Chapter 8
Ideal Sustainable Homes and Building Practices

There is a great need for the introduction of new values in our society,
where bigger is not necessarily better, where slower can be faster,
and where less can be more. - Gaylord Nelson

Opening Questions:

Is sustainable living possible?
What is an ideal home in the US?
What are the ideal energy systems?
What is an ideal design for sustainability?
What is the value of architectural services?
What are best practices for selecting a builder?
Should I negotiate contract or use competitive bid?
How do I ensure objective and effective quality control?
What are helpful tips in navigating the selections process?
What do these findings offer for renovating more sustainably?

Data and Analysis:

Sustainable living is certainly possible; in Chapter 2 we briefly sketched the history of human abodes to find examples, past and present. Unfortunately, most Americans are living in ways that are far from sustainable, and that includes the choices we make around housing and transportation[1]. It is the ecological impact of *modern life* on the *natural world* that has humanity on an unsustainable path. Since Americans (and others of wealth around the world) appear not willing to return to living in igloos, dugouts, or teepees, this research team set out to explore whether sustainable living is possible *with* the modern conveniences of conditioned homes with lighting, cooking, warm showers, and electricity to power our many devices. The answer is not only *yes*, but at a surprising cost that should allow all to participate. These conclusions should spur a rapid transition and a significant step toward sustainable living. In this chapter we assemble together many of our findings to offer ideal approaches and best practices.

The solutions unearthed in this analysis reduce the embodied energy in physical structures that can also be designed to produce all the net operational energy needs of the home from a clean and renewable source. The ideas also scale, meaning that operational energy can be eliminated from any sized home, large or small, and a standard (code-minimum) thermal envelope will have less embodied energy than an upgraded envelope at any given size. This research team is concerned that widespread adoption of these principles could lead to an unintended

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[1] Housing and transportation account for more than half of the average American's ecological footprint.

consequence; larger homes. In a world of finite and limited-renewable resources, it is still better to use fewer rather than more of those limited gifts of nature. In overall size of house, smaller is better from a resource use and embodied energy perspective. Tiny houses have garnered more interest and adoption recently. We applaud those who commit to living at that scale from a resource-use perspective, both in choice of shelter, and in the forced limitation of other physical assets (because of space to use or store). However, expecting that the tiny house movement will remain niche in the U.S., our purpose is to target housing that can appeal to--or appease--most Americans.

An Ideal Single Family Home of Modest Size

The target of our research and analysis has been independent single family housing (SFH) since that type of unit shelters most Americans. SFH comprises 60% of the total U.S. housing inventory, 70% of Americans currently live in SFH, and 80% aspire to that as an end goal (U.S. Census Bureau, 2018; O'Malley, 2013). Before moving to notions of an ideal single-family home, a few notes about higher-density living. High density housing (HDH) has environmental benefits over SFH in embodied and operational energy, per square foot of living space; this is due to some shared structural elements and insulating properties. However, most HDH units do not have sufficient space for solar capture that could provide all (net) household energy, much less power EV transportation. Many HDHs also lack practical arrangements for EV charging, though that is beginning to change with new developments. Unless or until public energy grids transition entirely away from fossil fuels, the overall package of SFH with solar PV providing all (net) energy is ecologically preferable to HDH without onsite solar, or with partial solar. High density housing could reclaim preferred ranking if/when they gain access to fully renewable energy.

A single family home with three bedrooms does not need to be larger than 2,000-2,500 square feet, except for families of atypically large size (another niche population). Bedrooms of 120 square feet are adequate, since most time spent in those rooms is sleeping. If children need more floor space for play, beds can be bunked, lofted, or cleverly hidden when not in use. Bathrooms almost always serve one person at a time; 40-45 square feet will allow a full tub/shower, commode, and vanity sink. Three bedrooms and 2.5-3 bathrooms can be designed and packaged in as little as 500 square feet; that still leaves 1,500-2,000 square feet of livable space for the common living areas. The following chart offers other elements of an ideal home and some general recommendations:

Topic	Description
Size of house	Small-modest; plan for only as much space as needed for most occasions
Site topography	Flat land is ideal, with unobstructed south exposure for solar (PV/passive)
Site orientation	Ideal if oriented to true south, or allow for orientation of the house to south

Site geometry	Ideally allows east-west long axis of house for best solar (PV and passive)
Levels/stories[2]	One level if possible; stairs are unusable (wasted) floor space (added cost)
Quality control[3]	Skilled, third-party, quality control employed throughout construction phase
Foundation	Slab eliminates many foundation problems; may top slab with softer surface
Walls/structure	2x4[4] wood stud if utilities kept out of exterior walls; otherwise 2x6 wood stud
Windows	Double pane sufficient in lower 49 states; select on functionality & durability
Doors	Standard insulated exterior doors; select on tight fit and quality sealing
Air gap control	Blower door test before insulation to identify and seal all air gaps in structure
Insulation[5]	Cellulose (blown) prefered in cavities + exterior continuous 1” rigid rockwool
Heating/cooling	Basic air-source heat pump (base SEER) with central ducted distribution
Ventilation	ERV integrated with ducted draw/distribution, or passive pipe on return side
Energy medium	Electricity as the only energy medium; no direct-use fossil fuel equipment
Energy source	Solar PV(grid-tied), sized[6] to meet all household and EV[7] transport needs
Roofing	Asphalt shingles best combination of finance (return) and ecology (energy)
Siding	Basic and least-costly option is adequate; select on durability and value
Finishes	Basic and least-costly finishes are likely to have the least embodied energy
Appliances	Basic and standard models, even if they use more energy (see Chap. 7)
Lighting	LED throughout; do not compromise insulation cavity with can housings

[2] Multiple levels add cost per living space. Egress elements (e.g., stairs, hallways) become wasted living space with development, conditioning, and maintenance costs. Foundation walls are more expensive fulfilling needs of moisture resistance and extra strength for lateral pressure and vertical superstructure.
[3] Code-compliant structures have proven durable and long lasting if constructed with quality and maintained adequately; this is an important qualification of sustainability from a resource-use perspective.
[4] Ideal wall: 2x4 wood stud, with OSB sheathing, 1-inch rockwool rigid board continous, and house wrap. Note that unless utility boxes/pipes kept out of exterior walls, we recommend 2x6 wood stud. We prefer blown cellulose insulation both because it performs well and is less damaging to environment than others.
[5] See Chapter 5 for greater detail on materials, breaking thermal bridges, and options for ceiling insulation.
[6] Some electric utilities cap home solar to household use; we need advocacy for including transportation.
[7] See Chapter 7 for comparison of EV and ICE vehicles (cost, value and economic/environmental impact).

Note that recommendations favor natural materials (wood superstructure, cellulose insulation and rockwool rigid board); these have proven to be renewable when managed effectively. Even though asphalt shingles contain fossil fuels, they are recyclable at end of life, and compared with other roofing materials, they represent the best combination of environmental and economic benefit[8]. Finishes, equipment, and appliances are recommended to be basic, standard, and simple, not only for less environmental impact, but because they also offer the best financial value and return.

In most areas of the U.S. a single family house with these features can be built for $100 per square foot or less. Using the guideline limit of 2,000-2,500 square feet, maximum cost for new construction should not top $200,000-$250,000, and this can be achieved for much less for smaller houses. Additionally, houses with these features are very likely to appraise at or above constructed cost, in most areas and markets, making it possible even for low asset buyers to secure financing. With solar PV producing all the (net) energy needed to power both household and transportation, this package immediately removes about half of the ecological footprint of the household and its occupants. Further, if finishes and equipment are held to simple baseline standards, this package is the least costly. Even though the solar investment seems large initially, the continuous stream of benefits make the energy system less costly than most utility rates (see Chapter 3).

This big picture building package is so counterintuitive and counter-conventional, that it bears repeating for simplicity, clarity, implications and impacts:

Household Element	Dollar Cost/Value	Environmental Impact
Electricity planned as the sole energy medium	Less than alternatives, both to develop and maintain	Less embodied energy & dramatic cuts in operational energy/impact
Solar PV onsite sized for home and EV transport	Less than utility rates over life of system, even on loan	Cuts operational climate emissions for both home and transportation
Basic, code-minimum structure (thermal env.)	Less than all alternatives, and most likely to appraise	Less resources/embodied energy; sufficient for operational energy
Simple, basic & electric equipment & appliances	Lower purchase price than alternatives (no tanks/piping)	Less embodied energy in equip. and allows zero emissions with PV

[8] Our team performed analysis of a number of roofing choices to arrive at a recommendation of asphalt shingles. This may seem surprising, given the thrust of this book; see full analysis at http:cscs.org/housing

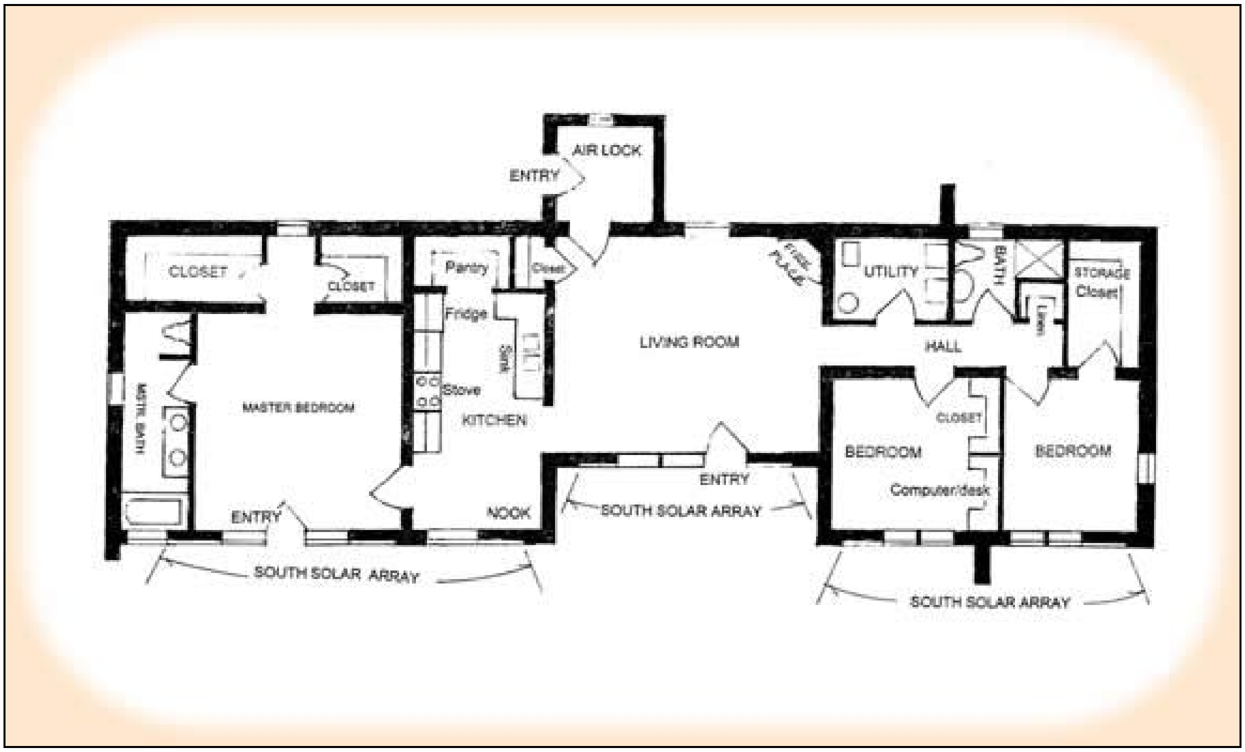
The conventional wisdom has drifted so far from what the data and current possibilities support, that a shift now from common understanding and application to this more sustainable package offers win-win outcomes. What we are terming the SOLO[9] House offers these nine benefits:

Solar plus Low Cost (SOLO) home's win-win(x9) outcomes	
Cost initially	Least costly to build, buy, or renovate
Cost operationally	Less costly than alternatives (prevailing common practices) w/ solar PV
Appraisal/financing	Most likely to appraise at constructed cost; financing available/affordable
Resale and ROI	More likely/quickly to sell on the market and better ROI than alternatives
Access/availability	Wider access; more than would-be homeowners in current conditions
Resource use	Fewer resources embodied in structure, systems, equip., & appliances
Emissions	Operational emissions/pollution reduced to near-zero for home/ & ransp.
Adoption pace	Lower cost (primarily) will drive rapid adoption; ecology is the beneficiary
Ecological impact	Dramatic reduction in climate emissions; moderate drop in resource use

People building a new home typically find it very difficult to resist cost creep; adding a bit of space here or an upgraded appliance there. Each individual upgrade or size expansion seems small in the decisive moment, yet the collective impact of several or many of these choices can be enormous. Adding livable space not only increases cost and resource use at construction, but it commits the owner (and society) to maintain and condition the space continuously thereafter. There is another tragedy of this phenomenon from an ecological perspective, and that is the opportunity costs that people do not always consider. Homeowners too often tap out their assets (or budget or financing) with many small upgrades and then find solar PV or transition to EV unaffordable. Priority must favor onsite solar PV!

Passive solar could be pursued, if the orientation is ideal, and if it adds little to no cost, though review Chapter 6 for assessment of trade-offs and complexities. However, from an opportunity cost perspective, as well as for environmental and financial return, passive solar should not be wedged-in if it comes at the sacrifice of active solar and EV transportation. Still, if homeowners desire windows for natural light or ventilation, designing for their placement on the south side will get the most out of these weak links in the thermal envelope. Here is an example of a 3-bedroom, single-story, ranch-style home with most windows on the southern elevation. This mild-passive design can be achieved without adding cost.

[9] SOLO is an acronym for Solar + Lower cost (both in dollar terms and environmental impact).



This design and orientation also provides an ideal roof space for active solar PV. With the ridge of an A-frame roof running east-west (a low-cost structural design) the south pitch of the roof provides an uninterrupted pitched plane for the solar array; the angle of the roof could be optimized for solar production based on latitude, though roof cost should also be considered. The house plan above could also be considered ideal in meeting other criteria, as it is single story and could be anchored by a concrete slab foundation.

Professional Services

Working with an architect on a residential project is typically optional. Certified engineered plans can be downloaded from the web or purchased wholesale; builders may also provide plans that have been reviewed and permitted in previous work. Since employing an independent architect would add to the overall cost to the project, homeowners should carefully consider the value proposition. Earlier in this chapter we wrote about the potentially large explicit and hidden costs of adding footprint space to a house design. A skilled architect could more than pay for their service fee by designing or redesigning plans to reduce or eliminate wasted space; they are also trained to find efficiencies. Hallways and steps are cost and space wasters, but a good architect might find alternative design to avoid them, or to creatively use space in or around them. If an architect can eliminate 80 square feet from the footprint with more efficient design, they will have saved the homeowner roughly $8,000 in construction cost, and there will be lifetime savings in conditioning and maintenance.

Architects are better known for their value in adding artistic and aesthetic design; that could be a bonus if an architect more than compensates for their professional fee by lowering construction and operating costs. However, since architects have no personal or professional incentive to contain costs on behalf of others, some may prioritize design and aesthetics over budget. Some architects may not be as deeply driven by values around energy, environment, or sustainability. Finding the best match of principles and values will be important for the homeowner; here is a list of criteria we recommend employing to interview and select an architect:

Architectural Services Research and Selection Criteria		
1	Environment	Are they knowledgeable and committed to sustainable housing?
2	Energy	Do they know the benefits & integration of solar PV and energy systems?
3	Economics	Do they understand diminishing returns, NMB, and opportunity costs?
4	Budget/cost	Are they committed to holding costs to budgets and targets?
5	Design/artistry	Review previous projects for sense of design and artistry
6	Quality control	Are they willing and skilled to perform onsite quality control inspections?

Homeowners who want to be environmentally responsible in the house they build or renovate, will need some expertise on design, materials, energy, equipment, and quality control. We think a homeowner with a little bit of construction experience and savvy could use a resource like this book to provide or organize these decisions, but most will do well to rely on the professional services of an informed architect. An architect can also be an objective accountability source for the builder and can provide oversight, quality control, and inspection. We have noted in several contexts the importance of quality craftsmanship in construction; it is only on that basis that we are confident to recommend code-minimum structural standards. If the homeowner does not have another source for effective quality control, we strongly recommend hiring an architect, who will also provide the services listed above as a bonus.

Selecting a builder is one of the most critical decisions in new home construction, and many homeowners struggle with the process and choice. The most common approach in the U.S. is to invite several competitive bids based on a set of plans, but homeowners may lack necessary expertise or experience to effectively evaluate and compare proposals. The lowest bid may not result in the lowest overall cost, depending on included scope, contingencies, and change order management. There may also be vast differences among contractors in communication skills, adherence to schedule, quality craftsmanship, and professionalism (working relationship). This highlights another benefit of employing architectural services; an architect should serve as an advocate for the homeowner in communication and decision making with the primary builder, and other industry professionals.

An architect could also manage a bid or negotiation process with contractors to help the homeowner select the builder and negotiate the contract. Architects are likely to know the reputation of builders in their region to help guide the best match with a homeowner and their specific interests. If the homeowner connects with a builder that they already know and trust, negotiating a contract can be done with integrity if an objective third party (as in an architect) can validate rates, processes, price and schedule. That would avoid the competitive bid process that incentivizes contractors to pare proposals to be competitive initially, but that later encounter disagreements over scope, potential cost overruns, and possibly personal or professional conflicts.

As with architects, builders do not have the same incentive as homeowners to contain costs; however, a few processes can be employed to keep all stakeholders appraised of changes that have implications for cost or schedule. We have a list similar to architects in interviewing and selecting a builder, and then some recommendations about managing assumptions and communications throughout the project:

Building/Contractor Research and Selection Criteria		
1	Environment	Are they knowledgeable and committed to sustainable housing?
2	Energy	Do they know the benefits & integration of solar PV and energy systems?
3	Economics	Do they understand diminishing returns, NMB, and opportunity costs?
4	Budget/cost	Will they commit to hold to budgets and targets, unless by agreement?
5	Quality control	Will they allow and respond to third-party quality control inspections?
Builder/Contractor Commitments and Processes		
6	Base Pricing	For every selection, will the builder commit to providing the specifications and price of the least-costly base option so that every stakeholder knows the benchmark for comparison? (preferably in a shared online document)
7	Upgrades	For every upgrade from base, will the builder log the selection, along with specifications and price? Adding this data to the Base Pricing document (preferably shared online) allows stakeholders to follow and monitor costs
8	Schedule	Will the builder commit to placing the construction schedule on a shared online document for all stakeholders to follow, and then update as needed with adjustments and revised timeline for milestones and completion?
9	Changes	Will the builder commit to maintaining a log of agreed changes (preferably in a shared online document), with cost implications for each change and summary impact on total contract price? (running dynamic pricing)

The big decisions of overall building size, design, and structure are made before the contract is signed and construction begins. It is the myriad smaller choices that need to made along the way that become challenging for a wide variety of reasons. Windows, doors, paints, appliances, faucets, light fixtures, trim style, cabinets, countertops; this is just a subset of a list that seems endless. These *selections*, as they are termed, need to made by the homeowners because they reflect personal preferences and cost implications. Builders often handle the delicate issue of selections with allowances. These lump sum amounts per category are helpful initially to estimate their contributions to the overall contract, but it is very difficult to monitor impact of each decision as they are made rapidly throughout the project.

Whether or not the builder employs the allowance mechanism, starting with shared knowledge of the cost and specifications of baseline selections allows homeowners to evaluate potential upgrades on the basis of price premium. If the selections list is then updated as decisions are made, the homeowner can track impact on both category allowances and the overall contract; it would also allow them to consider opportunity cost implications throughout the project. Stated more simply, prices must be attached to every choice beyond the baseline benchmark so that homeowners can make informed decisions knowing the implications. This level of transparency is generally lacking in the building industry.

Since very few (if any) upgrades return operational benefits that would allow the cost premium to break even over its expected life (Chapters 5-7), homeowners can consider upgrade premiums as driven by personal preferences. Each upgrade, and the accumulating costs, can then be assessed against alternative use of limited funds; the opportunity costs. If premium selections are driving the homeowner away from solar PV or EV transition, those choices have enormous implications for the household ecological footprint. Sharing live and updating documents can check homeowners against their budgets and overall goals and objectives.

Renovating sustainably

The findings of this study lend greater support for renovating older buildings rather than demolishing and starting anew. The prevailing notion that bigger, thicker, and more robust thermal envelope elements provide unquestioned benefits in reduced heat loss and energy bills, immediately places older structures at a perceived disadvantage. However, if the structure of an older building is sound, or it can be bolstered where needed, our conclusions suggest that it is preferable from both a dollar cost and environmental perspective to use what is salvagable instead of unnecessarily adding waste to a landfill and demanding fresh resources.

Due to diminishing returns on the most insulated sections of the thermal envelope, and the fact that building codes in the U.S. already require more insulation than the net marginal benefit (NMB) optimum, rebuilding the thermal envelope beyond what code requires returns ***negative*** NMB, both financially and environmentally. Financial returns are negative because significant premium costs are never recovered by relatively small benefits in operational savings.

Environmental returns are negative because the additional embodied energy of thermal envelope upgrades, either beyond code compliance, or in full in the case of a rebuild, are not fully offset because operational energy savings are relatively small.

The primary concern in any renovation project, and the first dollars committed, should be to transition the building to a clean(er) and renewable energy source. In the U.S., that most often means installing enough solar PV to displace fossil fuel laden, utility-provided, electricity. Remember that solar PV in most U.S. regions is less expensive over the life of the system than grid-provided energy, and since solar PV is the optimal system for distributed small-scale onsite energy generation, a renovation may provide opportunity to rework or reorient solar capture zones.

Arguments outlined in this book[10] acknowledge weak links in the thermal envelope as features that diminish the relative value of the most insulated elements. Even in new construction, therefore, the best spending on thermal envelope upgrades--if any--should address weak links first. Typical weak link elements, such as windows, have improved significantly and relatively more than stronger elements over the past two decades; therefore, the gap between weakest and strongest elements of the thermal envelope is wider in older buildings. This gives stronger rationale to upgrading the weakest links in renovating older buildings, and weaker rationale to upgrading the strongest elements. The following chart offers a ranked priority list in building renovation; note that these recommendations generally support better financial returns and lower environmental impact.

Priorities (ranked) in Renovating Buildings: Economic and Ecological Win-Wins	
Structure	Ensure structure is safe and expected to provide continued foreseeable life
Energy Source	Add solar PV at a size to meet all (net) energy demand of building and EVs
Energy Medium	Remove direct fossil fuel systems & plan for electricity as sole energy use
Air Gaps	Seal gaps identified with blower door test before interior insulation reapplied
Weak Links	Reduce number, if possible, then prioritize replacement of weakest links
Code R-value	Insulation (favor natural materials) to current and local code-compliance
Materials (old)	Minimize waste to the extent possible by reusing, repurposing, or recycling
Materials (new)	Favor natural materials that are, or can be, sustainably grown & marketed

[10] See Chapters 5-7

One of the tragedies of many renovation or rebuilding projects is the loss of heritage; the history, culture, design, and style from the past. While demolition and rebuilding is necessary in cases where the structure is sufficiently compromised, historical and cultural treasures rarely need to be sacrificed in the name of dollar cost or ecological responsibility. Each case is unique, and there may certainly be exceptions; however, our analysis of financial return and ecological impact in the building process will almost always favor renovation over rebuilding, if the structure is salvageable. Adding solar PV can be achieved in discrete ways that retain the historical appearance[11]. Keeping waste materials out of landfills, and reducing extraction and processing of new building materials, extends the utilization of scarce and limited resources. The reoriented thinking and priorities unearthed in this comprehensive view of energy and materials should reorient the calculus on when to demolish and rebuild, and how to prioritize renovations.

Case Study:

The case home was conceived from the beginning to be carbon-neutral--or better--in operations, and that is what brought together the team for this applied research project. We knew that the carbon/climate goal was achievable at a price premium, but we wanted to apply full cost pricing[12] to hopefully demonstrate attractive long-term financial returns, which would drive actions that would also reduce environmental damage. We believed that sustainable living, as defined by operational energy needed for residential living, was possible. What we discovered, by surprise and contrary to conventional wisdom, is that achieving sustainability in the operation of a modern American home is not only possible, but offers the best overall financial return and ecological impact, combining operational and embodied energy.

The building lot for the case home was ideal in some ways, but not in others. Ideally, the lot was undeveloped and rectangular, with the long axis oriented predominantly east-west; this would ordinarily set up ideally for solar capture. However, the lot sloped significantly from east to west, which would have made a house with a long axis on east-west orientation cost-prohibitive. This topography forced a long axis orientation north-south, and the severe slope made a multi-story design most suitable. Both the multi-story design and orientation of the house do not meet ideal criteria, and it required additional cost for a design that would accommodate sufficient solar PV and maximize passive solar heating.

This research team (architect, builder, and homeowner) did not consider the premium cost of foundation walls because there was already a commitment to use insulated concrete form (ICF) walls from ground to roof; this was based on significant research of the construction literature (conventional wisdom). Through the lens of that understanding, a walk-out basement with two subgrade elevations seemed like bonus space. The research data and analysis we performed during and after construction fully debunks the notion of net benefits from thermal envelope

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[11] Standard solar arrays can be integrated with the roof line with careful design and a little more cost, and solar shingles are just entering mass production and distribution at the time of this writing; that solution will be apropos to historical renovations.

[12] Full cost pricing includes all costs, explicit and implicit; in this case, the environmental cost of energy.

upgrades beyond code compliance, and that makes subgrade walls suddenly more expensive because they need to be effective at resisting lateral pressure (weight and moisture) and vertical weight (multi-story). If subgrade foundation walls abut living space, we strongly recommend ICF, Superior Walls, poured walls, or other engineered system for that application; that adds expense that would not be needed for single story on slab construction.

Some of the outcomes on the case study home were dictated by the physical features of the building lot, though we did not know at the time how much that would increase comparative costs. Some decisions were correct from the planning stage, including electricity as the sole energy medium, and installing enough solar PV to power both house and homeowner transportation via EVs. The economics and ecology of solar PV turned out to be even more favorable than advertised, when we applied the tools of finance to acquire realistic cost and return on investment. Our analysis on roofing was timely enough to avoid a mistake; the original plan specified standing seam metal until our analysis showed asphalt shingles as favorable on both financial return and environmental impact. On most other criteria, our findings were a surprise, and arrived too late for correction on the case home; here is the same list of criteria offered for an ideal home, along with our self-imposed grade on the case study project with explanation.

Topic/Grade	Description of Ideal; then *Rationale for Grade against the Ideal*
Size of house **B**	Small-modest; plan for only as much space as needed for most occasions *2500 SF total; bedrooms/bathrooms A+, commons spaces larger than need*
Site topography **D**	Flat land is ideal, with unobstructed south exposure for solar (PV/passive) *Exposure to south was adequate, but building lot was sloped (in worst way)*
Site orientation **C**	Ideal if oriented to true south, or allow for orientation of the house to south *Allowed orientation of house to south, but not long axis, & not perfect south*
Site geometry **F**	Ideally allows east-west long axis of house for best solar (PV and passive) *Allowed only north-south long axis, and even short side restricted to 188°*
Levels/stories **F**	One level if possible; stairs are unusable (wasted) floor space (added cost) *Lot topography and solar PV capture on roof resulted in 3 levels, 2 stairs*
Quality control **B**	Skilled, third-party, quality control employed throughout construction phase *Homeowner, with some construction background, monitored for quality*
Foundation **F**	Slab eliminates many foundation problems; may top slab with softer surface *Lot topography added heavy cost for excavation, rock removal, found. walls*
Walls/structure **F**	2x4 wood stud if utilities kept out of exterior walls; otherwise 2x6 wood stud *Extensive cost premium for ICF without discernible benefit; surface utilities*
Windows	Double pane sufficient in lower 49 states; select on functionality & durability

B	*F for selecting 3-pane; fortunately, secured 3-pane for price of 2-pane*[13]
Doors **B**	Standard insulated exterior doors; select on tight fit and quality sealing *Selected standard doors; in retrospect, would investigate fit & seal qualities*
Air gap control **B**	Blower door test before insulation to identify and seal all air gaps in structure *Did not conduct blower door test, but inspected fastidiously for cracks/seal*
Insulation **D**	Cellulose (blown) prefered in cavities + exterior continuous 1” rigid rockwool *Sufficient R-value (ICF/spray foam), but would now prefer natural materials*
Heating/cooling **D**	Basic air-source heat pump (base SEER) with central ducted distribution *Geothermal heat pump added cost without operational energy savings*
Ventilation **B**	ERV integrated with ducted draw/distribution, or passive pipe on return side *ERV effective, but at high oper. costs; should have run RA to all bedrooms*
Energy medium **A**	Electricity as the only energy medium; no direct-use fossil fuel equipment *Case study home is all electric and powered by onsite solar PV*
Energy source **A**	Solar PV(grid-tied), sized to meet all household and EV transport needs *7.2 KW solar PV system adequate for household and transportation w/EVs*
Roofing **A**	Asphalt shingles best combination of finance (return) and ecology (energy) *Discovered full cost of roofing materials in time to inform this selection*
Siding **B**	Basic and least-costly option is adequate; select on durability and value *Selected fiber cement siding; durable & long lasting, but at a cost premium*
Finishes **C**	Basic and least-costly finishes are likely to have the least embodied energy *Most basic or next step above; upgraded faucets and kitchen countertop*
Appliances **D**	Basic and standard models, even if they use more energy (see Chap. 7) *Learned this lesson too late; all appliances upgraded, though not top of line*
Lighting **A**	LED throughout; do not compromise insulation cavity with can housings *LED throughout; thin-depth recessed can look-alikes used on ceilings*

Our team and planning excelled in regard to the energy systems on the case project, and we can feel satisfied in decisions made on roofing, ventilation, doors and windows, though the latter having more to do with favorable circumstantial foreign exchange rates. It pains us to accept and share the less favorable choices and outcomes, but we do that in the interest of learning and transparency; it also helps highlight where our findings flip the script on conventional wisdom. The most unfortunate outcome came in our plan and action on the thermal envelope,

[13] Triple-pane windows from Canada were comparable in price to US/local-sourced 2-pane windows due to favorable exchange rate prevailing at the time of order.

not for our lack of research or understanding, but in what we have discovered as new realities; this is explained more fully in Chapters 5 and 6.

As the homeowner, I started conversations with an architect, and together we identified a builder who we both knew and trusted, and who shared our concerns about environmental degradation and needing to find more sustainable solutions. The architect was credentialed with a graduate degree in building science, with a focus on sustainable solutions. The builder was known in the region for environmental sensitivities in design and practical application, and he stays current in the literature to remain abreast of new discoveries. I had also been reading extensively about research and recommendations, and each of us had arrived at positions consistent with the conventional wisdom of the building industry, and specifically from the green building movement.

From this building experience I can vouch for the importance of trusted relationships among these parties. The number of decisions on a building project is enormous, and almost all of them require discretion by one of the three parties, and some by two or all three. There seem to be infinite opportunities for the homeowner to question the veracity of the builder, and sometimes the architect, especially since they do not have the same financial incentives as the homeowner. To have lingering questions and concerns on top of fragile or broken trust could become excruciating for all parties during the project, and lead to animosity by the end, and beyond.

When the architect and homeowner arrived at a common understanding of project scope and professional services, we negotiated a lump sum architectural fee (as opposed to percentage of contract). The fixed fee arrangement removed a potential conflict of interest; the architect would not benefit from increasing costs, and that gave me (homeowner) peace about his intentions. The architect then produced a detailed scope of works document, which was priced by our prefered builder. On the basis of extensive knowledge of pricing on local materials, and the reputation of many regional builders and projects, the architect was able to evaluate the builder estimate. After a few adjustments negotiated on scope and pricing, we entered into contract with the builder. We did not engage a bid process with several contractors; this decision emerged from trust that the architect was advocating for the homeowner, with sufficient knowledge to qualify both the builder and estimate.

In retrospect, we should have negotiated the builder's fee (profit margin) the same way we had negotiated the architect fee. This could have been accomplished by calculating a percentage of contract, estimated at that stage, but then fixing it as a set dollar amount. That would have removed for the builder, the same conflict of interest noted above for the architect. During the project, the builder did a fine job keeping the homeowner updated and apprised of concerns, changes, and delays, but there is room for improvement as detailed earlier in this chapter.

Summary and Conclusions:

Sustainable living is certainly possible, as demonstrated daily by those around the world with the fewest assets. The question we posed is whether sustainability is possible in modern life, in homes typical of the U.S. and other high income countries. In terms household operational energy at net neutral (or better), this form of sustainable living is not only possible but proven, yet current prescriptions for achieving this objective require a very high entry price, and negative return on investment. The new discoveries from this fresh analysis, adding the tools of finance and ecology, show that this objective can be achieved at the lowest possible price and environmental impact, while adhering to building codes. This reorientation of understanding and practice changes the recommendation for an ideal sustainable home, which no longer advises an expensive, heavy, and complicated thermal envelope.

The ideal sustainable home starts with an optimal building lot that allows good orientation for solar (active and possibly passive), and good topography for low-cost development in dollars and ecology. An ideal design for a sustainable home is single-story on grade (slab) with long axis running east-west and windows predominantly on the south side. Other ideal design elements avoid or minimize hallways and stairs, since they are poorly utilized spaces that cost the homeowner in construction initially, and then conditioning and maintenance for life. The following chart offers an assessment of the 30-year cost of stairs, along with opportunity costs in solar PV or transition to EV.

Cost of Stairs (levels); principle can be applied to other egress elements		
Cost Element	**Straight Stairs, Standard Size**	**Stairs w/ Switchback Landing**
Square Footage impact	40	80
Constructed Cost initially	$4,000-$6,000	$8,000-$12,000
Conditioning for 30 years	$500	$1,000
Maintenance for 30 years	$500	$1,000
Total 30-yr. commitment	$5,200-$7,300	$10,000-$14,000
Opportunity costs	Solar PV (half) or EV (quarter)	Solar PV (most) or EV (half)

Metrics and Assumptions (no inclusion of environmental cost of energy production):

1. Square footage assumes standard stair width and length for standard floor depth
2. Constructed cost represents a range of $100-$150 per square foot, basic finishes
3. Conditioning calculated on average annual energy cost/household for ($934 in U.S.)
4. Maintenance is rough estimate for 30 years (e.g., hardware, refinishing, recarpeting)
5. Opportunity costs reflect alternative use of funds; significant toward solar PV or EV
6. No cost of funds or energy escalation built into these calculations (would be minor)

Ideal energy systems must begin with renewable energy, and in most areas of the U.S. that requires the homeowner to take initiative and action for onsite generation. Fortunately, onsite solar PV is not only a surprisingly good financial investment, but more importantly it can provide clean(er) and renewable energy to power an electricity-only house, and possibly transportation. The package of home and vehicle fueled by solar energy removes carbon emissions from 50% of the average American footprint, and it completely changes the recommendation for the thermal envelope, equipment, and appliances. Passive solar heating could also be exploited if the home orientation is ideal, but benefits from passive pale in comparison to active solar potential, and should not be wedged-in when it requires significant sacrifices.

Whereas the current thinking places preeminent value on energy-efficient equipment and appliances, our findings suggest that the ideal sustainable home installs the most basic and simple models; these are also the least expensive and likely to experience greater longevity. Centralized air-source heat pumps with ducted distribution of supply and return air provides heating, cooling, dehumidification, and effective ventilation when paired with an ERV or other passive system. This is also one of the least expensive packages, with lower environmental impact compared with most other alternatives.

The ideal sustainable home is about as inexpensive as can be constructed and equipped within compliance of building codes. All who strive to be homeowners by today’s standards can now aspire to own a sustainable home, because the combination of solar PV energy, code-minimum thermal envelope, and simple basic equipment and appliances is the least costly package. A shift to this building formula can be driven by the simple economics of low cost, a stronger case for appraisal and financing, and best return on investment. That should speed the transition with the bonus of removing more than half the carbon emissions from the American footprint.

Homeowners may need the assistance of professional services to build the most sustainable modern home. Even though this package is less complex than conventional thinking, it remains non-intuitive and grinds against entrenched ideas and practices. An architect who has studied this new reality can help a homeowner navigate the tricky process of home design, contracting and building, including concerns for site selection, house placement and orientation, design for solar, and counsel on HVAC, ventilation, appliances and finishes. A retained architect can also provide objective quality control throughout the project to ensure structural integrity and quality craftsmanship in construction and installation.

While employing an architect on a residential project is optional, finding one who understands the SOLO house principles and is skilled at finding efficiencies in design, will more than pay for their services in saved costs to the client. In addition to design work and quality control, an architect will also serve as an advocate and representative for the homeowner to other professional services. If an architect is retained, that arrangement should be organized first so that they can be involved in reviewing and selecting the builder, which may be bid or negotiated. The architect is in the best position to evaluate the goals and objectives of the homeowner and match that to one or several potential builders. If a best match is identified, negotiating a contract often works better than using the competitive bid process.

Homeowners will do well to acknowledge that an architect and builder do not carry the burden of final cost; they therefore have a different set of innate incentives. Even if these professionals have good intentions for cost containment, the homeowner needs to assert their unique concern, perspective and influence at every critical decision point. Homeowners should strive to negotiate set professional fees with the architect and builder that do not change with overall cost. Systems can also be employed to work at this incentive gap during the project with greater information, transparency, and objectivity; we have offered a few ideas in this chapter. Trusted relationships are critical among the primary stakeholders (builder, architect, and homeowner) of a building project, and it is worth taking the necessary time to build and gain trust before contracting for services.

This chapter began with an opening quote suggesting the need for new values that recognize that *bigger is not necessarily* better, and where *less can be more*. Those values aptly describe a new set of principles to drive affordability in modern housing that also makes dramatic strides in sustainability. In general, smaller houses are better for affordability and sustainability. Solar PV systems on residential roofs are certainly smaller than the massive power generation and distribution grids of public utilities. We have also learned that building code requirements on structure and insulation already provide value beyond the cost-benefit optimum; bigger is not better, and in fact it is worse in both financial and environmental impact. Finally, basic equipment in HVAC and appliances demonstrates where less can be more. Solar-powered, low-cost, and low-impact (SOLO) is the ideal sustainable modern home.

Dos and Don'ts:

Dos related to ideal sustainable homes and building practices

1. Consider retaining an architect, if they understand the SOLO principles
2. If retaining an architect, negotiate a fixed dollar fee structure
3. If constructing new, secure a building lot that is flat and offers southern orientation
4. Start with the ideal design for sustainability; single-story on slab, south orientation
5. Plan for solar PV sized to power all (net) household and transportation (EV) systems
6. Ensure system of quality control, either architect or other qualified and trusted third party
7. Plan for code-minimum thermal envelope (structure and insulation)
8. Plan for basic equipment, appliances, and finishes, or understand the cost of upgrades
9. Contract with a builder who is trusted and well-regarded with fixed dollar service fee
10. Invite systems of accountability and communication with the builder (see examples)

Don'ts related to ideal sustainable homes and building practices

1. Don't retain an architect if they do not understand or support the SOLO principles

2. Don’t assume that thermal envelope upgrades provide financial or ecological benefits
3. Don’t assume that HVAC equipment upgrades provide financial or ecological benefits
4. Don’t assume that appliance upgrades provide financial or ecological benefits
5. Don’t assume that solar PV is more expensive than utility grid over life of system

Chapter notes:

O’Malley, Charlotte (2013), *80% of Americans Prefer Single-Family Homeownership*, Builder Online, Available at URL: https://www.builderonline.com/money/economics/80-percent-of-americans-prefer-single-family-homeownership_o

U.S. Census Bureau (2018), *Historical Census of Housing Tables*, Available at URL: https://www.census.gov/hhes/www/housing/census/historic/units.html