[target ~50m; rehearsal ~65m; actual ~72m slightly embroidered; * = click to build/animate/transition]
“Innovative Pathways to Low-Carbon, Healthy Construction” panel w Kirsten Stasio
13th Annual NSBAIDRD AIA Nevada CEU Seminar

Superefficient, better, cheaper buildings through integrative design

AIA Continuing Education Webinar during the
Nevada State Board of Architects Annual Conference

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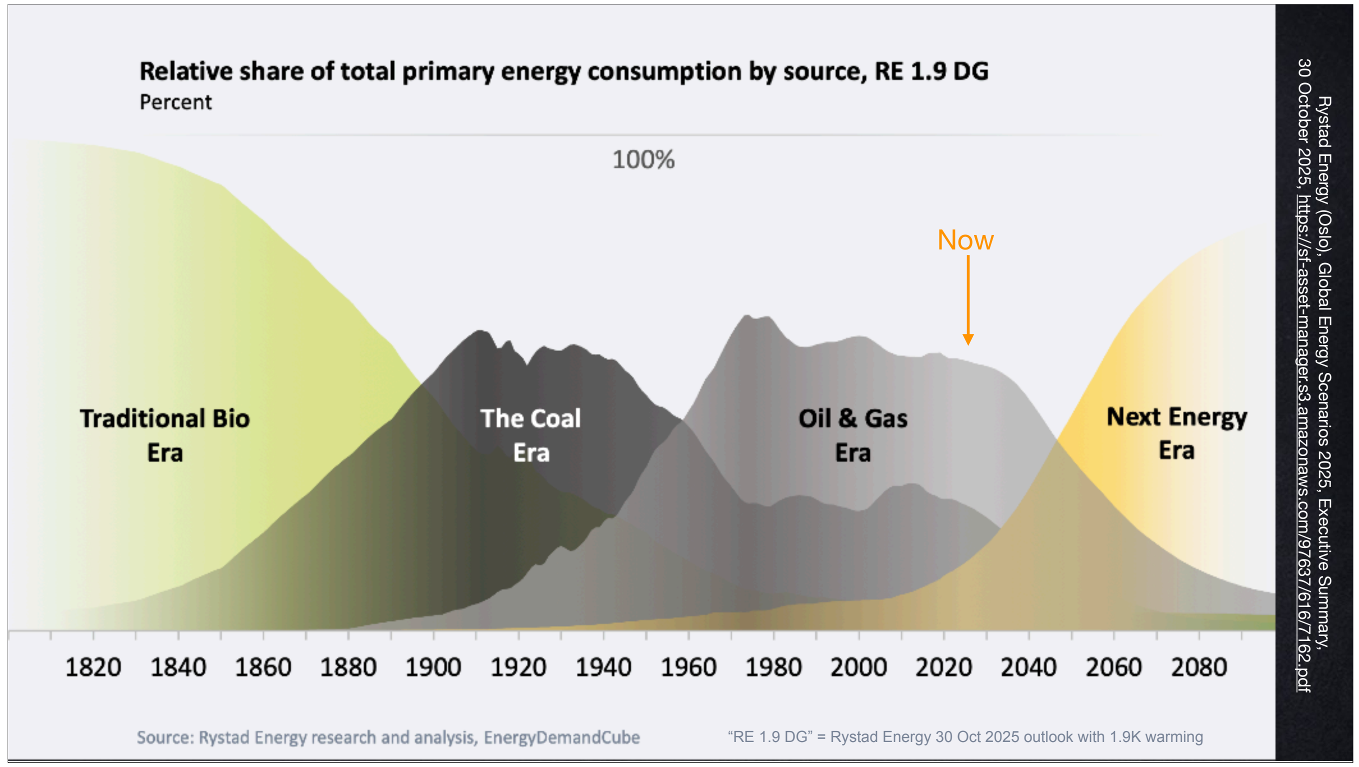
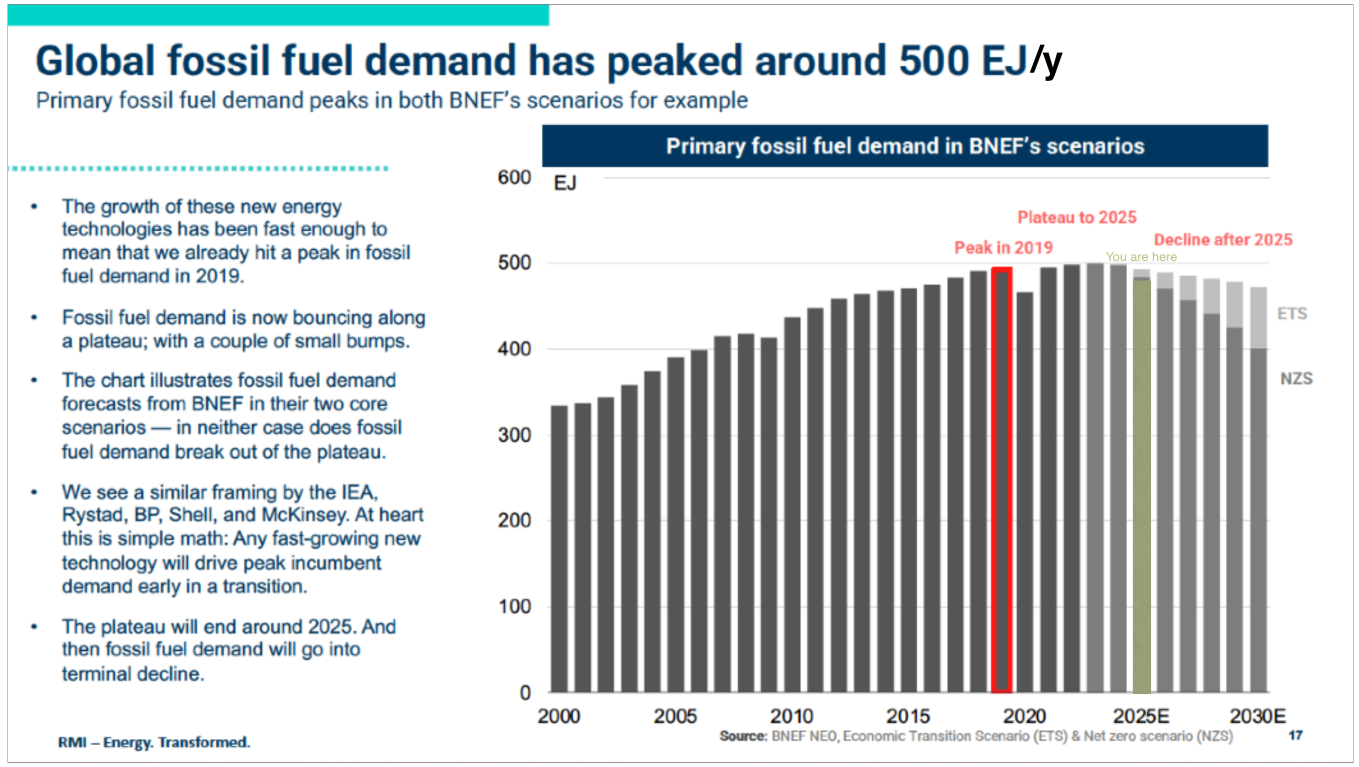
Good day! A global energy revolution is swiftly taking us to a cheaper, resilient, and carbon-neutral future by shifting from fossil fuels to renewables, fuels to electricity, centralized to distributed supply, and inefficient to efficient use—my topic today. [It may depend little on partisan rhetoric: ever since the second Bush Administration, US fossil-fuel use in all sectors has been declining and renewable energy has been growing exponentially, regardless of the party in national power, and almost identically in blue and red states. Texas is installing renewables and batteries faster than California, helping cut its risk of a blackout from 16% last summer to <1% this summer.] * I'll summarize how to use delivered energy five times more efficiently.

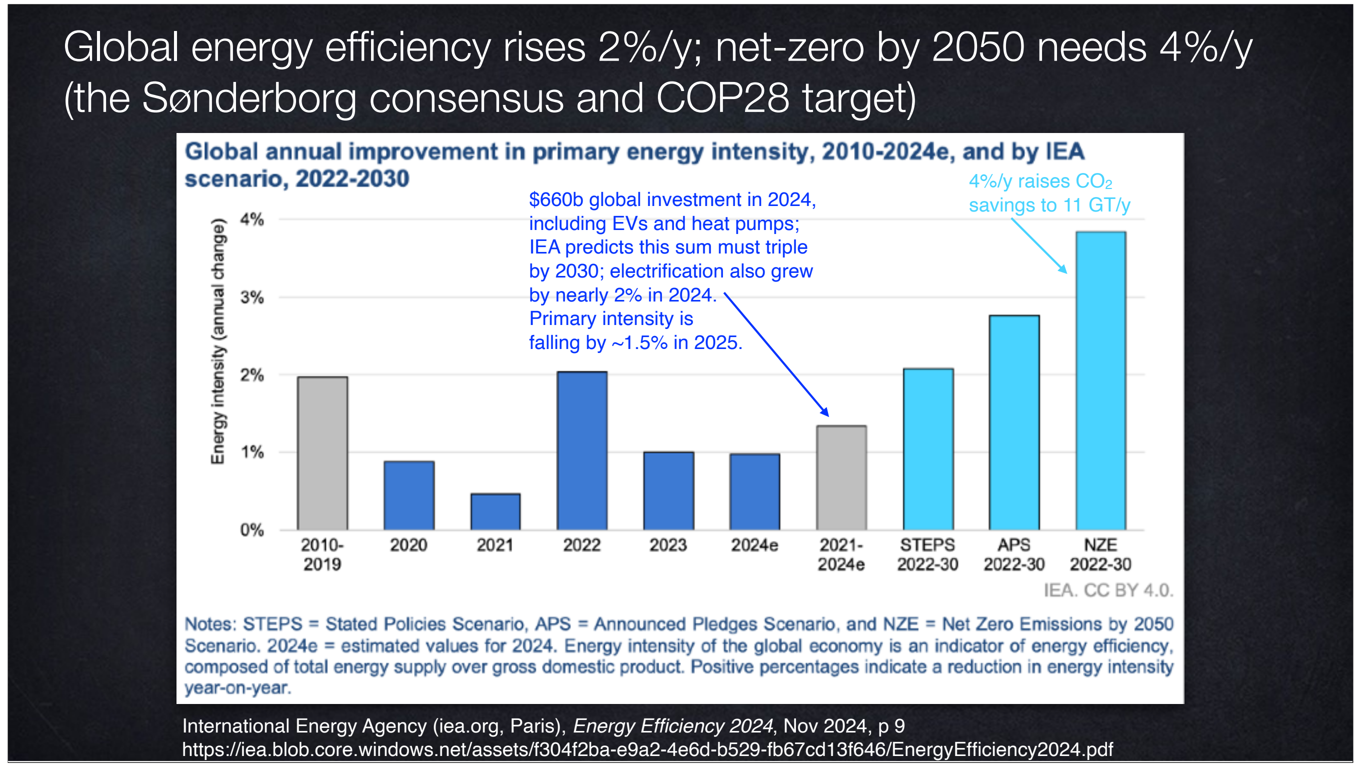
This * Five Eta improvement needs no magic or miracle, nor even new technology. It needs beginner's mind, whole-system thinking, rigorously simple design, and meticulous attention to detail—and then, to get it implemented, gentle diplomacy and relentless patience. Integrative design applies orthodox engineering principles, but asks different design questions in a different order. It's the most-overlooked part of the energy revolution, with the most white space.
I'll sketch how "integrative design" can optimize whole systems for multiple benefits to achieve radical energy efficiency in all sectors. Joel Swisher and I teach this proven practice at Stanford, using lectures posted at a new site at the bottom of this slide, efficiencyhub.stanford.edu. *



Over the past few centuries, the world has transitioned from wood to coal to oil and gas. (Nuclear power isn't shown because it peaked at ~4% share and will keep falling for lack of a business case or operational need.) Excitingly, right now the renewables entering on the right are shifting from *adding to* fossil fuels to *displacing and reducing* fossil fuels. *

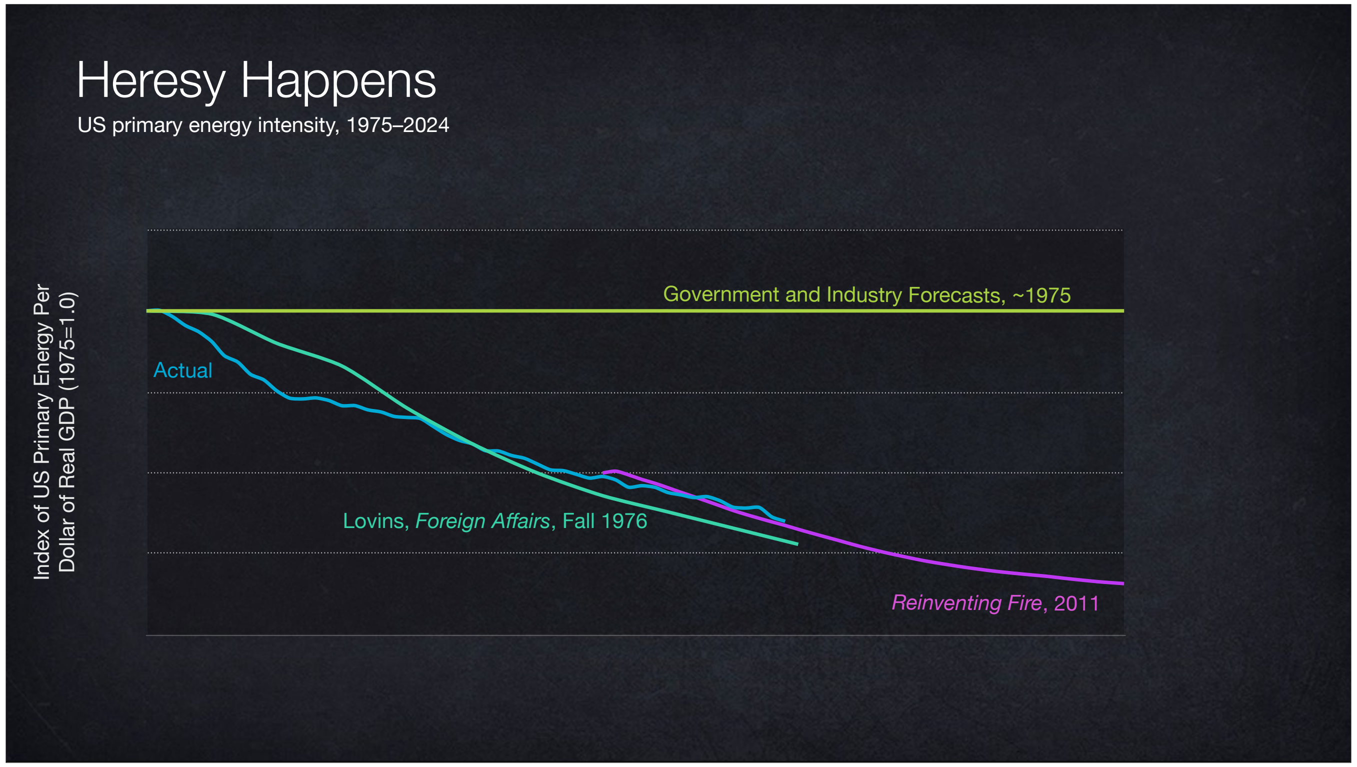


Global use of fossil fuels plateaued about six years ago and is bumping along with minor excursions due to weather or war. [Fossil fuels peaked in industry in 2014 and in buildings in 2018, so] All growth in final demand is now in electricity. Its carbon-free generation grew to meet all demand growth, then more, even as electricity replaces more fuels, all tipping fossil fuels into steepening decline. [The two gray [light-gray and dark-gray "Existing Trends" and "Net Zero"] scenarios shown at the right are from Bloomberg New Energy Finance (BNEF) last year [2024], but were similarly framed by the International Energy Agency (IEA), BP, Shell, McKinsey, Rystad, and others. They] The most respected forecasts all say the trend of the previous two centuries is now starting to reverse, so the burning of fossil fuels will now begin to fall, ever faster. Indeed, China's carbon emissions just peaked, mainly because over half its new cars are electric and China sells more electric cars than the US sells total cars, and because China met its 2030 solar-and-wind target in summer 2024, six years early. India was five years early. *

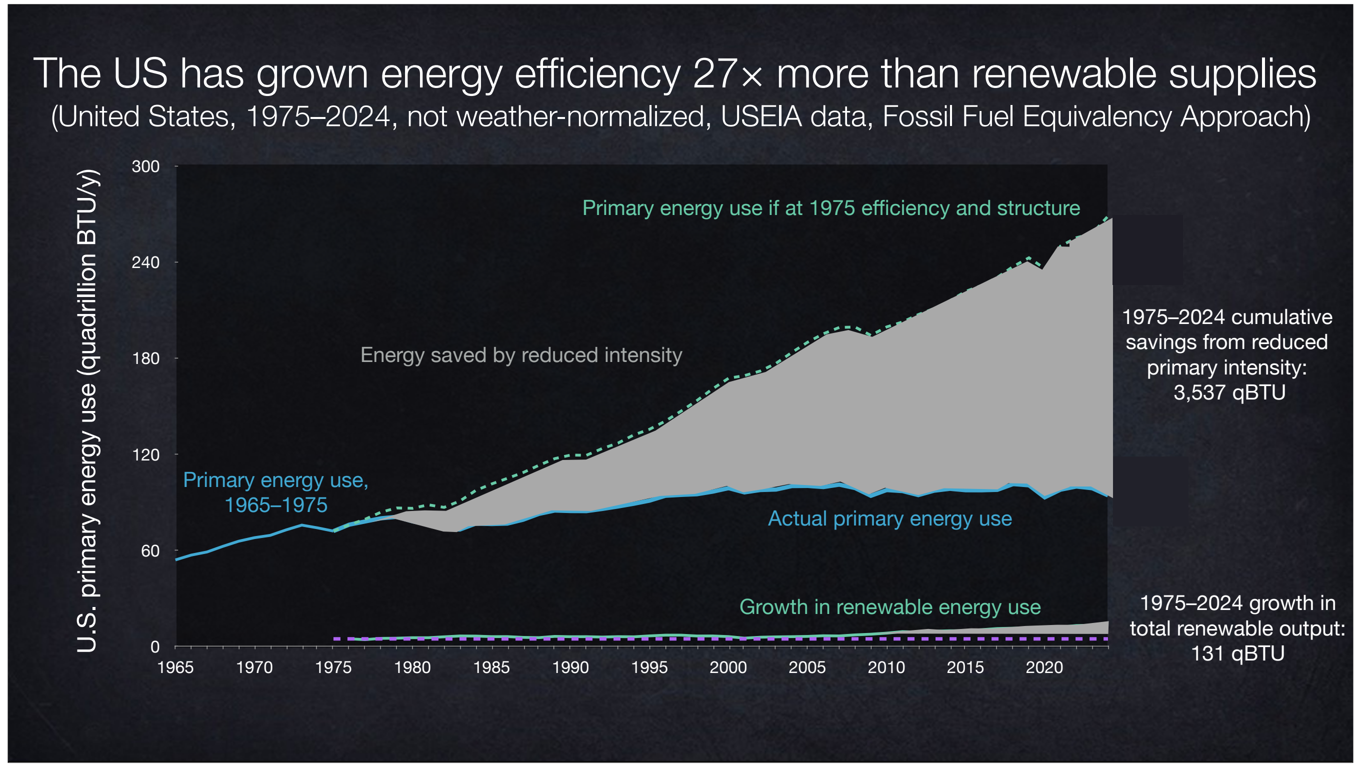


That's about energy *supply*, but the world's biggest "source" of energy services, bigger than oil, is using energy more efficiently. That work employs around 20 million people and invests about $0.8 trillion per year. [IEA says efficiency] It has delivered half of the past 20 years' decarbonization, but its pace must now rise from ~1½%/y to 4%/y to reach net zero by 2050. That's much easier in fast-growing economies like Nevada's, because it's easier to build things right than fix them later. Buildings use three-fourths of America's electricity and half the world's electricity. So I'm excited to be talking to the folks who design buildings in Nevada!

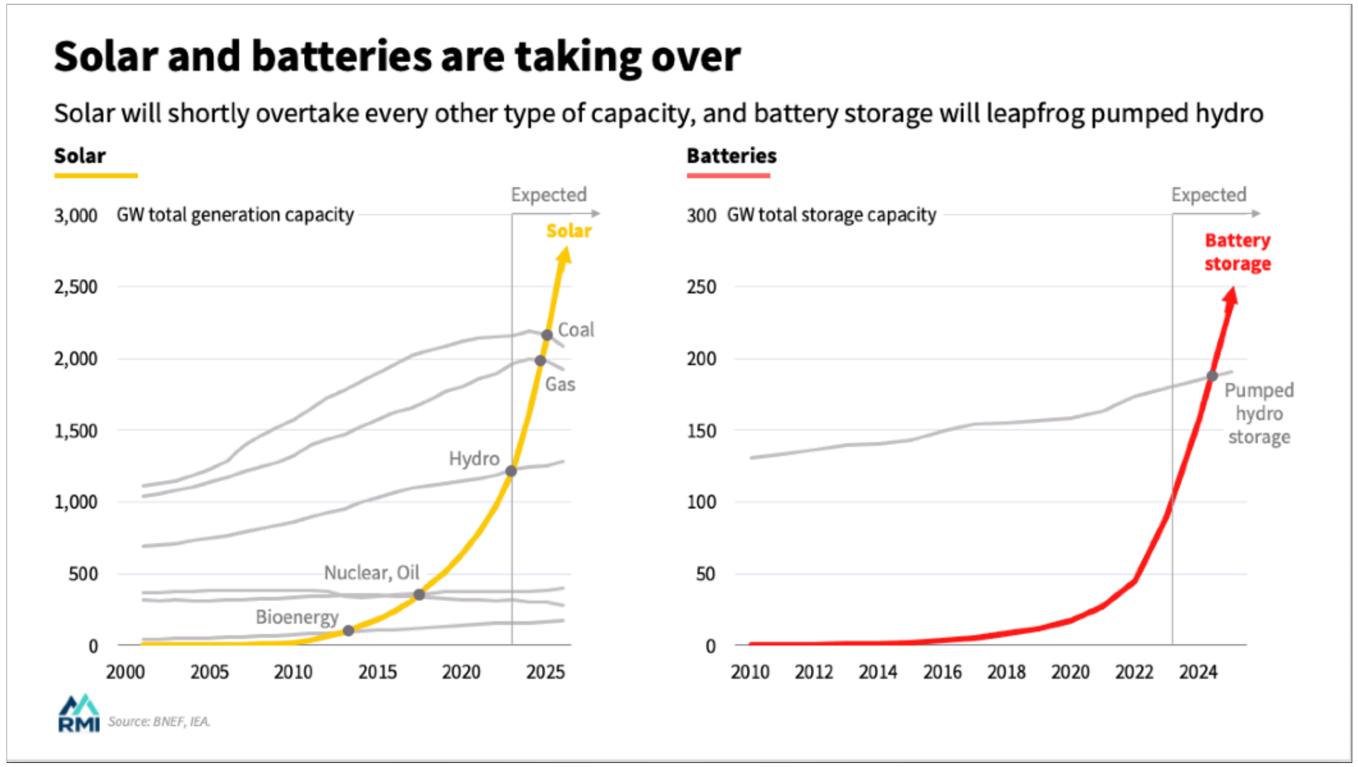
[IPCC's finding [AR6, WG3, §C.10] that efficiency can deliver 40–70% of *future* decarbonization is understated because it includes only subsets of technology and policy. I'll sketch how their full spectrum, plus innovative design and new business models, can make that efficiency resource severalfold larger, so global end-use energy efficiency can *quintuple* at a pace within IEA's forecast range (aqua). That's not a limit.] *



A little history: Around 1975, US government and industry all said the * total input energy needed to make a dollar of real GDP could never drop. * A year later I heretically suggested it could drop 72% in 50 years. * In the first 49 years, it's dropped 65% despite frequent federal and incumbent hostility: the hydrocarbon industries outspent the clean-energy industries by 27× to influence federal legislation in the decade to 2018, and far more lately. Yet just the efficiency innovations already added by 2010 * can save *another* threefold, twice what I originally thought, at a third the real cost. And today that looks conservative, because optimizing buildings, vehicles, and factories as whole systems, not as piles of isolated parts, can often make very big energy savings cost *less* than small or no savings, turning diminishing returns into *increasing* returns. *



When * saved energy, * about two-thirds * due to smarter technologies, * dropped US energy use by 65%, * the cumulative savings were immense. * Renewables meanwhile nearly tripled (2.88×), but with * 27× less cumulative impact. Who knew? Renewables get virtually all the headlines, because they're visible, while energy is invisible, and the energy you *don't use* is almost unimaginable. *

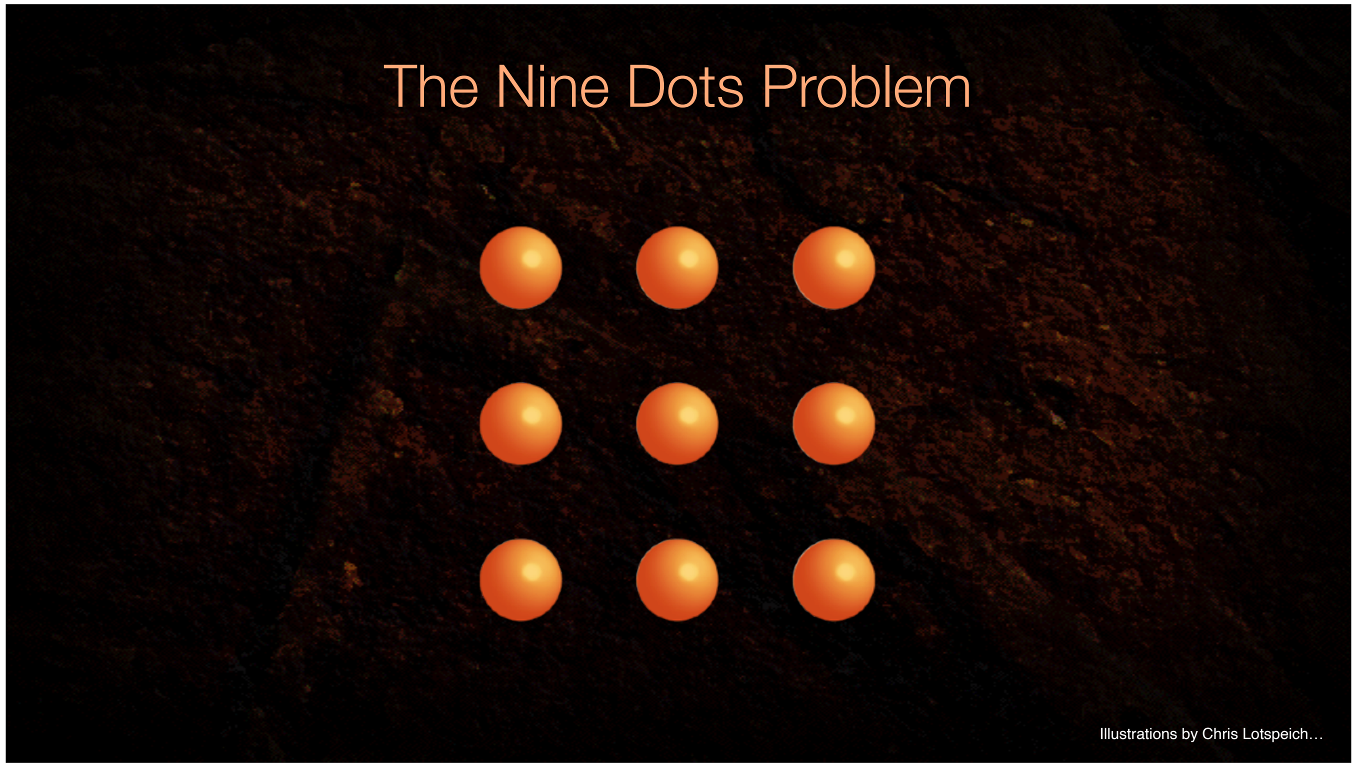


Last year and this year [2025], solar capacity alone is blasting past every other global source of electricity, probably surpassing the yellow curve, while battery storage exceeds pumped hydro storage capacity. We just passed the tipping point where the cheapest bulk power source on Earth is now solar (or windpower) plus batteries or other backup, which comes in ten carbon-free flavors on the supply and demand sides. But wringing more work out of our energy is generally even cheaper—especially with integrative design. *

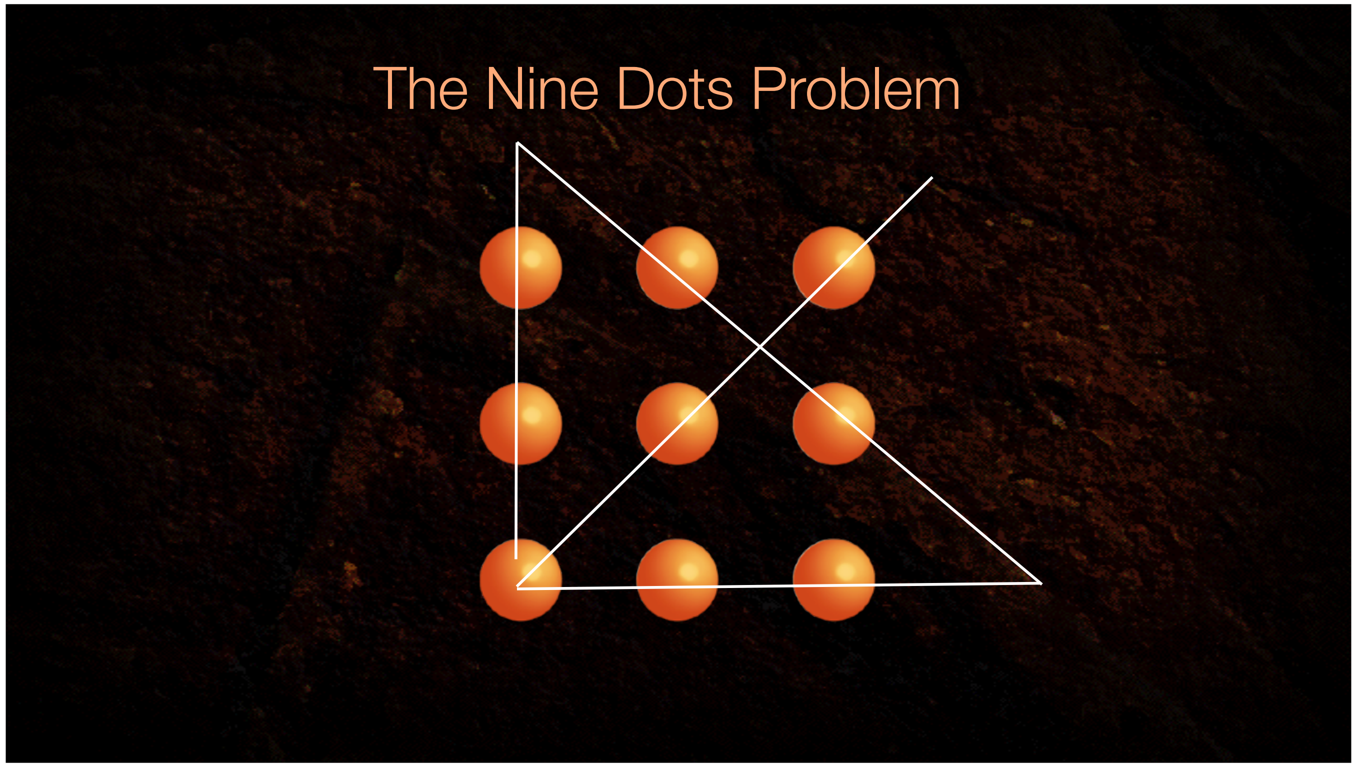
This seven-year-old paper explains how making energy savings severalfold bigger can actually cost *less*, because it uses not more but fewer devices, and not fancier but simpler devices—more artfully chosen, combined, timed, and sequenced.

We're used to resources like copper orebodies and oil reservoirs—finite and depletable assemblages of *atoms.* But energy efficiency resources are different: they're infinitely expandable assemblages of *ideas*, depleting only stupidity—a very abundant resource. *

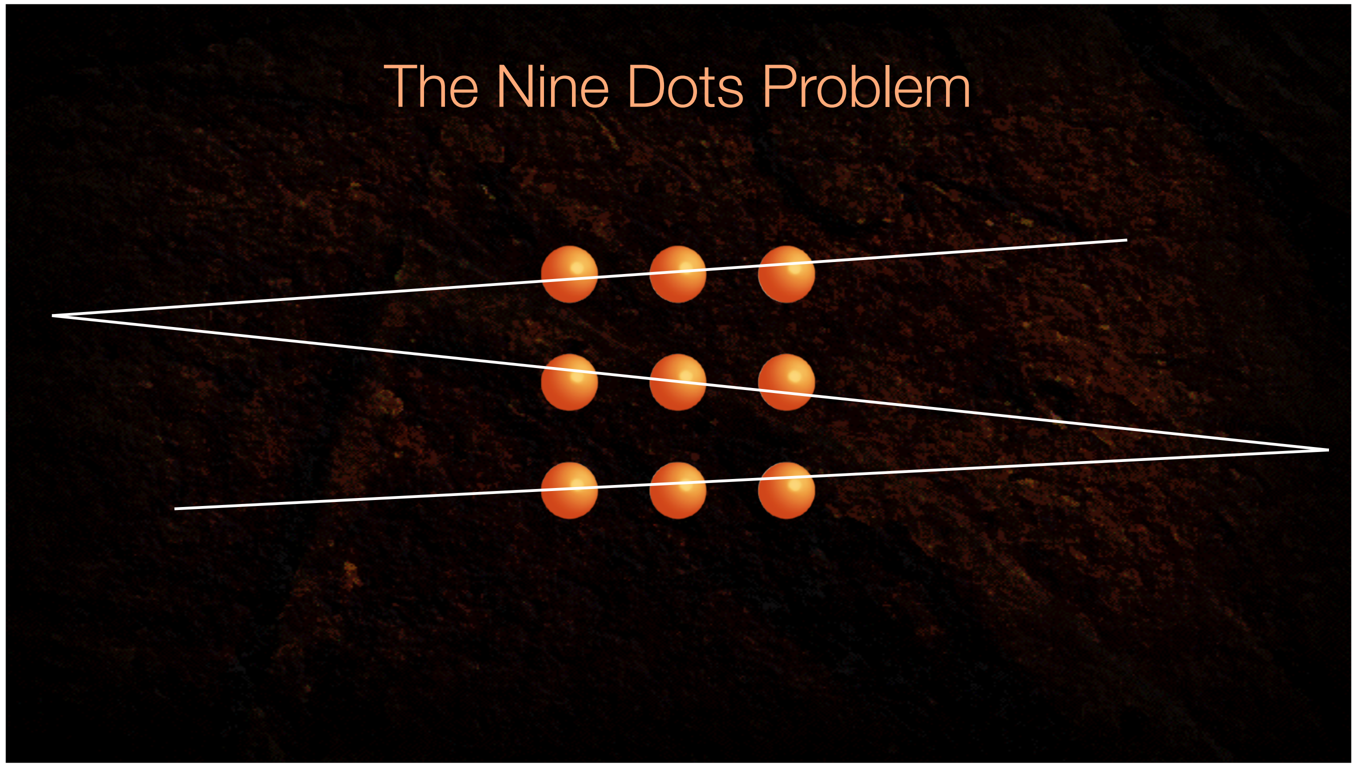
Efficiency’s magic starts with an open mind. One of my early mentors, the inventor Edwin Land, said, “Don’t undertake a project unless it is manifestly important and nearly impossible.” He also said, * “People who seem to have had a new idea have often just stopped having an old idea.” * Asian tradition likewise urges us to seek original mind, beginner’s mind, child mind—opening ourselves to new ideas by shedding all assumptions and preconceptions. *



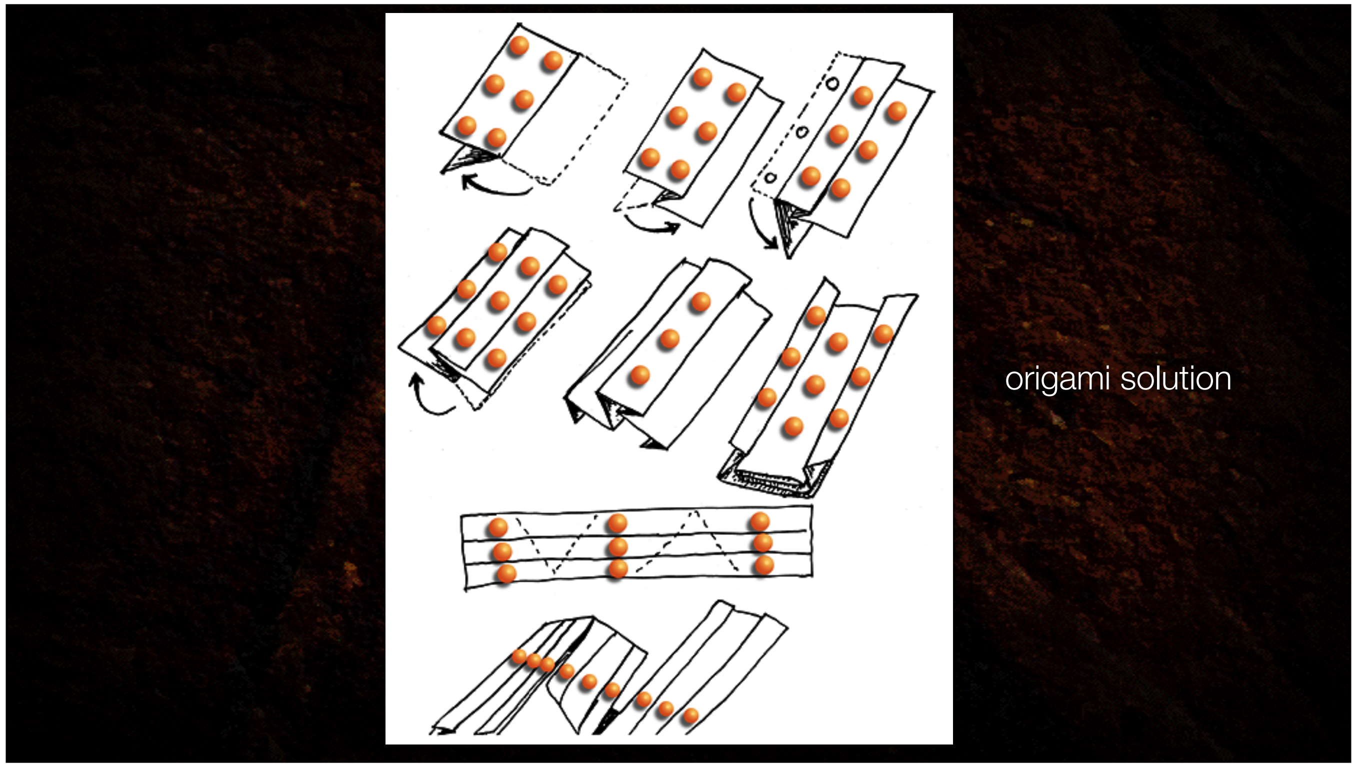
So in that spirit, CalTech’s late great aerodynamicist Paul MacCready reminded us that decades of textbooks on creative thinking have posed this problem as “Find the solution that connects these nine dots with just four lines without lifting your pen from the paper.” You can try going around the perimeter, or diagonally, but nothing works… *



...until you think “outside the box” (which is where the expression comes from). But one day, a student said she’d solved the problem with just *three* lines. Gee, four was hard enough! How do you do it with just three? Dots are infinitely small. Hmmm...these are actually rather plump dots, and you needn’t go through their centers, so if your paper is wide enough... *



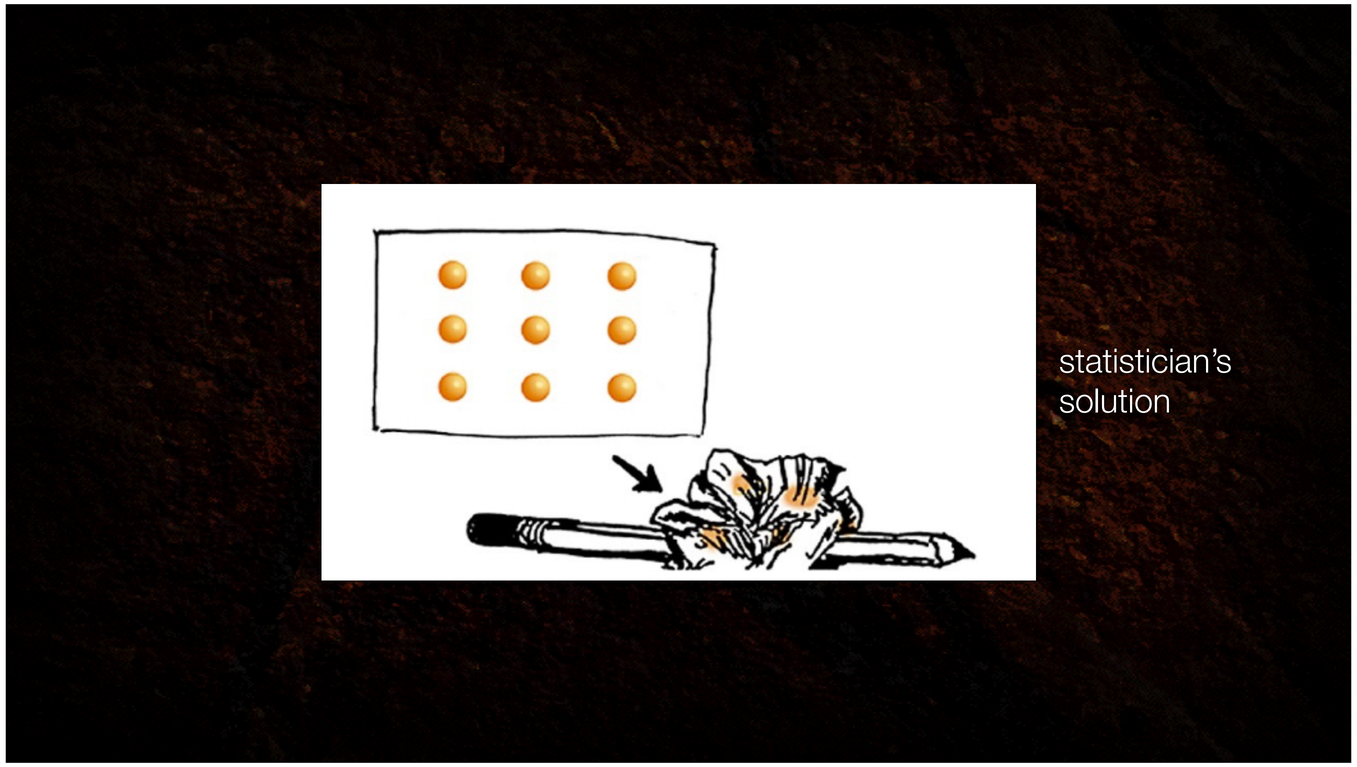
...you can do this! Then the students started to feel liberated, and began solving the problem with just *one* line! Here are a few of their many solutions...*



If you’re Japanese, you might think of the origami solution....*

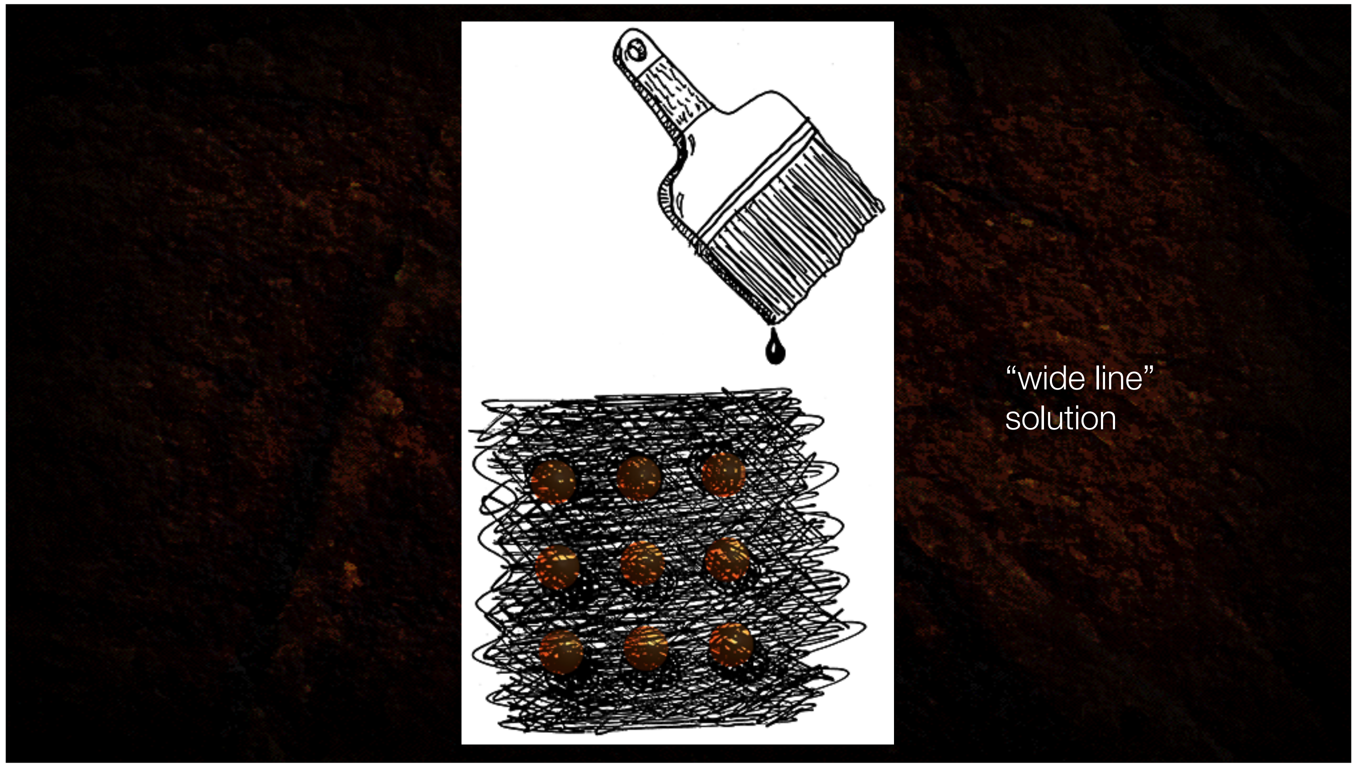
Or if you're a geographer, you might use a very *long* line....*

Or if you're a mechanical engineer, a tool-using creature, you might use a tool called a scissors to cut out the dots and impale them….*



Or if you're a statistician, you might crumple up the paper, and if you stab it over and over again enough times with the pencil, eventually you'll go through all nine dots at the same instant.

The solution I liked best came from a nine-year-old girl who said, "You didn't say it had to be a *thin* line...*

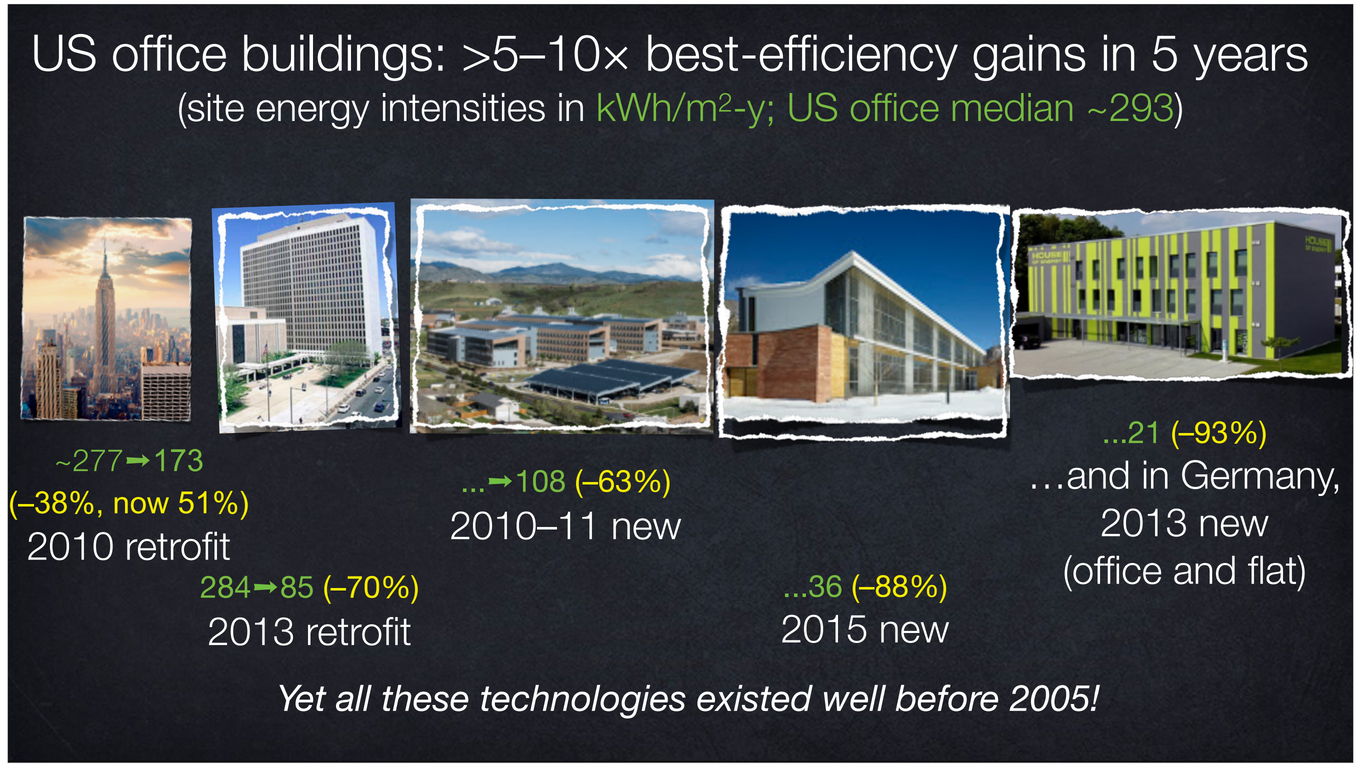


...so I used a really *thick* line!"

As MacCready said, this "tyranny of the word *the*"—find *the* solution with four lines—puts us back in the box and keeps us from being more creative in finding more elegantly frugal solutions.

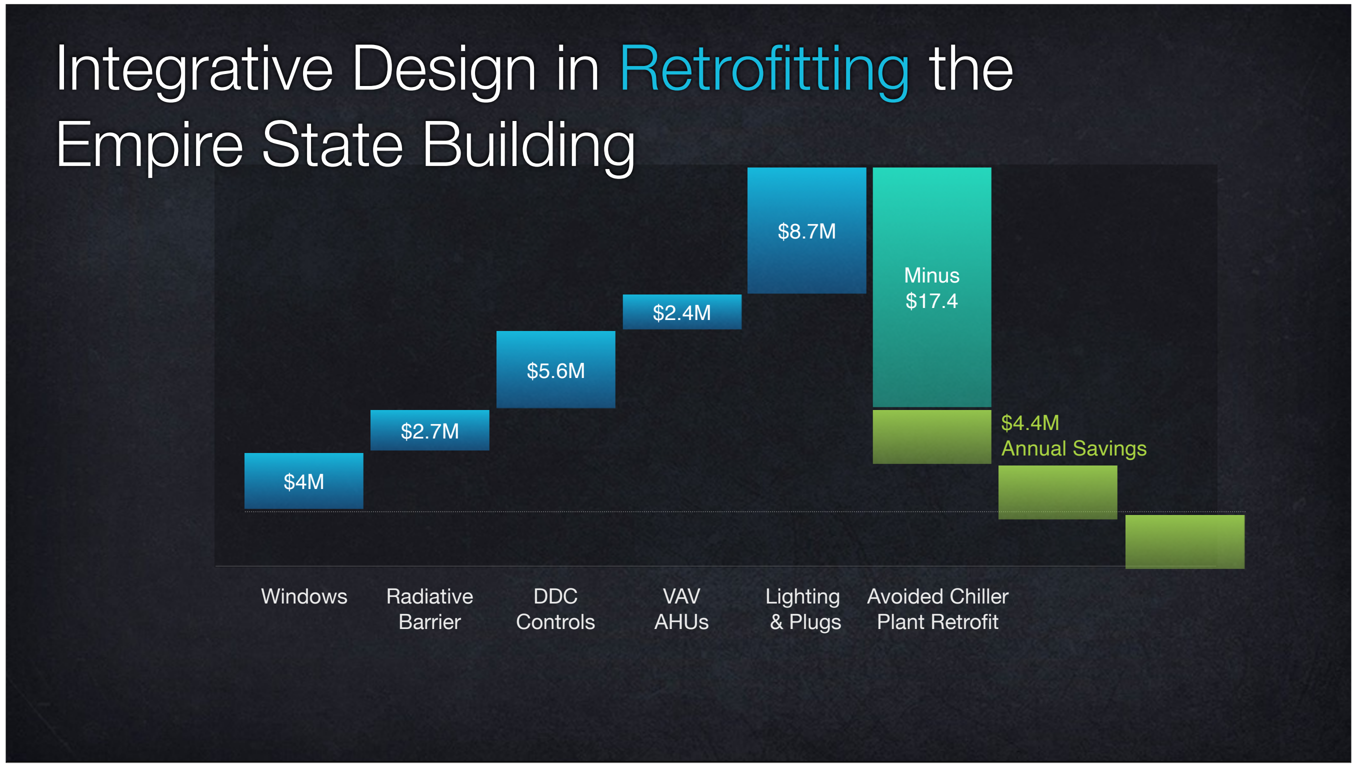
So with beginner's mind, never before having built a house, so I didn't know what was impossible, in 1982 I did the conceptual and energy design of the owner-builder house…*

…where my wife and I live near Aspen, Colorado, 7100’ above sea level, where * temperatures used to dip to –47˚F and we’ve seen 39 days of continuous midwinter cloud. Yet our house does no combustion (that’s so 20th-Century). Superinsulation, ventilation heat recovery, and big superwindows insulating like 16–22 sheets of glass (but looking like 2 and costing less than 3) make it 99% passive-solar heated, 1% active-solar. Superefficiency added less construction cost than eliminating the heating system subtracted, so construction cost fell slightly. Reinvesting that saving plus some more saved 99% of the space- and water-heating energy, ~90% of the household electricity, and half the water, all with a 10-month payback in 1983. Today’s technologies are better and cheaper, and we keep improving them. I’m now testing 11mm-thick tempered glazing units from LuxWall with center-of-glass R14–R18 from just a 1-mm vacuum gap, one low-e coating, and all-glass-to-glass-to-glass edge welds with no glass-to-polymer seals. /
Our central * atrium, seen here in a February snowstorm, has so far produced * 83 passive-solar banana crops. Our house helped inspire several hundred thousand European passive buildings with little or no heating and roughly normal construction cost.
Analogous designs work well in Bangkok. Almost everyone on Earth lives in a climate between Bangkok and Old Snowmass. Integrative design gives many benefits from each expenditure: this white arch *[point]* has 12 functions but only one cost. *



Integrative design let our * Empire State Building retrofit save 38% of its energy (now 51%) with a 3-year payback, as I'll explain in a moment. Three years later, our * cost-effective retrofit saved *70*%, making this half-century-old federal complex in Denver *more* efficient than the * then-best *new* US office (at NREL)—which in turn is * one-third as efficient as RMI's net-positive, no-mechanicals, passive Innovation Center in Basalt, Colorado. * This southern German building reportedly uses two-fifths less energy still! Yet all these technologies existed two decades ago; what * mainly improved is not so much technology as *design*—how we put the pieces together. *

How did our 2010 retrofit save two-fifths of the Empire State Building's energy? * Remanufacturing its 6,514 windows *onsite* (in a temporary window factory operated by Teamsters on a vacant floor) into superwindows, plus… *



...better lights, office equipment, air-handling units, etc., cut the maximum cooling load by one-third. Then renovating smaller chillers instead of adding bigger chillers * *saved $17 million of capital cost,* paying for most of those improvements * and cutting the payback to three years (or under one year if we'd counted non-energy benefits). A big Energy Service Company using *dis*-integrated design had offered the same three-year payback with only one-sixth our initial savings—a hint of integrative design's importance. The owner now wants to go back and boost the savings from the current 51% to 80%. *

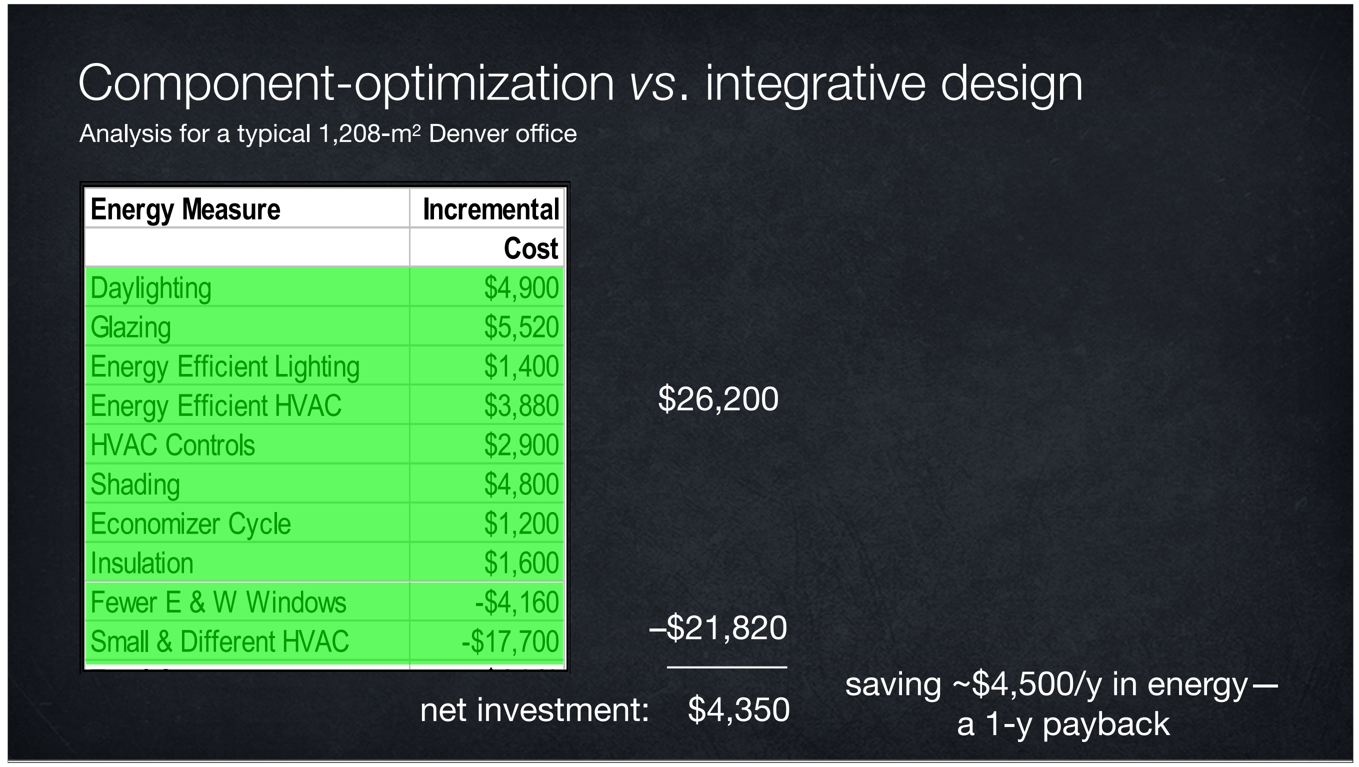
Component-optimization *vs*. integrative design

Typical analysis for a 1,208-m² Denver office

Energy Measure	Incremental Cost	Annual Savings	Payback Period (yrs)
Daylighting	$4,900	$1,560	3.14
Glazing	$5,520	$1,321	4.18
Energy Efficient Lighting	$1,400	$860	1.63
Energy Efficient HVAC	$3,880	$739	5.25
HVAC Controls	$2,900	$506	5.73
Shading	$4,800	$325	14.77
Economizer Cycle	$1,200	$165	7.27
Insulation	$1,600	$101	15.84

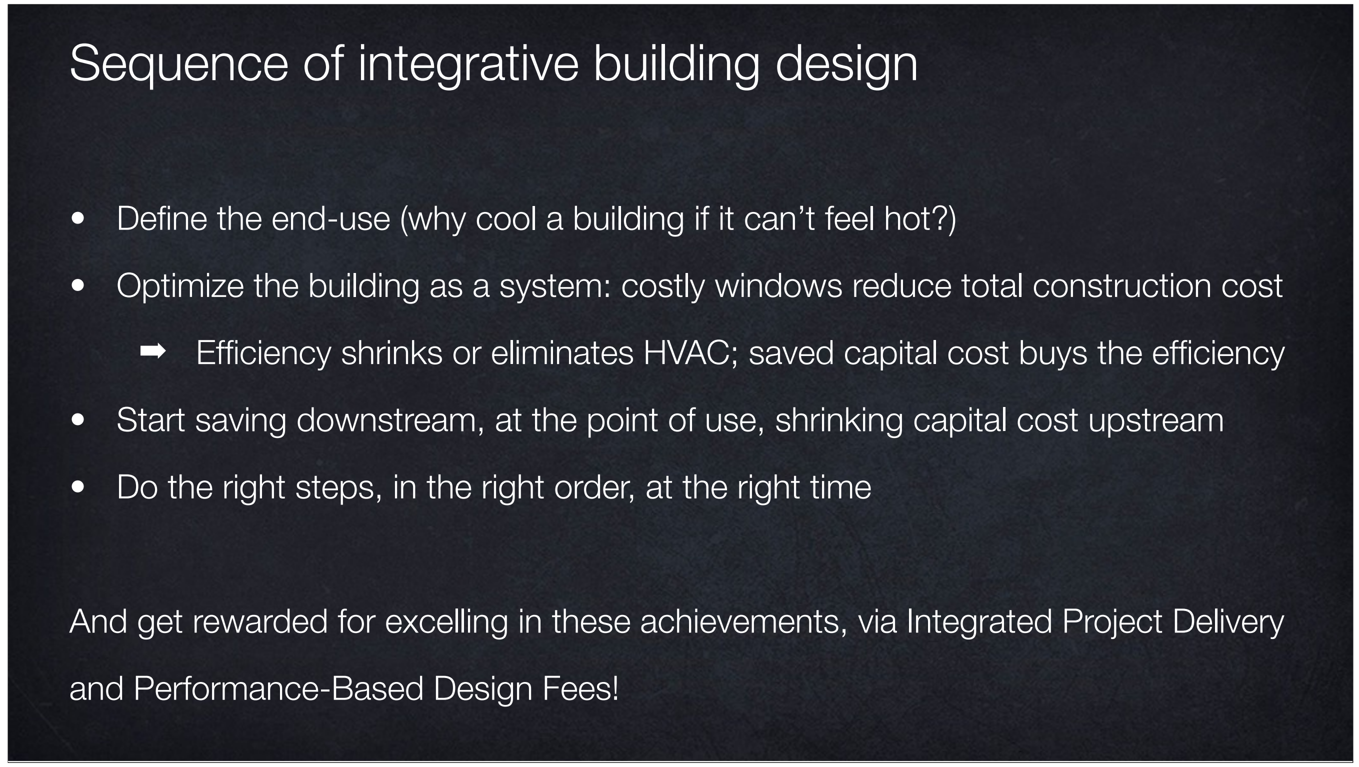
Each improvement by itself is too expensive for a cash-short developer.

Here’s a simpler design example. If a cash-constrained developer asked her architect to suggest ways to make a new small office greener and more efficient, she’d probably be handed a list like this with payback times in the right-hand column…and conclude that few if any items could pay back fast enough. But what happens if we optimize the whole building together? *



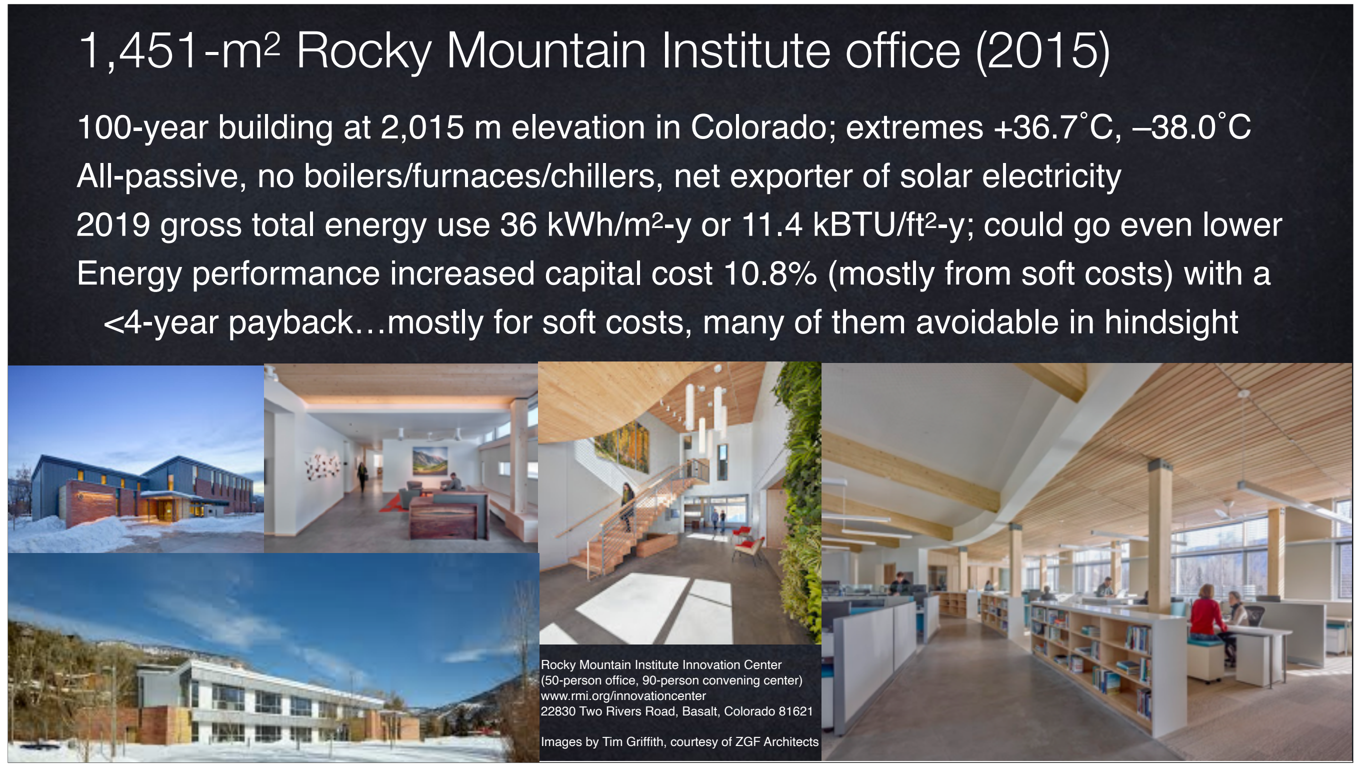
If the developer chose *everything* on the list, the better daylighting and reduced internal heat gain would create a new ability to move some * fenestration and shrink the mechanicals for smaller loads, so most of the efficiency's extra * costs would be offset up front by the * capital costs they save. The * *net* capital cost, just over $4,000, would * pay back in a year—more quickly than any one measure alone! RMI's team has applied this approach to more than a thousand buildings. *

In the opposite climate, in six muggy Indian cities, 16 million ft^2 of integratively designed offices used 80% less energy than the Indian norm, with 10–20% lower construction cost, 60% less cooling capacity, and superior comfort and satisfaction. Glarefree daylighting is delivered throughout by contract: if workers complain of glare and demand blinds, the architect doesn't get paid. *



The sequence is thus: * Start with the end-use effect you intend; * optimize buildings as whole systems (so often the key to cutting construction cost is to use expensive glazings); * pay for the efficiency through the mechanical shrinkage it causes; * cut the most capital cost by saving from downstream to upstream, as I'll explain; * optimize the sequence and timing of design steps; and ** reward the design professionals for what they save, not what they spend.

What can this approach achieve? *



A decade ago, these innovative processes brought in RMI's Innovation Center, 10 minutes from my Banana Farm, slightly under budget and ahead of schedule, yet of the 20 most efficient commercial buildings in North America, it's the most efficient we know of in the two coldest climate zones, using one-ninth the normal amount of energy. Like my house, it's passive, net-positive, and no-mechanicals. It keeps people cool by 11 and warm by 10 passive methods. My favorite space is the 25-m² Nega-Mechanicals Room, where I want to sneak in one night and outline on the floor in yellow industrial tape, like bodies at a crime scene, where the boilers and chillers were supposed to go before we designed them out. We expect this building's cost premium and <4-y payback would drop to about zero with wider experience, as occurred in Germany's best passive buildings. / The photo on the right shows a nice bit of integrative structural design. The building is curved to echo the adjacent river-bend, so the beams that hold up this ceiling and floor act like sideways arches. The floors can't rack in a crosswind because the arches would need to compress. This avoids having to install the X-braces usually needed to provide that stiffness against side-thrust forces. Another neat trick was using Cross-Laminated Timber structures where the grain runs in all three directions, so the wood serves equally well as a post or a beam. Those structures' computer-controlled manufacture left interior channels for the sprinkler pipes, wiring, and air ducts (which were one-fourth the usual size because they carry only fresh air, not hot or cold air). This avoided most of the plenum height [between the top of each ceiling and the bottom of the floor above], enabling higher ceilings with deeper daylighting. Or a typical office with a 23-m low-rise height limit could use the shallow plenum to fit in an extra (sixth) floor and save a 15-cm-high strip of costly façade at each floor, with wonderful financial results. *

Performance-based design fees

- Corrects *one* of the roughly two dozen perverse incentives that have made the U.S. misallocate $1 *trillion* of capital just to air-conditioning
- Get paid for what you save, not what you spend
- Five successful experiments, simple protocol*
- Use models (Energy10, DOE-2,…) to back out changes in weather, occupancy, etc.
- Balanced rewards/penalties for over/under-performance *vs.* preset target (code or better)
- Distinguishes the best designers in the market
- Maybe “wellness doctor” relationship afterwards?

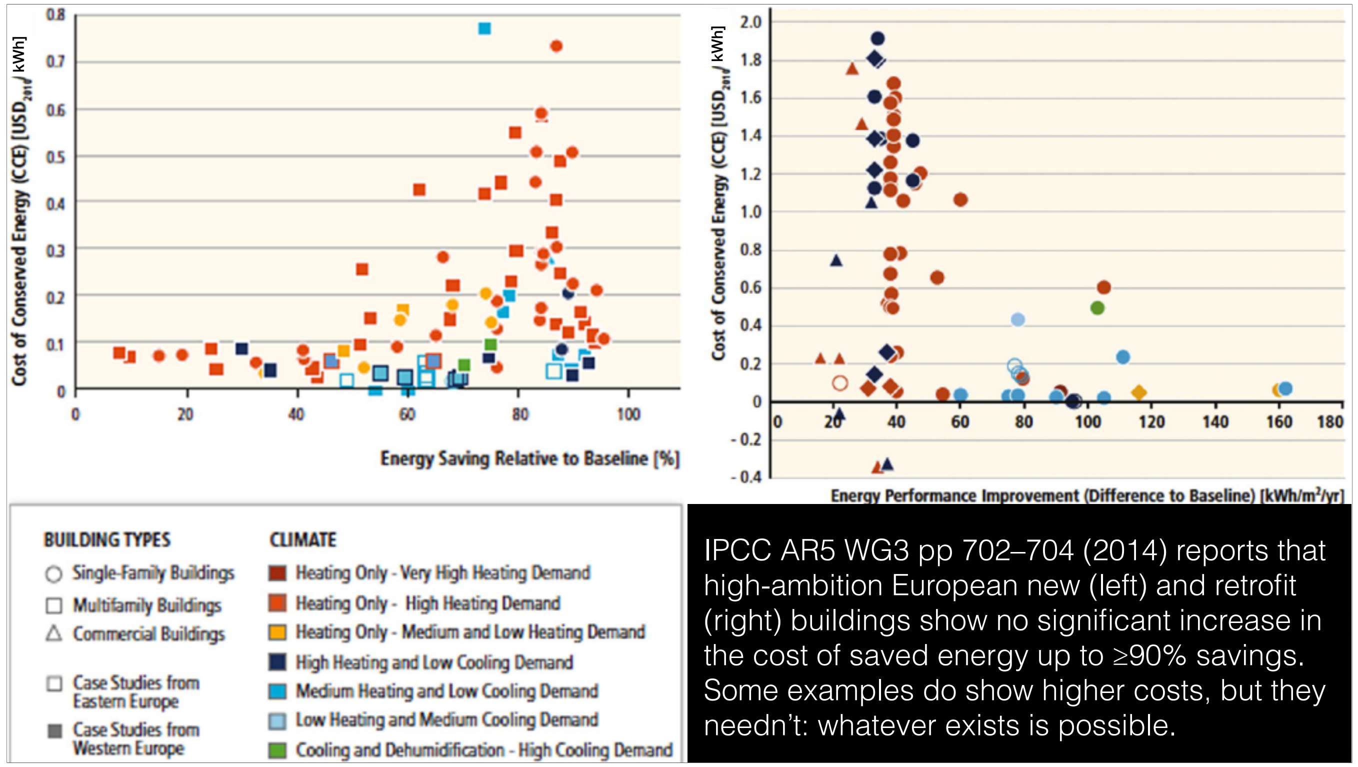
*http://eley.com/sites/default/files/pdfs/energy_performance_contracting_for_new_buildings_rmi_ef.pdf
(RMI Publication #D04-23, “Energy Performance Contracting for New Buildings”)

RMI’s Innovation Center’s Integrated Project Delivery is described at https://rmi.org/our-work/buildings/scaling-zero-net-carbon/rmi-innovation-center/design-process/

[Integrated Project Delivery aligns incentives and ensures seamless collaboration between owner, designer, and builder, as we did in RMI’s Innovation Center to bring it in slightly below budget and schedule. Modern Building Information Management systems give all parties the same complete and up-to-date data at all times. Performance-Based Design Fees reward design professionals for savings, not expenditures. These processes are just as important as the design, technology, and construction that they support and steer. They all help correct * misallocations of capital so gigantic that by 1990, the US had bought a trillion dollars’ worth of air-conditioning equipment and power supplies to run it that wouldn’t have been bought if the buildings had been properly designed.]

* Performance-Based Design Fees, validated by * five RMI experiments through 2004, * reward design professionals for measured savings, not by a traditional fraction of expenditures. This simple method holds designers accountable for what they can control, not what they can’t (like weather or occupancy), which get factored out by standard modeling tools. * The net result drives predictable compensation. * The best designers like this because it distinguishes them in a crowded market. Clients like it too, because they can more easily find the best designers who will stand behind their work, and of course their energy and often capital costs will go down. Yet such fee structures remain rare. You could help spread them.

* You can even imagine going one step further: turning design from a transaction into a continuing relationship by contracting, after occupancy and commissioning and measurement, to pay the designers a modest fee each year so long as building performance keeps improving, but stopping the fee if it gets worse. That’s like the old Chinese “wellness doctor” system, where you pay your doctor for keeping you well, and stop paying if you get sick. * It would give the holders of the original design intent a strong incentive to keep improving technology, training, and operations for mutual benefit. *



IPCC AR5 WG3 pp 702–704 (2014) reports that high-ambition European new (left) and retrofit (right) buildings show no significant increase in the cost of saved energy up to ≥90% savings. Some examples do show higher costs, but they needn't: whatever exists is possible.

Let me offer further data and examples. IPCC reported decade-old data showing the best European new buildings on the left, and retrofits on the right. Both graphs show bigger savings toward the right and cheaper savings toward the bottom. These diverse buildings could save up to at least 90% of their energy use *without costing more per unit of saved energy*. Even such huge savings in diverse new and old buildings can be very cheap—nearly down on the horizontal axis—if integratively designed. The big vertical cost scatter in both graphs just shows the opportunity to conform inferior projects to best practices. *

Benchmarking a big new office

(~10,000+ m², semitropical climate, no PVs, USA; ~2012 Japan; 2015 1,451-m² RMI Innovation Center; ~2012 India

	Normal	*Better*	*Best*
delivered MJ/m²-y	1,100/1,737	450–680/566	100–230/126/130/158–194
del. el. kWh/m²-y (EPI)	270/203/~200–400	160/195	20–40/35/36/<75 (25 cooling)
lighting W/m² as-used	16–24/12	10	1–3/2/1/<1.6
plug W/m² as-used	50–90/12	10–20	2
glazing W/m²K center-of-glass	2.9	1.4	0.3–0.5/0.43/1.1
glazing T_{vis}/SC	1.0	1.2	>2.0
perimeter heating	extensive	medium	none/none
roof α, ε	0.8, 0.2	0.4, 0.4	0.08, 0.97/0.1,0.9
m²/kW_{th} cooling	7–9	13–16	26–32+/∞/20–26 (750–1000sf/TR)
cooling syst. COP	1.85	2.3/2.0–2.7	6.8–25+/–/>6.4 (<0.55 kW/TR)
relative cap. cost	1.0	1.03	0.95–0.97/1.11/0.85–0.90
relative space eff.	1.0	1.01	1.05–1.06/1.01

Japan standard: median of 40 buildings, Energy Conservation Center of Japan; better: average of six SHASEJ Junen Award-winning buildings; best: the most efficient of those six buildings (Nissei Yokkaichi Building, 293 MJ), now Takanaka Higashi Kantō 2015 retrofit, ~126 MJ); data courtesy of Urabe-san, CRIEPI, via Asano-sensei, Todai; 2 W/m² lighting is Shimizu Building 2012. India: empirical Infosys new-office performance data from Rohan Parikh; standard estimate from Indian designers—100 of the 200–400 (nom ~250) is cooling.

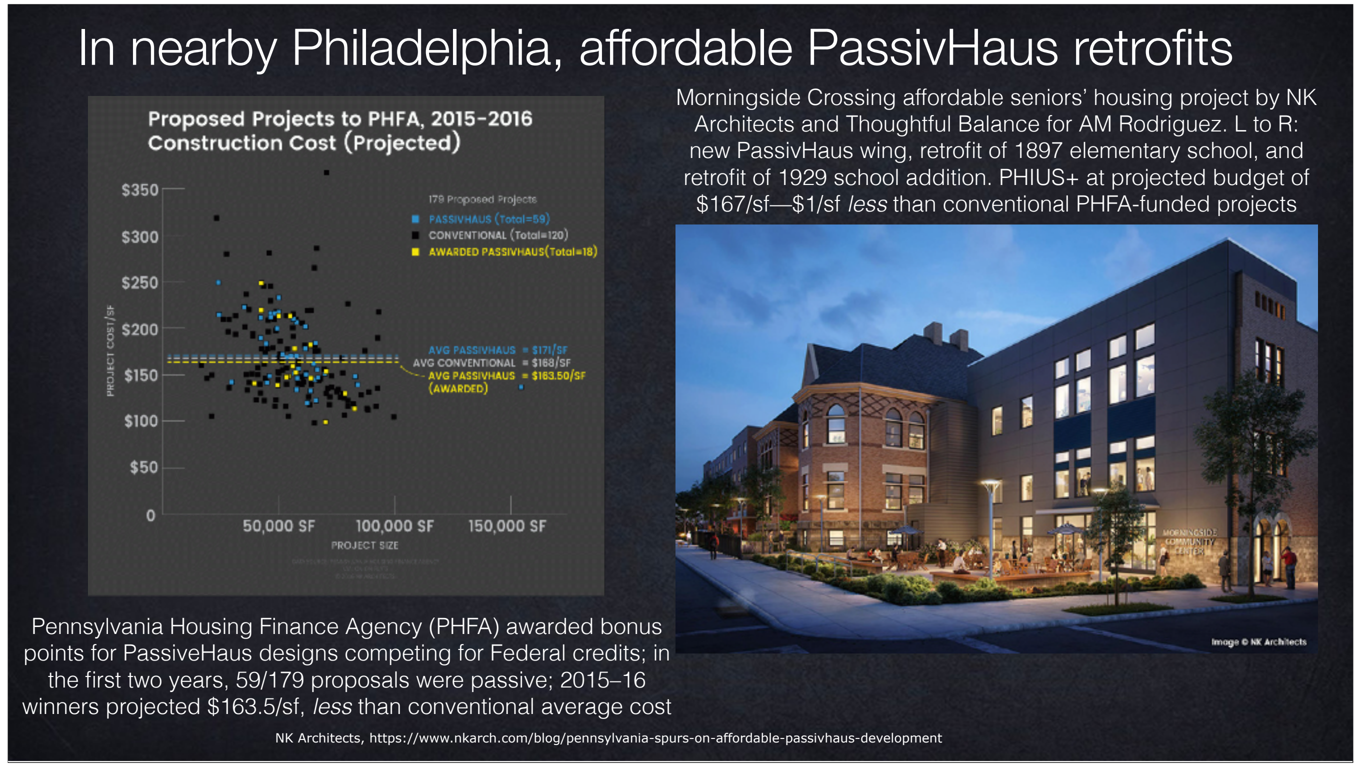
This eyechart, which you can study later in the PDF I'll provide, summarizes technical efficiency benchmarks for big new office buildings in three efficiency categories and four color-coded countries [—normal (like >90% of the stock), better, and best. White data are US, blue Japan, green the RMI office you saw, and red India]. The best buildings need 3–5× less cooling *and* 4–13× less electricity per unit of cooling than standard practice, with better comfort, lower construction cost, and better space efficiency. Whatever exists is possible.

[Comparing the left with the far-right column, you can see that best US practice cuts total and electrical needs by 5–10×, as-used lighting power density by 5–24×, and plug loads by even more. Glazings improve by an order of magnitude and become almost perfectly selective in sorting light from heat. Add superinsulation (not shown) and a heat-rejecting roof, and you need 3–5× less cooling. Then you can make the cooling system ~4–13× more efficient, or even eliminate it altogether. Mechanical savings help reduce capital cost by several percent and use the space ~1–6% more efficiently.] *

Right-timing deep retrofits is also critical. When retrofitting a big glass office tower, superwindows plus efficient lights and equipment can save three-fourths of the peak cooling loads, more than paying up front for the efficiencies that shrank the cooling equipment. Doing that in the old Chicago office tower shown at the rear right could thus pay back in about *negative* five months—cheaper than the routine 20-year renovation that saves nothing—*if* you coordinate that deep retrofit with the routine renewal of the curtainwall. Our tools at Retrofit Depot can design this right-timing for a real-estate portfolio. *

Thus by coordinating with a major renovation, we helped Deutsche Bank’s twin towers in Frankfurt cut heating and cooling energy by 67%, electricity use by 55%, water use by 74%, and carbon emissions by 89% [55% from efficiency, 39% from green power] while improving amenity and making every second window operable. Higher ceilings with radiant cooling improved daylight distribution. Space efficiency rose by 20%[, accommodating 600 more people: in one tower, smaller mechanicals freed an entire floor for other uses]. *

These apartment buildings in Austria and Germany confirm that passive housing can be affordable in challenging climates, similar respectively to those of Buffalo and of Chicago or Boston. Notice, on the upper left, the Austrian passive apartments renting for less than many US cities' poorly insulated apartments. *



The cost premium expected for diverse low-income public-housing projects built to PassivHaus standards in Philadelphia is roughly zero, or even negative, as it was for * this passive *retrofit* of roughly century-old buildings into affordable senior housing. [Philadelphia's 1% design temperature is –9˚C in winter, and in summer, 32˚C with a 23˚C mean coincident wetbulb.]

[In northeast British Columbia's Fort St. John, where the 1% design temperature is –25˚F –32˚C), the average new house costs C$250–350/sf, while a passive version costs $276/sf. There's even a certified PassiveHaus in the Canadian high Arctic.] *

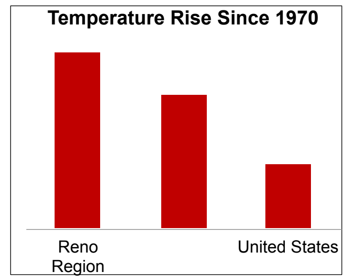
Passive techniques are spreading in our cities, like this New York apartment on the L, built at normal cost. Architect Chris Benedict designed it to save ~85% of normal energy use for heat and hot water. She emphasizes airtightness, innovative ventilation design, and working thermostats in each room. The continuous superoutsulation traps thermal mass, stabilizing indoor temperatures. All these improvements are more than paid for by dramatically downsizing heating equipment, so this apartment building's superefficient rooftop gas boiler needs only a 20-cm chimney—smaller than for many single-family houses. Her superoutsulated Bronx hotel at the upper R gets its hot water free from the hydronic air conditioner. Now her $20-million outsulation *retrofit* project, Casa Pasiva, is cost-effectively retrofitting nine plain old Brooklyn apartment buildings to PassiveHouse standard and all-electric, saving 80% of their energy cost, *without disturbing the occupants*! That's an archetype for retrofitting the whole city's million-plus buildings. *

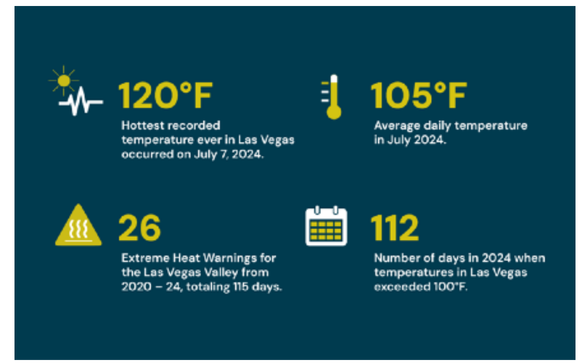
Industrializing mass retrofits to net-zero or better, while streamlining their finance and soft costs, is now getting cheap enough to finance entirely from saved energy, while extending building life and improving amenity, health, and value. This whole retrofit, like bolting on a factory-customized tea-cozy around your house, is now installable in as little as a single day while you’re off at work. Efficiency is roughly quintupled, so the solar roof provides all annual energy needs. This Dutch method, called “Energiesprong” or “Energy leapfrog,” is now coming to the US through RMI’s REALIZE program. *

[“Outsulate” superinsulation including new modular roof with integrated solar PVs (eliminating gas connection and bill), air-tighten, replace all windows, provide heating/(cooling)/hot water with an efficient air-to-water heat pump in a 3-m^3 module, renovate kitchen and bathroom, retrofit lights; total retrofit cost ~€40–60k/unit (already fell from €130k to €80k in 2 y).]

Climate Change Exacerbates Energy Burdens

- Since 1970, Las Vegas and Reno temperatures rose 5.9°F and 7.8°F, making them the fastest-warming cities in the U.S.
- Rising temperatures, rising energy costs, aridification, load growth, and dramatically less federal support strain power resources and prices in the region.





Sources: Climate Central (April 2025); All-In Clark County (2024), courtesy of Kirsten Stasio, CEO, Nevada Clean Energy Fund

Of course, not all Nevadans live in Tahoe; most of your projects are probably in very hot sites, and Las Vegas and Reno are the fastest-warming cities in America. *

Then again, your housing stock has unusual room for improvement

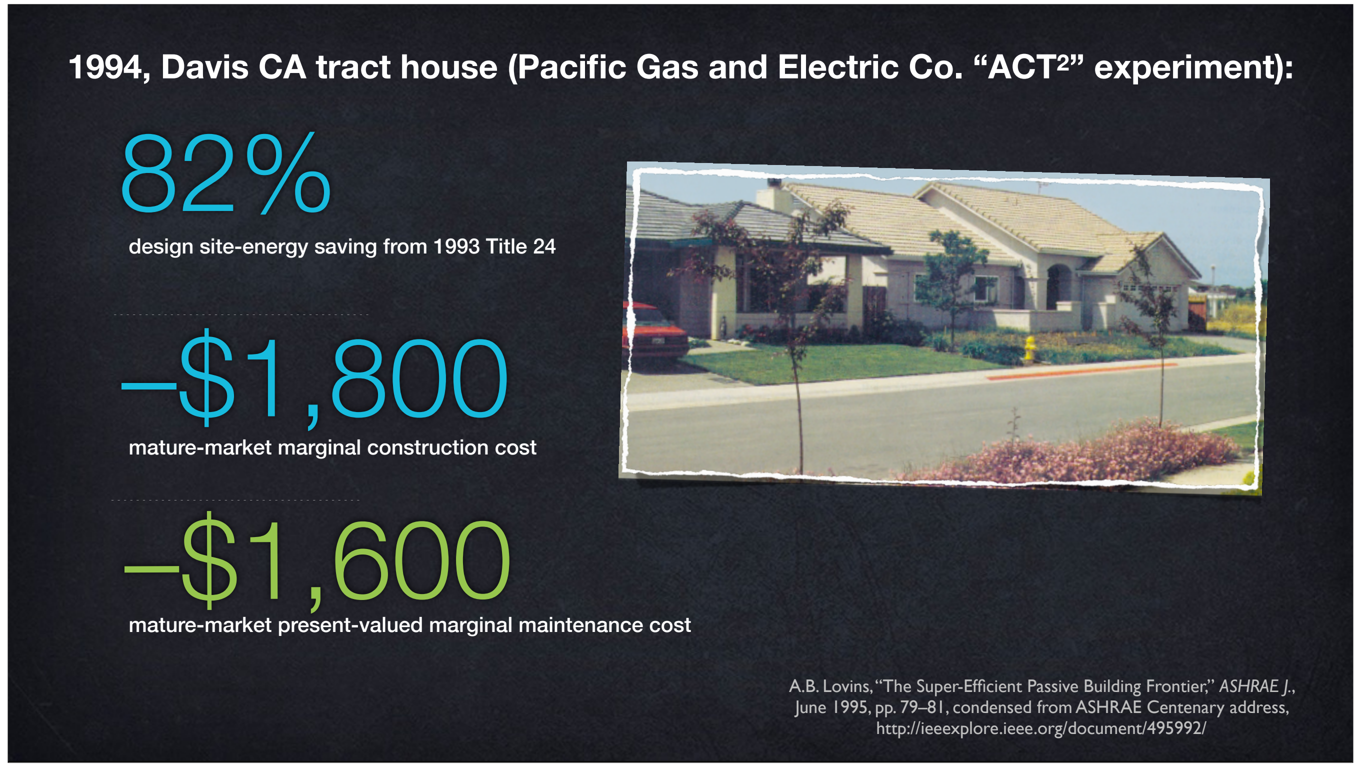
typical 1984 Las Vegas tract house	**summer kW_p**	**winter kW_p**	**MWh/y**	**energy cost**	**customer investment**	**utility coal-plant investment (excl. associated grid)**
per NPC	8.6	8.4	26.9			
NPC's 1984 "optimized" design	5.4	5.8	18.7	~$930/y	+$479/kW	
Lovins 1985 better design*	1.4	0.6	3.7	$463/y	less than el. savings	–$20k
Lovins 2025 estimate, w/o solar	<1	<0.6	<2	?; <0 with solar	?	far greater benefit

* Simple upgrades to 1985 market technology would cut to 3.4 kW, 3.4 kW, and 10.9 MWh/y

- EER-12 a/c, selective W glazing, better lights/applncs, DHW efficiency, HSFP-10.24 winter heat pump
- Or a 1985 COP-10 evap cooler cuts summer peak to 2.0 kW, avoiding $9k of new coal capacity
- Better glazings, gas space heat, heat-pump DHW, yield 1.4 kW summer, 0.6 winter, 3.7 MWh/y with same construction cost, halved energy cost, and $10k less capex for Nevada Power, *w/1985 tech*
- That's 68% less summer peak, 89% less winter peak, and 78% fewer MWh/y than NPC's "optimized" design

A.B. Lovins, Direct Testimony in Nevada Power Company docket 84-724, Public Service Commission of Nevada, 9 Aug 1985

Happily, the Las Vegas area's inefficient housing stock invites mass retrofits and superefficient, roughly net-zero, successors. My PSC testimony 40 years ago noted that what was then Nevada Power Company had suggested modest and supposedly optimized improvements to the standard tract homes that were using 8 peak kW and 27 MWh/y. I dug deeper and found cost-effective ways to save 91% of peak load and 93% of annual electricity while cutting energy bills in half and avoiding over $20,000 worth of coal-fired capacity. Now, four decades later, far better efficiency technologies and designs could save even more electricity, and with rooftop solar, could even make the house net-positive and resilient, with major economic benefits to homeowners, financiers, and NV Energy. Many of these improvements can probably be retrofitted, and we may be coming up on the second appliance replacement cycle right around now. *



Some Nevada homebuilders could adapt this three-decade-old passive house in Davis CA. Neighbors whose five-ton air conditioners couldn't withstand California's 113˚F [45˚C] heatstorms took refuge in this house with *no* air conditioner. In today's value, the sponsoring utility, PG&E, figured that in a mature market, not a one-off experiment, this house would cost ~$5,500 *less* than normal (in today's dollars) to build and maintain. *

Now let's dig deeper into an example of how to design a superefficient house. This ordinary-looking 155-m^2 [1668-ft^2] new house was designed in 1994 by Davis Energy Group for PG&E's ACT^2 experiment. Its design would use 82% less energy than was allowed by California Title 24, the nation's strictest energy code, which supposedly included all cost-effective savings! Huh? Well, the site had a 40˚C/105˚F design temperature and a ~45˚C/113˚F actual peak temperature, yet the house achieved superior comfort *with no air-conditioner and lower construction cost.* Dick Bourne's team first improved the floorplan and eliminated 7 m/22' or 11% of superfluous perimeter; optimized the windows' area and direction; put thermal breaks in their sashes; and designed an oriented-strandboard wall that saved 74% of the wood, nearly doubled the insulating value [to a true R-27], improved strength, airtightness, durability, stability, and speed of construction, and cost $2,000 less to build. All this saved 17% of site energy and $4,000 of construction cost. Next, the designers systematically improved the lights, appliances, glazings, and hot-water system, including making the 1–3%-efficient bathroom exhaust fans 5× more efficient at no extra cost. Water-cooling the refrigerator made it more efficient, gave free water-heating, and turned the device into a summer space-cooler by sending building heat down the drain. These ~20 improvements together raised the total energy savings to ~60% and eliminated the $2,050 furnace and its ductwork—replaced with a hydronic radiant slab coil fed by the 94%-efficient gas water heater they were paying for anyway. By then, net extra cost had risen by nearly $1,900, and any more efficiency would cost more than the energy it saved. But one-third of the original 3.5-ton cooling capacity remained. Now what? Well, the designers had thoughtfully reserved a special "potential cooling elimination" basket where they put all measures that didn't save enough *energy* to pay for themselves but that *did* also cut *cooling* load. Together, seven such measures^ more than eliminated the remaining air conditioning and its ducts, wires, and controls, raising the total energy savings to * 82% and avoiding another $1,500 of construction cost. In a mature market (not a one-off experiment), this house would cost * ~$1,800 less to build and * $1,600 less in present value to maintain [, while saving 80% of the site energy for space and water heating, space cooling, refrigeration, and lighting]. Despite compromises introduced by the owner, it still performed so well that neighbors took refuge in this passively cooled home during a heat storm when their 5-ton air conditioners couldn't cope. When the owner later sold the house, he insisted on installing a window air conditioner anyway: he knew it would never run, but felt he couldn't sell it without one! *

^e.g., better superwindows, core-zone double drywall, ceramic floor tile to help ride through daily heat peaks…$2,600 in all—thus eliminating (w/44% safety margin) the last $1,500 worth of a/c & $800 of maint., earning their way onboard and raising space-cooling savings to 100% (92% w/fans).

Pay attention (2025)

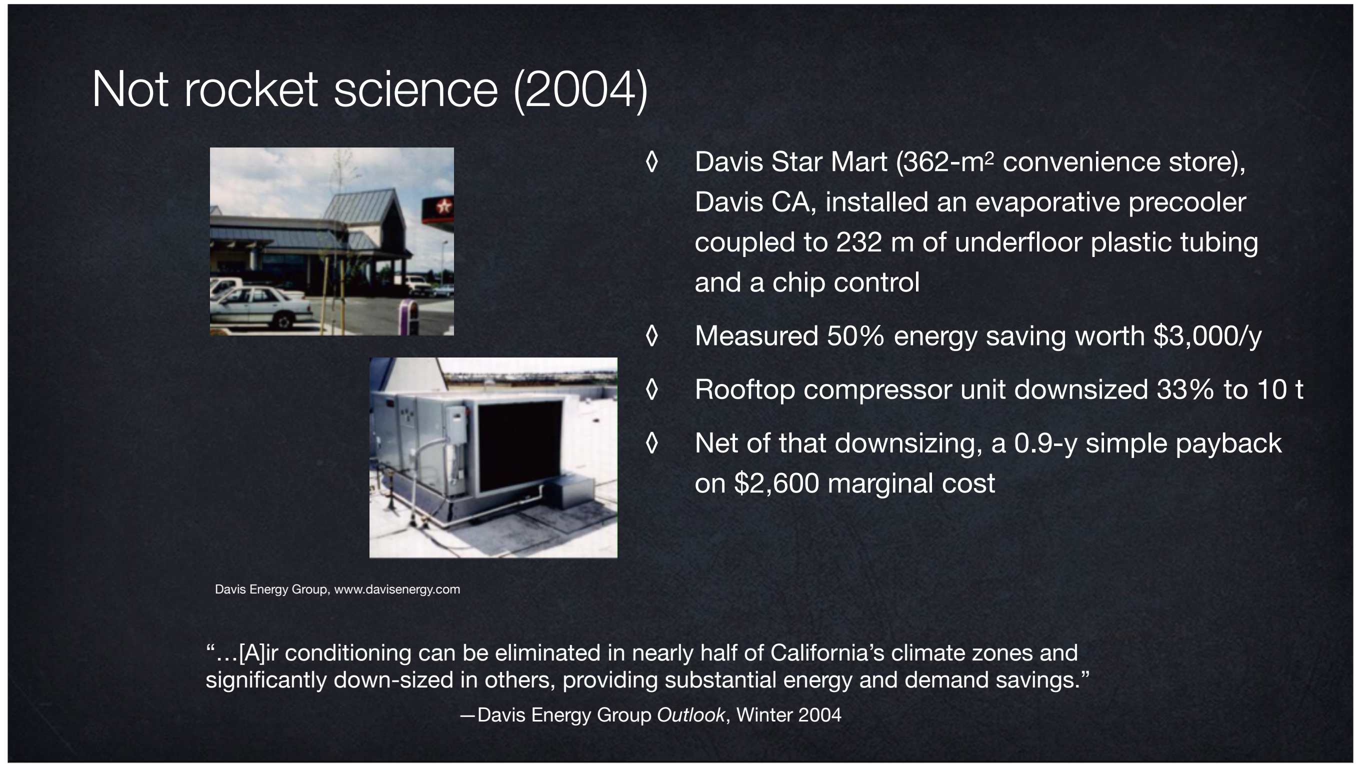
- ◊ Josh Neutel just sent me this lovely snapshot from a Stanford office with erratic temperatures, often too cold:

  The right-most of the three white plates on the wall is the thermostat. It’s heated by hot air from the display panel. This cause of discomfort went unnoticed for years.
- ◊ He also found a supposedly hot room always calling cooling, but actually it was already very cold. It was miswired—controlled by the thermostat next door in a hot electrical-equipment room. The resulting setpoint errors drove inefficiency in the whole building.
- ◊ In 10 commercial buildings, 14–52% savings in cooling energy were driven by only 14% of responding zones, due to heterogeneous needs and pervasive overcooling. Most of the feasible savings from easy operational changes can come from prioritizing a small number of zones.

Personal comm., 10 October 2025, re Lathrop 142 and Gates 271/271A; J Neutel *et al., Energy and Buildings* 350 *(2026):116579*, 16 Oct 2025, https://doi.org/10.1016/j.enbuild.2025.116579/

Many improvements are simple tweaks needing no investment. A Stanford student just sent me two lovely examples of what his walkthrough survey team found in some campus buildings. The first was a perpetually cold office. **** It was cold because its * thermostat was constantly heated by a display screen that someone else had mounted in front of it. The team lacked authority and budget to move the thermostat or screen, but reset the thermostat’s priority to zero in software. * A different room, reporting too hot but actually too cold, was controlled by a miswired thermostat in the adjacent room—a hot electric-equipment closet. They were able to rewire it.

This stuff is ubiquitous. The more you look, the more you find. Josh and his team just published an important paper showing that in ~88,000 m^2 of Stanford offices and labs, up to 52% of space-cooling could be saved by adjusting setpoints in just 14% of zones, making fixes much easier. *



And then there's the equipment. Ubiquitous packaged rooftop units are typically so bad that in a convenience store retrofit in hot Davis CA, * 50% energy savings paid back in less than a year from adding * an evaporative precooler, a control, and a little plastic tubing. * The compressor shrank by one-third. * Even a dozen years ago, the best units elicited by DOE's [2013] Advanced RTU [rooftop unit] Campaign are nearly twice as efficient as ASHRAE's 90.1 standard issued three years later, so their full use in the common 10- and 20-t sizes could save ~$1b/y in US commercial buildings. And regular maintenance is essential: as with much equipment, a bad unit well maintained will often outperform a good unit badly maintained.*

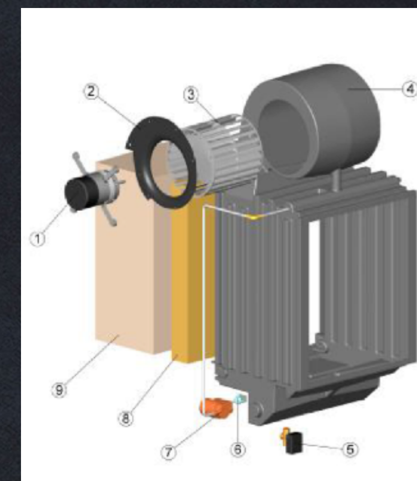
https://www.facilitiesnet.com/hvac/article/Understanding-High-Efficiency-Rooftop-Air-Conditioning-Units--18423 (13 May 2019)

80–90% California cooling energy and demand savings without active dehumidification (2003)

- ◊ EER-40–135 (COP 12–40) steady-state, depending on airflow
- ◊ 0.5-max-kW indirect-direct evaporative cooler replaces 2–3-ton refrigerative system
- ◊ 100% outside air
- ◊ CEC-funded Davis Energy Group development made by Speakman CRS

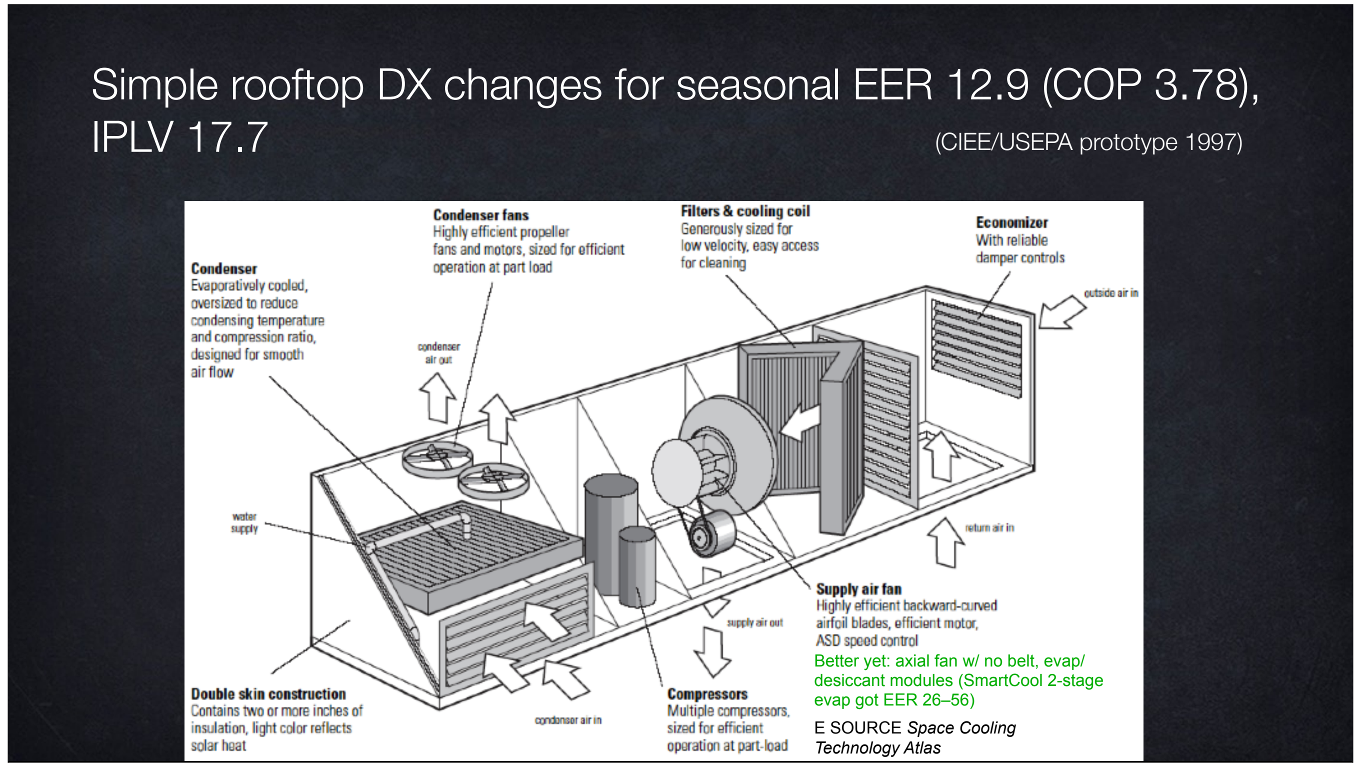
www.davisenergy.com

www.speakmancrs.com



1: 3/4-hp GE ECM2.3 variable-speed motor. 2. Venturi mounting plate. 3: Morrison 11–11 squirrel-cage blower. 4: polyethylene cabinet. 5: Drain valve. 6: Fill valve. 7: Taco 003 water circulator pump. 8: Munter's CELdek® direct cooling stage. 9: Speakman indirect cooling stage.

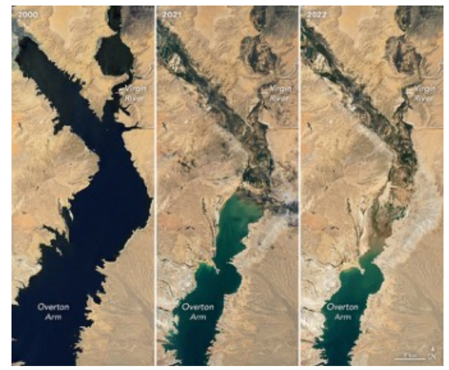
Davis Energy Group also showed that just * improving the * components of a * simple rooftop chiller * using 2003 technology could * raise the savings to * 80–90% in relatively dry climates. *



Combining even more good stuff in a standard rooftop box could do even better, as was prototyped 28 years ago, then it could be * further improved with a direct-drive axial fan and added evaporative and desiccant modules. * Today's best units with two-stage evap have demonstrated IEER 26–56. *

Evaporative Cooling Ban in New Commercial Buildings in Southern Nevada

- In Nevada, two-thirds of the state's population relies on the Colorado River for its water supply.
- Aridification of the American Southwest is threatening essential water supplies.
- In 2023, the Southern Nevada Water Authority banned evaporative cooling in new commercial buildings.
- Evaporative cooling consumes approximately 10% of Southern Nevada's water supply.



Sources: ***Financial Times*** **(21 May 2022), NASA (2022); courtesy of Kirsten Stasio, CEO, Nevada Clean Energy Fund**

Does Southern Nevada's ban on evaporative cooling in new commercial buildings block big energy savings (perhaps making some water-cooled power stations work harder)? No; the best IPLV (Daikin Pathfinder) for a dry unit in 2025 is still an impressive >22 EER.

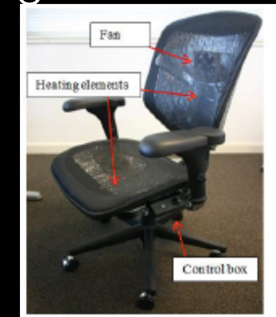
The Water Authority could free up wasted water by retrofitting existing evap systems, commercial and then residential, with superefficient wet or dry models. They could make a market in that saved water, much as they pay for xeriscape or what I call "negaturf." They could even partner with NV Energy to prioritize areas with cost hotspots from constrained electric distribution capacity. And they could harvest even more evap-cooling water *by comprehensively reducing cooling needs*. Here's how. *

The Right Steps in the Right Order

In 2021, two major Asian air-conditioner makers won our Global Cooling Prize by far surpassing its goal of at least 5× lower climate impact from affordable window air conditioners. But that’s just one important part of a whole-system approach that can aim to squeeze out the need for those air conditioners by expanding the system boundary and taking *the right steps in the right order.* *

Classically, thermal comfort depends on six variables (actually there are more). RMI's Innovation Center systematically exploits all six. It illustrates the correct sequence of space-cooling efficiencies. How did we design out all the chillers? *

The right steps in the right order: space cooling



Max heating power 14 W
Max cooling power 3.6 W

0. Cool the people, not the building
1. Expand comfort envelope (check assumptions!)
2. Minimize unwanted heat gains
3. Passive cooling
   - Ventilative, radiative, ground-/H_2O-coupling, icepond
4. Active nonrefrigerative cooling
   - Evap, desiccant (CDQ), ab/adsorption, hybrids: COP >100
   - Direct/indirect evap + VFD recip in CA: COP 25
5. ~~Superefficient refrigerative cooling: COP ≥6.8 (≤0.52 kW/t) (Singapore water-cooled centrifugal system, supply fan through cooling towers at design hour)~~
6. Coolth storage and controls

Cumulative energy saving: ~90–100%, better comfort & uptime, lower capex

Decades ago, I asked my hostess in Japan why she didn't heat her nearly-uninsulated house. She looked puzzled and replied, "Why should I—is the house cold?" People have nervous systems and comfort sensations, but buildings don't, so we should keep *people* comfortable, not buildings, and deliver "task comfort," like task lighting. Each person in RMI's Innovation Center has a * Hyperchair® that delivers the desired real-time comfort. Its 2.7 W of silent fans and 14 W of car-seat heaters, all powered by a laptop battery, * maintain ASHRAE comfort in indoor air temperatures from 61 to 84˚F [16 to ~29˚C][though the building is actually being run in a tight setband just a few degrees wide, so it's still using more energy than it should]. Excellent ceiling fans further expand the summer comfort range by 9–13F˚ [5–7C˚], not the normally assumed 5. * Superwindows that pass light but block heat slash the radiant loads and insulate like 14 sheets of glass. We recover 93% of ventilation heat or coolth. This building is superinsulated, nearly twice as airtight as a PassivHaus, and * passively cooled by active exterior shading and natural ventilation, including automated night-flush to cool phase-change walls. We therefore don't need * other passive options [such as ground-coupling, groundwater-coupling, geothermal heat pipes, or a seasonal-storage icepond], nor * active nonrefrigerative cooling [—evaporative, desiccant, absorption, adsorption, and hybrids like Pennington and van Zyl cycles] * that can yield >100 units of cooling per * unit of electricity, nor * refrigerative cooling, nor * fancy storage and controls. Even in the most severe climates, this whole-system approach can * save ~90–100% of cooling energy with better comfort, lower capital cost, and higher uptime. Yet most practitioners pursue these options in reverse order, worst buys first. *

Superefficient big refrigerative HVAC too

(100,000+ ft² water-cooled centrifugal, Singapore, turbulent induction air delivery—but underfloor displacement could save even more energy)

Element	Std kW/t	Best kW/t	How
Supply fan	0.6	0.061	Best vaneaxial, ~1.5–3" TSH (less w/UFDV), VAV
ChWP	0.16	0.018	20–40' head, efficient pump/ motor, no pri/sec
Chiller	0.75	0.481	1–2F° approaches, optimal impeller speed
CWP	0.14	0.018	20–30' head, efficient pump/ motor
CT	0.1	0.01	Big fill area, big slow fan at variable speed
TOTAL	1.75	0.588 (–66%)	*Better uptime & comfort, less capex*

or 0.52 (incl. 0.41 chiller) = COP 6.8 = –70% w/dual ChW temperature

In big new buildings' water-cooled centrifugal systems, the Singaporean wizard LEE Eng Lock routinely triples efficiency, shifting design kW/t for each major component from the second to the third column, with lower total capital cost and better comfort and reliability. [(Exceptionally, let me do this in barbaric units—I'll add it in metric in a moment.) Mr. Lee rigorously designs out duct and piping friction, so the supply fan has only about 1.3–3"wg of total static head—less, even 1" or less, with underfloor displacement ventilation. His low-face-velocity coils (<200 fpm) have ~5% the normal airside pressure drop. The chilled and condenser water loops have heads of only 20-odd feet. Here Mr. Lee used Woods variable-speed vaneaxial fans from Britain, typically Papst pumps from Germany, and no primary/secondary pumping, which is a sign of excessive piping friction. These improvements together cut fluid-handling parasitic loads by an order of magnitude. His chillers have optimized impeller speed (at no extra cost, because one gear ratio costs the same as another—you just need to specify it correctly), and very close approach temperatures, often around 1 F°, because copper is cheaper than kilowatt-hours. His cooling towers, typically Shinwa, save 90% of their energy by being specified big, squat, and fat, with big slow fans rather than small fast fans (again, basic physics), and of course all towers are dispatched in parallel at variable speed.] His measured system total, from supply fans through cooling towers, is 0.588 kW/t at the Singapore design hour—or just 0.52 if you use *two* separately optimized coils, 4.5˚C for condensing and 12˚C for sensible cooling. That raises the total energy saving to 70% from supposedly good normal practice, at lower capital cost, with better comfort. This practice spreads slowly to mechanical engineers paid a percentage of their project's cost! *

Superefficient big refrigerative HVAC, improved 4/21, 10/21

(~10,000+ m² office, water-cooled centrifugal chiller system, Singapore, turbulent induction air delivery; measured design-hour [peak-load] performance in white, from master engineer LEE Eng Lock 李永禄)

Component	Std kW/t	Best kW/t	How
Supply fan	0.6	~~0.061~~ 0.058 fanless 0.00	Best vaneaxial, ~0.2–0.7 kPa TSH (less w/UFDV), VAV; convective
ChW pump	0.16	0.018	120–150 kPa head, efficient pump/motor, no pri/sec
Chiller	0.75	~~0.481~~ 0.33	0.6–1C° approaches, optimal impeller speed; 10˚C coil(s)
CW pump	0.14	0.018	~90 kPa head, efficient pump/ motor; ?+ a bit for tall CT?
Cooling twr	0.1	0.01	Big fill area, big slow fan at variable speed; or tall convective?
TOTAL	1.75 (COP 2.0)	~~0.588~~ (0.376, ~~–66~~ 79%, COP 9.5)	*Better comfort & uptime, lower capital cost*

Next options (estimated):

Underfloor displacement ventilation, low-pressure plenum: ~0.1 kW/t supply fan

+ passive latent heat exchanger: ~0.15 kW/t chiller, ~halve others

OR, BETTER,

Purely radiant coolth delivery and passive radiant heat rejection (coupled by a heat pipe), so even lossy distributed piping with a good 3-W minipump uses 0.002 kW/t for supply pumping—or much less if demand-controlled

~0.27, –84%

≤0.002, –99.9%

What I just described for big HVAC systems is *1990s* best practice. In April 2021, I asked Mr. Lee how much better he could do now. His red markup improved that 3× efficiency gain *to as much as* 5×. [Some Singapore buildings now simply pump the chilled water higher—hardly adding pumping head because it's a low-friction closed loop—and then let the cool air flow downward convectively. The cooling-tower fans could likewise be eliminated by using old-fashioned taller towers that run convectively with no fans, incurring a slight extra pumping head. And the chiller could drop to 0.33 kW/t using optimal 10˚C [50˚F] coils.] * But what's next? First, in green, * about half the remaining cooling power could be saved by underfloor displacement ventilation plus a passive latent heat exchanger if you have enough humidity to justify it. But even more radically, in magenta, *radiant* coolth delivery plus radiant heat rejection, even with an efficient minipump circulating cool water to radiant panels, could probably cut total cooling power to roughly *one-thousandth* of standard practice, with much lower capital cost. How would that work? *

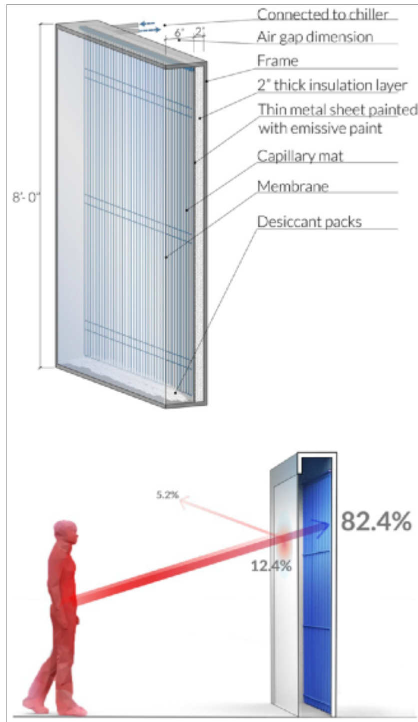
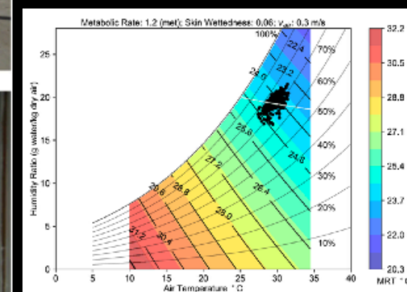


Fig. 1. Schematic of a Cold Tube radiant cooling panel (*Upper*) and radiant heat transfer through the IR-transparent membrane (*Lower*).

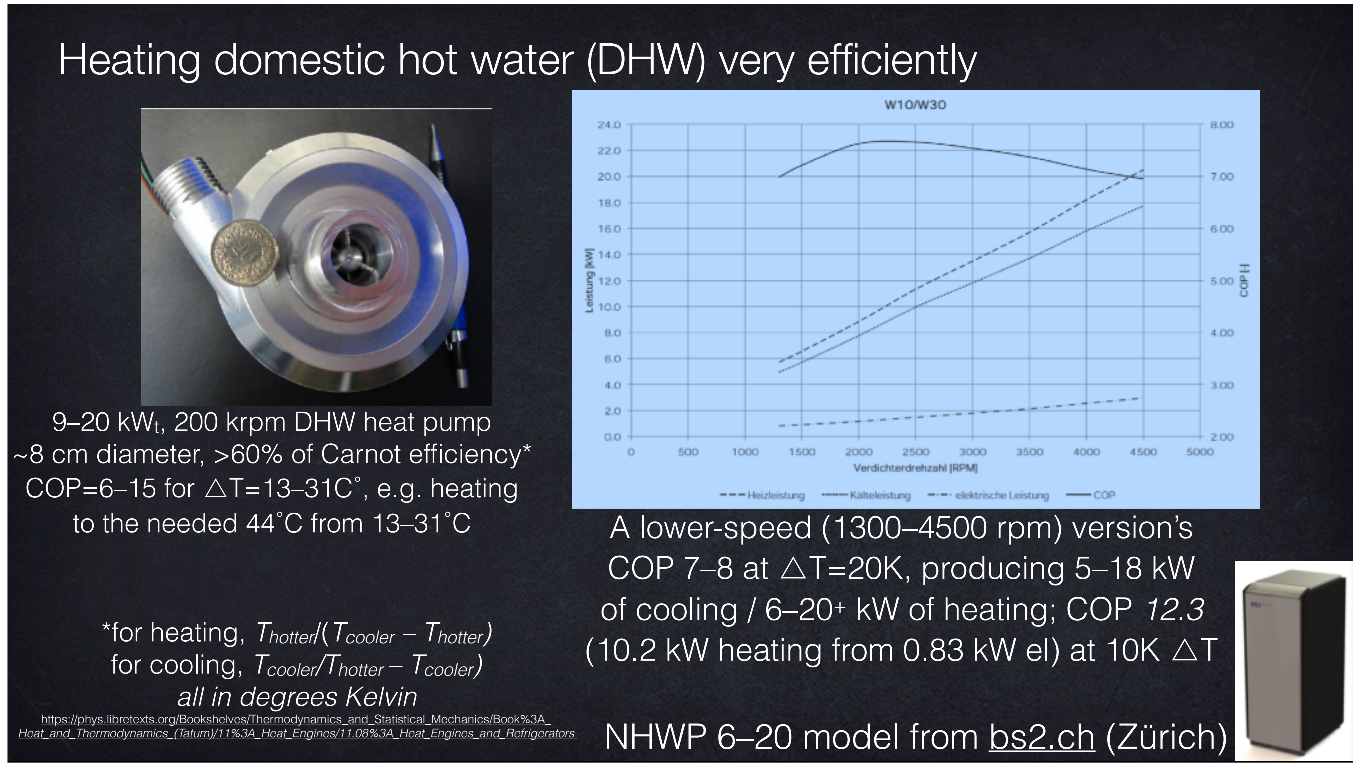

Fig. 2. The completed Cold Tube.

Pure-radiant-cooling 2019 breakthrough: *outdoor* comfort in the Singapore summer with shading but no chiller, 0.3 m/s air movement, and no condensation!



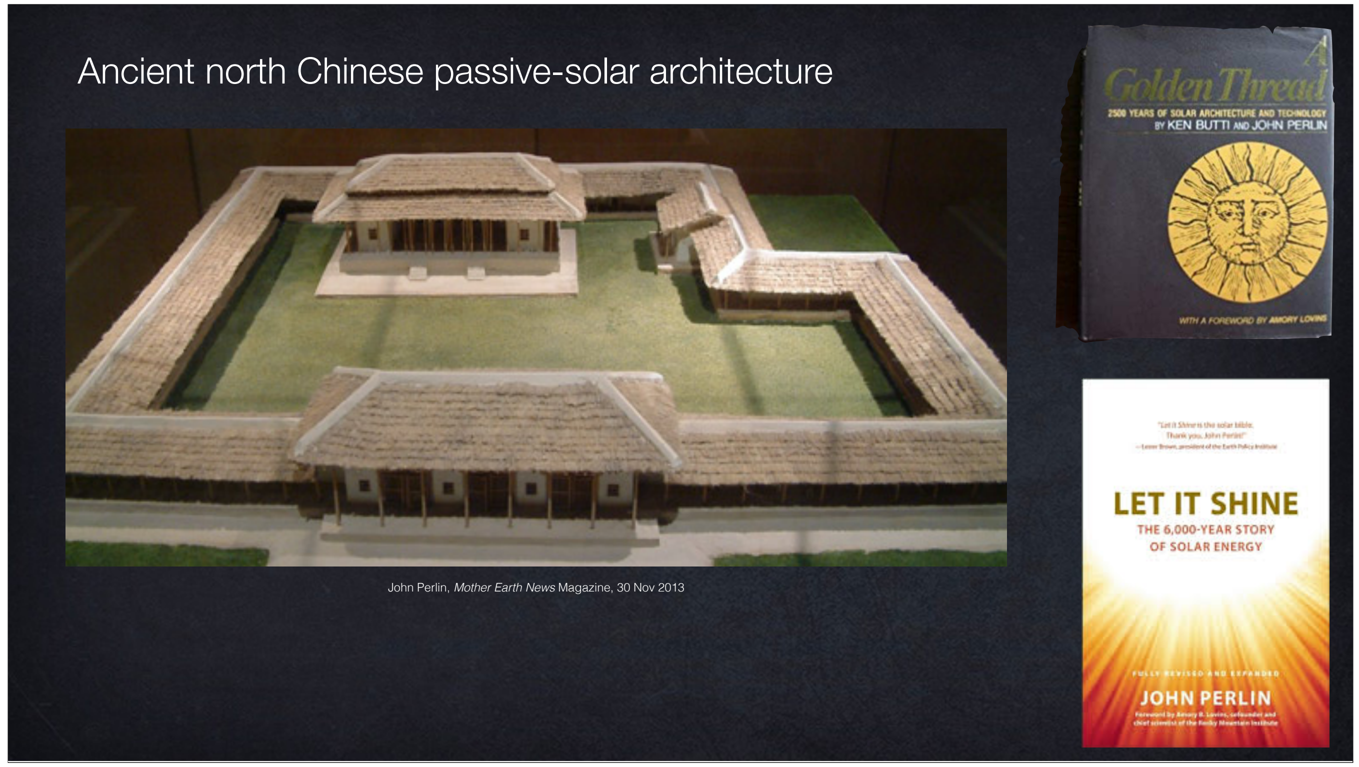
E. Teitelbaum *et al.*, *Proc. Natl. Acad. Scis. [USA]* **117**(35):21162–21169, 1 Sep 2020, www.pnas.org/cgi/doi/10.1073/pnas.2001678117
A. Lovins, SAE, 2023, https://doi.org/10.4271/13-04-01-0008

Here's the next gamechanger: a Princeton experiment kept Singaporeans comfortable *outdoors* in * a shaded open-ended pavilion with 0.3 m/s air movement but without drying or cooling the hot, humid air! People were instead cooled * *radiatively* by absorbing far-infrared radiation from their bodies into vertical panels circulating 17˚C water, separated from humid air by a plastic film. Panels cooled to ~23–25˚ can thus deliver thermal comfort * in 32˚ air with 80% relative humidity. That water's mild cooling can be done passively by [Stanford Prof. Shànhuí Fàn's (范汕洄)] special surfaces that radiate infrared to the sky in any weather. Combining these passive technologies may provide tropical-climate comfort in new or old buildings or in * vehicles, using no or almost no electricity. [A snap-together plastic version might even be cheaply retrofittable into the world's apartment blocks and slum dwellings. Let's go try it. It may virtually eliminate long-term growth in the world's peak demand for electricity. What are we waiting for?]*



I also wonder about your efficiency of both using and producing hot water. The Swiss miniature heat pump on the left can produce 6–15 units of hot water per unit of electricity, and some early commercial models on the right are nearly that good. Such systems can often provide both domestic hot water *and* backup space-heating, increasing confidence that a good home envelope retrofit can avoid a separate heating appliance. *

How much cooling do Nevada buildings (actually just the people inside them!) really need? Passive design, described in this classic text, can keep you cool as well as warm. Smart people have done that for millennia, from China, India, Rome, Persia, and Arabia to the American Southwest, as * these two histories richly illustrate. My house just modernizes 6,000-year-old North Chinese passive architecture… *



…where Neolithic villagers faced their homes’ sole opening towards the south to catch the low winter sun and trap it in indoor thermal mass, while an overhanging thatched roof blocked the high sun in summer, probably augmented by summer cross-ventilation. [About four thousand years ago, Chinese scholars carefully studied solar motions and started laying out all towns’ main streets E-W so the houses could face south; Beijing shows this influence today. Facing south is a deep-seated cultural norm: the Emperor would hold audiences facing south to symbolize brightness and enlightenment.

Again, many diverse cultures had long mastered similar methods until they were often lately forgotten.] *

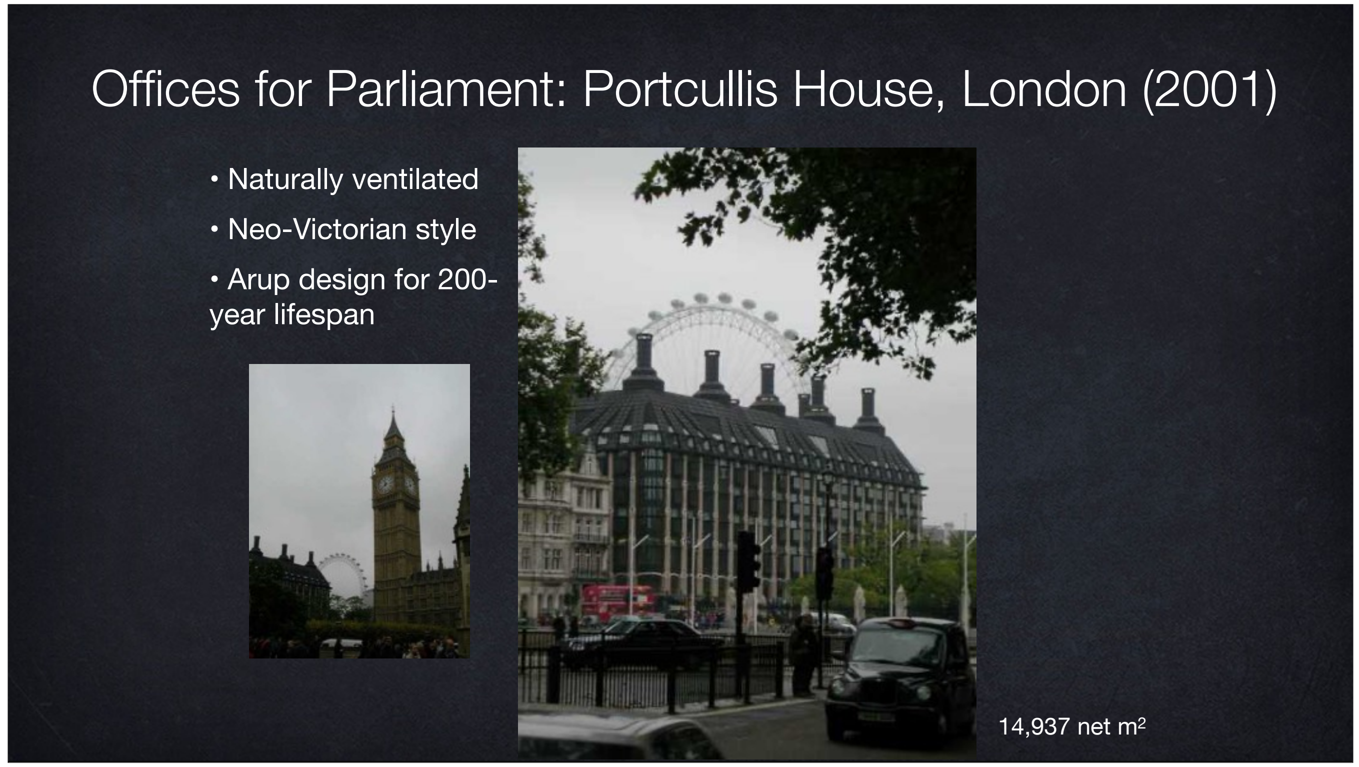
High deserts are blazing hot in the summer but subfreezing much of the winter. Yet more than 1,200 years ago, up to 1,000 people, apparently of Asian heritage, lived in this four-story Anasazi settlement of Pueblo Bonito, whose interior temperature varied less than one-third as much as the exterior, even though it had no windows—only holes in the thick walls. Some ancient cliff dwellings, like those at the lower right, were built under overhangs to maintain even tighter temperature bands.

An underused desert resource is its clear access to the sky, especially at night. The radiant temperature of clear sky is about –40˚. Thus the ancient Persians made sorbet for the Shah by putting a dish of water at the bottom of a well, so it could radiate up to the sky but the sun couldn't shine in. The water would reliably freeze overnight even in the hot desert.

When Professor Takeo SAITOH taught at Tohoku University, he used selective compound-parabolic solar "decollectors" to reject heat year-round to the sky, yielding at most 15˚C daytime and <10˚C night temperatures through the summer. Even in the humid Kansai climate, similar to Houston's, he could cool all but the lowest-temperature food cases purely passively, using no compressors. Now commercial far-infrared radiative surfaces like SkyCool can reject heat passively with even greater efficiency. *

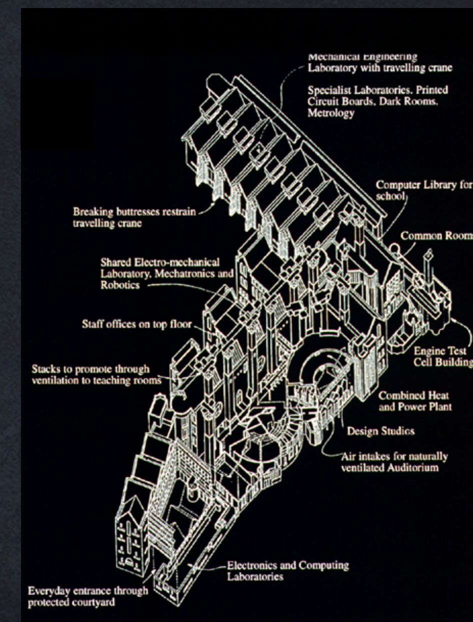
Zimbabwe's biggest office and shopping complex, Harare's Eastgate Centre, uses passive design inspired by termite mounds, whose sophisticated air oscillations and passive controls hold temperatures within a tight band to support the fungi that the termites farm. The building uses 90% less mechanical energy to deliver normal or better comfort with normal construction cost and 20% lower rents. *

The 1871 Old Executive Office Building next to the White House had a brilliantly designed passive cooling and ventilation system. Three decades ago, RMI's and AIA's Greening of the White House launched its restoration. [It was driven by convective heating in six solar-heated domes (supplemented by steam pipes on cloudy days). Their convective suction pulled in outside air through slots under the windows. The air would passively cool and drop out condensate on its way through meter-thick granite walls. The cool air would waft across your office, up a shaft or out the transom over the door and down the hall, then up to exit out the dome vents. Over decades, the purpose of these components was forgotten, airshafts got blocked, the domes were painted black for wartime blackout, and 782 noisy, inefficient window air conditioners plus some larger units were installed. One aim of our Greening of the White House was to gradually return the building to original design intent so the occupants doing the nation's business aren't distracted by noise and discomfort.] *



One hundred thirty years after the Old Executive Office Building, the British Parliament’s expanded offices used completely passive ventilation. *

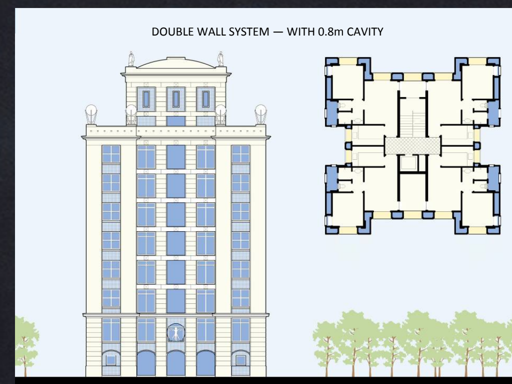
Queen’s Building, DeMontfort U. (Leicester, 1994, 9,850 m^2)

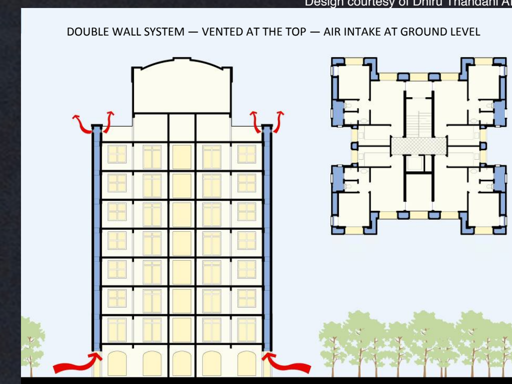


This 2,000-person English lecture and lab building saved half its energy and $1.4 million net capital cost by passive cooling and ventilation, making it one of the cheapest university labs ever built. Even machine-shop heat gains as high as 7 W/ft^2 are removed passively [by convective airflows of 2–6 m^3/s through decorative chimneys]: the greater the heat, the stronger the convection. [Likewise, air enters the auditorium through plena under the raised seating, convectively cooling people directly.] Engineering students read about chillers and fans in a building that contains neither. [The campus’s Chief Engineer said that] In a very hot summer [1995], of all the University’s 2.6 million ft^2 of buildings, this one with no chillers offered the best refuge from the heat. *

Cooling midrise apartment buildings in India

Design courtesy of Dhiru Thandani AIA





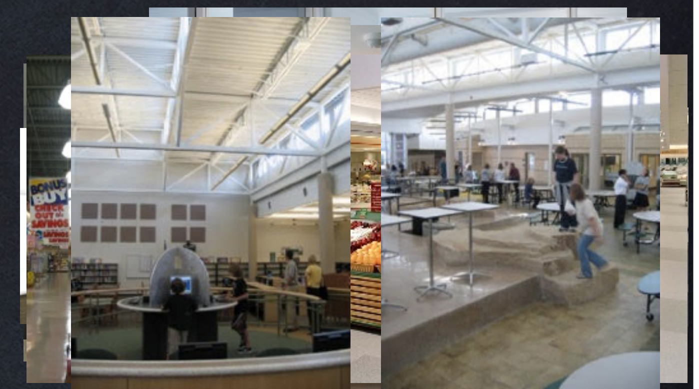
These convectively cooled double-wall building envelopes make you feel 11–12C° cooler (normal with traditional Indian passive techniques), and with efficient ceiling fans, *16–19C° cooler*, so they need little or no air conditioning

0.2 million m^2, costing 2% extra, were sold in 1998–2000 near Mumbai

Taller residential buildings * can also shrink or displace cooling equipment. These passively cooled midrise apartments by Dhiru Thandani, proven popular in Mumbai's monsoon, use convectively vented double walls and superefficient ceiling fans to keep you feeling 29–34F° cooler, at just 2% higher construction cost. A few further refinements could let them deliver decent comfort with *no* air-conditioning. That should be much easier here, without Mumbai's sweltering humidity. *

The right steps in the right order: lighting

1. Improve visual quality of task
2. Improve geometry of space, cavity reflectance
3. Improve lighting quality (cut veiling reflections and discomfort glare)
4. Optimize lighting quantity
5. Harvest/distribute natural light
6. Optimize luminaires
7. Controls, maintenance, training

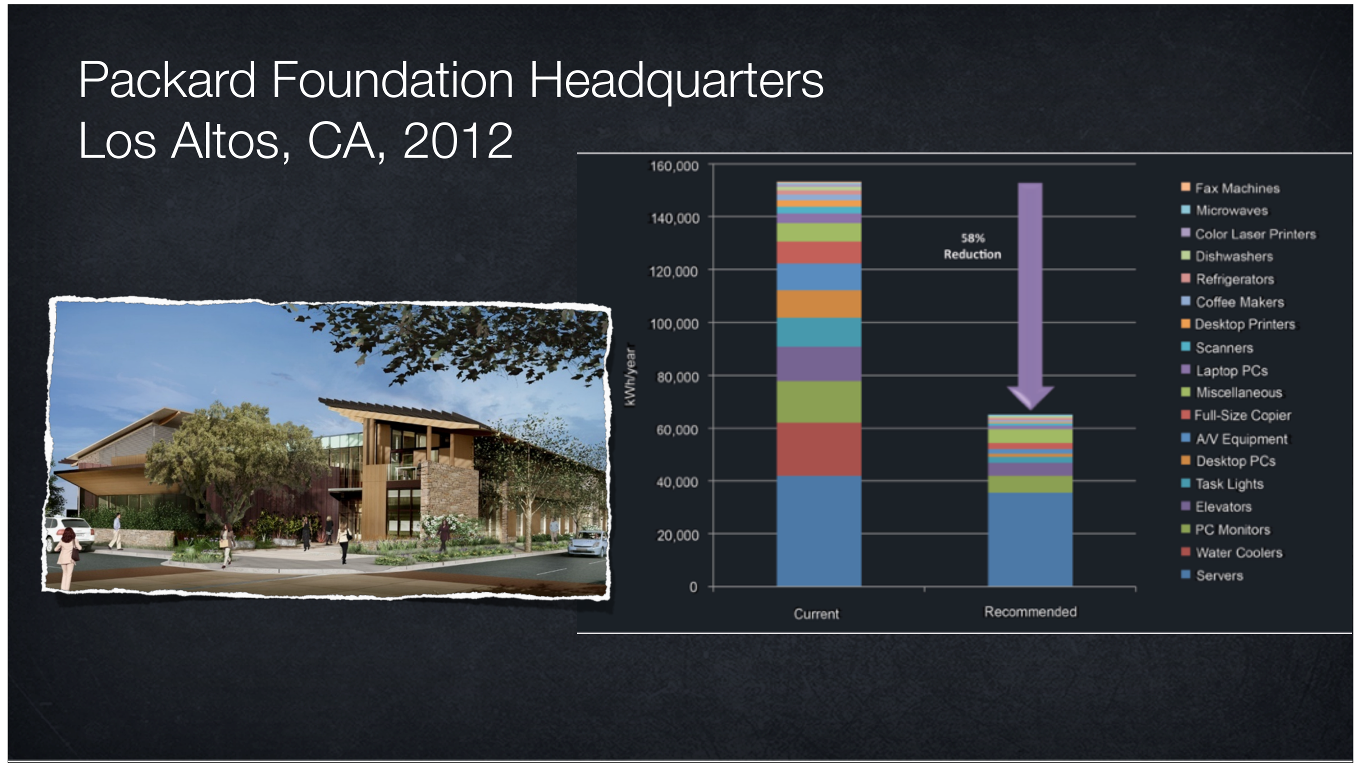


Unknown Store
Fossil Ridge High School, Fort Collins, CO
USGBC Headquarters
Stop and Shop Grocery Store (Greg Franta FAIA, RMI)

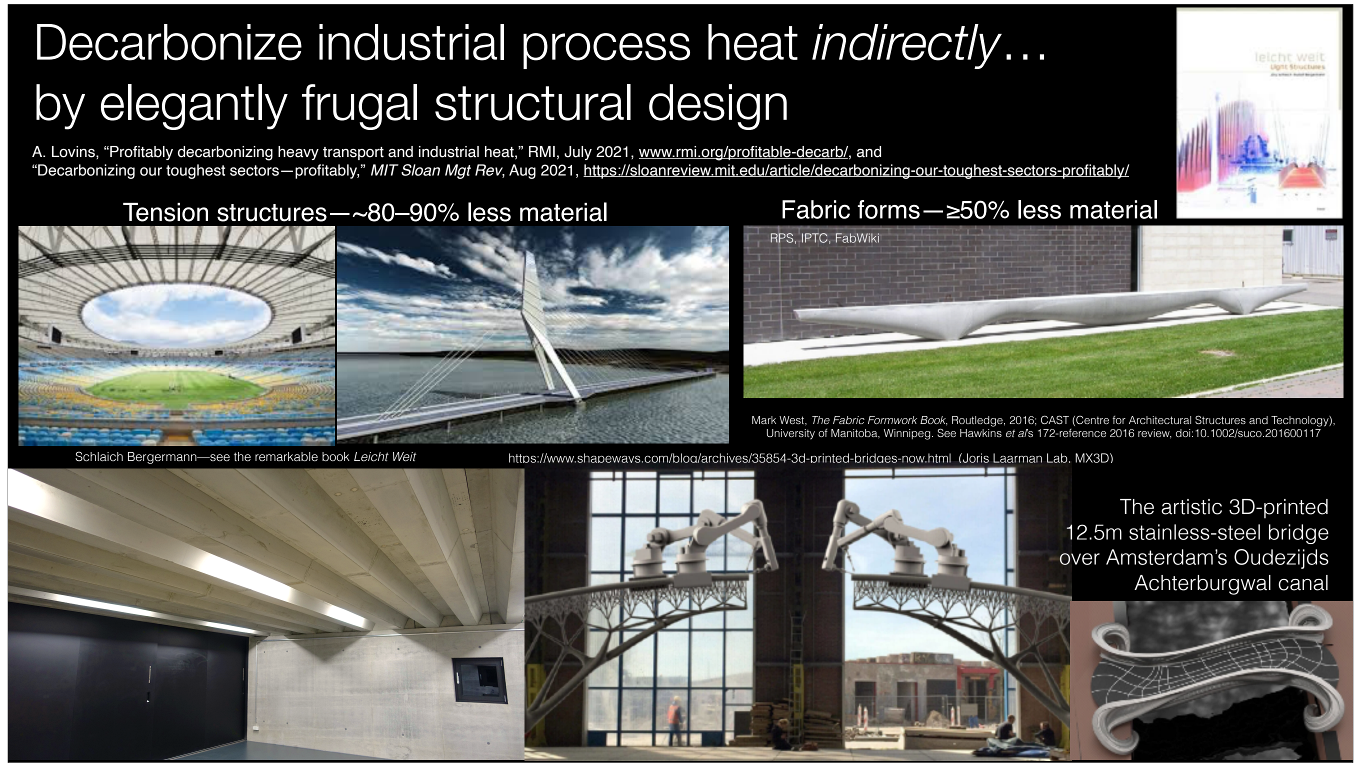
Photos courtesy of Clanton & Associates, Boulder, CO

What's the correct sequence for lighting retrofits? Most practitioners start by installing higher-efficacy light sources and better controls. But that's backwards, so the luminaires don't become fewer and the illumination doesn't get better. What are the right steps in the right order? The IES *Handbook of Fundamentals* rightly tells us * first to improve the visual quality of the task, * then the geometry and cavity reflectance of the space, * then the lighting quality (cutting veiling reflections and discomfort glare), * then optimize illuminance, * then harvest and distribute natural light, and * *only then* optimize the luminaires and the * controls, maintenance, and training. This correct sequence can often save an order of magnitude more energy, with better visual performance and esthetics. *

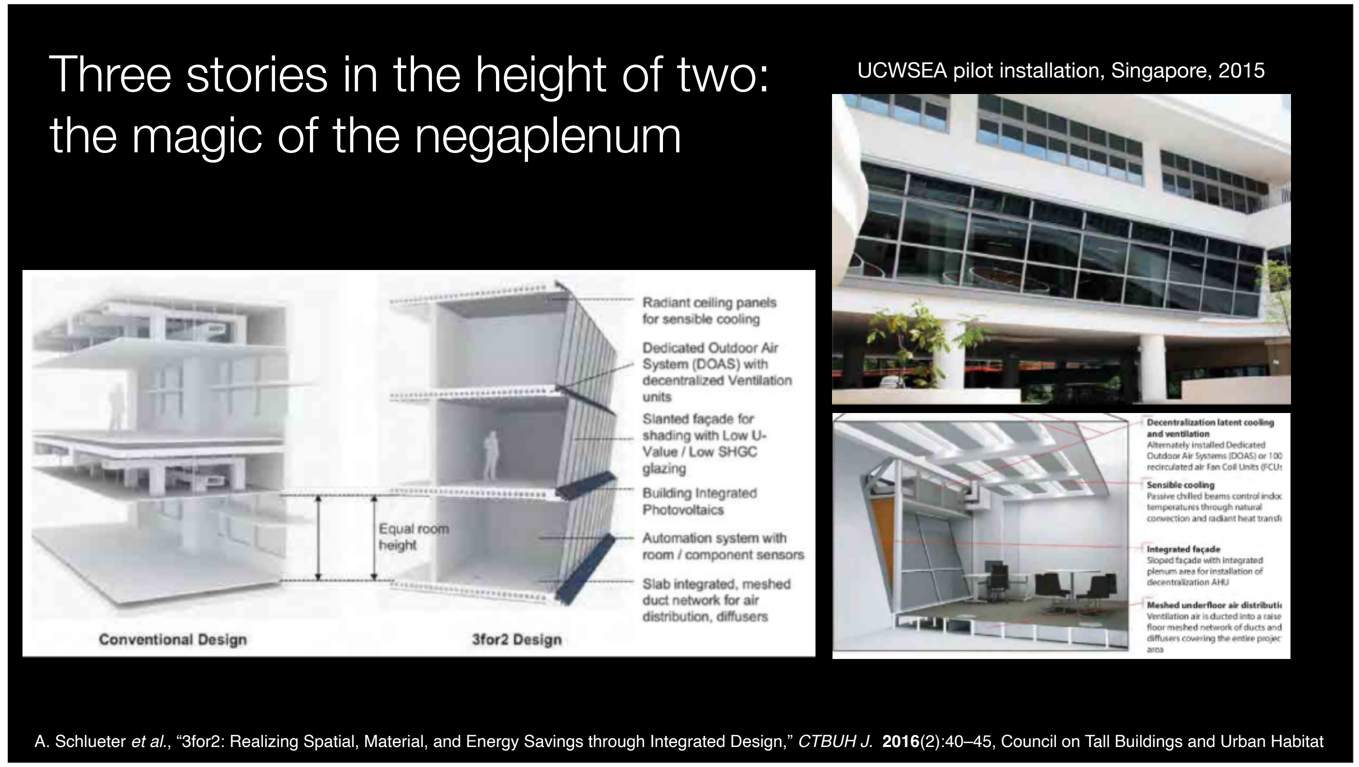
Daylighting is an art as much as a science, but its technology can be arrestingly simple. This primary school in Curitiba, Brazil had a roof overhang too shallow to stop glare on the windows. In the nearer room, on the right, * the glare was so strong you couldn't see with the lights off, because there was too much light in the wrong place with excessive luminance ratios. But adding a shade outside the other window, continuing on the inside as a * lightshelf that bounced light up and back along the ceiling, let you see very well, still with the lights off, and save three-fourths of the electricity, paying for textbooks. Students also learn ~20–26% faster in well-daylit classrooms. So those cheap sheets of wood, cloth, or plastic to distribute daylight properly are important to democracy, development, and hence global security. *



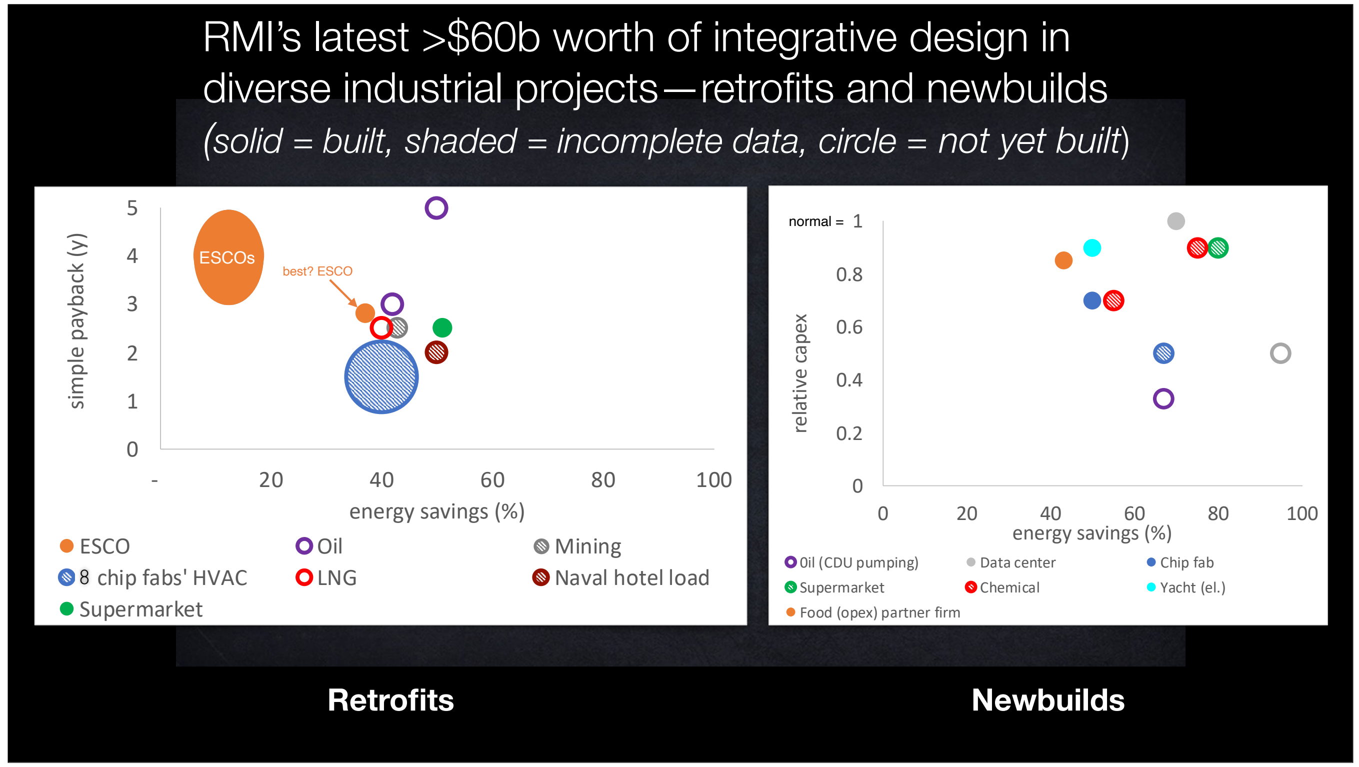
What about plug loads? The Packard Foundation's new office saved a third of the photovoltaics needed to make it net-zero—a valuable saving at the PV prices of 2012. How? I thought the energy budget for plug loads looked high. The designers protested, "But they're all Energy Star!" So Peter Rumsey shopped more carefully and cut plug loads by a further 58%, at no extra cost, with uncompromised functionality. (The same trick also helped make the PVs small enough to fit atop the superefficient Bullitt building in cloudy Seattle.) My home's north hallway has an energy display screen using one-fifth the energy of the worst similar Energy Star model, yet costing no more. [So shop carefully, and use current market offerings because they keep changing!] *



Designers can also save energy-intensive materials. Two 2021 papers showed how smarter structural design can profitably save at least half of the world's cement and steel that now release 15% of global CO_2. * Substituting tension for compression structures typically looks better, costs less, and uses *one-eighth* the tons. * Pouring concrete into curvy fabric forms, not rigid prismatic forms, can often save over half the concrete by putting strength and stiffness only where they're needed—and then the weight savings compound because you need less strength to hold up less weight. * An airy 3D-printed bridge can carry mainly its users while massive concrete structures support mainly their own weight. * This beautiful stainless-steel bridge was 3D-printed. * Most importantly, floor slabs are about half the total weight of a typical mid- or high-rise building. A 5-cm-thick folded concrete floorslab (or a shallow vaulted dome) replaces a 30-cm-thick flat slab, costs less, and saves three-fourths of the cement and all the steel. *

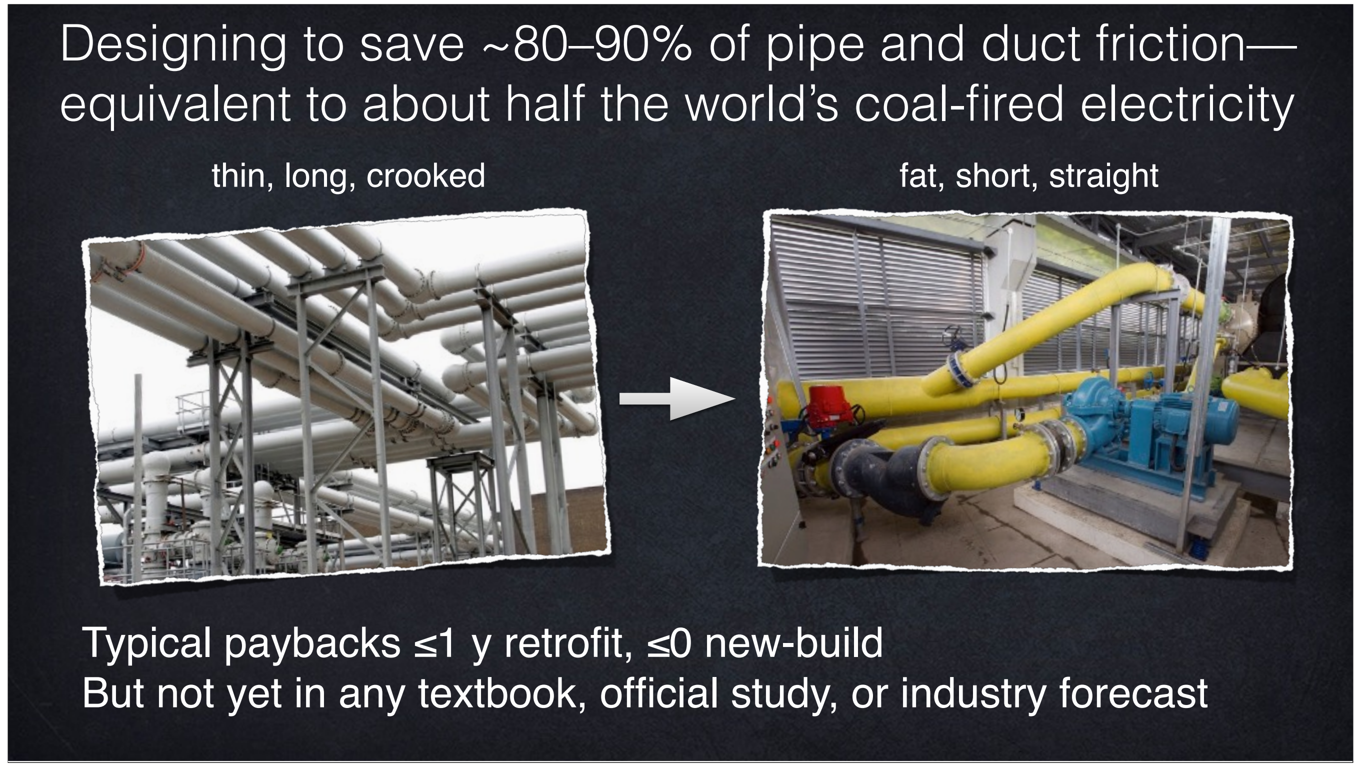


A new building can then save a *further* ~15% of core structural materials, 9% of glazing, and ~77% of energy use while increasing net rentable space by a stunning 55%. Designing out a vertical meter-odd of mechanical plenum at each story lets three stories with normal 9’2” [2.8m] ceiling height fit in the vertical space normally needed for two stories. Cost, complexity, and time fall dramatically. Everything gets better. What are we waiting for? *

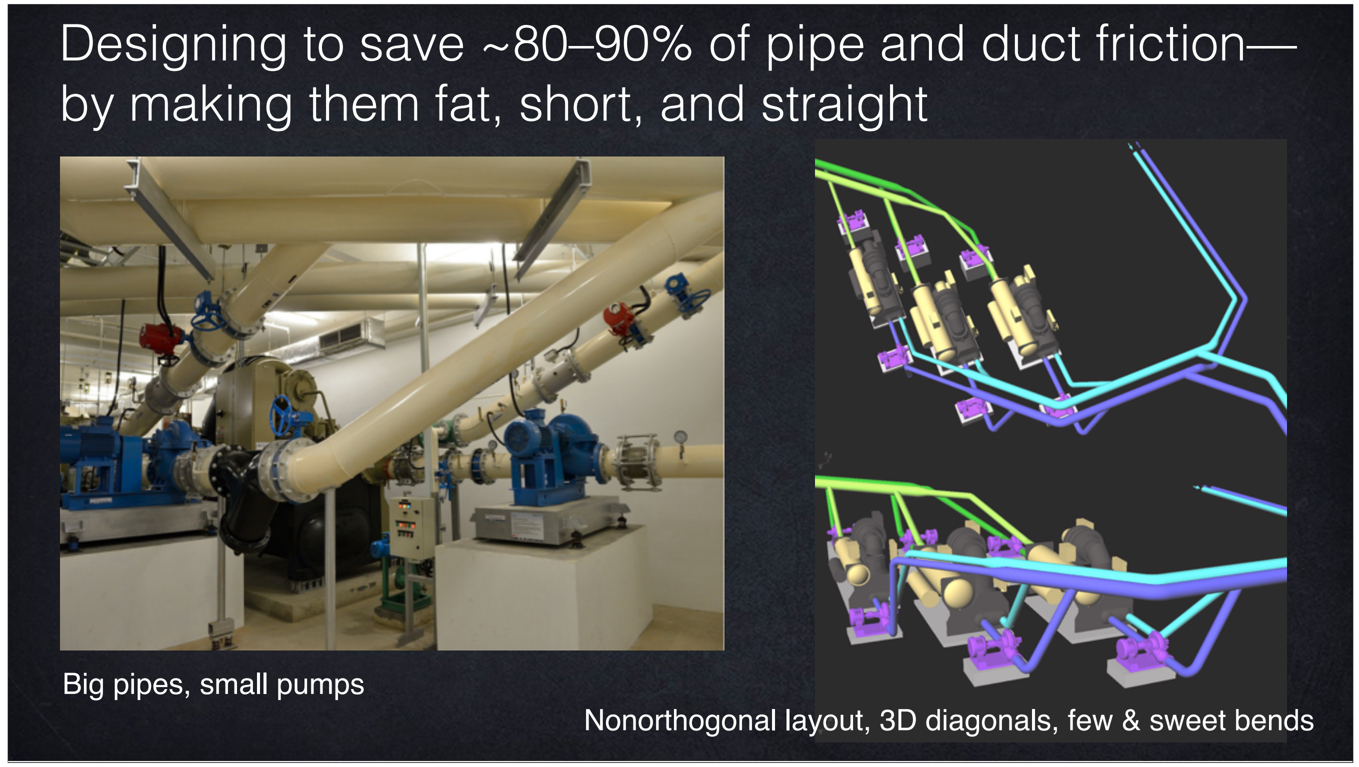


Industry uses half the world's energy and electricity. RMI's latest $60+ billion worth of industrial redesigns typically found ~30–60% energy savings on retrofit, paying back in a few years and far outperforming the brown zone in the upper left, where most Energy Service Companies deliver *dis*-integrated design. * In new projects, integrative design generally yielded ~40–90+% energy savings with *lower*-than-normal capital cost. Much of that efficiency is in fluid-handling—also important in big buildings' HVAC systems. *

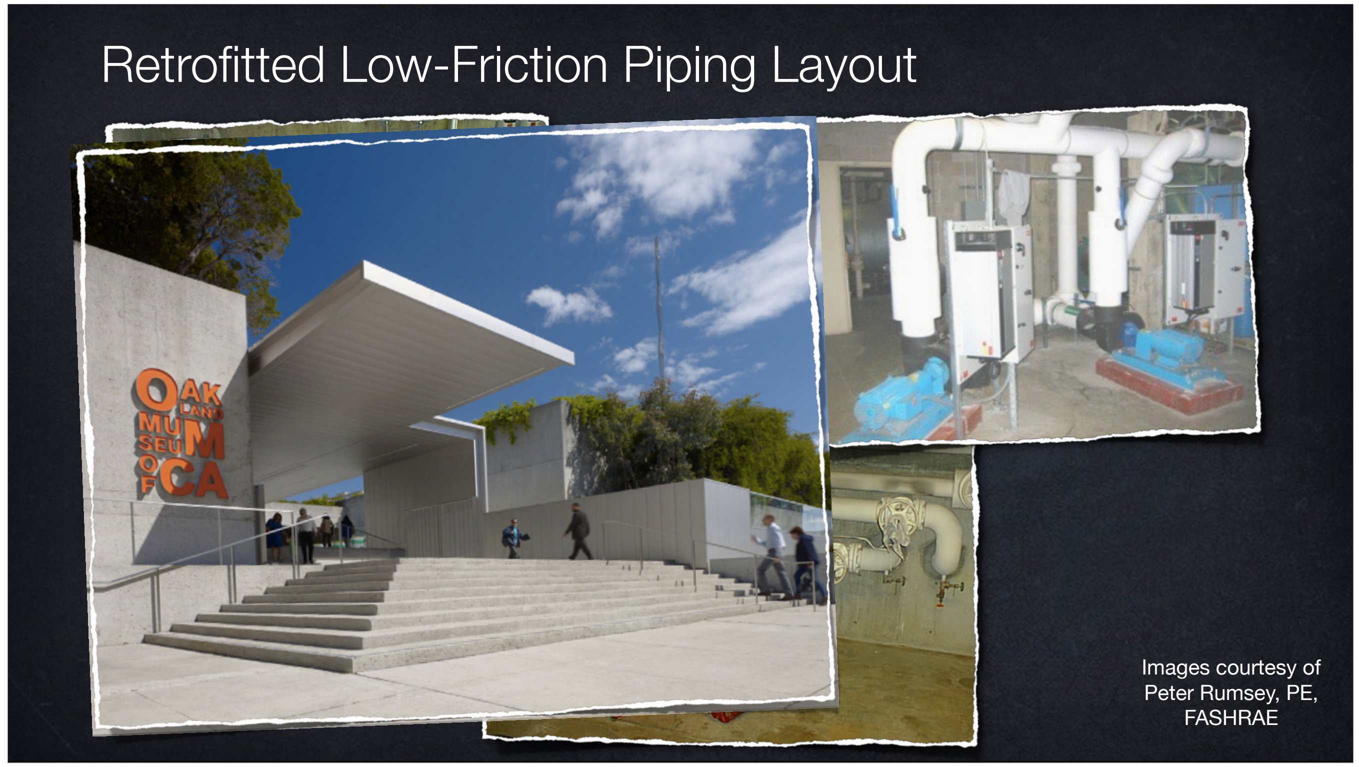
[One of the best ESCOs, Crowley Carbon, delivered the smaller brown dot for its 62 industrial retrofit projects in 22 countries, saving an average of 37% of primary energy with a 2.8-y payback without yet using most of our integrative-design techniques. We're not aware of other practices that routinely deliver the large savings at lower capex shown on the right for newbuilds.] *



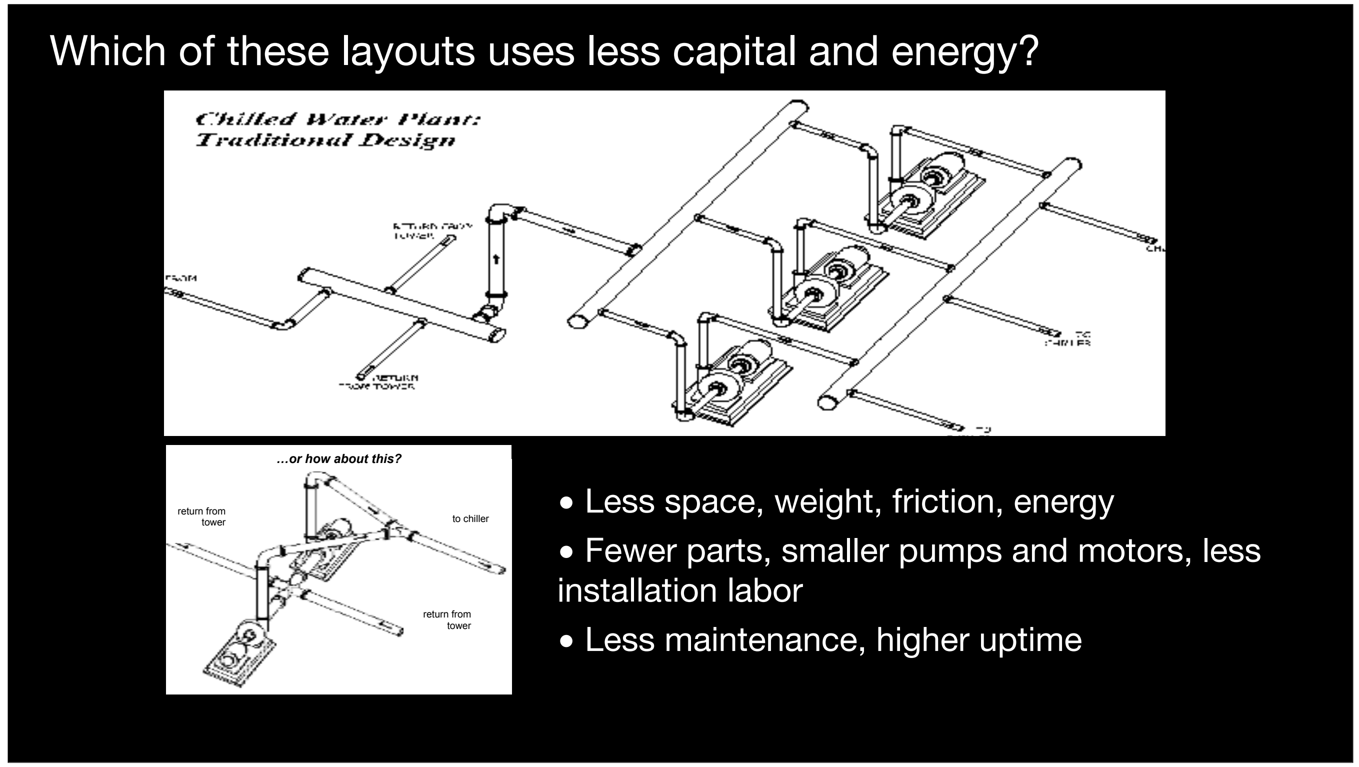
Most electricity runs motors, half to run pumps and fans. * Just better pipe and duct design * can save ~80–90+% of friction and therefore of pump and fan power. If done everywhere, this could save about a fifth of the world's electricity or half the coal-fired electricity, with * paybacks typically under a year in retrofit and instant in newbuild. But it's not in any standard engineering textbook, official study, industry forecast, or climate model. Why not? Because it's not a technology; it's a *design* method, and few people yet think of design as a way to scale rapid change. *



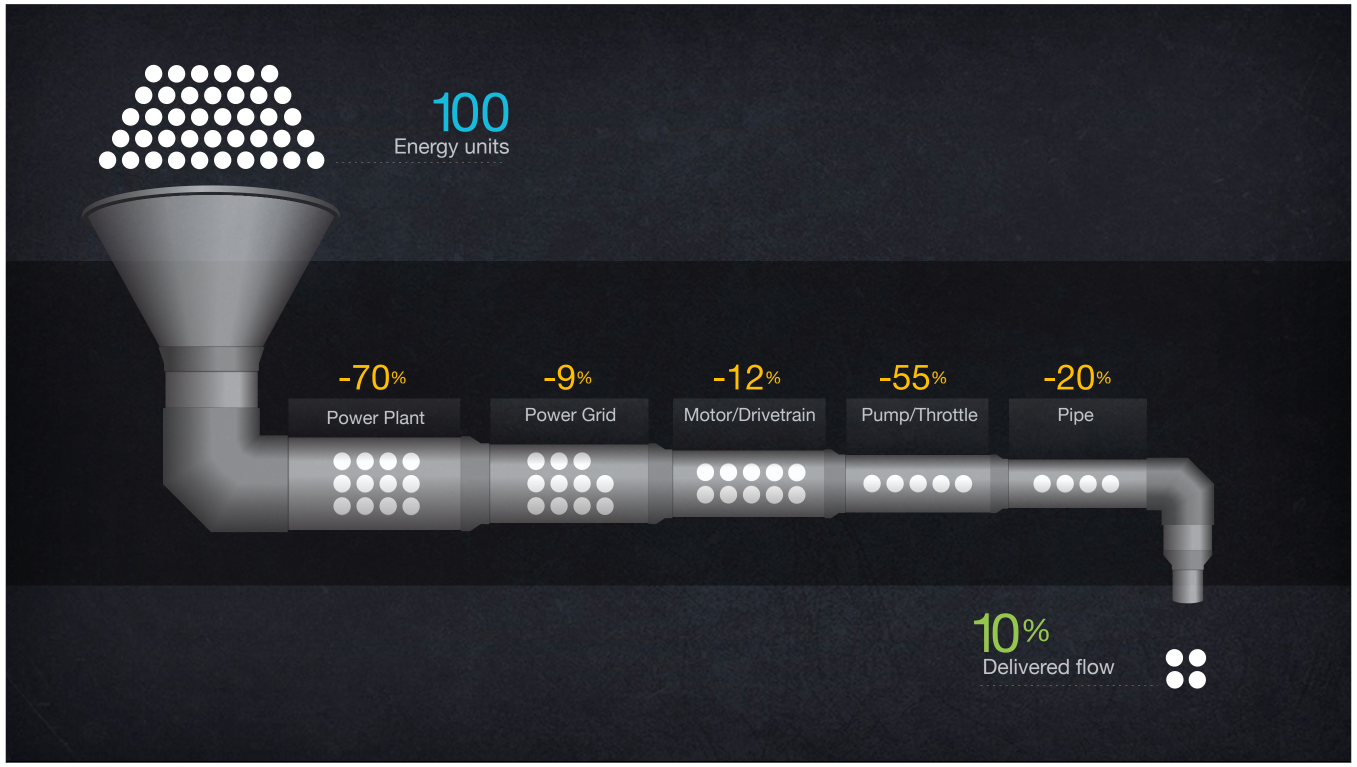
We need to * use big pipes and *small* pumps, not small pipes and big pumps. (Notice that we raise the pump up to meet the pipe rather than dipping the pipe down to the floor and back up.) And * to eliminate elbows and their friction, we stagger the tan chillers, normally in a neat row, by laying out the pipes first, then the equipment. *



In * the Oakland Museum, Peter Rumsey *retrofitted* * an efficient piping layout into the condenser-water pumping loop, cutting pumping energy by three-fourths with a 2–3-month payback—* *and* eliminating 15 pumps that will never again waste energy and maintenance costs. * Repiping the chilled-water loop and adding variable-frequency drives doubled the flow *and* saved 85% of the energy. To help pipefitters understand how to minimize friction, he simply asked them to lay out the supply pipes *as if they were drains*. *



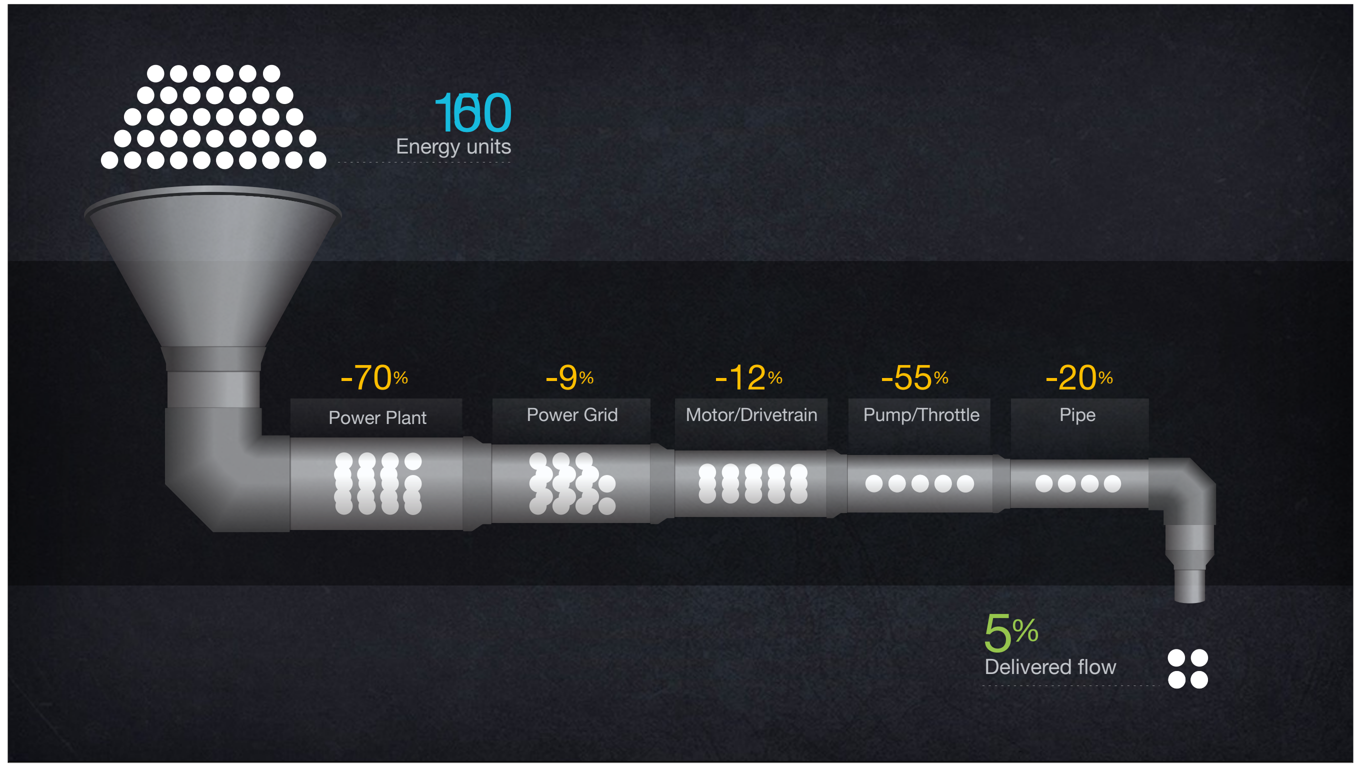
Here’s how most big buildings pipe cooling-tower water back to the chiller’s condenser. But if we lay it out instead as * Peter does, everything gets * better [: less space, weight, noise, friction, and energy; fewer parts; smaller pumps and motors; less installation labor; less maintenance, higher uptime]. The only obstacle is force of habit. We should bend minds, not pipes. *



Now think of the whole power and pumping *system.*

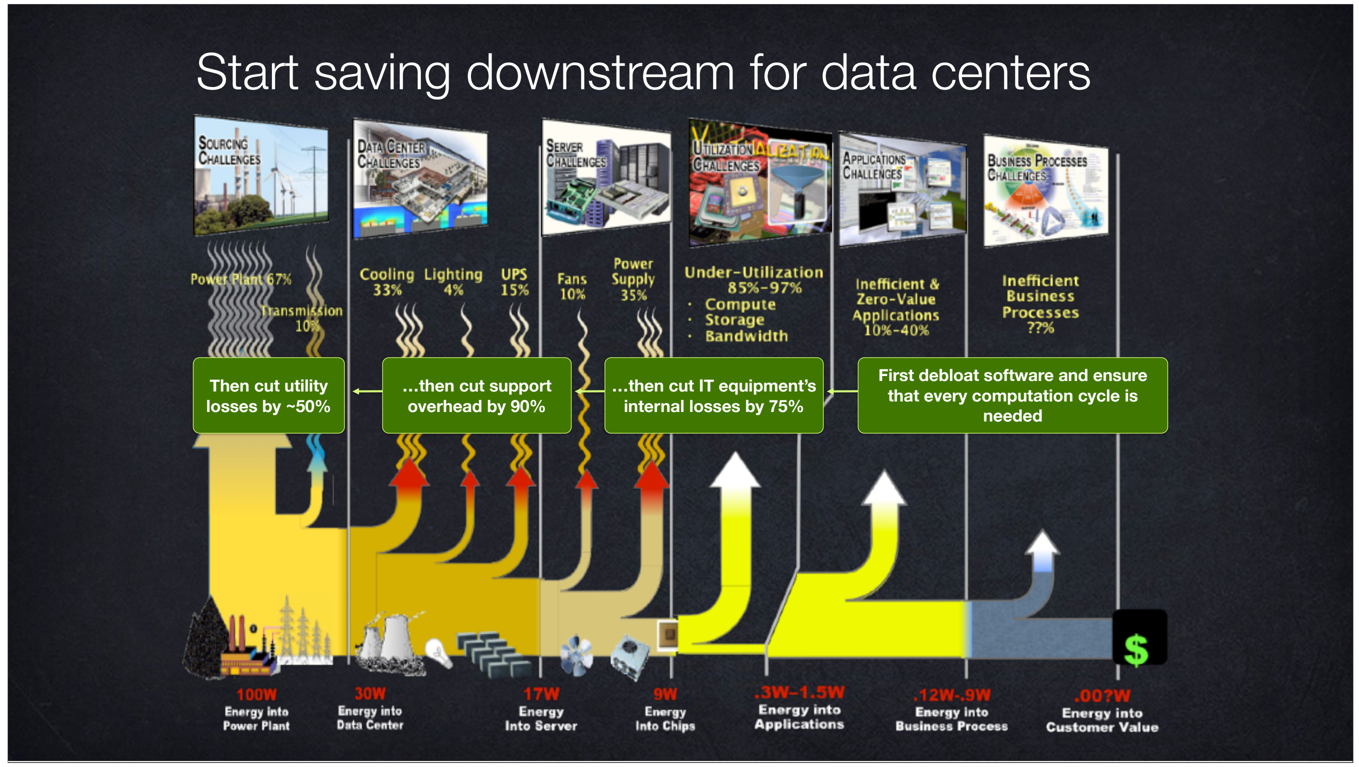
From the fuel burned in the thermal power plant to the end use, many successive losses compound, so only a tenth of the energy in the fuel comes out the pipe as flow.

But now turn those compounding losses around backwards... *



...into compounding *savings* (from right to left), and every unit of flow or friction you save in the pipe saves *ten* units of fuel, cost, emissions, and “global weirding” at the power plant. And as you go back upstream, the components get smaller and cheaper, so the total capital cost goes *down*.

And of course, once your pump or fan needs 5–10× less torque, replacing the big, inefficient motor system with a new, rightsized, superefficient one can save around half the remaining energy by 35 integrated improvements, of which 28 are free byproducts of the first 7. Then you save twice as much drivesystem energy as the usual two dis-integrated improvements, and at a fifth their unit cost. *



Now let's apply the same logic to big old data centers. * Two-thirds of fuel fed into the thermal power plant is lost in the plant and grid. * Half the metered electricity is lost in the cooling system and uninterruptible power supplies [–together, half the total capital cost–] before reaching the servers. * Half the server energy doesn't reach the chips because it's lost in inefficient, usually very underloaded power supplies and many superfluous fans. * Next comes severe underutilization of computing resources, partly through insufficient virtualization. The resulting energy flow is about to vanish, so let's * magnify it. Next comes sloppy bloatware running many unnecessary threads and processes and making simple tasks complex because compute cycles were cheaper than programmers' attention, and someone else bought the energy. * Downstream of all that you may even have inefficient business processes. In all, the red numbers at the bottom reveal that just a few *hundred-thousandths* of the original fuel energy actually delivers customer value. / Where should we start fixing this? Downstream. * First write elegantly terse code, optimally compiled, with the goal that every compute cycle is a needed and wanted one. (I'd assumed this could save one order of magnitude in compute cycles, but recent tests found two orders of magnitude, and that was before AI coding. The shift to mobile devices now makes efficient code valuably stretch battery life.) * Then at least quadruple server efficiency—now even more—and the servers * will need far less cooling and power supply, both doable in smarter ways. * We could even save half the utility losses by using fuel-cell trigeneration cheaper than the UPSs it displaces. / Multiplying these savings from downstream to upstream cuts total energy use by at least two orders of magnitude. When we made this diagram in 2009, our client rejected most of our recommendations, so very disappointingly, we were only able to triple efficiency at the same capital cost, but our partner EDS said that had they all been adopted, we'd have saved ~95% of the energy and half the capital cost. *

“Artificial Intelligence Meets Natural Stupidity: Managing the Risks”

A B Lovins, May 2025, ai-electricity.stanford.edu

- In 1999, the US coal industry funded a campaign claiming the Internet would need half of US electricity by 2020, requiring massive power-plant construction. Dot-com bubble burst 2002, vaporizing ~$120b and freezing ~$80b
- A dubious Big Tech bet on scaling Large Language Models drove trillions of dollar’s worth of AI data centers, subsidized by 36 states and in 2025 elevated to a vital national security imperative. Gas and nuclear interests drove 1999-like power-shortage hysteria to win subsidies and mandates, since they couldn’t compete with renewables
- Only ~5% of 2024 global growth in electric usage was for new data centers (mostly not AI); 5–10% expected to ’30
- AI is mostly in US, but 2023 US electricity use fell; 2024 use grew 2%, including ~0.1% from all new data centers; barely more expected in 2025–26; hotspot growth misreported as national and projected future growth as current
- IEA expects renewables to raise world el. generation 10–20× more than data centers (mostly non-AI) raise demand
- Big Tech prefers & buys renewables that US government tries to block; both like nuclear that capital markets reject
- Gas plants’ price doubled, turbines sold out to ~2031+, nuclear even slower; only renewables are fast enough
- Ignored by official assessments, a big AI use is to make oil & gas bigger/cheaper; may more than offset en. savings
- Many data center projects are speculative; huge competitive risks; AI was *all* of 1H2025 GDP growth; bet against:
  - AI’s specific valuable uses look far too limited to yield enough durable revenue to repay/reward $3t investments
  - LLM bet is failing; small models often win; data centers depreciate swiftly; el/AI service drops ~4× per year
  - Slightly flexible data-center operation (Google) can power expected US projects with just *existing* utility assets
  - “Power Couples” (data center, renewables, & storage behind existing little-used gas plant) are fast, cheap, secure
  - Cheapest power solution: efficiency there & elsewhere, plus renewables onsite or elsewhere, w/storage as needed
- Data centers that aren’t built or don’t thrive risk stranding generation and grid investments; then who pays?
- Take-or-pay long-term power contracts backed by surety bond or insurance policy mitigate that risk to investors

My May essay on AI data centers analyzes the risk that what increasingly looks like a multi-trillion-dollar bubble can put utilities and their customers at risk of a 12-figure overbuild that weakens finances and credit. Today’s AI hype rhymes with a * 1999 campaign, funded by the coal industry, to convince Americans that the Internet would eat the grid without urgent construction of new coal-fired power plants. That campaign overestimated data-center power use by tenfold, but by the time investors woke up, they’d lost about $200b on hundreds of unneeded plants plus grid investments. * Today, several firms that make up 30% of the S&P are betting several trillion dollars on new AI data centers, hoped to yield superintelligence and subsidized by taxpayers in three dozen states including Nevada, and now also federally. The federal government tries to mandate new data centers and their gas and nuclear power supplies under a “national energy emergency,” which seems to mean that those sources can’t compete with renewables, so they get boosted while faster, cheaper renewables are blocked. * All new data centers, only a fraction of which run AI, cause only ~5% of global electric demand growth, and that might rise to ~10%, but the “exploding” demand growth trumpeted in the US is * not visible in national statistics—only in some local hotspots—and if it happened, it would be overwhelmed by renewable growth, as * Big Tech prefers, partly because gas plants are far too slow and costly. * Small Modular Reactors are not a thing and are even slower and costlier, and only the renewables that the federal government is trying to kill are fast enough to meet its AI ambitions. * This contradiction may be good for climate, since one of AI’s biggest uses is making oil and gas production bigger and cheaper, plausibly raising emissions more than its efficiency gains reduce them. * Many if not most new AI data centers are speculative proposals facing major risks now widely considered a bubble that could hazard the whole US economy, since AI growth accounted for almost all GDP growth in the first half of this year [2025]. * Those data centers bet against the order-of-magnitude gap between plausible AI revenues and needed repayments, and * the big risk that superintelligence won’t emerge from the giant models, small lean models will continue to win for most uses, and depreciation will keep outpacing revenues. Meanwhile, better hardware, software, and system architecture are about quadrupling AI system efficiency each year, with about a millionfold to go, so to use and pay for the same amount of electricity, a data center must quadruple its AI service sales every year for decades. (Ethereum’s new system architecture cut its energy use 99.9%.) * Google is already selling to utilities the data-center operational flexibility that makes new power supplies unnecessary. * Another competitor combines an existing gas plant with renewables, storage, and a data center all behind it. * Often the best buy will be efficiency and renewables, onsite or elsewhere, as I’ll show you in a moment. * All that is a lot to bet against. If the developer loses any of those bets, other electric customers shouldn’t be stuck with the bill. * I’ve therefore suggested a take-or-pay power contract to pay off the supply investment, backed by a surety bond or insurance policy to protect other customers or investors from a failed project. Then the risk is priced by independent risk-management experts in the capital market and charged to the developer who hopes to profit. *

Even if gas and nuclear plants could compete with renewables on cost, they can’t on reliability or speed. In late June [2025] I visited North America’s biggest microgrid, just built *in four months* in Sparks, Nevada by Redwood Energy. They laid 20 MW_{DC} of PVs on the ground, then used novel power electronics and software to meld the world’s biggest array of second-life electric-car batteries, ~800 packs each wrapped in a white tarp and set on cinderblocks, into 62 MWh of unified storage. Those batteries provide 2–48 hours of storage as needed for a few years, then they each get hot-swapped and recycled. The result is a 100%-solar, 24/7/365 power supply delivering 12 MW_{AC} for onsite Crusoe modular data centers—more reliably than grid power, and cheaper than its 8¢/kWh price. So we no longer need to guess or argue about which new big loads will be built and thrive: we needn’t build a power supply until an AI data center is already mostly built, then vendors can compete to supply it. Solar microgrids are safe, silent, virtually water- and maintenance-free, zero-emission, profitable, scaleable, and if necessary portable. *

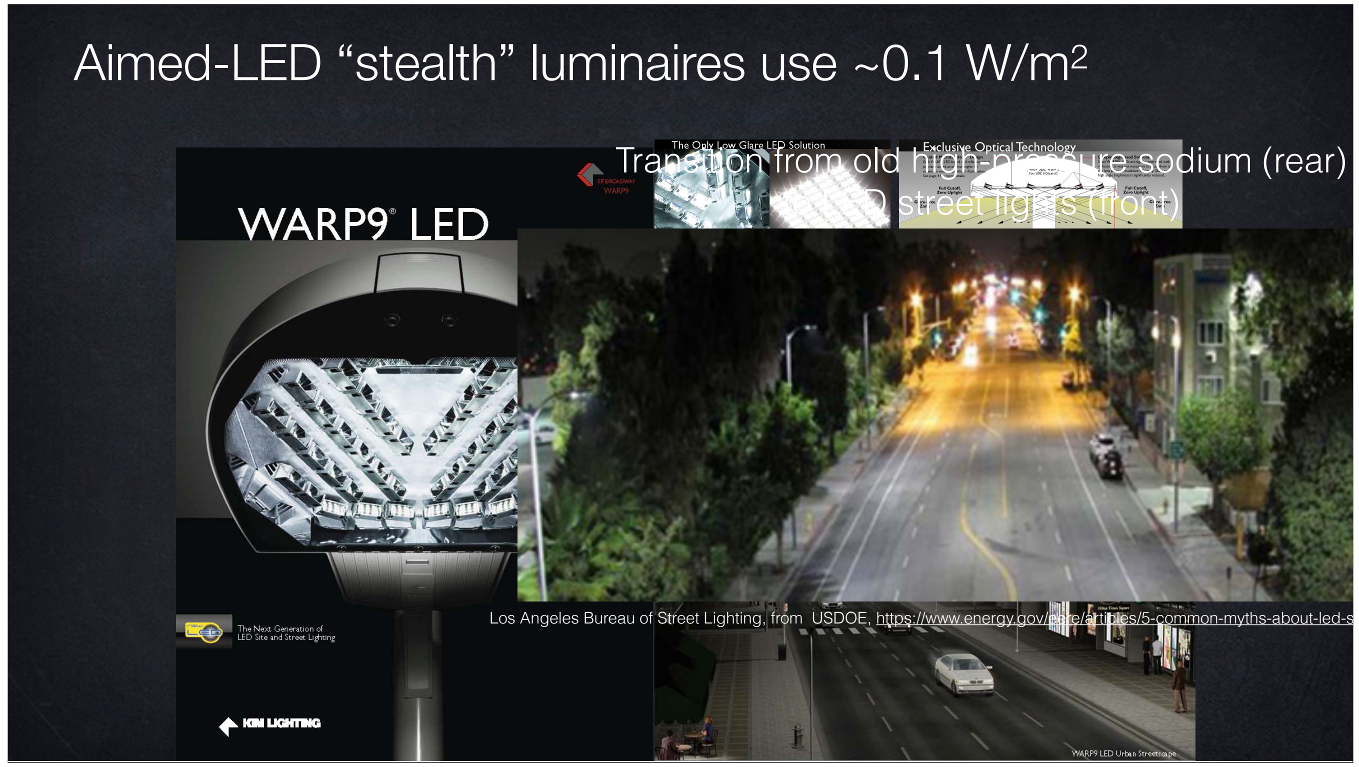
Rethinking buildings' context

Finally, let's go *out*side the building. Smart siting integrates where people live, work, shop, play, and pray, so they're already mainly where they want to be and almost all destinations are within a five-minute walk. Landscape architects can do magic. Trees and parks and microfarms can green cities. Desubsidizing cars lets drivers get what they pay for but also pay for what they get. And there's more…*

Integrative design: parking lots

A standard big-box store's or shopping mall's parking lot is paved with dark asphalt. Its radiant heat and hot air roast the store, cars, and customers, and soak up light so ever higher lighting is called for to provide security at night—light that becomes so dazzling, customers are temporarily blinded as they drive off the lot, so they have a collision and the owner gets sued anyway!

An integrative designer would use light-colored paving. It *cools* the store, cars, and customers; lasts longer; reflects light better for night security and saved lighting fixtures and energy; and even has a pervious surface to shrink or eliminate stormwater infrastructure. *



Light-colored paving is also synergistic with the outdoor lighting revolution. That’s not only about * the now-familiar replacement of high-intensity discharge lamps with LEDs. LEDs also permit advanced luminaires * with a small aimed * mirror for each emitter creating a seamless checkerboard of extraordinarily efficient, effective, and attractive visibility, though even this model, the best a few years ago, may already have been surpassed. And light-colored paving can then reduce the parking-lot lighting to as little as 0.01 W/ft^2, ~2% of the ASHRAE norm, with much better visibility and no dangerous dazzling of drivers. *

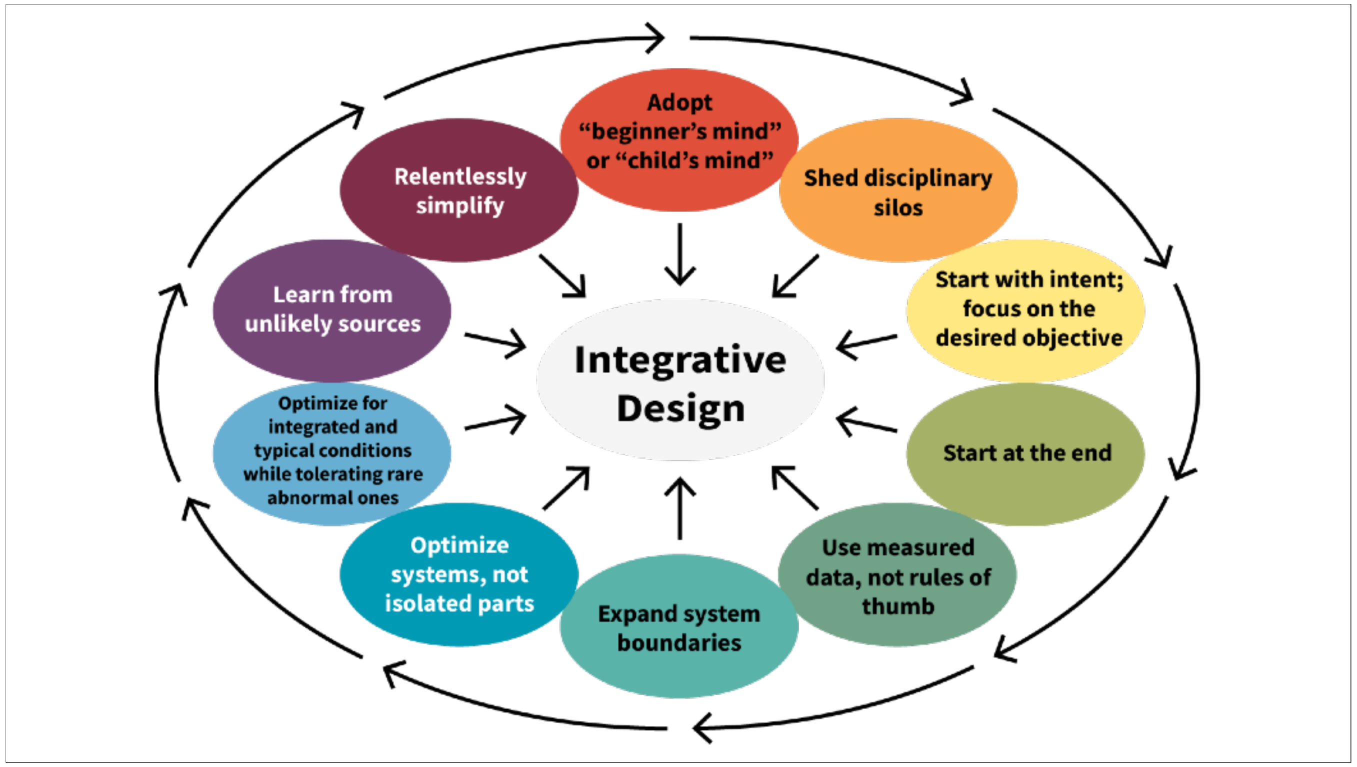
Benefits multiply as we expand the system boundary. * In New York City, Mayor Bloomberg and Al Gore promoted white roofs on old and new buildings. In very round numbers, 100 m^2 of white roof has a similar climate effect to taking 10 T/y of CO_2 out of the air, just like an urban water-wise tree cools the city about as well as nine window air conditioners [(which of course cool the indoors by heating the outdoors)]. Berkeley Lab has shown that replacing dark with light-colored roofs and pavements, plus shade trees and vegetation, can bounce solar heat away so well that their * widespread adoption could cool Los Angeles by ~4 C° [~6 F°], cutting the city's cooling loads by ~20%). Since the photochemical reactions that cause smog double in speed for each ~10 C°, cooler air would also cut smog by ~12%, improving public health. Just in Los Angeles, the total *indirect* savings would be worth ~$0.5 billion per year. Berkeley Lab's * database lets designers pick paints, shingles, and coatings that reject solar heat but are various pastel colors rather than white. / Another important point is how buildings affect neighbors. Saitoh-sensei measured around Shinjuku in downtown Tōkyō that on a hot (37.2°C) summer day, a bystander would receive a radiant flux of ~800 W—enough to kill you over some hours. Only ~150 W was insolation; the other three-fourths was reflected from or radiated by adjacent buildings and pavement. So "urban heat island" phenomena are important to basic health and survival. *

The next simplification: no buried pipes or wires?

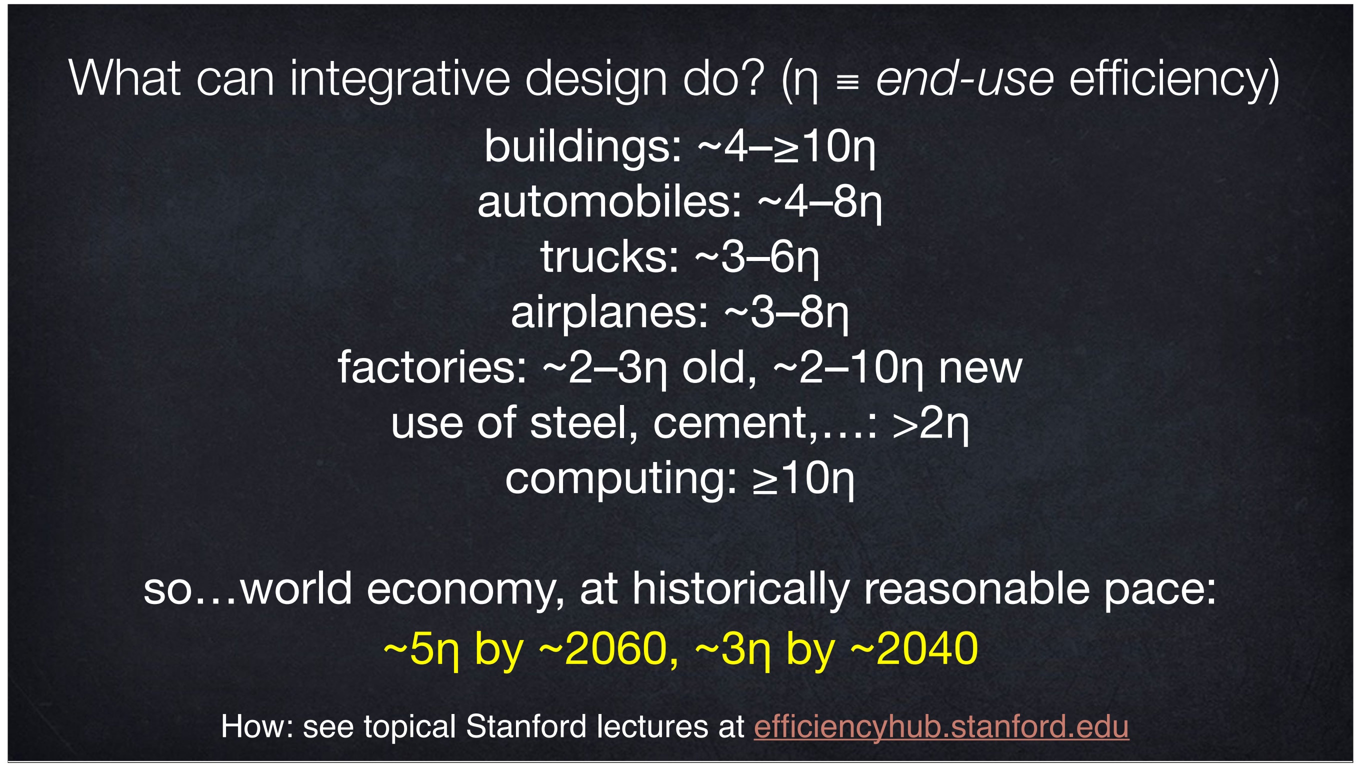
1. Electricity: radical efficiency + PVs (or better)—islandable, resilient, favoring critical circuits, optionally in an islandable microgrid.
2. Telecommunications: wireless WAN or equivalent, VOIP
3. Fuel: passive heating and cooling; cook with electricity or biogas of PV H_2
4. Potable water: rainwater capture and cisterns, efficiency, graywater recovery
5. Stormwater: landscape design
6. Sanitation: modern onsite solution such as Swedish/German urine-separating toilets, feeding onsite gardens

Far more resilient. Cheaper for society, and perhaps for the developer too.

Where else can we extend energy and resource efficiency beyond the building? Spongy landscapes, walking/biking designs, New Urbanist layout—but here, let's just consider the six reasons developers put pipes and wires in the ground to connect new housing to remote infrastructure: telecoms, electricity, cooking fuel, potable water, sanitation, and stormwater management. Today we have comparable or better onsite solutions for each of these needs: * net-zero buildings [though no wires bars net-positive buildings], * wireless telecoms, * all-electric or solar-thermal cooking, * rainwater capture and graywater reuse with water efficiency, * landscape-based stormwater management, and * onsite sanitation. If we combined all six, we'd no longer need to bury pipes and wires, like throwing money in a trench and covering it up. You'd gain better siting and phasing flexibility and better cashflow. Onsite maintenance might cost a little more, but the decades-long burdens of the costly remote systems and the pipes and wires in between should plummet, and you own all those costs. * Resilience would rise. Total cost would almost certainly fall, and some anecdotal evidence suggests that even the *developer*'s capital cost may fall too. This seems an idea well worth trying. But to get the box out of the box, we have to realize *there is no box.* *



My Stanford students build their skills in applying these ten principles or "pillars" of integrative design. Their consistent use can radically save energy, water, and materials across the whole economy, in every sector and nearly every use. The examples I've given, and hundreds more, illustrate that astonishing potential. How much energy can it add up to? *



Across all sectors, this summary shows the immense end-use energy efficiency potential, *not* counting the ~3× upstream savings nor improvements in urban form, landscapes, and other things outside the building. Yet this five-eta potential is seldom recognized, taught, delivered, expected, or rewarded. The same design errors are common in our textbooks and classrooms. So I'm hatching a plot for—to put it a mite impolitely—the nonviolent overthrow of dis-integrated design, because it condemns our descendants to perpetual retrofit of inefficient stuff—not a worthy legacy. To help us be good ancestors, I'm seeking fellow-students, -teachers, and -practitioners to collaborate on making integrative design move swiftly from rare to common. [I'd like to help gently retread in-practice design professionals and the skilled tradespeople, like pipefitters, sheetmetal-workers, and mechanical contractors, who informally design many systems; help improve design software to allow and coach integrative design; and find iconic CEOs to apply Five Eta in their firms and proselytize their peers, as Jack Welch did with Six Sigma. Last year, partners in India, Australia, and Sweden hosted my teach-the-teachers course to improve our pedagogy together. Our Stanford course has been refined in 14 iterations, and * its lectures were just posted at efficiencyhub.stanford.edu. Now I'm eager to test all ~20 known scaling vectors, see what works, and start to make integrative design as common as grass.]

[Demand growth for air conditioning, electric vehicles, data centers, and industry can be modest if best practice spreads rapidly and if efficiency is fairly competed or compared with new supply. A prosperous, fair, climate-stabilized world could then need far less supply growth than widely assumed, and it'd be far more distributed, due to the economics and security advantages shown in my * early-1980s books *Small Is Profitable* and *Brittle Power*.] *

Then we won't need speculative, slow, and costly technologies like nuclear fusion and fission—* except, of course, the well-engineered and remotely sited free fusion reactor already thoughtfully provided, and cheaper to harvest than to replicate. *

Climate-science models conservatively understate the speed and runaway potential of climate change. Models of climate choices and consequences, at least as conservatively, understate what we can do to stop climate change. Offsetting those two contrary biases, the race of our lives—the race *for* our lives—is very much on. The outcome is up to each of us. Despair and complacency are equally unwarranted.

Our responsibility is to enable the new energy system, not protect the old, so the energy transformation can move at the pace and cost of design and software, not of infrastructure, and can be not constrained by the inertia of incumbents but sped by the ambition of insurgents—like, I daresay, many of you.

Just remember Marshall McLuhan’s * remark that “Only puny secrets need protection. Big discoveries are protected by public incredulity.” So how incredulous are you? I’m eager to learn what’s on your minds. Thank you. *