.

The designers' payback horizon, where they have any at all, is usually two years or less and seldom takes credit for potential downsizing or elimination of equipment. Finally, if they do save any cost, they get to keep none of it. Very rarely are they assured of any financial reward for saving energy; they see in it only cost and risk for which the possibility of an ASHRAE award or other kudos is scant compensation. The U.S. Office of Technology Assessment summarizes:

> It is usually easier for the designer to follow accepted, standard practice, especially if the designer's fee is the same in either case. As one interviewee said, "The path of least resistance does not include energy innovative design."[31]

Design professionals' fee structures

Another key challenge is breaking through the perverse incentives faced by the design community. Traditionally, U.S. engineers' competition was supposed to be on design qualifications only, not price, although their absolute ethical bar on price competition (or even on quoting a price before selection) was removed in the 1970s under heavy pressure from Federal antitrust litigation alleging restraint of trade. Even so, selection of consulting engineers is still supposed to be predominantly, if not overwhelmingly, based on professional qualifications. It seldom is.

Unfortunately, those who *procure* engineering and other design services are heavily cost-driven and do not happen to subscribe to the same ethical principle: as a classic text states, "No code has ever been written by clients outlining appropriate ethical practices toward the consulting engineer."[32] This is especially true in the non-Federal public sector, where special courage and justification are needed to deviate from procurement based on pure cost.[33] Even where qualification and price proposals are submitted in separate sealed envelopes, the presumption that the price envelope will not be opened until contenders' qualifications have been evaluated and ranked is "often violated."[34] Price competition

> . . . is likely to involve a form other than open bidding. Thus clients face the dilemma of balancing qualifications against price—an evaluation that is difficult, if not impossible. . . . The hazard of selecting consultants on a price basis is that clients are less likely to receive the high-quality professional services to which they are entitled. This is because professional services cannot be effectively specified either as to quantity or quality. . . . Unfortunately, no one has yet devised a quality control system capable of measuring professional performance. . . . When a consultant is selected at a bargain-rate fee, corner-cutting is inevitable unless a loss on the engagement is accepted. . . . [This] takes the form of using less staff time or assigning less qualified professionals and technicians whose compensation levels are lower. When this occurs, performance suffers. The degree of care and creativity drops. Fewer alternatives or solutions are examined. Plans and specifications are less complete and thorough. Quality suffers because less time is given to checking and reviewing engineering work. . . . [C]onstruction cost may be excessive because of . . . inefficient design. Life-cycle costs may be excessive because of inadequate attention to design factors affecting operating costs. . . . The result inevitably is second-rate engineering.[35]

Another, similar commentary confirmed:

> Engineering involves comparison of alternative solutions and choosing the best to meet a customer's particular needs. Often, the low-cost provider [of engineering services] is not allowed time to make these comparisons, and the customer gets a cookbook approach.[36]

Even if design services are procured largely or wholly on qualifications, post-selection negotiation of fees is highly competitive. A relentless effort to drive down design costs has tended to level and standardize them at or, usually, below the "typical" fees shown in tables published by groups other than U.S. engineering societies, which can no longer legally do so.[37] Firms that do more and better work at higher-than-standard costs very often do not get the job, and if they do, they are likely to lose money on it unless they have an unusually generous and foresighted client who fully values such exceptional services.

Price competition thus creates a widespread tendency to buy, accept, and expect the lowest common denominator—"catalog engineering," which is not really engineering at all, but only the application of crude and outmoded rules-of-thumb to selecting common listings from major vendors' catalogs. *This procedure is at the root of today's appallingly low mechanical-system efficiencies.* Good engineers are not happy about it: in a recent survey of the largest U.S. engineering firms, one of the most common complaints about the state of the profession was the difficulty of being properly and adequately compensated for careful design by buyers who procure design services largely by price and compensate all designers too meagerly, creating unconscionable risks for everyone.[38] A recent professional-practice forum reflected the "high level of frustration within the engineering community"[39] with such comments as these:

> Engineers all over have more pressure because owners want buildings . . . faster and cheaper . . . Owners are decreasing the amount they are willing to pay for engineering. Therefore, engineers are not always able to complete drawings and specifications to the level they should be developed . . . In many instances, a design professional is caught in a bind. He cannot do everything for the fee he is getting, so he farms out the specifications, having respective contractors and vendors do a lot of design that heretofore he may have done himself. . . . Projects are put up for competitive bid rather than qualifying an organization and working with that organization to determine what is required to do an adequate design.[40]

In these circumstances, unimaginative work, often based on simply copying what worked last time, is inevitable. This unwanted result flows logically from the incentives designers see. Clients get what they pay for. In this case, they are paying for, and getting, plain Vanilla. If they are lucky, they get Vanilla with Almonds. But they do not get Rainforest Crunch or other premium flavors, because they didn't ask for it and didn't reward its provision.

Perverse incentives inherent in fee structures

The reason for this unintended result is not only the inadequate level but also, in many instances, the perverse *structure* of engineering fees. Until the mid-1970s in the United States, and to this day in Europe, most of Asia, and most other regions, *engineering fees have been customarily based on a percentage of the capital cost of the project, subcontract (*e.g., *electrical or mechanical), or equipment installed.* A typical set of percentage-of-cost fee curves is shown in **Figure 2**, taken originally from a 1972 "Guide for the Engagement of Engineering Services" published by the American Society of Civil Engineers.[41] Similar curves were published by the organization through the early 1980s and are still widely published abroad, *e.g.,* by the Federation Internationale des Ingenieurs Conseils.

This percentage-of-cost basis specifically rewards oversizing, and since oversizing is assumed in rule-of-thumb costing, it tends to fit within the capital budget expected by the owner. Not surprisingly, given this reward structure and the completely asymmetrical tendency to avoid potential liability by oversizing, two HVAC experts state that "oversizing of pumps and air handlers is pervasive and represents by far the largest source of inefficiency in HVAC systems."[42]

Yet the perversity of this kind of fee structure goes far beyond an oversizing incentive; it goes to the very heart of the quality of engineering that clients want, reward, and get. Designers who do extra work to design and size innovative HVAC systems exactly right, thereby cutting their clients' capital and operating costs, are directly penalized by lower fees and profits as a result, in two different ways: they are getting the same percentage of a smaller cost, *and* they are doing more work for that smaller fee, hence incurring higher costs and retaining less profit. They also capture none of the energy-cost savings themselves. As one mechanical engineer said of an ASHRAE-award building he engineered under a percentage-of-cost fee, "We worked very hard, innovated, saved the client half a million dollars' capital cost and most of the energy, thereby cut our fee, and lost our shirts. We had negative motivation to do it right."

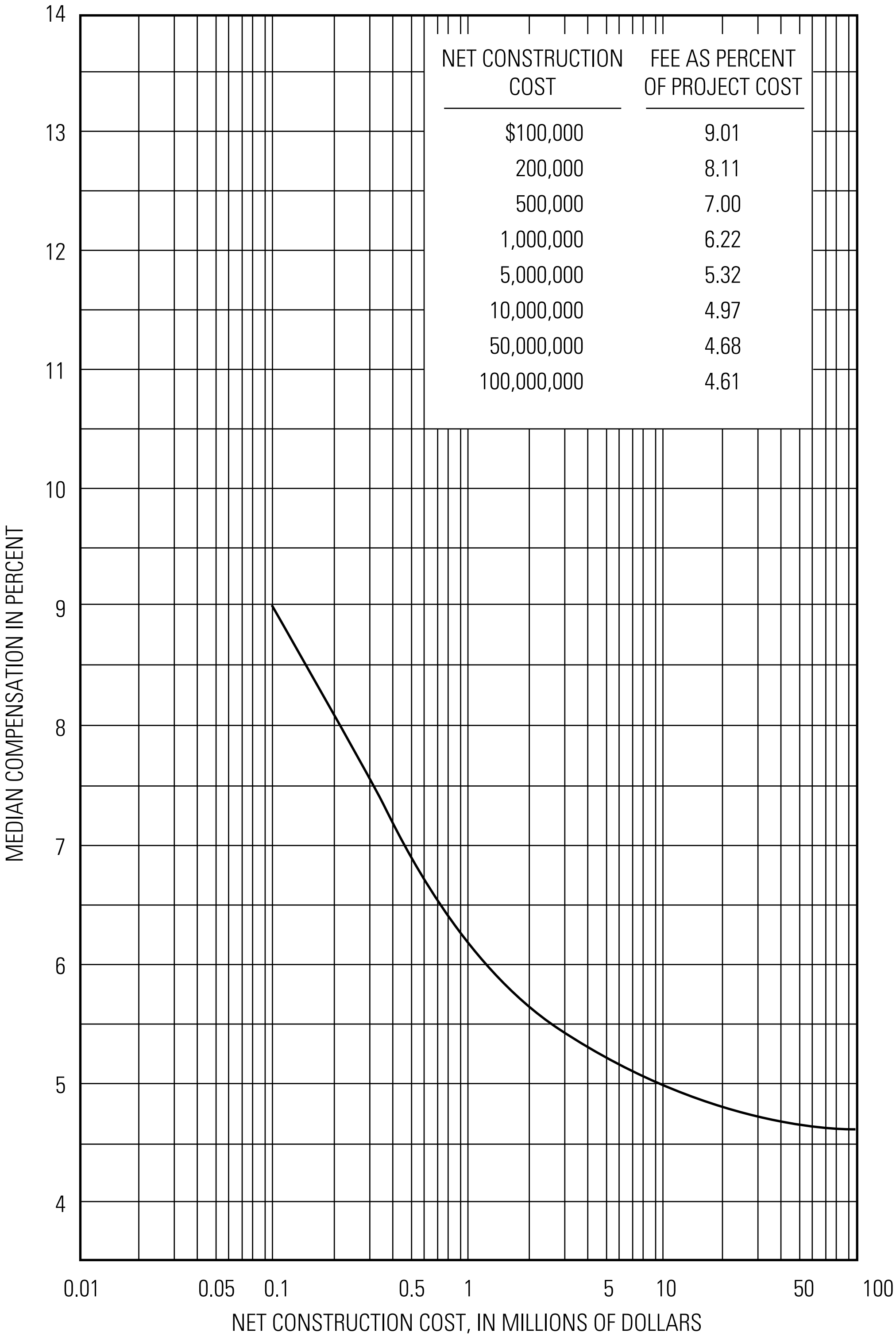
In many engineering contracts in the United States today, matters might at first appear to be seldom this bad. To explain this requires a brief excursion into the history of engineering fee structures. Almost all U.S. consulting engineers used to bid their services as a percentage of cost, on a sliding scale depending on project size and complexity, until the Environmental Protection Agency around 1973 banned this practice because it was believed to result in "gold-plating" of wastewater-treatment plants. Meanwhile, starting in 1971, U.S. Department of Justice antitrust actions against the professional associations of designers made them stop publishing typical percentage-of-cost curves or in any other way discussing or recommending particular levels of fees. To all outward appearances, percentage-of-cost fee structures went out of fashion, being largely displaced by lump-sum and hourly (*e.g.*, cost-plus/not-to-exceed) fee structures.

Today, the leading U.S. consultant on design fees believes that only ~7–10% of all U.S. mechanical engineering services are bid and contracted for on a percentage-of-cost basis, although this fraction is much higher (even 100% in some cases) for certain kinds of buildings.[43] Other common bases are lump sum (firm fixed price), time (including profit)

Figure 2

Median Compensation for Basic Engineering Services: 1972

(expressed as a percentage of construction cost for projects of "average complexity")



NET CONSTRUCTION COST	FEE AS PERCENT OF PROJECT COST
$100,000	9.01
200,000	8.11
500,000	7.00
1,000,000	6.22
5,000,000	5.32
10,000,000	4.97
50,000,000	4.68
100,000,000	4.61

Source: American Society of Civil Engineers, Manual No. 45, 1972.

plus expenses, cost-plus-profit, and retainer, with many of the time- or cost-based fees capped by a not-to-exceed clause. The percentage-of-cost fee structure has the merit of simplicity; is relatively predictable (since project costs are usually fairly stable); provides some protection to the client against unbudgeted costs from change orders; demands no detailed documentation or audit of the consultant's time and costs; and has a more or less built-in correction for monetary inflation.

ENGINEERING FEES REWARD OVERSIZING.

On closer examination, however, what has changed is *only the outward form* of the fee structure, not the calculation or psychology underlying it. Regardless of the apparent contractual form, both the designer and the procurer of design services still generally base their fee *negotiation* on percentage-of-cost curves, just as if nothing had changed. In low-rise office projects, for example, 70% of U.S. designers estimate their fees as a percentage of project cost, even though only 15% bid them in that form; for low-rise hotels, 100% *vs.* 50%; for apartments, 50% *vs.* 5%. Even when negotiating fees with Federal agencies that must select by qualifications rather than price, the designers generally know what the client considers a "typical" fee, and may even have obtained the agencies' internal cost curves under the Freedom of Information Act.[44]

Many experienced mechanical engineers have confirmed to E SOURCE that their normal practice is to take the percentage-of-cost-curve fee level as the maximum the client will tolerate, divide by the auditable hourly billing rate to obtain the number of hours, bid accordingly, and negotiate downwards as needed to keep the job. (Services such as value engineering, commissioning, etc. also get unbundled and negotiated separately, partly as a way of making the total fee more nearly adequate without seeming to go above the typical-fee curve.) The resulting fee ceiling is likely to equal, or to exceed only trivially, the actual fee finally billed.

Much the same is often true when consulting engineers negotiate fees as subcontractors to architects, who do not want to share more of their own design fee than they need to—especially if they have underbid in order to get the job in the first place in today's intensely competitive market. Indeed, some engineers believe that many architects are more willing to compromise engineering quality than the owner would be if the consulting engineer were working directly for the owner. In recent years, consulting engineers have often contracted directly with owners, both in hope of faster payment and because some architects believed this might relieve them of responsibility for potential liability for engineering problems. Both hopes have proven largely illusory, coordination between architects and engineers has suffered, and direct contracting has benefitted nobody; nor has it yielded fees sufficient to support whole-system engineering.

Percentage-of-cost bidding remains the norm throughout almost all of Europe and Asia, where the typical-fee curves are still officially published just as they were in the U.S. 20 years ago.[45] While this officially sanctioned uniform pricing is being reexamined in a more competition-oriented Europe, much as it was in the U.S. during the 1970s, one can infer that even if displaced, it may continue, also as in the U.S., to exert an unseen and powerful influence on behavior just as if it were still in place.

In summary, in almost every part of the world today, percentage-of-cost or its functional equivalent (such as dollars per square meter) dominates design clients' reviewing and budgeting functions and designers' compensation and behavior. It underlies how most lump-sum and other non-percentage-basis fees are still derived and negotiated in practice. Therefore, higher energy efficiency

> . . . has created a dual squeeze on the engineering-design profession by decreasing cost and size of the equipment installed in a building, thus lowering our available fees, while at the same time demanding a significant increase in the amount of engineering required to properly design, specify and assist the contractor in understanding the design. . . . Education of our ultimate clients is imperative so that an understanding of why engineering must have higher fees than the traditional architectural fee schedule allows is necessary if engineering as we know it is to survive.[46]

2.6 SUBSTITUTION OF PACKAGED UNITS FOR DESIGN

So far we have discussed the design process as if it actually occurred. But in a large and rising fraction of commercial buildings, even this assumption is incorrect, because design has vanished into the pages of packaged-unit equipment catalogs.

Custom-designed central chiller systems were used in about half of pre-1960 U.S. commercial HVAC installations, but by 1987–89 that fraction had fallen to only 22% (though it was still two-thirds in the biggest buildings). By 1989, *only 27%* of cooled U.S. commercial floorspace was in buildings with central chillers.[47] The faster the turnover of real-estate and its conversion from one use to another, the greater the apparent incentive to use packaged units. As in the residential sector, therefore, packaged units containing all mechanical equipment are simply plopped onto the roof or next to the building. They are sized in principle according to computed loads, but in practice often according to tons-per-square-foot rules-of-thumb, plus usually excessive safety margins. In this alternative process, all specification except for the size, number, and placement of the packaged units and their distribution piping and ducting is left to their manufacturers. They in turn have the standard incentive of most original equipment manufacturers—to substitute operating cost for capital cost—with the unhappy results described in §6.5 of *The State of the Art: Space Cooling and Air Handling*.[48]

2.7 CONSTRUCTION

The construction contractor and subcontractors can have a major impact on the energy efficiency of a building. Like other parties, they are interested in their profit margin on the job, in staying within the schedule and budget, and in maintaining acceptable quality. They want to buy familiar components from known and preferably local vendors, get them on time, and install them in the way they're used to. Given these pressures, contractors will sometimes substitute inefficient for efficient equipment—not out of malice but out of force of habit, technological ignorance, wish to save money to make up for a cost overrun elsewhere, and desire to fulfill the contract expeditiously. The fixed budget and schedule discourage innovation and encourage reliance on the familiar. Designers often rubber-stamp such substitutions rather than cause a delay.[49]

Persistent anecdotal reports indicate that contractors to whom the "or equal" specification gives considerable flexibility in brand choice, and to some extent designers too, can be subjected to improper influences (small gifts, free travel[50], and rebates or other preferential pricing[51], shading into kickbacks, commissions, and bribes) by equipment vendors eager to see their equipment chosen. In some parts of the world, such ways of doing business are notorious, but they are not unknown in major industrial countries, despite heavy penalties for those caught in such corruption in countries such as the United States where it is flatly illegal. Its extent could be considerable but is unclear and controversial: honest informants are unlikely to have been solicited, while dishonest ones wouldn't admit it.

The contractor and subcontractors, though they have great practical knowledge of installation, are unlikely to know or care much about the theory of how the building systems work and interact, so they will occasionally resolve problems in ways that meet their needs, not the designers' or clients'. If a pump isn't readily available from a certain vendor or in a certain size or type, the handiest one may go in, and it may well be larger, because the installer, too, wants protection from liability for undersizing. If a duct doesn't fit, it may be made to fit, no matter what the cost in air resistance.

Some installers cannot even be relied upon to obey the drawings: designers who draw a duct in an unusual but superior location may have to order it ripped out of the wrong but traditional location and reinstalled. More likely, the designers are back in their offices, working on a new project, and will never get or check as-built drawings to see the difference between what they wanted and what was done. The onsite construction managers are there to represent the owner's and designer's interests, but are seldom acquainted with the subtleties of innovative mechanical design. And once the mechanicals are buttoned up behind walls and ceiling (which happens quickly at that late stage of construction), out of sight is out of mind.

2.8 COMMISSIONING

The people (if any) responsible for commissioning a building and training its operators often inherit a schedule that is already late. They want occupancy and they want it now: the project is eating interest but yielding no revenue. What matters at this stage is the punchlist: meeting code, ensuring adequate initial comfort, getting signatures, getting occupancies, and getting out. The builder's or owner's commissioning team is seldom knowledgeable about, interested in, or rewarded for how efficiently the building is "tuned" and whether the operators understand the subtleties of operation and maintenance. If the team encounters a problem, such as an indoor air quality problem, it usually adopts the handiest and fastest solution, such as disabling fanspeed controls to ensure maximum airflow at all times. Design flaws, unforeseen interactions between devices, and fundamentally inadequate control systems are often encountered at this stage, when it is too late for any but superficial and cosmetic solutions. In many cases there is not even time for proper diagnosis.

OPERATING PROCEDURES FOR BUILDINGS' ENERGY SYSTEMS ARE RARELY DOCUMENTED.

Sound, thorough, and clear documentation of how the building was designed and how to run it optimally is also rare.[52] Many building operators are lucky if they get more than the most cursory and ill-informed training on how control systems really work and what maintenance points are critical to performance. They are then likely to disable whatever they do not understand or cannot make work, making the system default to simple, manual, and suboptimal operation. And the tenants, who can influence the building's behavior as much as the operators, are practically never given a manual or operating instructions.

It is virtually unheard-of for any HVAC equipment vendor to take responsibility for the performance of a total HVAC system in terms of measured, onsite, real-world system kW/t. Manufacturers of *components*, such as chillers, rarely even guarantee in writing their products' *onsite* fulfillment of their specified kW/t ratings (in one engineer's widespread Asian experience, only York would do so). It is nearly as rare for system operators to have and use adequate and accurate monitoring devices to record the components' or systems' energy performance in a way that could support comparison with the specification. Without such monitoring, warranties are unenforceable even if proffered.

Much HVAC equipment—certain cooling towers, for example—often fails to meet its specified capacity and efficiency ratings. Without careful measurement, however, nobody can tell, especially since such equipment is typically oversized.

Moreover, cooling towers are typically sold at a "nominal" design rating.[53] One authoritative vendor of built-up towers who is often retained by utilities to explain these matters to customers states that he has *never* known a mass-produced cooling tower to meet its capacity specification. Most manufacturers, he says, rely on the need to correct actual to nominal wetbulb temperature in lieu of direct measurement, and sell "nominal" cooling towers in the same sense in which lumberyards sell "nominal" two-by-four-inch lumber that is actually much smaller. The dictionary definition of "nominal" is "in name only . . . relating to a designated or theoretical size that may vary from the actual." Such "nominal" ratings can also be found in other kinds of HVAC components, and are standard with evaporative cooling equipment, which unscrupulous vendors may rate as if the fan had no ductwork static head to work against. Few designers, fewer contractors, and virtually no owners are sufficiently alert to such subtleties.

2.9 Operation and monitoring

Poor operation often undercuts the value of efficiency measures that survive design, construction, and commissioning. This little-noticed, unglamorous "back end" of the process is at least as important as the previous stages, because *an inefficient system well run will often work better than an efficient system poorly run*. But the building operators probably never met the architect or mechanical engineer and don't understand their intentions. The operators, too, don't use energy but only control it; the energy is *used* by tenants, janitors, HVAC designers, and others over whom the operators have no control.

This problem is of special significance for utility demand-side management programs. Even the best such programs, which track efficiency measures through construction and commissioning phases, are ill-equipped to provide ongoing support to assure that the equipment is run properly.

Commercial building operators are paid to minimize complaints to themselves and their bosses. They try to make things work (or at least seem to work sufficiently to resolve complaints), not to make them efficient. The controls that the operators manipulate were designed and are run to try to make people comfortable, not to save energy, and if the operators think (rightly or wrongly) that these objectives conflict, comfort will win every time. Comfort theory suggests that at least 5% of the people even in a thermally uniform building will *always* be uncomfortable, simply because people differ so much, and the actual figure is often much higher. Nonetheless, complaints by one or two individuals may still drive changes that affect the whole system:

> It is thus rather common for operating personnel to change the temperature level simply because of complaints from individual persons in a large group. These particular persons will perhaps then be satisfied, but on the other hand, others will become dissatisfied. Even a larger number than before may complain, if an optimal condition existed previously. Complaints cannot be avoided . . .[54]

The operators are very unlikely to have good training or intuition about how to optimize the behavior of all the building systems in their intricate ballet of invisible interactions. Efforts to optimize particular subsystems, such as the chiller or the central air-handler, may make the whole building work worse, but lacking benchmarks, lucid displays, and optimized software, the operators can't tell.[55] The operators' compensation is typically a small fraction of the value of the energy costs they influence—in a 100,000-ft^2 office, perhaps about one-fourth (~$40,000 per year *vs.* $160,000 per year)—and is seldom augmented by bonuses based on cost savings achieved.

Only a handful of mechanical engineers worldwide ensure that their HVAC systems are equipped with ample, high-quality, well-calibrated sensors and with the hardware and software needed to collect and archive operating data and to present them to building operators in an operationally useful form. This is not the same as simply installing an energy-management system: for lack of adequate sensors and software, many such systems are in practice little more than glorified dataloggers or timeclocks.[56]

HVAC systems worldwide suffer from a pervasive, indeed a nearly universal, lack of high-quality monitoring. Without good data on how systems and components *actually work*, understanding of how best to improve them remains limited, and one is treated to the unedifying spectacle of eminent engineers debating matters that should have been empirically settled decades ago.[57]

2.10 Post-occupancy evaluation

Similar ignorance pervades our understanding of how well building *occupants* think the buildings work and how, specifically, to improve them. "Post-occupancy evaluation" using in-depth interviews and technical monitoring is a surprisingly novel concept to at least 90% of developers: tenants' degree of satisfaction is most commonly inferred from the highly aggregated and imprecise metric of lease renewals. Although organizations like BOMA

> BUILDINGS ARE NORMALLY DESIGNED WITH NO CUSTOMER FEEDBACK.

conduct simple attitudinal surveys, and the Environmental Design Research Association[58] uses more sophisticated techniques, real-estate developers remain astonishingly isolated from direct and detailed customer feedback, and any system without feedback is likely to make mistakes.

There is a disturbing analogy between how buildings are made and how, for example, cars were made in the United States before the threat of Japanese competition came to be taken seriously in recent years. Cars, like many U.S. manufactured products, used to be designed with minimal customer feedback: to be sure, there was market research (chiefly on styling and options), but automakers did not include salespeople with intimate customer knowledge in the design team, as Toyota now does; nor did aircraft manufacturers include ground maintenance staff and flight crews in the aircraft design team, as Boeing now does. Including in the design process those who in various ways *use* the product yields many surprising and valuable lessons.

Modern, successful manufacturing businesses routinely integrate into their design process the whole range of their capabilities and markets, all the way from research scientists to ultimate customers. But this kind of responsiveness and integration is not yet even a dream for most real-estate developers. The building industry is in this sense quite primitive: we would not dream of running a manufacturing business with so little and oblique contact with our customers, and if we tried to, we'd soon be out of business. But that is what the building industry tries to do with its complete disjunction of design, manufacturing, marketing, sales, delivery, repair, and renovation or demolition.

2.11 MAINTENANCE

Commercial buildings' maintenance staffs are complaint-driven. They solve problems. They are often paid whether they work or not, but they're seldom idle, because all buildings have problems. (To paraphrase entrepreneur/author Paul Hawken's remarks about businesses, bad buildings have dull problems; good buildings have interesting problems.) If a ballast has burned out and the lights have to go back on, whatever ballast is handy is likely to be

MANY BUILDINGS ARE FULL OF HALF-DEAD ZOMBIE CONTROLS; IN THE NIGHT THEY ARISE AND WALK.

installed. If disabling some mechanical control—say, a fan-control stop or thermostat setpoint or chiller reset—might provide comfort to those complaining of discomfort, disabled it will be. Parts of the control system still work as planned, other parts don't. Soon the building is full of half-dead zombie controls. In the night they arise and walk. The building starts behaving in bizarre ways never contemplated by its designers. This ghostly infestation causes still more complaints and more well-meant meddling with an increasingly unpredictable and undocumented system. Conversely, routine calibration, testing, and maintenance fall to the bottom of the list of priorities.[59]

All too often, where energy costs are tracked at all, money spent to save energy is accounted for as a cost to the maintenance department, while the resulting saving is credited somewhere else. To the extent innovative systems require more commissioning, fine-tuning, and operational attention, "The costs to the operator are in the form of increased complaints [while the] . . . chief benefit, reduced energy costs, typically flows to the . . . owner and not to the operator."[60] In fact, the operator may never see the meter readings or the energy bills.

In addition, maintenance staff are seldom trained in modern digital electronics and software. They know valves and steam traps. They are good at sweat joints, bearings, and filters. Many of the older school, however, say bad words when they open a black box and find it full not of relays but of microchips. And though they are typically resourceful people, able to master new technologies, they are seldom equipped or empowered to do so, so their self-image inadequately reflects their latent talents. Especially common, and offensive, is the experience of the facilities manager for a big commercial complex, who with ill-concealed irony remarked, "We simple folk who operate and maintain systems are given state-of-the-art equipment to operate, and when things don't go well we are frequently told we don't know what we are doing."[61] The more such humiliations operators experience, and the less credit they are given—or, accordingly, give themselves—for being as smart as they are, the more wary they will be of further innovations. As Mark Twain remarked, a cat that sits on a hot stove lid will not do so again—but neither will it sit on a cold one.

2.12 SUPPLIERS

The vendors who customarily supply replacement parts such as lamps, cleaning supplies, etc. to the maintenance staff have little incentive to research, procure, and stock unfamiliar items. They want to keep on selling what they have and know. Some new products could actually harm their trade—people who use imaging specular reflectors buy only half as many fluorescent lamps to go under them—so vendors may discourage competing products that save customers' dollars and energy at the expense of their own sales.

Vendors' incentives form an especially unhealthy combination with those of purchasing departments, which often do not know which specifications are critical. Purchasers tend to care about price, delivery time, familiarity, and perhaps warranty—not about efficiency, maintainability, longevity, or detailed engineering compatibility with other parts of a complex system. They are responsible for a capital budget, not operating budget or comfort. Just as poetry, in Robert Frost's definition, is "what gets lost in translation," so even the best mechanical designs can get garbled into meaninglessness by specifiers and purchasers. But vendors have no incentive to ask if what they are being asked to supply is what the designers really wanted: even the most conscientious vendor knows that asking too many questions may delay or lose the sale.

2.13 LEASING AND SALES

Commercial leasing brokers aren't energy experts and most don't expect their clients to be interested in energy either. Few know how energy efficiency can help them make deals. Brokers do deals for commissions. When preparing a *pro forma* for prospective tenants, brokers usually use rule-of-thumb energy costs, not actuals or building-specific projections. Efficient net-leased buildings therefore get no credit for costing less to run, while inefficient buildings aren't penalized in the market. Actual energy bills may even be hard to inspect; there are hardly any commercial-sector "truth-in-renting" energy-disclosure rules as there are for rental housing in many jurisdictions, and even if you can get the data, there's no local average or range to compare your building against. Although in principle the various building owners' and managers' associations can help greatly to collect and report such data more fully, consistently, and usefully than they do now, their membership may not think it is desirable to create better ways to force building owners to compete: tenants have much more interest in this than landlords do.

Both the amount and the structure of rents are negotiable. Most leases provide some, and single-occupancy long-term leases to large corporations provide extensive, rights for the tenant to modify the property. The result is a set of arrangements of often byzantine complexity. Energy costs and the incentives that affect their reduction tend to get lost in the shuffle, taken for granted by all parties; they can be negotiated about, but tricky questions such as assigning residual value after the lease expires will be resolved largely according to the tenant's bargaining power and persuasiveness. Above all, landlords will want energy-billing and -saving arrangements that do not look strange, do not need arcane explanations to tenants or brokers or accountants, can be smoothly administered by low-level bookkeepers, and will not generate tenant disputes.[62]

The incentive structure of parties invisible to the tenant may affect the efficiency of the lease arrangements. Leasing agents, for example, are typically paid a commission based on fixed rent, so they have an incentive to capitalize more items into the lease, while property managers are traditionally compensated with a percentage of gross income including passthroughs, so they have an incentive favoring both higher operating expenses and higher fixed rents incorporating added investments. Property-management supervisors may have an incentive based on net operating income, but may not handle leasing and often contract it out to another firm. And if the property is part of an investment manager's portfolio, that manager's incentives may be completely divorced from anything related to energy efficiency: *e.g.*, they may seek to maximize current cashflow, market value, or account activity.

Many commercial leases, too, are still written on a "gross" basis (*i.e.*, they include energy and other operating costs in a total rent figure), giving the tenant no incentive to save even though the landlord could in principle keep the saving. "Net" leases reverse this problem to the extent that energy cost components, typically for lights and plug loads but sometimes also for space-conditioning, are individually metered and billed. Neither lease form, as conventionally written, gives *both* parties an appropriate incentive to save. Both commercial and residential leases, in short, typically split incentives between tenant and landlord (why should I pay to fix up my landlord's building? or why should the landlord invest to save energy that the tenants pay for?), so money-saving and value-enhancing improvements often don't get made.

In surprisingly many places, such as New York City and parts of Singapore, commercial landlords customarily mark up tenants' utility bills by a fixed percentage and treat them as a significant profit center, giving the landlord a specific incentive to *oppose* energy efficiency. And since turnover in much rented commercial space is rapid, those choosing tenant-finish equipment, such as lighting systems, will often be especially sensitive to capital but not to operating costs.

Obstacles in residential markets are analogous, with an obvious split incentive between builders and buyers. About 35% of U.S. housing (compared with one-fourth of commercial-building floorspace) is rented. In nearly half of the rented housing, energy bills are paid through the rent rather than directly, removing any incentive for savings, while in the rest, the landlord has no incentive to save either.[63]

In the U.S. market, Fannie Mae and Freddie Mac (FNMA and FHLMC, the two Federally chartered secondary mortgage marketmakers) do offer "energy-efficient mortgages" that relax qualification ratios by up to two percentage points for borrowers with low energy bills. This is perfectly logical, since the increased discretionary income will permit more debt to be serviced from the same gross income with less risk of default. But only some regions actually enforce this provision, few borrowers or agents are aware of it, many mortgage originators do not want to be bothered to fill out the form, and only in spring 1992 did Fannie Mae clarify that the energy advantage was independent and separate from other factors, not to be given with one hand and taken away with the other (by penalizing the borrower with a corresponding adjustment in some other risk factor). The lack of standard energy rating systems in most states greatly contributes to this reluctance to enforce a sensible rule.

Finally, most realtors oppose energy-efficiency rating schemes, because they've never seen a house that isn't energy-efficient: only the degree of the superlative matters (energy-efficient, superefficient, ultra-efficient, etc.) to a realtor trying to market a house, however dubious its actual efficiency.

2.14 TENANTS

Few commercial tenants know or care much about energy efficiency. Notable exceptions exist: in Sydney, Australia, it has become fashionable to compete on how efficient and "smart" one's office building is, and many tenants ask penetrating questions about details of design and efficiency down to the component level.[64] But in most markets worldwide, this is very unusual.

Commercial, and often residential, billpayers are often surprisingly fatalistic about their energy bills unless they have directly experienced major efficiency improvements. Many shopping-mall managers who closely query a $100 invoice for tools or shrubs will unquestioningly sign a $200,000 energy bill every month, as if it were as immutable as death and taxes.

Building occupants can strongly influence mechanical loads not only by their behavior (whether they turn off unused lights and computers, open and close windows and doors, etc.) and their choice of tenant-finish specifications, but also by their choices of the equipment they bring into the building. An ordinarily computerized office can easily use several times as much energy, and release several times as much heat, by using normally inefficient office equipment as by using even modern lighting. Specifying and using office equipment very carefully[65] can reduce a new office building's capital cost by up to $2–3/ft^2 ($24–31/m^2), and, in some cases, can yield electricity savings over the life of the building equal to more than half the building's initial cost.[66] Yet even in build-to-suit and owner-occupier projects, this opportunity is very seldom grasped. In most third-party developments, even if the tenant saves the plug-load energy, the developer and mechanical engineers will generally be reluctant to downsize the mechanicals correspondingly, either because they don't believe the calculation or because they want to ensure that they can cool other, less efficient tenants later. The potentially large (~2–6%) saving in project capital cost will thus be lost, and the oversized equipment may also incur major operating-cost penalties by running even less efficiently than expected.

In multi-tenant occupancies, too, such as shopping malls and non-submetered office space, tenants are often master-metered and charged for energy *pro rata* on floorspace, thus penalizing the efficient: in a case-study New Jersey mall, 58% of store managers never saw their electricity bills, which were sent directly to the accountant or to a central office.[67] Indeed, in many cases no single person may see *all* the energy bills for a multi-use or multi-tenant structure. Even with submetering, the common practice of billing tenants for their own plug loads and perhaps for lighting, but *pro rata* on floorspace for building mechanical energy and all common-space energy (typically about a third of U.S. commercial buildings' total energy bills[68]), fails to reward those whose efficiency in their own space reduces mechanical capital and operating costs for the whole building. Efficient tenants then subsidize their neighbors and landlord. And the annual calculation of passthroughs typically results in a delay of up to 15 months in price signals reflecting changes in buildings' equipment or operation.

In the residential sector, "The perception that energy efficiency requires sacrifice is very persistent and acts as a significant barrier to wider use [and proper operation] of energy efficient technologies."[69] Most people, when asked how they can save energy, respond only with actions that reduce comfort, such as changed thermostat settings; few mention more efficient technologies or their more effective operation. Similarly, "A survey of small businesses found that energy efficiency was thought to require turning down heat or turning off lights, and these were not considered acceptable options, because a cold, underlit store would discourage customers."[70]

3.
REINVENTING THE BUILDING DESIGN PROCESS

Fixing these problems is possible, practical, and rewarding. It would require a combination of education, incentives, and organization, based on an understanding of each of the actors and how they interact. The following sections offer some suggestions for what is really needed: no less than *reinventing the building design process*, and with it, much current real-estate practice. Many of the technological and design elements needed are described in *The State of the Art: Space Cooling and Air Handling* and its sister reports; but without institutional and cultural reform on the following lines, they cannot be widely implemented.

3.1 RESTRUCTURING DESIGN PROFESSIONALS' FEES

The perverse incentives provided by fee structures for professional engineers, which reward inefficient design and penalize efficient design, are arguably the highest priority for reform. There are three obvious ways to remedy the flaws in this system:

- Reform not just the outward form but also the underlying method by which both designers and clients express and negotiate professional fee structures. This is the most basic solution but will not be easy or quick—especially since the design professions, after costly encounters with the U.S. Department of Justice, are reluctant to risk any possible tangle with complex antitrust laws by discussing anything connected to fees. Perhaps a new Attorney General could encourage discussion by issuing an opinion letter that the professional societies may openly discuss fee *structures*, as opposed to fee *levels*, without raising antitrust concerns.
- Educate clients to demand, and alert design firms to tender, two-part fee bids: one term for the normal "plain vanilla" design, plus an incentive term that rewards the designer for cutting energy cost or total lifecycle cost. Some clients and their design selection process may be slow to learn why this is in their interest, but their competitors will soon show them why, by procuring superior designs that outcompete traditional ones. This approach requires no governmental action or approval, and could rapidly distinguish in the market those design firms that successfully apply it first. Under the rubric "value-based compensation," it is starting to attract support within the profession and among building owners and managers.[71]

- Since the majority of U.S. electric utilities, and an increasing number abroad, already pay cash rebates to customers for installing efficient equipment, simply earmark a small part of their hardware rebate budgets for *soft-cost (design) rebates.* Pay those rebates directly to designers according to success, not effort: not how many extra hours they work, but how much lifecycle cost (or energy) they save, verified *post hoc* compared to a baseline such as ASHRAE recommendations, California's Title 24 building standards, or normal local practice. *Post hoc* verification gives the designers an important incentive to follow through and ensure that their intentions are properly executed in construction, commissioning, operation, and maintenance. Since this idea was first proposed at the 1991 COMPETITEK Members' Forum, many utilities have been considering it. The first to launch it, Ontario Hydro, announced in April 1992 that it will pay a rebate—to be shared among the developer (who also needs an incentive to participate and approve), architect, and consulting engineers—equivalent to three years' energy savings. As will be seen, three years' savings can be several dollars per square foot—roughly the same size as the total design fees.

The measured savings upon which design rebates would be based could be corrected for weather, occupancy, etc. using the same techniques already used in many utility programs; indeed, the same measurement would have to be done in many cases anyhow, either for sound utility program management or as a regulatory requirement. The predicted savings used to compute any prepayment of the estimated soft-cost rebate should be based on detailed thermal simulation that takes account of interactions and system-integration effects; perhaps more of the rebate should be paid up front when supported by higher-quality simulations. A "deadband" could surround the zero-rebate normal efficiency level, so that no rebate is earned unless a significant saving is achieved compared with the baseline, although it may be simpler not to provide an incentive for discontinuous behavior. Of course, a desirable side-effect of even just hardware rebates is that utilities' measurement of the savings can motivate, facilitate, and reduce the transaction costs of all kinds of value-based compensation for the designers.

FOR A MODERN OFFICE BUILDING, ENERGY COSTS ARE TEN TO A HUNDRED TIMES LARGER THAN DESIGN FEES.

Design rebates could have extraordinary leverage, because, for example, *the present-valued energy cost of a typical modern office building is ten to a hundred times its total design fees.* Paying the consulting engineers a "royalty" equivalent to, say, an eighth of their energy savings for the first ten years, if as a result they saved 50% of the energy used by a 50-year building, could more than double their fees. That will certainly get their attention in a soft market for design services. It is also closer to a fair reward for their hard work. The Ontario Hydro rebate, depending on its allocation among the parties, could be even juicier. And it in turn could be usefully combined with additional design incentives.

While Northeast Utilities, for example, does not pay an open-ended incentive to designers according to how much they save, it does offer a $1,000/project "brainstorming honorarium" for an initial design charette at the schematic design phase, helps pay for energy performance simulations, pays the estimated incremental design cost of each measure costing up to 2¢ per kilowatt-hour saved, adds a bonus (the greater of $500 or 30% of that design incentive) if the simulated reduction of electric consumption totals at least 20%, and pays additional incentives for both efficient hardware and commissioning services. The design and hardware incentives are subject to a joint cap within which they are traded off against each other. By the end of 1992, about 27 million ft^2 of commercial/industrial space will have been constructed under incentives provided by NU's Energy Conscious Construction Program. Since the program was launched in November 1988, market capture has risen to nearly 40% of all new commercial/industrial construction.[72]

Absent such innovations, most clients will simply never see the superefficient building designs that are possible. An educated and demanding client is not enough; correct incentives are essential too.

3.2 STRENGTHENING THE DESIGN PROCESS

The design process, now dis-integrated, must be re-integrated. To start with, only a fully coordinated, multidisciplinary, cross-boundary design team seems capable of producing exemplary results—and then only if at least one of its members (preferably the team leader but possibly an outside "energy ombudsperson") serves as its "energy conscience" and ensures that cross-cutting issues critical to whole-system performance are solidly addressed. This is most important to do at the very earliest stages of preconceptual and conceptual design: a sound architectural program must rest on a detailed understanding of desired amenity, financial performance, and their relationship. One of the foundations of that understanding is using total present-valued life-cycle occupancy cost as a financial objective function. Very few owners now do this.[73] Another foundation is full involvement of the occupants—actual workers and other users, not just their managerial and financial representatives and superiors—in an inclusive and collaborative goal-setting process prior to setting the program.

3.3 EDUCATING DEVELOPERS AND FINANCIERS

Developers apparently value design services up to two orders of magnitude less than the energy that those designers could largely save them. This suggests an urgent need to educate developers about the effect of energy costs on project economics. For example, only a handful of commercial developers and virtually no commercial lenders, lawyers, investment advisors, and appraisers now appreciate that:

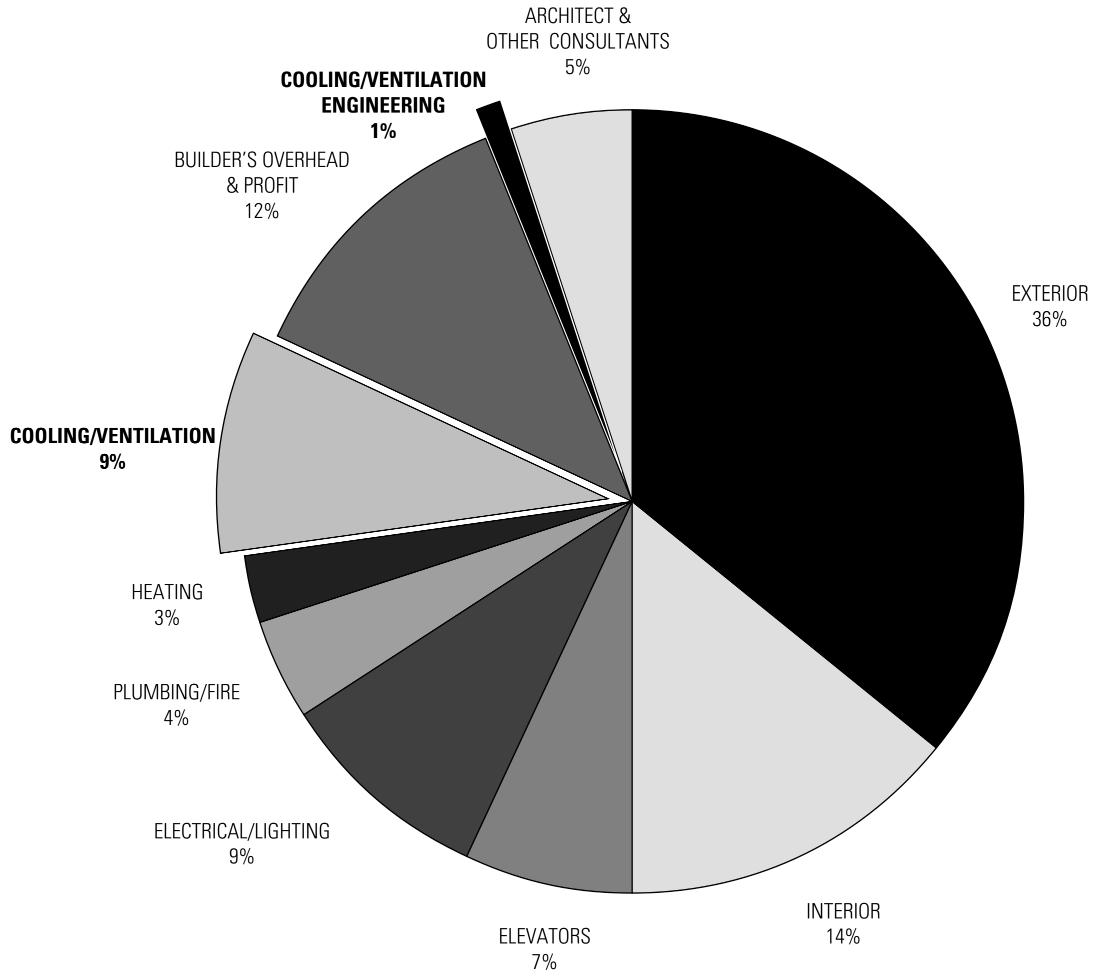
- avoidable present-valued energy costs can be comparable to the building's entire capital cost and can enhance its market value accordingly;
- proper mechanical design and avoidance of unnecessary cooling loads can sometimes reduce project *capital* cost by several percent; and
- even where better mechanical systems do cost extra, that marginal cost may be quickly repaid, at least in owner-occupied buildings, by the gains in productivity arising from better comfort, since the present-valued costs of paying people who work in a building are tens of times the total energy bill, hence *thousands* of times the capital cost of the entire mechanical system. A $1/ft^2 investment in a better HVAC system (or in its design) could be repaid by productivity gains equivalent to 90 seconds per officeworker per day in the first year alone.[74]

EVEN MINISCULE GAINS IN WORKER PRODUCTIVITY WILL OUTWEIGH THE MARGINAL COST OF SUPERIOR HVAC SYSTEMS.

For illustration, standard 1992-$ construction-cost tables for an average United States site (**Figure 3**) show that each gross square foot (0.093 m^2) of a new ~140,000-ft^2 (~13,011-m^2) 15-story U.S. office building costs $86.45 to build.[75] The cooling and air-handling system—mainly ducts and pipes, the rest equipment and controls—contributes $7.62 of this total project cost (*e.g.*, 280 ft^2/t @ $2,134/t), or 8.8% of total project cost—the fourth biggest cost component, and 62% as costly as interior construction and finish. Total design services cost $4.91 (5.7% of total project direct cost). These design fees include ~$1.02 for the mechanical and electrical engineering[76], of which roughly 60%, or ~$0.61 (more like 50% in buildings with complex computer and communications wiring), is estimated to go to the mechanical consultant.[77] Of that, deducting the design costs for plumbing, fire protection, and space heating leaves somewhat under $0.50 for designing the space cooling and air handling equipment. Thus the mechanical engineer gets ≤7% as much to design that equipment as it costs; the mechanical and electrical consulting engineers together are paid only ~2.9% of the 50-year present value of the building's energy costs.

What does this building cost to operate per rentable ft^2-y (noting that some of the categories considered are subsets of others)? Based on a national survey of the stock of such offices for 1990[78], as summarized in **Figure 4**, electricity typically costs ~$1.53 (85% of the total

Figure 3
Construction Costs of a Typical U.S. 140,000-sq-ft, 15-Story Office Building

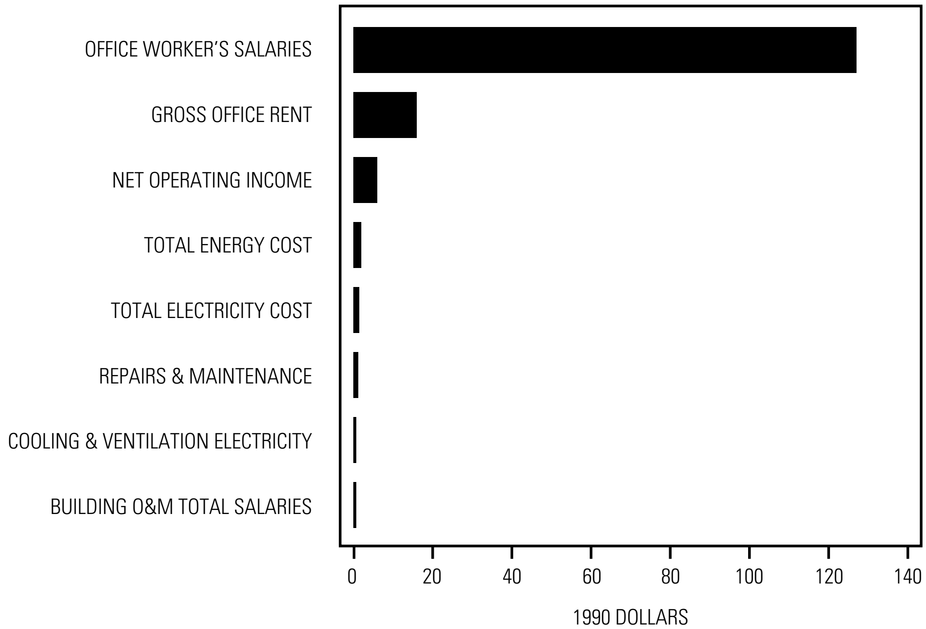


Data from *Means Square Foot Costs 1992.*

energy bill), of which space cooling and air handling account for about $0.61[79]; repairs and maintenance typically add another about $1.37[80]; both contribute to the gross office-space rent (including all utilities and support services) of $15.85. Yet paying the officeworkers costs about $130.[81] Thus *the officeworkers' salaries cost ~160 times as much as the operating cost of the space cooling and air handling system*. This ratio makes it hard for HVAC efficiency to get managers' attention—unless they realize how heavily HVAC effectiveness, reliability, and hence comfort can leverage workers' productivity.

Another eye-opener: although HVAC operating costs are only 0.6% of officeworkers' salaries, HVAC operating costs are 14% of net operating income—the building owner's Holy Grail, as it represents the funds available for debt service and profit. If, for example, debt service happened to represent as little as half of NOI, then HVAC operating costs *would represent 28% of pretax profits*. This leverage can be even higher in some cases. Thus even a small saving in HVAC operating cost can directly and dramatically boost the owner's profits. The boost is

Figure 4
Approximate Operating Costs for a Typical Large Commercial Building
(dollars per rentable square foot per year)



Data from Building Owners and Managers Association; EPRI; *Statistical Abstract of the United States 1991.*

even greater if the owner further leverages the savings by using them to reduce gross occupancy costs in the early years and thus attract more tenants to create more cashflow—a sound strategy in soft leasing markets where gross-rent or passthrough discounts can give the owner a big jump on market recovery.

In this example, the entire capital cost of the space cooling and air handling system that enables the officeworkers to do their jobs is equivalent to only three weeks' worth of their salaries. Even if a superefficient mechanical system cost twice as much as a normal one (which is hardly conceivable, since cost-effective energy savings that reduce cooling loads often make mechanical systems severalfold *smaller* to produce the same comfort), paying for it would therefore require only a ~6% productivity gain. Moreover, leasing and retention, and worker productivity, depend critically on the quality of the HVAC design that was so poorly compensated in the first place: *rental and salary cashflows with a present value thousands of times the initial mechanical design fee can be jeopardized by poor, or secured and enhanced by good, mechanical engineering*. Thus the benefit/cost ratio of superior HVAC design can be on the order of 1,000 or more. In this light, the cost of superlative mechanical design is trivial, while the cost of not doing it can be catastrophic. This is true also of other design fees whose results affect comfort performance.

Even neglecting these critical indirect values of comfort, the mechanical design fee of less than $0.50/ft^2 equals only ~7 months' worth of the *direct operating costs* of the space cooling and air handling system. An experienced energy designer states[82] that the total marginal soft cost of superefficient commercial-building design is typically less than 1% of total project cost. In our example, that 1% extra soft cost would be about 86¢/ft^2. If this resulted in saving 75% of the building's energy, the extra design effort would pay back in less than a year.

Investments in building commissioning are equally cost effective: Canadian and British data suggest that commissioning adds only ~1–4% to the HVAC contract cost[83], *i.e.*, in our example, ~0.09–0.35% of project cost or ~8–30¢/ft^2. Yet not making this tiny marginal investment can sacrifice enormously larger benefits in worker productivity, tenant satisfaction, and leasing income.

Other interesting comparisons revealed by this example include:

- The capital cost of the space cooling and air handling equipment equals ~9 years of its operating cost or ~12 years of its energy cost—in striking contrast to, say, industrial motors, which typically consume their own capital cost's worth of electricity every few *weeks.*
- The salaries of the building's technical (operating and maintenance) staff are about fourfold smaller than the operating costs (energy, repair, and maintenance) of the energy systems under their control.
- Saving ~75% of the electricity (as is being achieved in several current retrofit projects in U.S. offices) would be equivalent to 5% (\$1.15/ft^2-y) flexibility on the rent, offering the owner considerable opportunity for higher occupancy and profit.

These illustrative figures show why it is penny-wise and pound-foolish to underinvest in mechanical design or equipment: even the tiniest resulting loss in workers' productivity or tenants' willingness to renew their leases will immediately wipe out the supposed savings. Complaints of discomfort are the most effective known way to repel prospective tenants and lose existing ones. Complaints of being too hot or too cold top most surveyed tenants' concerns, from America[84] to Australia[85]. In the numerical example above, equipment or operational choices that cut the space cooling and air handling electric bill by, say, 20% (12¢/ft^2-y) through curtailment of service quality rather than through improved efficiency would lose profits for the owner if in consequence the vacancy rate rose by only 0.6%.[86]

In soft leasing markets, developers sometimes compete over rent differences of as little as 10¢/ft^2-y. The operating-cost savings from good mechanical (and general energy) design are on the order of 10–35 times that big. Whichever developer first captures that opportunity, therefore, will have a huge competitive advantage: the saved energy dollars can be used for buildout, initial rent concessions, or other ways to attract and retain wavering tenants, so the early adopters will take market share from their less alert competitors.[87] The cashflow advantage of occupancy cannot be overstated: lost occupancy is forever lost, just like that other most perishable of commodities—airline seats. Educational campaigns being undertaken by some utilities and by other organizations, such as Rocky Mountain Institute, are already emphasizing these points to financiers and to fiduciary investors' real-estate advisors: many wallowing in nonperforming loans for largely vacant commercial properties may find in advanced electric efficiency the key to much-needed market advantage.

Further outreach is clearly needed, however, to some additional key constituencies, such as lenders' counsel, appraisers, title insurance companies, and advisers to fiduciary real-estate investors. If they understood how remarkably sensitive a building's financial performance is to its mechanical design quality and its energy efficiency generally, energy performance would be near the top of their list of due-diligence items. Currently, it's seldom even *on* the list.

3.4 PROFESSIONAL EDUCATION

The professional engineering societies, notably the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), the Illuminating Engineering Society, the American Society of Mechanical Engineers, and the Association of Energy Engineers, sponsor very extensive and often valuable programs of research, standard-setting, publishing, conferences, and other kinds of outreach and education. ASHRAE in particular deserves praise for its noteworthy *Handbook* series, which describe in detail the engineering principles applied and reintegrated in *The State of the Art: Space Cooling and Air Handling.* Yet these societies' efforts tend to consolidate traditional practice rather than "pushing the edge of the envelope" of conventional design. Innovative techniques, especially involving high levels of system integration, are sometimes present but often weak, and buildings selected for ASHRAE awards are generally unimpressive by E SOURCE's efficiency standards. The societies' somewhat ponderous committee and bureaucratic structure are not well suited

THERE
IS NO
"NEGAWATT UNIVERSITY."

to fast-moving technical innovation. Nor is much being done at these official levels to address basic issues such as oversizing, obsolete rules-of-thumb, and the almost universal paucity of authentic engineering optimization. Such organizations can be stimulated from within to do more, and some efforts to this end are underway. But they are most likely to respond vigorously to market pressures felt by their members. The other suggestions made here, such as design rebates, may help to spark livelier internal debate and more fundamental action.[88]

The integration of building energy systems, let alone their other implications (from structure to acoustics to site planning to indoor air quality), is hardly taught at all in U.S., and most foreign, schools of architecture and engineering. There is no "Negawatt University" to which designers seeking retraining can go to study systematically how to save energy. A bare handful of graduate students per year emerge from more policy-oriented programs such as those at Berkeley and Princeton, and almost none of them practice in the design professions. The American Institute of Architects sent an unfortunate signal by dissolving its Energy Committee in 1985, and has since had to start rebuilding those capabilities.[89] A major educational renaissance is clearly needed for designers. It will need to reintegrate the design process and to increase curricular flexibility: current accreditation procedures leave many engineering students, for example, only ~2–3 elective courses during their entire schooling.

3.5 RULES-OF-THUMB

Most fundamentally, design reform will require a frontal attack on the use of rules-of-thumb and a return to classical concepts of engineering optimization. Many of today's rules-of-thumb are obsolete and misleading for reasons such as the following:

- They often assume outdated real electricity prices that are far below today's.
- Rules-of-thumb normally reflect a very high implicit discount rate, corresponding to a payback horizon of about two years. (For a device that lasts 15–20 years, the equivalent real discount rate is 64% per year.) This is about ten times the discount rate used by utilities for the power plants they will normally build if customers remain inefficient and demand keeps growing. To allocate societal resources efficiently, the utilities' ~5–6% per year real discount rate should therefore be applied to the customer's design choices too. Otherwise, the electricity price signal is effectively diluted by about tenfold.
- Rules-of-thumb seldom take account of interactions with and within the HVAC system—for example, that lighting and fanpower add to the cooling load.
- Nor do they count indirect benefits of efficiency—*e.g.*, that more efficient mechanicals can increase net rentable space, increase stories per unit height, reduce noise, reduce maintenance[90], and reduce structural requirements.
- Finally, rules-of-thumb typically assume high cooling loads (in offices, for example, ~3 W/ft^2 lighting, ~5–8 W/ft^2 plug loads[91], and unselective glazings), and hence assume a large, control-hungry, refrigerative HVAC system rather than more passive options. These high loads are themselves uneconomic, but are often considered outside the province of the mechanical designer. Similarly, normal air-conditioner sizing rules-of-thumb implicitly assume very inefficient building shells.[92] High flow resistance in duct systems (static heads around 4-6" wg rather than ≤1.5) and piping systems (~100–180' rather than ~20–30) are similarly consistent with cheap energy and fast paybacks, not with utilities' financial criteria.[93] Wire sizing is implicitly optimized at a few tenths of a cent per kilowatt-hour; it is meant to prevent fires, not to save energy.[94] To avoid these errors, nothing less than full reintegration of all elements of the building's design will do; but this will require significant changes in the role of specialists and of the coordinating architect.

From a societal perspective, rules-of-thumb may still be suboptimal even after these flaws have been remedied so long as utility rates fail to reflect peak-period costs or environmental externalities. Reforming, updating, or even eliminating obsolete rules-of-thumb would be a major change in how designers think and work. This should be a major responsibility for the professional societies. Utilities could encourage them by conditioning rebates on using updated rules-of-thumb or, much better still, real optimization.

3.6 DESIGN TOOLS

Reeducating practicing design professionals will take several decades. At the same time, the technologies and design options for creating efficient buildings will continue to evolve rapidly. It is therefore important for designers to have access to sophisticated but user-friendly expert systems that ask the right questions, in the right sequence, to elicit optimal (or nearly optimal) design solutions. Early efforts at writing expert systems for efficient lighting systems need to be greatly broadened to include plug loads, glazings, other building-shell components, daylighting, interior design, and mechanical design. This will require a major effort and a commitment of resources far greater than those currently given to such centers of excellence as the Center for Building Science at Lawrence Berkeley Laboratory. Now that powerful engineering workstations with advanced graphics capabilities are widespread and affordable, it is also not too early to be thinking about integrating nearly-instant energy simulations with walk-through virtual-reality computer-aided-design (CAD) programs, supporting quick "what-if" option-testing energy calculations for visually-oriented designers.

Unfortunately, the standard toolkit of even the computerized, CAD-equipped design professional is far below this hoped-for standard. While a full discussion of the strengths and weaknesses of building simulation models is beyond the scope of this analysis, it is worth noting here that *none* of the most widely used design tools, such as DOE-2.*x*, BLAST, or TRACE, adequately simulates the detailed performance of mechanical systems or the operation of important alternative and adjunctive cooling methods. This by itself could defeat the intentions of the most enthusiastic designer. It is hard to demonstrate the virtues of, say, a desiccant or a staged evaporative cooling system if one cannot be confident that DOE-2 is modeling it correctly.

3.7 RISK-SHARING AND FLEXIBILITY

Consulting engineers are often unwilling to downsize mechanical systems in response to reduced cooling loads, especially when, as is usually the case, the responsibility for reducing the loads lies with other members of the design team with whom the mechanical engineer has little contact.

Overcoming resistance to downsizing will require several steps:

- Publishers of standard reference works, such as R.S. Means Co. and ASHRAE, will have to revise the presentation of sizing rules-of-thumb.[95] Meant as a convenience, these have become in most projects not merely a substitute for *but a major barrier to* engineering optimization. Time after time, an engineer who judiciously sizes equipment fails to get the job, or has sizing recommendations rejected, because some less informed person infers that their dissonance with rules-of-thumb (often by a factor of severalfold) means they're wrong, not that they improved on those rules' tacit assumptions. Sizing rules-of-thumb are used less by engineers than by estimators, but they still influence the design process indirectly. Many mechanical engineers admit that even if their load calculations show ample scope for downsizing, they are likely to skirt controversy by rounding to the rule-of-thumb sizing and calling the difference a "safety margin."

- Authors will also have to call special attention to the conservatism of sizing rules-of-thumb in today's rapidly changing conditions. For example, many designers are still using the 1989 ASHRAE *Fundamentals* volume as a general technical reference. Yet it gives as "typical," for purposes of sizing residential air-conditioners, a refrigerator/freezer consumption of 4.7 kilowatt-hours per day (1,715 kilowatt-hours per year).[96] This figure, based on a 1981 compilation which in turn used 1980 data, is ~20% higher than the 1992 stock, and ~148% higher than new units sold in and after 1993 are legally permitted to be in the United States. Most of the other assumptions suggested are similarly outdated. Many HVAC texts in widespread use in 1992 are simply reprints of *ca*. 1960–70 editions that barely mention "electric computing machinery"—now the dominant internal load in modern offices—and almost all modern HVAC texts advise using "manufacturer's data" for how much energy office equipment uses, without mentioning that such equipment's nameplate ratings are typically ~2–5 times higher than actual power consumption.[97]
- Tenants and developers who really want to save capital cost as well as operating cost through optimal sizing, and who have designers able to do so, may need to offer concurrences or waivers of liability to increase the designers' (or their errors-and-omissions insurers') level of comfort with the unconventional sizing.[98] (It is also possible that working directly with those insurers could result in useful guidance to their client designers, but E SOURCE has not yet explored this concept.)
- HVAC capacity specified in standard-form lease provisions will have to be specified in leases as appropriate for the actual loads of the specific design, not for arbitrary and absurdly high one-number-covers-all-cases load specifications (§3.13).
- In areas where designers are especially hesitant to incur a perceived liability risk, utilities may have to pay marginal costs of errors-and-omissions insurance for the first few buildings using novel designs, and can help to educate the E&O insurers about modern practice.

Moreover, designers often oversize HVAC systems because of a quite sensible desire to be able to adapt to higher cooling loads, such as might be associated with a change in tenancy. There is, however, a simpler and far cheaper solution: the mechanical engineer can simply specify pads and stub-outs, and size ducts and pipes, so as to accommodate additional chillers and other equipment if they later need to be added. But at least their capital and operating costs are avoided initially, and may be avoided forever. This kind of capacity flexibility is cheap insurance against later changes of use, and for that matter of refrigerant or of global climate. It is a better option than built-in oversizing, and should be both expected and rewarded by clients and financiers.

3.8 DESIGN SUPPORT

Some electric utilities already provide their own design professionals[99], or pay wholly or partly for customers' designers, to improve the energy design of proposed new buildings. This support may be topical, *e.g.* daylighting, or general. Such design support, however, is usually too little and (worse) too late. Too often it is merely a plan-check for a design already done and for a project already on a tight schedule. The time for a utility's designers to have the greatest influence on energy-related features, at the least cost, with the least risk of delay, is in preconceptual and conceptual design. This means that the utility marketing staff must work closely with local development, land-use, and code officials[100] and with trade allies such as realtors and leasing brokers to gain early intelligence of proposed projects. Liaison just with local designers and financiers may not be enough, because projects may use out-of-town resources. The developer's concurrence in the design-support process must be gained when the project is somewhere between a gleam in the eye and an early conceptual design, not when it is already in working drawings and approvals. At such an early stage, full integration between the various designers, including especially the mechanical designer at an early stage, is more likely to be achieved, especially if the architect, engineers, and developer are "sold" design rebates as an incentive to do their best together.

"DESIGN REBATES"
COULD ENCOURAGE BETTER INTEGRATION
OF ENERGY FEATURES.

In small projects—especially in small residential projects, which in the very fragmented U.S. homebuilding industry are often built from packaged or no plans by small builders who do one or a few houses at a time—design support is essential. Small builders often resist energy innovation until they realize how it can help with their marketing, to which we turn next.

3.9 MARKETING SUPPORT

Electric utilities have long helped builders to market slightly more efficient, electrically heated houses through the "Gold Medallion" and "Good Cents" programs, and their analogues abroad. Given new regulatory incentives for demand-side measures, however, some utilities are now developing programs that go much further in encouraging whole-building energy efficiency. The utility's active participation in marketing efficient buildings can help to overcome the initial resistance of builders who believe energy efficiency will raise their costs and hurt their marketing.

In the residential sector, for example, superefficient houses have been successfully showcased by several utilities in the U.S. and Canada. Workshops and written materials are used to introduce concepts and practical details to builders, subcontractors, and realtors. Such programs have had a demonstrable impact on public awareness of efficiency options. For example, effective government promotions made superinsulated designs the norm in most of Saskatchewan during the mid-1980s.

One especially promising alternative is the use of feebates to create direct financial incentives for efficient new housing. When a new house is connected to the electric grid, the owner pays a fee or gets a rebate: the level of the feebate depends on how efficient the house is, and the fees pay for the rebates.[101] The rebate for an efficient new house should be somewhat more than the builder's marginal cost of making it efficient. The builder thus makes a profit off the top. Even a small surplus is an important addition to the builder's usual profit margin.

- Utility programs that support energy-efficient residential design can also lend credence to innovative approaches now being developed by other parties: Builders can market houses by saying, "For the first five years you own this house, I'll pay all the energy bills, no questions asked," or "I'll guarantee you a $100-a-year cap on your electric bill, and if it's higher, I'll pay the difference." (One Montana builder of superinsulated houses originally offered a $50-a-year guarantee. Nobody believed him, so he raised it to $100, and within a few years had captured 60% of his three-county market and had a waiting list from hundreds of miles away.) Perhaps the leading practitioner of this approach has found it highly successful in a competitive Midwestern market for traditional-looking but internally innovative speculative tract houses at modest prices ($65–85,000 for townhouses and $80–120,000 for single-family houses, all in 1992 $).[102] The energy-bill guarantee doesn't sell many houses *per se*, but it generates traffic, enabling sales to be closed on other merits.
- The builder can use energy-efficient mortgages (§2.13) to expand the universe of qualified buyers: in effect, houses can now be sold to buyers with annual income ~20% lower than would otherwise qualify (because the two-percentage-point relaxation of the qualification ratio is leveraged tenfold by the borrowing), or houses costing ~$20,000 more can be sold to the same buyer.
- The "point system" or other approaches used to rate the house's efficiency for purposes of the energy-efficient mortgage[103] can also be used, under local ordinance, as the basis for efficiency labeling on the "FOR SALE" or "FOR RENT" sign. Buyers will then know that, say, a five-star house is likely to regain ~15–25 years' worth of energy savings as extra equity on resale. This knowledge becomes internalized in market value.

The utility's motive, of course, is that it can save ~5–10 times the value of the rebate that induced the builder to make the house efficient in the first place: indeed, the utility can sometimes save, in present value, *more than the entire cost of the house!* Thus everyone wins—most of all the homebuilder and buyer.

In the commercial sector, feebates could have similar effects. They would reinforce strong efficiency efforts by developers not yet convinced that major reductions in cooling loads can cut total capital cost by downsizing mechanicals. This incentive could in turn be reflected in preferential lease arrangements—bigger initial rent concessions, lower rents, etc.—for tenants who undertake to achieve certain targets for maximum power density in their lighting and plug loads, thus supporting the downsizing and the reduction in HVAC capital cost.

In all kinds of buildings, of course, the energy savings would have to be verified, not just estimated. Neither measurement nor renormalization to occupancy, behavior, weather, etc. presents insuperable difficulties or costs to the skilled evaluator today, especially given the low cost of miniature dataloggers. But to simplify verification, utility rebates should require wiring patterns that facilitate submetering, should outlaw master-metering, and should specify mutually agreeable principles for measurement and evaluation. The utility's support in coordinating the design and construction process would also be wise to ensure that systems are well designed, drawn and specified as designed, and built as drawn and specified; otherwise it may be impossible to verify who is responsible for any shortfall (or unexpectedly large gain) in performance.

Finally, utilities have a critical role in helping to market high-efficiency, high-amenity buildings *to tenants* and their representatives. The occupants' business is seldom energy; they need to be sold persuasive reasons to be interested in energy, or at least in the amenity consequences of thoughtfully raising energy efficiency. Utilities that have done exemplary retrofits of their own headquarters and branch offices first will of course find this sale easier to make, because their own employees will have experienced the benefits firsthand, and others will be able to come visit the retrofitted buildings and "kick the tires."

3.10 PERFORMANCE CONTRACTING

Over the past two decades, entrepreneurs and some utility subsidiaries have taken advantage of the high rates of return available through energy-saving retrofits by offering their customers a variety of turnkey packages combining engineering, installation, and financing. Under many of these "performance contracting" arrangements, the energy service company recoups its investment by receiving an agreed share of the saved energy costs for a stipulated contract term. The contract can even provide the building owner with *no up-front investment requirement and no risk*—by guaranteeing a positive cashflow, laying off technical risks onto an insurance company, and structuring the contract so that the energy service company gets paid less per year but for more years.

The difficulty with many of these arrangements is that transaction costs, including marketing, contract negotiation, and measurement and verification, have often driven costs far above those the customer would have incurred by doing the retrofit unaided. The share of savings needed by the energy service company can then become 80–90%, removing much of the customer's incentive to enter the contract. Moreover, inferior choice and integration of technologies frequently led to payback periods and hence contract terms longer than the typical tenure of the customer's staff dealing with the contract, so some deals foundered on the need to keep explaining to new customer staff why the contractor was still being paid. Litigation could then eliminate the profit. And too many energy service companies thought they were selling a transaction rather than a relationship from which the customer needed to derive clear and continuing value.

In recent years, performance contracting has undergone something of a revival, largely through the boost offered by utility demand-side-management programs and least-cost planning. Many utilities have wanted to use energy service companies as their implementer and to lay off on those companies the business risks and complexities of implementation, in much the same way that most contract with architect/engineers and constructors to build their power plants. The client for the energy service company is then the utility, not the individual "host" customer, with accompanying economies of scale in explanation, contracting, verification, and compensation. The host customer then receives major benefits while needing to contribute very little to the cost.

Utility sponsorship, however, is far from a panacea: while the financial barriers to the end-user have been much reduced, the arrangement now has three parties rather than two. Contracts are needed between the energy service company and both of the others, and the utility's and customer's interest seldom coincide. The customer wants lower bills without disruption of corporate function—after all, the customer is interested in its own product, not the utility's; the utility wants measured savings meeting contractual levels per customer per year; and the energy service company must do both, or face substantial utility penalties for nonperformance, however caused. Inconsistency or lack of clarity in pursuing these goals can lead to trouble. For example:

- Very few industrial savings contracts are normalized to the plant's output; indeed, some explicitly seek "conservation, not efficiency," so for control measures such as occupancy sensors and variable-speed drives, the energy service company is hurt by full production and helped by crippled production, making its interests directly contrary to the customer's. The opposite is true for "pure" efficiency measures such as high-efficiency lamps or motors.
- Most commercial lighting savings contracts are written in terms of kilowatt-hours saved, not kilowatt-hours *per lumen-hour* —they are normalized to neither hours' operation nor illuminance. The energy service company's revenues and profits then depend strongly on customer behavior that is outside its control unless specified by detailed and onerous contracts with the customer. Worse, the savings and hence the contractor's profits can increase if the lights are run longer hours, creating a direct incentive for wasting energy.

While these structural flaws in the basic relationships among the three parties may seem elementary and easy to fix, they persist in practice. Indeed, the utility's financial contribution, though outwardly valuable, may in fact be largely or wholly consumed by added costs of contracting, monitoring, and complexity. This is not inevitable, but it remains common.

Even in non-utility relationships, performance contracting often succeeds or fails on the strength of the thought given beforehand to aligning the different parties' incentives. If the service provider and the building owner have opposite incentives—one to maximize and one to minimize the measured savings—then they spend a lot of time and money arguing about how much was saved. However, some deals have been structured in an innovative way that puts both parties on the same side of the table, giving them parallel incentives for success.[104] In such cases, the total cost of measurement with a precision and reliability satisfactory to both parties often falls, in the commercial sector, to only ~3% of the total project cost of the retrofit.[105]

Another noteworthy example of the power of simple incentives is an emerging practice used by one firm[106] for energy-saving commercial retrofits in Singapore: compensation is on a no-cure/no-pay basis. In addition, government retrofits have been solicited on the basis that any shortfall from the predicted and contracted-for saving incurs an instant penalty equal to ten years' worth of the shortfall. This gives the retrofitters an incentive for careful design and honest estimates.

One more successful psychological finding from performance contracting is transferable to internal efforts to sell efficiency to management: as Ron Perkins[107] advises, call the benefits increased profits, not reduced expenses, and ascribe them to investments, not to project costs.

3.11 OTHER CONTRACTUAL ISSUES

Specifications for equipment are often poorly drawn. An early step for any organization with a standard spec-book should be to review it in detail to ensure that it requires the right equipment and eliminates loopholes. The phrase "or equal" needs special scrutiny. Inserted to ensure multisource bidding, especially in government projects, it has become a license to substitute equipment that is of roughly the desired type and size but may have far worse energy performance. "Equal" is also often assumed by constructors to mean "of equal *or larger* size or capacity." That way lies serious waste of capital and energy.

Energy performance is often too complex, especially at part-load, to capture with a single number. Vague terms like "high-efficiency motor" can embrace, at any given size and type, a rated-full-load efficiency spread of many percentage points. Even excluding several less efficient brands that their makers dubiously so describe, the spread between the *best* brands is still at least one percentage point (worth >$10/hp in present value) in efficiency and tens of percentage points in power factor, depending on precisely which manufacturer, model, and vintage is procured. Similarly, "low-emissivity glass" can mean anything from an R-value of <2.0 (poor coating, airgap, and frame) to a superwindow with center-of-glass R>8.

Nothing should be left to chance, not even pipe and wire sizes, valve types and makes, or the type of tape used to secure insulation. Such details are frequently omitted even in specifications for the most carefully designed superefficient projects. At least until standard practice changes markedly, every last detail must be nailed down, with clear sanctions for noncompliance and sufficient onsite supervision to detect it in time for correction. Contracts must also provide for full commissioning, training, and documentation, preferably *by the design team* and at a minimum with their strong participation. Indeed, utilities could do well to hire and pay for a building commissioner active in the whole project from early design through and beyond acceptance, as Montgomery County (Maryland) now does.

3.12 OPERATIONAL AND MAINTENANCE PRACTICES

Without proper operation and maintenance, even the best system will fail. The less passive and more control-based it is, the faster and worse it will fail. Yet fewer than half of U.S. commercial buildings receive regular HVAC maintenance.[108]

FEWER THAN HALF OF U.S. COMMERCIAL BUILDINGS RECEIVE REGULAR HVAC MAINTENANCE.

A small example of the consequences: the leased research headquarters of one of the world's most sophisticated electric utilities was recently found to have severe control problems (hence simultaneous high-volume heating and cooling much of the time), a major fan wired backwards so it was fighting another fan, economizers stuck half open, vents clogged with bird droppings, all three second-stage compressors inoperative, average power factor ~0.7, and the like. The equipment, though not particularly complex, simply wasn't working because nobody was bothering to maintain it. Many occupants had long complained of uncomfortable temperatures and poor air movement, but their complaints were never translated into repairs. If that can happen with such a knowledgeable owner, how about other customers? Similarly, within *months* of commissioning some buildings in another major utility's showcase project, key equipment, such as fan ASDs, broke down because the maintenance staffs were not properly trained to keep them going or because of unclear responsibility for fixing bugs.

Such maintenance as does occur is nearly all fixing failed components, not preventing the failures in the first place. But using maintenance time freed by, say, more efficient lighting systems (which have fewer and longer-lived lamps and ballasts) to embark upon and stay abreast of a computerized preventive maintenance schedule, especially for HVAC, can yield enormous benefits in operating cost and effectiveness.

Access, time, budget, training, empowerment, supplier relationships, updating to reflect new opportunities, and other aspects of keeping systems running as designed must be *part of the initial design*, not *ad hoc* afterthoughts, and may require extensive resources. An experienced engineer offers this wise but demanding counsel:

> My intuition is that a poorly designed building with good O&M will usually outperform a well designed building with poor O&M. . . . This raises . . . [especially problematic] issues for incentives and training/education . . . because a designer can complete hundreds of buildings in a career but an O&M technician can only manage a handful . . . . Yet *the educational requirements for a good O&M technician may not be much less rigorous than for a good designer*. . . . As design becomes more sophisticated, the O&M staff have to be technically sophisticated simply to understand the design intent and avoid frustrating it by their subsequent work. The resources needed to adequately train O&M staff [nationwide] *may be an order of magnitude greater than for designers.*[109]

Naturally, the worse the visual user interface for the building's controls, the more engineering training and intuition the operator must have to infer what is happening from inadequately presented evidence. Good visual displays can make up for considerable lack of training[110], but most building automation systems are run without the benefit of either of these.

A critical element of proper operation of a large building is gathering accurate, frequent (typically one-minute) data from numerous, high-quality, carefully calibrated sensors; systematically examining those data both in real time on a proper user-interface screen and in periodic hindsight (say, weekly or every few days) with sophisticated graphics software that makes subtle patterns and abnormalities evident; and archiving the data for future reexamination. This important subject is discussed further in §7 of *The State of the Art: Space Cooling and Air Handling*. Ideally, the data should be collected and stored using an open protocol, such as ASHRAE's Building Automation and Control Network protocol, so that data can be exchanged and compared between buildings and operators. The SAS (Statistical Analysis System) database/statistical package[111] used in many utility projects, though useful for many purposes, is quite unsuitable for the level of visualization and analysis required of complex (often gigabyte-range) building-energy data sets.[112] And data screens should be set up to highlight anomalies or shortfalls in performance, not simply to bury operators in all the numbers that show what's working right.

Another critical element of good maintenance is having high-efficiency models of critical components locally available for immediate delivery in case of failures. If a premium motor isn't available to replace a burned-out standard-efficiency motor, the opportunity passes within hours. Utilities may be do well to help distributors pay carrying charges on stocking only the most efficient equipment, so that if someone calls for immediate delivery, they'll get good units.

A final element is having well-trained people. Some are coming out of the Armed Forces and out of military- and computer-related industries; more will be needed. A major education and training initiative involving such government departments as Energy, Defense, Labor, Education, and Environment could go far toward filling the increasingly urgent need for more sophisticated operators, not just designers, of energy-efficient buildings.

3.13 LEASING PRACTICES

One might at first glance suppose that tenants pay a gross effective occupancy cost and don't much care what it is called, while the building owner, given a $20/ft^2-y gross rent, would rather keep $18 and pay $2 to the utility than keep $16 and pay $4 to the utility. But both the legal details and the psychology of leases can make matters far more complex than that.

The discussion in §§2.13–14 suggested the general shape of needed reforms in commercial leasing practice. In the United States in early 1992, this author's proposed corporate initiative to this effect was endorsed and forwarded to the 25 very large member firms by the President's Council on Environmental Quality for their voluntary implementation over the next two years. Its adoption by some of these major players could go far toward changing leasing practice and encouraging emulation in other markets (including overseas markets) and by other lessors, lessees, and brokers. The general principles are clear, and about half of them are embodied in model agreements recently drawn up by a PCEQ Implementation Team for tenants, landlords, and brokers:[113]

- provide full and accurate information about actual energy costs (together with occupancy figures, presence of important process loads such as mini- or mainframe computers, explanations of unusual circumstances, etc.—with due provision made for tenants to report major events bearing on proper interpretation[114]);
- structure leases so that energy-saving, value-enhancing retrofits—and any utility incentives received for them—appropriately benefit both owner and tenants;
- provide per-occupant meters (not master-meters) for multiple tenancies, with submetering encouraged wherever possible, and with billing disaggregated and based on actual usage rather than pro-rated by floorspace;
- make specific provision for the equitable allocation of saved energy, capital (net of utility rebates), and maintenance costs arising from energy-saving retrofits;
- provide that the landlord cannot unreasonably withhold consent for retrofits, but on the contrary will make reasonable efforts to get tenants who share pro-rated energy bills but do not retrofit their own space either to match other tenants' retrofits or to renegotiate their passthrough energy costs (so that those who do retrofit will benefit rather than losing part of their savings to others who choose not to follow suit)[115];
- encourage local utilities, perhaps in collaboration with such groups as the Building Owners and Managers Association or the Institute for Real Estate Management[116], to publish periodic surveys of the mean, median, maximum, and minimum $/ft^2 electricity and gas costs for various categories of commercial buildings that they serve, so that prospective lessees can comparison-shop; and
- revise standard-form lease provisions that require the installation of HVAC capacity sufficient to serve very large (5–10 W/ft^2) plug loads and similarly outdated (2–3 W/ft^2) lighting loads—instead, require HVAC capacity adequate to provide ASHRAE comfort under design conditions with the actual design level of internal heat gains.

The last of these items merits an example. E SOURCE recently advised on a major real-estate project that did not look financially viable under normal conditions. It turned out, however, that the lease included the assumption that all tenants, including the preleasing anchor tenant, would use a total of 6 W/ft^2 for lights and plug loads; only higher loads would incur an extra charge. A highly efficient design would specify this total at 0.5 to 1.0 W/ft^2. This in turn would reduce the capital cost of the building (chiefly via smaller HVAC systems) by ~\$5/ft^2—enough to make the project profitable and the rent charged to complying tenants highly attractive. The obvious conclusion: do, if not zero-based, at least best-practice-based energy budgeting by changing the lease's energy target to ~0.5–1.0 W/ft^2; work with the anchor tenant to achieve that result in office-equipment procurement and in the lighting and other energy aspects of tenant finish; build in flexibility (pads and stub-outs) to accommodate less efficient future tenants; and charge them the marginal cost if they choose not to be that efficient, incurring extra HVAC capital and operating costs.[117]

3.14 RESEARCH INFRASTRUCTURE

A recent summary of new, energy-saving building technologies concluded:[118]

> An outside observer of the huge, mature commercial building industry might assume that, over time, mechanisms had evolved to predict the need for new technology; invent, develop, and test it; and guide it into the marketplace. You might expect to find a coordinated network of research and testing laboratories, data banks, and information centers, all linked to manufacturers and all directed by building professionals and a national policy-setting organization.
>
> However, no such mechanisms exist. While professional societies, trade associations, universities, government agencies, and manufacturers address some of the issues, most of these groups are small and have limited funds, many have competing agendas, coordination among them is minimal, few invest in high-risk innovation, and most lack incentives to promote technology actively. The industry is not configured to plan and manage the flow of technology systematically from basic research and development through commercialization and into the marketplace.
>
> No mechanisms are in place to direct the efforts of researchers, manufacturers, designers and builders, or to manage communication among industry members. Nor does any mechanism determine policy, decide what facets of the industry need improvement, and actively move research in that direction. . . . Investments in construction industry R&D in 1988 were estimated to be below 0.4 percent of the annual of all construction put in place by all elements of the industry. By comparison, the automotive and oil industries devoted about 1.7 and 2.9 percent of their revenues, respectively, to research that year. . . . One of the few government bodies involved in building technology, the National Institute of Building Sciences, has been operating on interest payments from a trust fund—a total of about \$500,000 annually. At the same time, federal outlays for research in the health and agriculture industries, which have shares of GNP similar to that of the construction industry, are proposed to be \$9.8 billion and \$2.0 billion, respectively, in fiscal 1992.

As a result, "Many new products and techniques need over 20 years to gain a foothold in the building market, and perhaps twice that to gain significant acceptance." In a country that spends the best part of $100 billion a year on constructing, and roughly the same in running, commercial buildings, this is hardly comprehensible, especially when contrasted with the far better coordinated establishments in such countries as Sweden and Japan, and when one recalls that expert analyses have identified the underlying shortcomings in the U.S. building industry for more than 20 years.

Such groups as the U.S. Congress's Office of Technology Assessment, National Academy of Sciences, Business Roundtable, and National Institute of Building Sciences have analyzed these problems and suggested what to do about them. We need not repeat their recommendations here. But clearly the first step is to see more effective and better applied R&D throughout the building industry as a national priority.

Utility initiatives can also be exceptionally important and may diffuse more quickly than government research. The "Golden Carrot" approach now being used to reward manufacturers who first bring superefficient refrigerators to market could be applied, for example, to rapidly commercializing a drop-in replacement for rooftop packaged HVAC units, or a truly modern air handling unit that integrates variable-speed superefficient (ideally switched-reluctance) drivesystem, 80+%-efficient vaneaxial fan, active noise-cancellation silencing, built-in flowmeter and other sensors integrated with software and onboard diagnostics, etc., or a comparably efficient and information-integrated cooling-tower, ceiling-fan, or evaporative-house-cooler package.[119] Just the rooftop-unit opportunity *could save about one-fourth of all HVAC electricity used in the U.S. commercial sector*, and is now proposed to be prototyped in 1993.[120]

* * *

In summary, overcoming the institutional problems identified in this paper can go far toward unleashing the latent creativity of many design professionals and rewarding them for money- and energy-saving choices. *The State of the Art: Space Cooling and Air Handling* and E SOURCE's other Hardware Reports describe more fully how to capture these opportunities by systematically applying the precepts and methods of good, though far from simple, engineering. E SOURCE hopes that the elegant simplicity of the resulting design solutions may help many designers not only to use their talents more fully but also to regain their sometimes frustrated sense of wonder and adventure.

REFERENCES AND NOTES

1 *The State of the Art: Space Cooling and Air Handling;* August 1992.

2 The latter phrase is due to CalTech's Marvin Goldberger, who was referring to the proposed Anti-Ballistic Missile system.

3 U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, OTA-E-518, May 1992, at p. 73.

4 Many are named in the Acknowledgements of *The State of the Art: Space Cooling and Air Handling*, although some wished to remain anonymous.

5 OTA [3], pp. 71–159.

6 Thirteen surveys with this finding are cited at pp. 2–3 of J.C. Koomey, *Energy Efficiency in New Office Buildings: An Investigation of Market Failure and Corrective Policies*, PhD dissertation, Energy & Resources Group, University of California, Berkeley, 1990. Dr. Koomey kindly provided this reference and helpful comments on a draft of this report. Chapter 4 of his dissertation demonstrates in detail the pervasiveness of market failures in buying office-building efficiency.

7 The depreciation period, usually 31.5 y in U.S. practice, is now several times as long as the buildings' period before typical technological obsolescence: Jack Beckering (Steelcase), personal communications, 18 June and 6 August 1992.

8 Koomey [6], p. 82. The twelve states mentioned are: Colorado, Kentucky, Maryland, Minnesota, Michigan, Missouri, Montana, Nevada, New York, South Carolina, Tennessee, Virginia, Wisconsin.

9 Owners tend to get their information on "typical" sizing and costs from estimators, a distinct subculture that also works for designers in helping estimate their fees and for constructors in helping control costs. In some countries, notably Britain, "quantity surveyors" have an even more dominant role in fixing costs as a basis for contractual relationships, and often are correspondingly better educated, but in the U.S. they lack a correspondingly well-established discipline.

10 Charles Smiler (real estate consultant, Montpelier, VT 802/229-0877), personal communication, 10 September 1992. Mr. Smiler has kindly informed much of this section.

11 Namely, the Building Research Establishment Energy Evaluation Method (Building Research Establishment; Herts, U.K., phone: 0923 894040) and BEPAC (University of British Columbia, Vancouver, B.C., phone: 604/822-2857).

12 OTA [3], pp. 74–75.

13 U.S. Department of Commerce, Bureau of the Census, *Characteristics of New Housing: 1990*, C25-9013, June 1991, at p. 3.

14 R. Berg, G. Brown, & R. Kellett, "An Analysis of U.S. Industrialized Housing," Center for Housing Innovation, University of Oregon, October 1990, at p. 24, and *Automated Builder*, January 1991, at p. 15, both cited in OTA [3], p. 75, Table 3-3.

15 However, many merchant builder homes (those in large developments built by very large and increasingly dominant firms) do offer an add-on package of energy features—higher-efficiency air conditioner, water-heater wrap, better appliances, etc. But these add capital cost while only slightly increasing energy efficiency, whereas major envelope improvements could save far more energy at little or no marginal cost. See W.D. Browning, *Green Development: The Cost of Environmentally Responsive Development*, MIT Center for Real Estate, 1991, at pp. 36–37 & 87.

16 U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987*, DOE/EIA-0314(87), May 1989, at p. 118.

17 P. Mihlmester, J. Gonos, L. Freeman, & M. Brown, *Technology Adoption Strategy for the Existing Buildings Efficiency Research Program*, ORNL/CON-286, Oak Ridge National Laboratory, June 1989, at p. 34, cited in OTA [3], p. 78, n. 15.

18 The Antioch building in Pacific Gas & Electric Co.'s "ACT^2" experiment; Steve Taber's team achieved this simulated result even though the base design was better than the new Title 24 standard to start with. Converting the base design from two stories to one with skylights for toplighting did not, in this case, use more land because the layout of the parking could also be improved.

19 Lee Eng Lock (Supersymmetry Services, Singapore), personal communication, June 1992.

20 Lee Eng Lock, personal communication, 30 June 1992.

21 Koomey [6], p. 67.

22 See E SOURCE's Strategic Issues Paper, *Air Conditioning Comfort: Behavioral and Cultural Issues,* November 1992.

23 These include impeller size, gear ratio (hence impeller speed), motor power, shell and tube geometries, two heat-exchanger sizes, two flow rates, and the refrigerant choice and flow friction. Other formulations are possible, such as approach temperatures. See *The State of the Art: Space Cooling and Air Handling*, especially at §6.1.2.1 and §6.2.1.1.

24 *For example,* by real-estate expert Charles Smiler [10] with whom the author is developing an exploratory project.

25 See *NMB Bank's Head Office* , NMB Bank Corporate Publications (PO Box 1800, 1000 BV Amsterdam, phone 020 + 56 344 89), 1988, and W.D. Browning, "NMB Bank Headquarters: The Impressive Performance of A Green Building," *Urban Land* **51**(6):23–25 (June 1992).

26 We are indebted to Jim Block PE (personal communication, 3 September 1992) for pointing out that the 27% stated in *The State of the Art: Space Cooling and Air Handling* is only a geometrical factor; it does not, as it should, take credit for round ducts' greater stiffness or for the thinner metal adequate for their more uniform internal pressure distribution.

27 This example was cited by Donald Ross PE (Javos Baum & Bolles, 345 Park Ave., New York NY 10054, 212/758-9000), one of the few firms that makes a special effort to capture such synergisms (personal communication, 21 May 1992).

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30 C.H. Burnette, *The Architect's Access to Information: Constraints on the Architect's Capacity to Seek, Obtain, Translate, and Apply Information*, AIA Research Corp. & National Bureau of Standards, NBS GCR 78-153, March 1979, cited by Koomey, [6], at p. 73.

31 OTA [3], p. 83.

32 C. Maxwell Stanley, *The Consulting Engineer*, Wiley (New York), 1982, 2d ed., at p. 35.

33 The Brooks Act (1972, P.L. 92-582) prohibited cost competition in Federal (including Department of Defense) procurement of design services, and most state governments follow the same principle**.** Many local governments and most private-sector actors, however, do not, and choose largely or wholly on price on the presumption that all registered Professional Engineers are deemed competent. (Stanley, *op. cit. supra*, states at p. 101 that the Department of Justice's 1971 intervention in design professionals' fee-setting procedures (described below) "encourages public bodies at state and local levels, as well as private sector organizations, to emphasize unduly the price factor when selecting consultants. This overemphasis undermines the ability of the consulting profession to render the scope and quality of services that best serve the interests of clients in particular and the public in general." The requirement to base procurement on qualifications, not price, also applies only to *selection of* the winning proposal, not to negotiation of the fee to be paid to the winning consultants.

34 Stanley [32], p. 44.

35 Stanley [32], pp. 44–45 and 51.

36 P. Duralia (Director of Quality, Lockwood Greene Engineers Inc., Spartanburg SC), in *Consulting–Specifying Engineer*, July 1992, p. 38.

37 For example, at p. 403 of *Means Mechanical Cost Data 1987* , Table 10.1-103 (R.S. Means Co., Kingston MA) states that "typical" mechanical and electrical engineering fees, included in architectural fees, fall from 6.4% of a $25,000 engineering design/install contract to 4.1% of a $1 million contract for simple structures; from 8.0 to 4.8% for intermediate structures; and from 12.0 to 7.0% for complex structures. (Retrofits and renovations are said to be ~15–25% higher than new designs in each case.) One experienced engineer recalls that years ago, some similar tables (published by others than Means) carried a warning that they represented the absolute minimum below which one cannot expect sound engineering, but such warnings vanished. Like their forerunners published by various engineering societies, such published tables and curves today are "rarely viewed as mandatory. Clients and consultants alike consider . . . them helpful references for negotiating fees appropriate to the size and complexity of each engagement." (Stanley [32], p. 53.) But fees tend to be bid *down from* such published values. This is especially harmful because those old nominal fees are already inadequate to support the design complexities of modern projects; engineers have tried, not always successfully, to compensate for their increasing losses by the productivity gains permitted by computerization, but that too has a significant capital cost, and may not help raise to raise hourly billings if it saves hours.

38 Paul Beck, Editor, *Consulting–Specifying Engineer*, 708/390-2183, personal communication, 12 May 1992.

39 Beck [38].

40 "Liability: Alternatives to Litigation," *Consulting–Specifying Engineer*, September 1989, pp. 28–35.

41 American Society of Civil Engineers, *Manual of Engineering Practice No. 45,* 1972.

42 E. Larson & L. Nilsson, "Electricity Use and Efficiency in Pumping and Air-Handling Systems," *ASHRAE Transactions* 97(2):363–377 (1991). In much of Asia, however, oversizing of chillers is an even bigger source of inefficiency.

43 Bill Fanning, Director of Research, Professional Management Associates (publishers of *Professional Service Management Journal*, usually called *PSMJ Surveys*), 271 Cross Gate Drive, Marietta GA 30068, 404/971-7586, personal communication, 14 May 1992. E SOURCE is grateful to Mr. Fanning for the insights in this and the following three paragraphs, in which he is the source of quotations not otherwise cited.

44 Yet even the Brooks Act that mandates this procedure prohibits first-time basic design costs over 6% of project cost.

45 In Germany, for example, under the HOAI system the government sets maximum design fees (at very high levels).

46 Howard Williamson (Director, TRA, Seattle), in *Consulting–Specifying Engineer*, July 1992, at pp. 38–39.

47 U.S. Department of Energy, Energy Information Administration, *Commercial Building Characteristics 1989*, DOE/EIA-0246(89), at p. 9, fig. 4. Surveys now underway should clarify how much of that floorspace is *cooled by* central systems; the 1989 survey did not fully disaggregate buildings cooled by more than one kind of equipment.

48 A project to build by early 1993 a prototype tripled-efficiency rooftop unit is now underway in California, but absent utility incentives, it is not clear the market is ready to welcome it with any enthusiasm.

49 In Germany, however, where designers provide exhaustive specifications and then guarantee component and subsystem performance to meet DIN standards, *e.g.* for air movement and temperature control, substitution is much less common and may be rejected (Mike Mirata [Commodore, 805/683-6453], personal communication, 29 May 1992).

50 There are typically in the form of educational seminars with extensive recreational content, or of sales incentives whose ubiquity can be inferred from T.A. Mahoney, "Most contractors weary of world travel as a sales incentive, *News* survey shows," pp. 1 & 3, *Air Conditioning, Heating, and Refrigeration News,* 23 July 1990. Another article (1 April 1991) reveals that 26.6% of 386 contractors surveyed say they might pay more for equipment because of "trip incentives"—and, interestingly, 68.2% because of utility rebates. (Of these, 43.4% would accept a price difference of ≥5%.)

51 Major vendors of some kinds of equipment can, in effect, determine which subcontractor submits the low bid by adjusting their supply prices to the various competitors. The potential for kickbacks is obvious.

52 The Uniform Mechanical Code requires only that the manufacturer's installation and operating instructions be left attached to each appliance. However, a new City of Austin (TX) standard for buildings >20,000 ft^2 requires an O&M manual to be prepared, from those manufacturers' guides, with two copies going to the owner, one on the premises, and one to the City. It appears that the designer is not obliged to add anything to those manufacturers' materials. G. Crow, "The Revised Austin Energy Code," *Proceedings Eighth Symposium on Improving Building Systems in Hot Humid Climates,* Dept. of Mech. Eng., Texas A&M, 13–14 May 1992, at pp. 104–107.

53 This is reckoned at 3 gpm/t with 95˚F entering and 85˚F leaving temperature at a 2.5% design condition of 78˚F wetbulb.

54 P.O. Fanger, *Thermal Comfort: Analysis and Applications in Environmental Engineering*, McGraw-Hill (New York), 1972, at p. 132. On the other hand, changing conditions in any direction often reduces complaints (for a while) simply because people are glad that someone cared to take any kind of remedial action.

55 For recommendations on user interface, see *The State of the Art: Space Cooling and Air Handling*, §7.2.3.

56 This is most commonly because the vendor of the energy management system fails to provide or is not required to provide a suitably customized software interface, even if the sensors and algorithms are otherwise suitable.

57 *E.g.*, see W.C. Stethem, W.J. Coad, R.A. Hegberg, F.L. Brown, & R. Petitjean's disparate views on balancing water flows in *ASHRAE Journal* 32(10):34–59 (1990).

58 Environmental Design Research Association (EDRA), P.O. Box 24083, Oklahoma City, OK 73124, tel 405-843-4863.

59 This is of course the operative principle for most residential systems, with horrendous results: see *e.g. The State of the Art: Space Cooling and Air Handling*, §6.6.4.

60 OTA [3], p. 83.

61 OTA [3], pp. 83–84.

62 E SOURCE is grateful to Charles Smiler for patiently explaining these matters.

63 OTA [3], pp. 4 & 80.

64 Doug Hibberd, personal communications, July 1992. An ethnographic study of how this Sydney fashion arose would be valuable elsewhere.

65 A.B. Lovins & H.R. Heede, Chapter 6 ("Office Equipment," pp. 279–450) in M. Shepard, A.B. Lovins, J. Neymark, D.J. Houghton, & H.R. Heede, *The State of the Art: Appliances*, COMPETITEK, August 1990.

66 That is, ~\$34/ft^2 at a tariff of 7.8¢/kW-h, present-valued at a 5%/y real discount rate over 40 y—perhaps a normal functional life for many older buildings, though longer than for some new ones. Assuming a decrease in the design plug load from 5.0 (U.S. Government and many private-sector specifications are now commonly ~5–8) to <1.0 W/ft^2, turning off idle equipment rather than leaving everything on during working hours and half of it always on, and \$2,000 capital saving per decremental ton of HVAC-system capacity. Under some conditions, the savings may be twice as large. For calculational details, see A.B. Lovins, "Notes of After-Dinner Remarks to the Workshop *Energy Efficient Office Technologies, The Outlook and Market*," EPRI workshop, San Jose, 17–18 June 1992. Interestingly, two mechanical engineers participating in that workshop (Alex Zimmerman of the British Columbia Buildings Corporation and Peter Icely of Ontario Hydro) stated that standard Canadian design practice is to assume ~1 W/ft^2 of plug loads—even though a separate survey of their U.S. counterparts, presented in the workshop papers, showed that nearly 70% would recommend ≥5 W/ft^2. The reasons for this difference merit investigation. These are all, of course, design loads; the *actual* peak-hour office-equipment loads shown in EPRI's 1990 COMMEND database are 0.37 W/ft^2 for large and 0.32 for small offices.

67 W. Kempton & P. Komor, "Maybe Somebody Forgot to Turn the Chiller On: Graphical Feedback for Small Businesses," *Procs. ACEEE 1990 Summer Study on Energy Efficiency in Buildings* **2**:75–76. This contrasts sharply with the late Sam Walton's philosophy of providing maximal information to people on the Wal-Mart sales floor so they can promptly understand how their own actions affect departmental, store, and corporate profitability.

68 President's Commission on Environmental Quality and Alliance to Save Energy, "Guidelines for Energy Efficient Commercial Leasing Practices," October 1992 draft, Washington DC.

69 W. Kempton, C. Harris, J. Keith, & J. Weihl, "Do Consumers Know 'What Works' in Energy Conservation?," in J. Harris & C. Blumstein, eds., *What Works: Documenting Energy Conservation in Buildings*, American Council for an Energy Efficient Economy (Washington DC), 1985; rev. in *Marriage and Family Review* **9**(1/2):115–133 (Fall 1985).

70 OTA [3], at pp. 84–85, citing P. Komor & R. Katzev, "Behavioral Determinants of Energy Use in Small Commercial Buildings: Implications for Energy Efficiency," *Energy Systems Pol.* **12**:237 (1988).

71 Jim Pierce, American Consulting Engineers Council, 202/347-7474, personal communication, 13 May 1992. Mr. Pierce reports that most, though not yet all, engineers consider this approach ethical; apparently some also believe it implies that plain-vanilla engineering is not the best available, but that is true and clients should learn it. Indeed, two authorities at the American Institute of Architects (personal communication, 15 & 18 May 1992) speculate that value-based compensation may *help* marketing by educating clients about the special value they get from superior designs. Designers' approach should be to sell the value and scope of services; clients who want to pay smaller fees should have to be explicit about which benefits they wish to sacrifice, and should explicitly relieve the designer of corresponding portions of liability.

72 Peter Morante, Northeast Utilities, personal communication, 1 October 1992.

73 One exception is William Evans, head of real estate worldwide for Mobil Oil.

74 S. Rosenfeld, "Worker Productivity: Hidden HVAC Cost," *Heating/Piping/Air Conditioning*, September 1989, pp. 69–70.

75 *Means Square Foot Costs 1992* , at pp. 166–167, for an archetypical 11–20-story office; the average for three size classes of offices (2–20 stories, at pp. 162–167) is \$72. These costs are direct hard and soft construction costs only, excluding land, financing, and approvals.

76 *Means Mechanical Cost Data 1992*, at p. 362, gives a typical *total* mechanical-plus-electrical engineering fee for an intermediate structure as ~4.8% of the electrical-and-mechanical subcontract cost, which in this case is \$21.26/ft^2.

77 This rough estimate of the split is by Paul Scanlon PE of Burt Hill Kosar Rittelmann, personal communication, 19 May 1992. He also estimated that ~20% of the mechanical engineering fee is for plumbing and fire protection, leaving in this example ~49¢ before deducting the design of the heating system. Note that the hard costs of mechanicals, electricals, and plumbing, excluding elevators, account for *25% of total project cost.*

78 Building Owners and Managers Association (Washington DC), *Experience Exchange Report 1991*, at p. 95, showing national means for downtown 100–300,000-ft^2 private-sector office buildings in 1990. Areas are net rentable space; income (\$21) is for the office area only, *vs.* \$16.68 for the entire building including retail space, parking, etc. The energy costs, and probably other costs and income, are probably somewhat higher for new offices than for the stock average described here, which is based on a sample of hundreds of

buildings totalling >70 million ft^2. E SOURCE is grateful to BOMA for kindly making these proprietary data available.

79 EPRI's COMMEND National Database (1991), kindly provided by EPRI's Phil Hummel and by Regional Economic Research's Stuart McMenamin (San Diego CA), shows that large (in EPRI's parlance, >50,000-ft^2) office buildings, whether stock average or new, use 39.6–39.8% of their electricity for space cooling and air handling. At the 1990 average commercial rate of 7.3¢/kW-h, the same source's total electric usage of 19.7 kW-h/ft^2-y for the stock and 21.1 for new large offices is respectively $1.44 and $1.54/ft^2-y, consistent with BOMA's 1990 stock average of $1.53/ft^2-y. "Guidelines for Energy Efficient Commercial Leasing Practices" (President's Commission on Environmental Quality and Alliance to Save Energy, Washington DC, October 1992 draft) states at p. 2 that typical office energy bills are ~$1.30–3.50/ft^2-y, and at p. 7 that Institute for Real Estate Management data suggest $1.30–$2.15/ft^2-y is more typical for downtown U.S. office buildings that are not unusually inefficient. The figure used here is toward the low end of these ranges, so the HVAC electric fraction derived from it may be understated. In fact, our $1.81/ft^2-y total energy bill is only slightly above the $1.50/ft^2-y implied by ASHRAE 90.1 for an ordinarily efficient *new* building.

80 BOMA [78]. Of this, 21¢ is stated to be for HVAC maintenance. That includes heating too, but does not count the HVAC portion of electricals (which total 7¢) or of unclassified repair and maintenance (25¢), nor any HVAC portion of the contracted-out 43¢ of repair and maintenance services, so it is probably a good approximation to the total internal-plus-contracted repair and maintenance cost just for space cooling and air handling.

81 The *Statistical Abstract of the United States 1991*, Table 678, p. 415, gives 1989 average office salaries whose weighted average was $27,939/y. We nominally adjust this by 4.12% for 1989–90 monetary inflation (implicit GNP real price deflator) and add an estimated 20% for taxes and benefits, then divide by the BOMA 1990 national average of 268 ft^2/officeworker in 100,000–300,000-ft^2 office buildings.

82 Greg Franta AIA (ENSAR Group, 303/449-5226), personal communication, 2 May 1992; Mr. Franta was formerly head of the AIA Energy Committee and of the Solar Energy Research Institute's commercial-buildings section.

83 B. Jones, "Building Commissioning Guidelines," Bonneville Power Administration, January 1992, at p. 1 (Bruce Jones & Associates, 3822 S.E. Kelly St., Portland OR 97202, 503/232-7036, FAX -0076).

84 A.M. Hayner, "Editor's Page: A Failing Grade," *Engineered Systems* **9**(3):6 (April 1992, Troy MI): being too hot was the first-ranked, and too cold the second-ranked, complaint in a survey sent to more than 7,400 members of the International Facility Management Association. BOMA got nearly identical results in a 1988 survey. The editor concludes: "The midterm report card is out. For the HVAC industry, the grade is F. . . . Precise, reliable, and efficient environmental [control] systems are not a luxury, but a necessity."

85 From a large-scale Trane study recently reported by Prof. Sam Luxton (Univ. of Adelaide), personal communication.

86 This illustration is in the spirit of S.I. Rosenfeld, "Worker Productivity: Hidden HVAC Cost," *Heating Piping Air Conditioning* **63**(9):46–48 (September 1991).

87 V. Hines, "Citicorp Managers Call Efficiency Key to Tenant Draw," *Energy User News* **16**(6):18–27 (June 1991), at p. 18.

88 There is a division of labor between ASHRAE and its kin and the American Consulting Engineers Council and the National Society of Professional Engineers. These two groups do discuss fee structures somewhat, but feel severely constrained by U.S. Department of Justice intimations that any discussion of fees, even in structure rather than amount, may be considered an illegal conspiracy in restraint of trade. These two groups

deal only with the business aspects of professional practice; groups such as ASHRAE tend to deal instead with the engineering content and to be even more reluctant to address fee structures.

89 Fortunately, Gregory Franta and others partly revived this work in late 1986 through an Energy and Environmental Task Group. This in turn formed the nucleus of the Environment Committee, which since mid-1989 has emerged as a leader in serving market demand for "green" designs that are sustainable and resource-efficient. The Environment Committee, too, now has an energy subgroup, and new AIA leadership is starting to intensify the re-emerging energy focus.

90 This is because of reduced low-load chiller surge and reduced cycling of compressor motors, contactors, etc.

91 A prominent designer (Donald Ross PE, JB&B) states (personal communication, 21 May 1992) that he sizes plug loads for ≤2 W/ft^2 whenever he succeeds in persuading a client who feels ~3–8 would be "safer"; then the client actually installs plug loads that would use 1 W/ft^2 if all on simultaneously but that in fact use only ~0.5 W/ft^2. This is typical.

92 For example, a widely used rule-of-thumb is that small-suite offices require air conditioning sized at 280 ft^2/t, which is equivalent to 12.6 W/ft^2 or 135 W/m^2 (*e.g. Means Mechanical Cost Data 1992*, at p. 386). Where might this come from? Conservatively assuming, with ASHRAE (*1985 Fundamentals Handbook*, at p. 28.12), one person per 100 ft^2 (2.7 times the U.S. average density cited by BOMA in 1990), occupants provide ~1.5 W/ft^2 of sensible plus latent load. The current ASHRAE office lighting recommendation is 1.5 W/ft^2–1.0 less than the old rule-of-thumb used in ASHRAE's 1985 example, half the obsolete lighting wiring requirement of the National Electrical Code, and ~5 times best practice of ~0.3 or less. (This as-used density is routinely achieved by such leading practitioners as Rising Sun Enterprises [Basalt CO]; it is net of control savings, so the corresponding installed lighting load is higher, typically ~0.7 W/ft^2. These values are ample to deliver extremely high-quality and attractive illuminances of 30 fc ambient, 50 on task. Even lower values are achievable: *e.g.*, a direct/indirect luminaire demonstrated at Seattle City Light's Lighting Laboratory provides virtually glarefree office illuminance of 25 ambient fc—ample to high for computer-rich spaces—with only 0.25 W/ft^2 *connected*, taking no credit for control savings. A well-daylit space can achieve ~0.1 W/ft^2 with superior lighting quality.) ASHRAE's published example assumes plug loads at 1.0 W/ft^2–5–8 times below many recent specifications, but typical of many offices, and ~5 times today's best practice of ~0.2 (about the usage implied by the findings of Ch. 6 of *The State of the Art: Appliances*, through full use of the most efficient commercially available 1990 hardware, software, and operational techniques, with unchanged or improved functionality and ergonomics). Internal gains with normal good practice thus total 4.0 W/ft^2 (about twice today's best practice at that workstation density). Makeup air at full ASHRAE 91-68 levels of 0.2 cfm/ft^2 could add another 3.6 W/ft^2, assuming 95˚F drybulb/80˚F wetbulb design conditions, *center*-of-zone ASHRAE comfort conditions (78˚F @ 50% relative humidity), and no air-to-air enthalpy exchange. That leaves at least 5.0 W/ft^2 to be accounted for—implying an alarmingly high level of unwanted heat gain through the building shell.

93 The poor design also compounds, *e.g.*, by adding globe valves to the high-friction piping systems to balance flows: with low friction, the flows tend to balance themselves, just as electrical flows to in adequately sized wiring systems. Rounding-up and adding safety margins also add more absolute losses or costs to oversized systems. See *The State of the Art: Space Cooling and Air Handling*, sections 5–6 and Appendix A.

94 Ned Brush at the Copper Development Association, however, plans to rewrite the copper-wire sizing tables to reflect true optimization at utilities' discount rates and long-run marginal electricity prices. A similar rewrite is needed for pipe sizes: see *The State of the Art: Space Cooling and Air Handling*, §6.4.2.2.

95 For example, Table 8.4-002, "Air Conditioning Requirements," in R.S. Means's *Means Mechanical Cost Data 1987*, at p. 398, and analogous tables in most engineering handbooks.

96 At p. 28.6, Table 1; the reference cited actually shows 1,700 kW-h/y, but this got rounded up.

97 M. Shepard, A.B. Lovins, J. Neymark, D.J. Houghton & H.R. Heede, *The State of the Art: Appliances*, COMPETITEK, 1990, at pp. 296–297, citing J. Harris, J. Roturier, L.K. Norford, & A. Rabl, *Technology Assessment: Electronic Office Equipment*, LBL-35558 Rev., November 1988, and p. 310, citing L.K. Norford, A. Hatcher, J. Harris, J. Roturier & O. Yu, "Electricity Use in Information Technologies," *Annual Review of Energy* **15**:425–453 (1990). See also Research Division, Southern California Edison Company (Rosemead CA), *Technogram* **1**(1):2 (1992).

98 Ron Perkins PE once did this at Compaq Computer Co., where he was Facilities Resource Development Manager, by signing a waiver absolving a designer of liability for inadequate mixing when a displacement system unfamiliar to him was specified instead of costly duct downcomers.

99 This is not in itself a guarantee that they will provide innovative design: one leading designer, having met with such engineers at a leading U.S. utility, recently remarked that he could make a good living retrofitting their retrofits.

100 Not to mention homeowners' associations and the enforcers of restrictive covenants. In the 1950s, for example, some U.S. utilities, seeking to promote the spread of appliances such as electric clothes dryers and water heaters, fostered prohibitions on the use of clotheslines and solar water heaters. The rationale of such prohibitions is now long forgotten, so they are often wrongly assumed to represent an aesthetic norm or an essential way of maintaining real-estate values. Yet removing such common residential restrictions can be extremely difficult, often requiring a new city ordinance or state law.

101 See A.B. Lovins & M. Shepard, "Implementation Paper #1: Financing Electric End-Use Efficiency," COMPETITEK, 1988, at pp. 27–34, and May 1989 Update, at p. 2.

102 Perry Bigelow of The Bigelow Group (708/705-6400) in northern Illinois offered $100-a-year guarantees starting in 1985. After three years he raised it to $200 a year for the larger single-family houses (and to $400 a year for his largest semi-custom houses), not because he was incurring material losses on the guarantee—he had to pay out only four times, twice to one owner, and always in the low two figures—but for credibility and because Commonwealth Edison Co. had major increases in electricity prices. An annual contest for the homeowners with the lowest bills helps elicit billing data; in 1989, for example, the winners, with $24 and $26 annual heating bills, both got free holidays in Hawaii or the Bahamas. Bigelow has received the Chicago *Sun-Times*'s annual energy-efficient builder award seven times and is well-known nationwide. Much of his cost saving comes from careful application of the National Association of Homebuilders' Optimum Value Engineering approach. Bigelow uses hydronic backup heat from the water heater rather than needing a separate furnace; his ductless HVAC approach is further described in E SOURCE's 1993 edition of the *Space Heating Technology Atlas.*

103 Point systems are exemplified by the California Energy Commission's Title 24 procedure (which comes with both prescriptive and performance options, both customized for each of 16 climatic zones) and by the rapidly spreading procedures developed by Energy-Rated Homes of America, Inc. (100 Main Street, Little Rock AR 72201, 501/374-7827).

104 For example, by Highland Energy Group (885 Arapahoe Ave., Boulder CO 80302, 303/786-9310, FAX -8033), and ERG International (Denver West Building #1, Suite 140, 13949 W. Colfax Boulevard, Golden CO 80401-3209, 303/233-4453, FAX -4234).

105 S. Lynn Sutcliffe, Sycom Enterprises (Bethesda MD), personal communication, 27 September 1991.

106 Supersymmetry Services Pte Ltd, Blk 73 Ayer Rajah Crescent #07-06/09, Ayer Rajah Industrial Estate, Singapore 0513, 65 + 777-7755, FAX 779-7608.

107 Supersymmetry USA (Houston, 800/755-2819 or 409/894-2819); Mr. Perkins was formerly in charge of facilities engineering at Compaq.

108 B. Korte, "HVAC/R Opportunities in Existing Buildings," *Heating Piping Air Conditioning* **63**(9):34–43 (September 1991), at p. 42, citing *Commercial Building Characteristics 1989*, DOE/EIA-0246(89).

109 Stephen B. Harding (206/789-8351), personal communication, 5 June 1992, emphasis added.

110 See *The State of the Art: Space Cooling and Air Handling*, §7.2.3.1.

111 SAS Institute, Inc., SAS Campus Drive, Cary NC 27513, 919/677-8200, FAX -8123.

112 An unusually flexible and powerful visualization package for this purpose is Electric Eye, available from Supersymmetry Services [106].

113 PCEQ/Alliance to Save Energy, "Guidelines for Energy Efficient Commercial Leasing Practices," October 1992 draft, Washington DC.

114 Some property firms decline to hire outside maintenance firms who don't collect such information.

115 PCEQ/Alliance to Save Energy [113], pp. 10–11.

116 However, such data must include all costs, not only those paid directly by the landlord, as is the IREM convention. Many of the official databases, too, are not occupancy-corrected and hence are not comparable. A standardized methodology is needed.

117 PCEQ/Alliance to Save Energy [113], discuss at pp. 23–24 a somewhat related issue: how to ensure that efficient tenants and those who work in normal hours do not unfairly subsidize those with unusually high energy usage or who work at unusual times, requiring whole-building energy systems to run when they would normally be turned off.

118 P.J. Segrist, "New Technology Advances Depend on Bldg. Owners," *Energy User News* **16**(6):13–17 (June 1991).

119 See, *e.g.*, *The State of the Art: Space Cooling and Air Handling*, §4.2.2.1 (evaporative coolers) and §6.5 (rooftop units).

120 An informal group including A.H. Rosenfeld, A.B. Lovins, and E.L. Lee has agreed to seek funding to build the first ~10-t unit in a quick *ad hoc* experiment to be coordinated by Doug Hibberd. The target whole-system efficiency including supply fan is ≤0.8 kW/t. Progress will be reported to E SOURCE members.