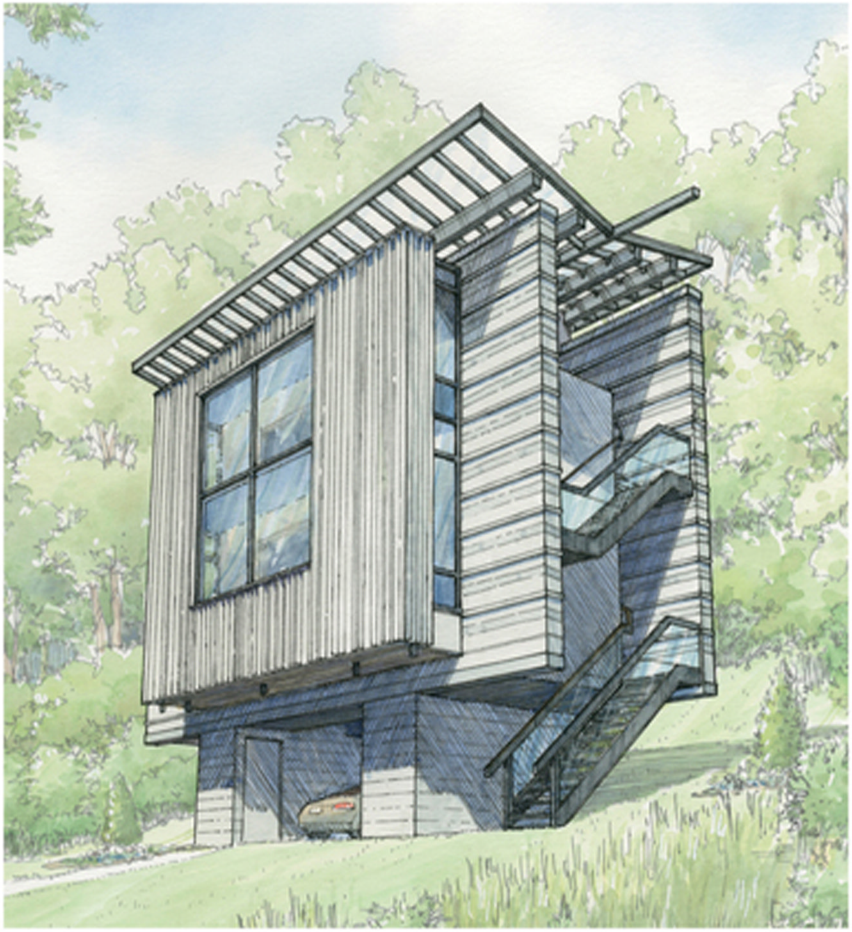
SUN, WIND & LIGHT

architectural design strategies

third edition



MARK DeKAY and G. Z. BROWN

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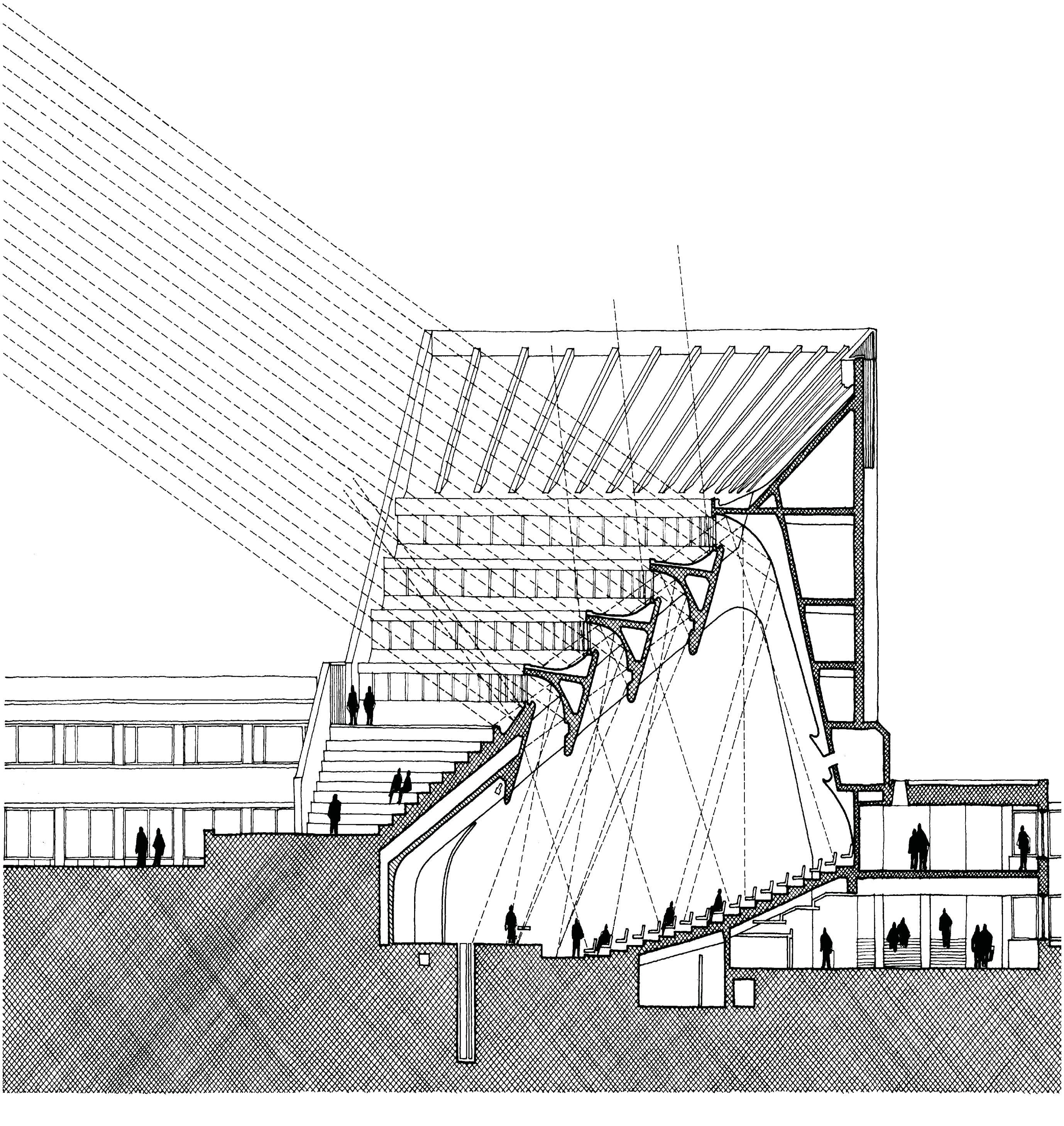

SUN, WIND & LIGHT

ARCHITECTURAL DESIGN STRATEGIES

third edition

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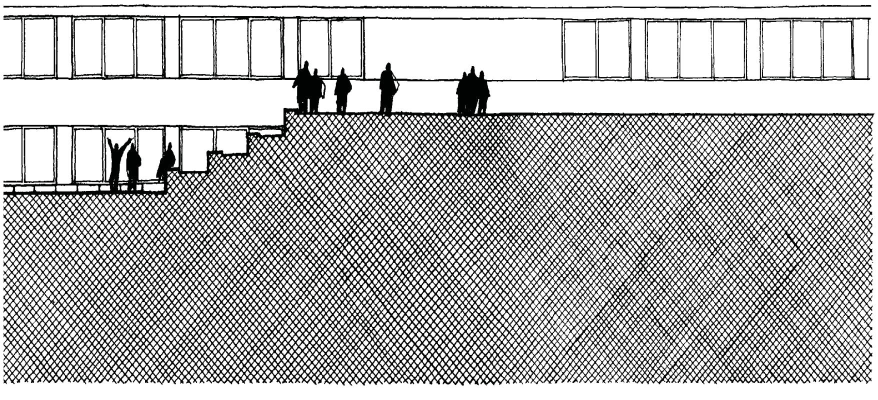

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FOR MY LOVING WIFE SUSANNE

mdk

Contents Overview

WHAT'S IN THE *SWL PRINTED*

WHAT'S IN THE *SWL ELECTRONIC*

SWL Printed Contents
abbreviated*

* All of the *SWL Printed* material is also included in electronic format in ⌿ *SWL Electronic*.

SWL Electronic Contents

abbreviated*

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* All of the *SWL Printed* material is also included in electronic format in ⌿ *SWL Electronic.*

** Strategies designated as "in *SWL4*" will appear in their fully developed form in the 4th edition.

Alphabetic Contents

of Strategies, Techniques, Bundles, Synergies and High-Performance Assessments

KEY

A = Analysis technique

B = Bundle

P = High-performance assessment

S = Synergy

No prefix = Design strategy

Preface

Purpose and evolution of *Sun, Wind & Light*

The purposes of this third edition of *Sun, Wind & Light (SWL)* are aligned with those outlined in the first edition preface: to help architectural designers who are not energy experts understand the energy consequences of their most basic design decisions. With this information they can then use energy issues to generate form rather than seeing them simply as limits that must be accommodated. Furthermore, this new edition is meant to provide designers with the preliminary design tools and strategies to meet and exceed the Architecture 2030 energy and carbon targets.

SWL has expanded in this edition from 109 to 150 Analysis Techniques and Design Strategies. It helps architects to design net-zero energy buildings by assisting them in creating sustainable designs based on site forces of sun, wind and light. *SWL* addresses issues of how to heat with the sun, cool with the wind and earth, light with the sky and make power with renewable energy. *SWL* serves both design professionals and students of design.

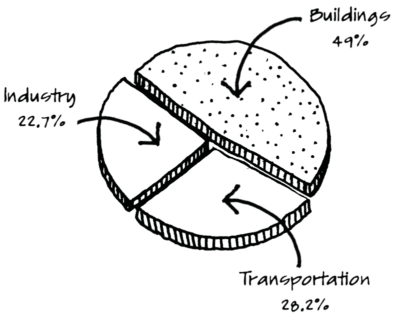
The new edition is not simply an update. Instead, it is a complete redesign and a mapping of the knowledge of preliminary phase net-zero energy design. Key to this new approach are three new methods:

1) The **Design Strategy Map method**, which allows us to map existing design strategies, identify missing strategies and reveal their hierarchical 'vertical' scalar structure.
2) The method of **Strategy Bundles** reveals the synergistic interrelationships among the strategies and issues.
3) A third approach, the **Design Decision Chart,** uses a design question-driven method for selecting design strategies and linking them together into **Bundles.**

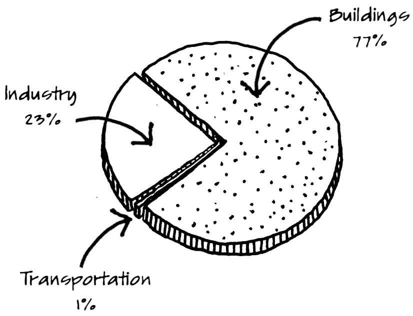
Finally, we combine all these methods and resources into a **searchable electronic resource**, ⌁ *SWL Electronic*, accessible in numerous ways not possible in print.

In addition to the new knowledge structure and new ways of navigating and representing the knowledge, we have also added 9 new bundle spreads, 7 synergies, 15 new design strategies, 4 new analysis techniques, 6 high-performance building assessment techniques, numerous concise design strategies and favorite design tools. Each has an average of 5 illustrations for approximately 225 new illustrations.

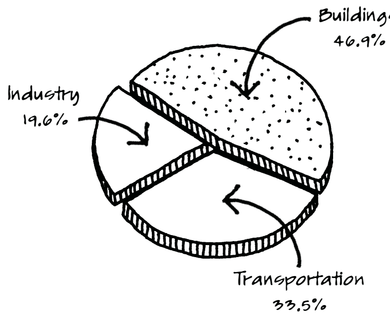
Sun, Wind & Light is one of the only sources to fundamentally integrate the formal language of architectural design with the discipline of building science. Climatic forces are important in architecture because a building's



U.S. Energy Consumption by Sector



U.S. Electricity Consumption by Sector



U.S. CO_2 Emissions by Sector

response to climate is directly related to its energy consumption, and because climate is a powerful local context giving designers a means of regional expression and place making. We are delighted that *SWL* has become a standard in courses on sustainable or low-energy design across the world. Uniquely among its peers, it bridges the worlds of engineering and architecture by connecting form and energy flows.

Organizational changes in the third edition

Veteran *SWL* users will notice that the work has been radically reorganized. The entire contents of the second edition is now located on the companion ⌁ *SWL Electronic*. The printed book, which we will refer to in the text as *SWL Printed*, is almost entirely new material, with the addition of selections and condensations of some of our favorite design strategies and design tools. The Analysis Techniques, which came first in *SWL2,* have been moved to the back of the sequence, partly to emphasize the importance of design thinking and strategies. The work now moves in *SWL Printed* from more general systems of navigation to the energy design process to associations of strategies in the bundles and finishes with new techniques for net-zero and carbon-neutral buildings. In ⌁ *SWL Electronic* the sequence moves from large- to small-scale design strategies, and finally to the detailed, more quantitative analysis techniques. Gone is the separate section for "Strategies for Supplementing Passive Systems." In general the distinction between passive and active systems is more useful conceptually than in practice, where most buildings are a combination of the two. Therefore the "supplemental" strategies have been folded into their appropriate sequence within the 'design strategies' section. Most of these more mechanically-oriented strategies fall into the scale of building parts.

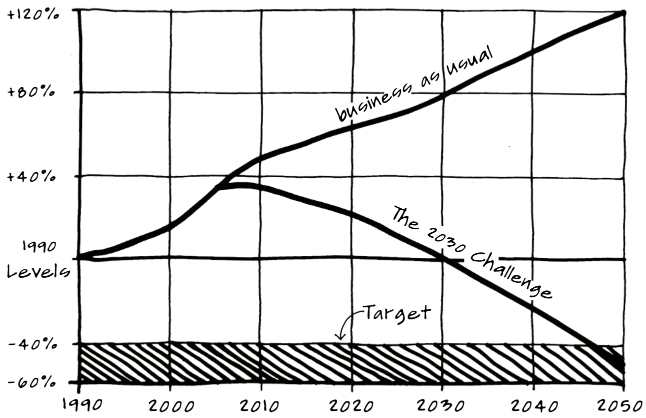
A new intention: reversing building emissions

In addition to the general purpose outlined above, this third edition's intent is focused on the potential impact of this work for one of the most significant issues of our time. As we have gained experience as authors, teachers and design consultants, we have become even more committed to sustainable design, more aware of the urgency of its discipline and more radical in our ambitions for architecture.

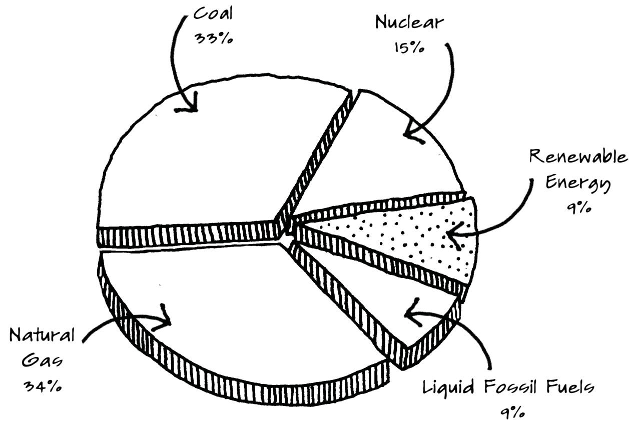
This new edition sets out two additional purposes:

1) **To map the knowledge base** of preliminary climatic design via new theoretical frameworks
2) **To provide accessible methods for net-zero energy design** with the intent of contributing to the massive effort by the building community to reduce greenhouse gas emissions from the building sector to pre-1990 levels by 2030.

The Architecture 2030 organization has made it unmistakably clear that the building community has a historic opportunity to turn around the North American



U.S. Building Sector CO_2 Emissions



Building Energy Consumption by Fuel Type, 2010

contribution to global climate change by meeting targets for fossil fuel reduction (and thus greenhouse gas reductions) leading to all new buildings being designed to *carbon-neutral performance standards by the year 2030*. Beyond this is the more ambitious goal of a site net-zero energy building, one which *produces as much renewable energy on site as it consumes*. Therefore, this edition sets as its task to help designers effectively begin the net-zero energy design process by selecting strategies that use site energy resources to reduce energy loads and produce green power, the two sides of the net-zero equation.

Building on *SWL*'s precedent of quick tools for schematic and preliminary design, *strategic tools* have been created that help the designer identify networks of related design strategies in support of net-zero design, along with *quick calculation methods* that can be done in a matter of minutes without expensive expert energy consultants. As in the previous editions, whenever possible these quantitative techniques have been presented in graphic ways that visually reveal (the audience is architects after all) the relationships among the most important variables and those variables that most influence architectural form.

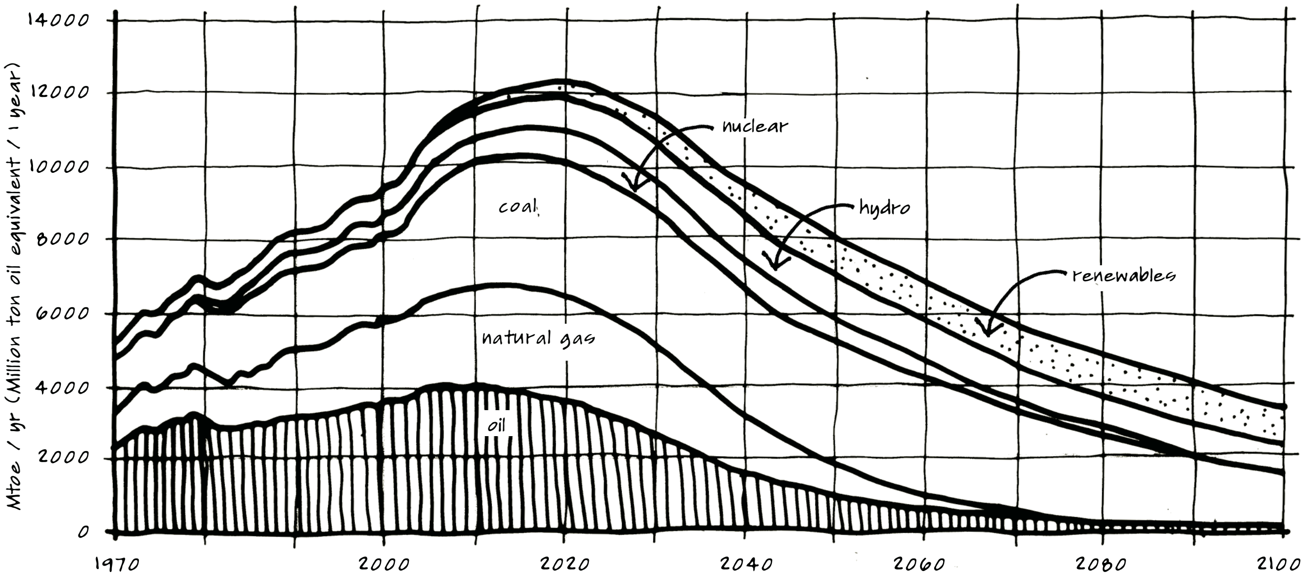
In the second edition introduction, it was noted that while fossil fuel resources are finite, the capability of natural systems to absorb society's wastes may be an even more stringent limit:

> *While saving energy has a high social benefit because it slows the depletion of finite reserves of fossil fuels, it is equally important in reducing the pollution caused by the extraction and burning of these fuels, and therefore in reducing acid rain, the potential for global climate change, and the localized ecological impact of practices such as strip coal mining. (SWL2)*

The three graphs from Architecture 2030 (previous page) show the significant contribution that buildings make to energy use and carbon emissions. Buildings are responsible for 49% of **U.S. Energy Consumption by Sector**, a dramatic 77% of **U.S. Electricity Consumption by Sector** and 47% of **U.S. Carbon Dioxide Emissions by Sector**. Globally, these percentages for buildings are even greater. According to Architecture 2030:

> *By the year 2035, approximately three-quarters (75%) of the built environment will be either new or renovated. This transformation over the next 30 years represents an historic opportunity for the architecture and building community to make the changes necessary to avoid dangerous climate change.* (Architecture 2030, 2011)

The graph of **U.S. Building Sector CO_2 Emissions** (previous page) shows projections for two paths. In the "business as usual" scenario, buildings continue current energy use and fossil fuel trends and become an increasing part of the global climate change problem. In the second, "The 2030 Challenge" scenario, radically reduced



World Energy Production, 1970-2100

fossil fuel targets are aggressively implemented, buildings reverse their CO_2 emissions to pre-1990 levels by 2030 and continue to reduce overall CO_2 emissions into the second half of the 21st century, even when accounting for projected growth in the building stock. This trend would have the effect of eliminating the need for all coal-fired power plants in the U.S., a dramatic impact on the country's responsibility for climate change!

Buildings built today outlive their energy sources

The graph of **Building Sector Energy Consumption by Fuel Type** shows the mix of fuels used in 2010 by buildings in the U.S. (Architecture 2030, 2011). Fossil fuels combine to provide 76% of building energy. Not only is the burning of these fuels responsible for producing greenhouse gases, but each of the three fossil fuels is predicted to reach its peak production and begin to decline by 2030 or before, both raising architecture's contribution to climate change and requiring a dramatic society-wide shift to alternative sources of energy.

Peak oil is the date when maximum global petroleum extraction was reached, after which production declines. U.S. oil production peaked in 1970. Since the 1970's, total new oil and gas discoveries have declined every year and domestic production has declined every year. Globally, the world's crude oil production peaked in 2004 (Inman, 2010; IEA, 2010).

US *peak natural gas* production was in 1973; new discoveries have raised production in recent years, but prices have risen as a result of increased demand for natural gas for electricity production. Most new power plants burn natural gas and relatively few new coal plants have been built in recent years. One-third of global energy comes from natural gas and demand is rising steadily. Estimates on global peak natural gas vary from the present to 2030.

In contrast to earlier predications of centuries-long supplies of coal, predictions are now much less optimistic for the date of *peak coal*. In 2007, the German think tank Energy Watch Group analyzed each country's coal reserves and production, concluding “global coal production [will] peak around 2025 at 30% above present production in the best case”(Energy Watch Group, 2001).

Paul Chefurka (2007) has done an excellent job of assembling projections of various fuel sources, as shown in the graph of **World Energy Production,** which predicts *world peak energy* (for all fuels) occurs somewhere around

2020 and declines in all fossil fuels over the rest of the century.

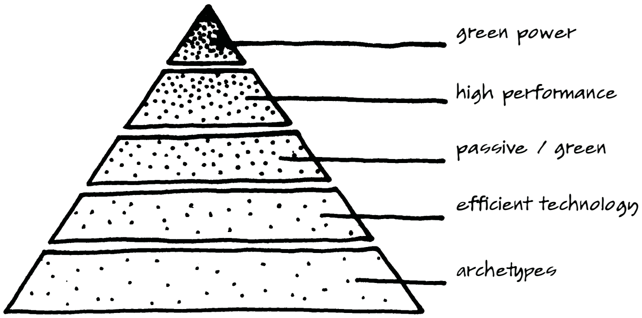
If we continue on the business-as-usual path for energy use in buildings, then the most likely scenario is for oil use in buildings (only 9% currently) to decline, while first natural gas and then coal-fired energy use in buildings will increase, exacerbating current greenhouse gas and climate change trends.

However, *there is a clear alternative to ongoing increases in demand and fossil fuel use for the building industry: the path of design*.

The design path can radically reduce energy consumption by buildings and end our dependency on fossil fuels for buildings. Using current knowledge and available technologies, ASHRAE has produced a series of *High-performance Building Design Guides* with targets of 30% and now 50% reduction from their own energy performance standards. These are prescriptive guides for different building types, with requirements varying by climate, which do not even employ passive design strategies. Such prescriptive requirements depend on specifications for efficiency of the building envelope and mechanical systems. Such efficiency measures are *out of order* in two ways:

- They miss the critical early steps toward net-zero energy buildings that architectural design provides. They focus only on what engineers do and miss what architects do.
- They are necessary but not sufficient to reach a *responsible* net-zero energy building that does not depend on high levels of renewable energy.

Sun, Wind & Light takes the approach that green power systems, such as photovoltaics and wind generation, are the most expensive and appropriately the last stage in a sequence of the **Hierarchy of Strategies for Net-Zero Building Design**, as shown in the diagram. The design strategies in *SWL3* run across these stages, but are centered in the lower three levels *where the design of buildings drives performance.* The diagram shows five levels of consideration. Each can be thought of as engaging Climate, Use, Design and Systems—fundamental perspectives that we will introduce later in Part II's section on "Buildings and Energy Use."



Hierarchy of Strategies for Net-Zero Building Design

Although these levels can be thought of in a sequence, and some design processes may proceed from larger questions to more detailed decisions, or from more formal to more technological questions, the sequence of consideration may be varied and the pyramid is not intended to imply a strict sequence. Instead, the way to think of these levels of concern is that each higher level depends on the lower level. For example, while it is conceptually possible to have a huge PV system (producing a high level of green power) to supply a poorly designed building with large energy loads, it is neither prudent nor rationally elegant. In the early days of the passive movement in architecture, proponents debated "mass and glass" vs. "light and tight" or "passive" vs. "active" approaches. The hierarchy of strategies transcends these polarities with a way of thinking and designing that integrates them while also providing a linkage between architecture and engineering logics.

The hierarchy suggests solving the energy design problem with the lowest level of technology possible and the least cost strategies, while also substituting embodied intelligence in architectural form for hardware.

The net-zero energy equation in a building can be solved in many different ways, however there are elegant and inelegant ways to reach net zero. There are ways that give all of the power and profits to utilities, green power equipment corporations, HVAC manufacturers and engineers, and there are ways that employ the power of architectural design to reduce the need and magnitude of these other players. Ethical distinctions of significant degree characterize these various approaches.

The hierarchy says that it is better to use site design to reduce the environmental stresses on buildings and to provide access to desired climatic resources to solve a portion of the energy problem *before* using building design to overcome what the building does not need to do. There is no point in designing a solar-heated or naturally ventilated building unless it is a low-load building to begin with. The hierarchy calls us to design effective passive systems for heating, cooling and lighting to radically reduce loads *before* designing and specifying a highly efficient HVAC system. Essentially, an efficient heating system with 25% of the load is better than an efficient system that has to be four times as big or run four times as many hours per year. When the first three levels are done well, the conventional heating or cooling system can sometimes be completely eliminated (such as in the PassiveHaus), what the Rocky Mountain Institute refers to as “tunnelling through the cost barrier.” The hierarchy says that *after* loads are thoroughly minimized by considering Design, Climate and Use at levels 1–3, then high-performance Systems become appropriate and a careful consideration of their integration with the passive systems can minimize the net loads of the building. Only then does making one's own electricity on-site make sense.

This bucks some current trends toward large surface areas of glass, double envelope buildings that attempt to reclaim the morality of the Miesian aesthetic, and wildly expensive demonstration projects covered in photovoltaics, looking forward to a time of cheap power-producing building surfacing. Such projects are bought at a high financial price, a high cost in embodied energy and carbon and in overall environmental impact. PVs, while yielding no emissions in producing their energy, do not come without an environmental cost. Indeed, even high-tech glass window walls with their metal frames have similar issues.

Perhaps the best argument for reclaiming the path of architectural design as the essential core of the energy design process is that it results in simpler buildings affordable to more of the world's burgeoning population. High-performance, high-technology buildings that ignore the fundamental levels of the net-zero energy design hierarchy are expensive, even when the technology used is “green.”

Over the decades, as buildings have become more complex, architects have ceded much of their responsibility over energy use in buildings to energy consultants or engineers. For a series of reasons, design and performance, what Lance Lavine calls, “mechanics and meaning in architecture,” in his book of the same name, have been isolated into separate professions, logics and methods. While architects definitely have a role in the upper two levels, and these levels have significant design implications for buildings, it is in the lower three levels where architects find their voice as those who configure space and form.

When architects claim the power of the design path in shaping the form of sustainable high-performance buildings, then rich human experiences of nature and its forces of sun, wind, light, earth, water and living things will be present. Further, when the entire spectrum of the hierarchy is passionately engaged by designers, these rich experiences have the potential to develop into meaningful cultural communications, into a symbolic language that places us into relationship with nature. Frank Lloyd Wright often spoke of the integral nature of design, the interconnection of forms, ideas and expression from the site to the details, as for example, embodied in Unity Temple. By engaging all five levels of this hierarchy, designers can aspire to a similar kind of continuity of expression about the relationship between humans and their designed artifacts, along with their context in Nature. The widespread cultural adoption of net-zero design may ultimately depend on such an aesthetic and cultural expression that only competent and conscious designers can manifest.

Level of Archetypes

The *level of archetypes* is the level of basic architectural design where issues of siting, orientation, location, shape, proportion and surface to volume ratio are considered, along with the neighborhood or urban fabric context of building groups that set the pattern for access to sun, wind and light. This third edition introduces a new set of neighborhood-scale design strategy bundles (configurations of strategies) that includes COOLING NEIGHBORHOOD, SOLAR NEIGHBORHOOD, NEIGHBORHOOD OF LIGHT and INTEGRATED URBAN PATTERN. These are considerations nowhere to be found in any high-performance building standards. In *SWL3,* many of the design strategies address these archetypes, such as SHARED SHADE, SOLAR ENVELOPES, BREEZY OR CALM STREETS, MIGRATION, EAST–WEST PLAN, DEEP SUN and ROOMS FACING THE SUN AND WIND. Additionally, at this fundamental level designers consider a range of zoning and room organization strategies that set the possibilities for what comes next. These include strategies such as DAYLIGHT ZONES, COOLING ZONES, HEATING ZONES, BORROWED DAYLIGHT, BUFFER ZONES, and so on.

This first level insures access to sun, wind and light, the formation of favorable outdoor microclimates, a good bioclimatic site location, and a preliminary building organizations that will work well for energy when more detailed and complex strategies are employed.

Level of Efficient Technology

The *level of efficient technology* is a prerequisite to the design of passive systems. For example, the European *PassiveHaus* standard is essentially a heating season envelope performance standard driven by efficient envelope technology. To use the relatively low grade (temperature difference) energy of the sun as a winter heat source, the building must have a low rate of heat loss so that a small supply of heat can meet the load. Similarly, in summer, a building with a high rate of heat gain from its internal loads and through the building skin will be difficult if not impossible to cool with natural forces. Consider the analogy of a bathtub in which the water level can be kept high with the drain open or closed. The open drain is like a building with high heat loads; it requires a large supply, with the tap wide open. When the drain is closed, the tap can be closed with only an occasional need to add small amounts of hot water to offset the trickle that escapes the imperfect drain seal. This is like a solar building with a tight envelope and a low heat loss rate; it can be heated with a relative trickle of energy from the sun.

SWL3 addresses this need for efficient buildings with strategies and analysis techniques such as EQUIPMENT HEAT GAIN, ELECTRIC LIGHTING HEAT GAIN, VENTILATION OR INFILTRATION GAIN AND LOSS, SKIN THICKNESS, WINDOW AND GLASS TYPES, EXTERIOR SURFACE COLOR and EXTERIOR SHADES. Also introduced in this edition is the strategy bundle RESPONSIVE ENVELOPE, which helps to sort out the complexities present when designing high-performance envelopes. Prescriptive envelope standards are often good at improving performance using this level. Although many of the decisions about envelope performance are detailed, and thus tend to come later in the design process, *SWL3* helps the designer make general typological choices up front about the performance needed even if the specific choice about the actual elements specified comes later.

Level of Passive Design

Much of *Sun, Wind & Light* helps designers with the *level of passive design*, in which the building is configured to consciously heat itself with the sun, light itself with the sky and cool itself with the wind and other natural forces. Given neighborhood, site and building massing solutions addressed at level one of *archetypes* and given an efficient envelope that reduces heat gain and loss insured by level two *efficient technology,* passive design becomes possible.

This is the level in which the designer can engage the various passive solar heating systems, such as DIRECT GAIN ROOMS, SUNSPACES, THERMAL STORAGE WALLS and so on, along with the details of these systems, such as THERMAL MASS, SOLAR APERTURES and MASS SURFACE ABSORPTANCE. This edition also introduces whole-building scale bundles including PASSIVE SOLAR BUILDING, PASSIVELY COOLED BUILDING, DAYLIGHT BUILDING and OUTDOOR MICROCLIMATE.

With respect to daylighting, the passive design level engages a series of strategies that bring light supplied by the design decisions made at previous levels to the scale of rooms and building parts, such as DAYLIGHT ROOM GEOMETRY, SIDELIGHT ROOM DEPTH, DAYLIGHT APERTURES and DAYLIGHT REFLECTING SURFACES. Similarly, passive cooling systems can be selected and designed at this level. Examples include CROSS-VENTILATION ROOMS, STACK-VENTILATION ROOMS, NIGHT-COOLED MASS, EVAPORATIVE COOLING TOWERS, VENTILATION APERTURES and DOUBLE SKIN MATERIALS.

SWL3 deals less with the two upper levels in the hierarchy, both because it focuses on preliminary design and because it focuses more on architectural issues than on engineering issues. *SWL* does, however, address these levels as they intersect preliminary design and assumptions needed for preliminary phase estimation of net-zero performance.

Level of High-Performance

The *level of high-performance* engages both sophisticated and efficient HVAC systems and their integration with architectural design and with passive systems. Strategies include ELECTRIC LIGHTING ZONES, MIXED MODE BUILDINGS, HEAT PUMPS, MANUAL OR AUTOMATED CONTROLS, MECHANICAL SPACE VENTILATION and so on.

Level of Green Power

In the current edition, we address the *level of green power* in strategies for PHOTOVOLTAIC WALLS AND ROOFS and for SOLAR HOT WATER, along with their associated analysis techniques. Both of these upper levels and the whole hierarchy of strategies for net-zero buildings are supported by a set of high-performance buildings assessment techniques designed to help users design and evaluate net-zero and carbon-neutral buildings. These include ENERGY TARGETS, ANNUAL ENERGY USE, NET-ZERO ENERGY BALANCE, ENERGY USE INTENSITY, EMISSIONS TARGETS and CARBON-NEUTRAL BUILDINGS.

New content in the third edition

In terms used by Paul Erlich, environmental impact in the form of greenhouse gas emissions is driven by energy use, and energy use is driven by energy demand. Energy demand can be thought of as being driven by three factors:

- *Population* (which continues on its exponential increase, passing 7 billion this year)
- *Affluence,* which is the volume of goods and services that a person or society expects (such as how many miles we drive or how many square feet we live in)
- *Technology,* which is the efficiency with which a given good or service is delivered (such as how much energy it takes us to stay warm or how much material it takes to span a roof)

Of these three drivers, design affects population little, if at all. However, design does impact both affluence and technology. Design is responsive to the demands and expectations of culture, but it is also in a dialogue with culture. Design can follow demand or create demand. It can be seen as a mere service, shifting responsibility to the client for its magnitude, such as the size of a building, or the comfort criteria expected. Consider a given need like a library that might be housed with a large building, or, with more effective design thought, could be accommodated in a much smaller building; a designer may take a proactive role with clients defining comfort criteria, occupancy schedules and so on, in the context of energy and environmental consequences. Particularly in its programming and pre-design stages, design reaches deep into the assumptions that drive culture and the variable of affluence.

A colleague who is a sustainability architect-analyst once told of a client who came to him and wanted to make sure that the 18,000 ft^2 (1672 m^2) house he had planned would use 50% less energy than conventional design. The architect said, “That's easy, why don't you simply build a 9,000 ft^2 house?” Nowhere in LEED or any other high-performance green guidelines or criteria will you find criteria for building size. According to the codes and standards, if you want to build 9,000 ft^2 (836 m^2) per person in your new house, that is fine, so long as you meet the energy criteria on a per unit area basis. When design meets environmental ethics such cultural insanity can be overcome.

New analysis techniques have been added to address some of these embedded assumptions in the process of building design. New techniques such as ADAPTIVE COMFORT CRITERIA, ENERGY PROGRAMMING and LOAD-RESPONSIVE SCHEDULING, along with new Synergies, including ENERGY CONSCIOUS OCCUPANTS. Some of the simplest and most cost effective strategies involve lowering the thermostat, turning on a ceiling fan to allow a higher summer temperature, scheduling to avoid peak cooling hours or changing the corporate dress code to respond to the seasons. These may seem like nonnegotiable cultural practices, but they have real financial and environmental impacts, and as it turns out, they are practices we have collectively created only relatively recently.

Much of this book is bout the relationship between energy use and architectural form at a range of scales. This edition fills in some of the holes in *SWL* as a knowledge base, thanks to students and clients.

New building groups scale content can be found in strategies to support a NEIGHBORHOOD OF LIGHT in the form of DAYLIGHT DENSITY and DAYLIGHT BLOCKS. The CLIMATIC ENVELOPES strategy helps designers create building massing that admits both winter sun and daylight all year, and in some cases creates summer shade with the help of the SHADOW UMBRELLA strategy.

The older *SWL2* strategy BALANCED URBAN PATTERNS, which addressed combinations of strategies for heating and cooling issues in different climates, has been incorporated into a new strategy bundle, INTEGRATED URBAN PATTERNS.

Two **zoning strategies** have been added: PERIODIC TRANSFORMATIONS, in which space is “switched” depending on seasonal or daily conditions (such as when a “thermal enclave” is created); and MIXED MODE COOLING, a strategy that recognizes the hybrid nature of many buildings as using both passive and mechanical strategies. The older strategy HEAT-PRODUCING ZONES has become HEATING ZONES to cover a wider range of rooms and activities that impacts heating. This is paired with the related COOLING ZONES, for designing to meet the overheated season.

SWL3 adds several **new daylighting design strategies** and makes several modifications to previous ones. The older ATRIUM has become ATRIUM BUILDING to address the planning and design options for a building's organization, while the sizing tools for the atrium itself have been spun off into a new TOPLIGHT ROOM strategy. SKYLIGHT BUILDING helps the designer with single-story rooms lighted with skylights, an issue not addressed in *SWL2*. DAYLIGHT ROOM GEOMETRY treats the room design as a lighting fixture.

Strategies at the scale of building parts for OPEN ROOF STRUCTURE and DAYLIGHT ROOF address how to bring more light through the roof assembly and roof structure, along with how to configure clerestories and monitors in roof systems. Guidance for the effect of arranging daylight apertures on daylight distribution is developed in the WINDOW PLACEMENT strategy.

Revisions to the ventilation strategies have updated the *SWL2* strategies of CROSS-VENTILATION and STACK-VENTILATION to become CROSS-VENTILATION ROOMS and STACK-VENTILATION ROOMS, which aligns them better with other room-scale design strategies that focus on room characteristics for a given issue. The aperture sizing tools previously found in these strategies are now located in a single VENTILATION APERTURES strategy that parallels the related SOLAR APERTURES and DAYLIGHT APERTURES.

Strategies for thermal or fresh air and distribution fill gaps from the second edition. Two strategies have been added to address the need to store heat or to use radiation as a means of delivering heat or cool. MOVING HEAT TO COLD ROOMS is useful when the designer needs to move heat from where it is collected (usually rooms with an equatorial orientation) to rooms that cannot collect their own heat. When rooms are adjacent, the CONVECTIVE LOOPS strategy helps insure the passive air distribution will work properly. In many buildings, MECHANICAL HEAT DISTRIBUTION is helpful in distributing passively generated heating or cooling, and can be used with both passive and active sources. Preliminary design guidance for the critical issue of controls is given in MANUAL OR AUTOMATED CONTROLS.

An expanded treatment of thermal storage and radiant distribution can be found in the significant expansion of the THERMAL MASS strategy to include sizing for not only direct masonry and water thermal mass in the room, but also remote and indirect masonry thermal mass coupled by convection, along with new sizing for phase change materials. A relatively detailed strategy on MASS ARRANGEMENT has been added to address where to put mass to be most effective for heating or cooling.

A series of new analysis techniques fill in a few holes and add an entire section called High-Performance Assessments. To design for daylighting, one can now begin with DAYLIGHT DESIGN FACTOR to set design targets.