THE ESSENTIAL ROLE OF INTEGRATED DAYLIGHTING AND SOLAR DESIGN IN THE QUEST FOR ZERO-ENERGY CARBON-NEUTRAL HOUSING

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ABSTRACT
Case studies of two recent zero-energy, carbon-neutral prototype houses – the Lighthouse in Watford, England, and the SOLTAG Energy Housing in Hørsholm, Denmark – reveal that the integration of daylighting and solar strategies is central to meeting performance standards for net zero-energy and carbon-neutrality as well as high quality design. The paper considers how daylighting is integrated with solar strategies, mechanical and renewable energy systems, and high-performance envelope design in each house.

1. INTRODUCTION

According to the Energy Information Administration (EIA), the average single-family detached house in the southern U.S. consumes 67.2 kBtu/Sq.Ft./Yr. In the western U.S., the rate is 86 kBtu/Sq.Ft./Yr.¹ Perhaps surprisingly, multi-family housing (with 2-4 units) consumes even more, with averages ranging from 78.8 kBtu/Sq.Ft./Yr. in the northeast to 113.6 kBtu/Sq.Ft./Yr. in the south. The EIA estimates that residential homes account for 37% of all U.S. electricity consumption and 22% of all U.S. primary energy consumption (EIA 2005).²

The successful combination of daylighting with passive and active solar strategies goes beyond merely providing the proper quality and quantity of illumination by striving to achieve a pragmatic and poetic integration of architectural design and the technological strategies for heating, cooling, ventilation, and energy production. In looking at the role of daylighting in zero-energy housing, it is essential to reconsider how light, thermal, and renewable systems intersect to support zero-energy and carbon-neutral performance as well as qualitative design goals. High quality design is critical in dispelling lingering negative stereotypes of solar housing from the 1960s and 1970s, which often persist with design professionals and interfere with promoting the next generation of solar housing.

To achieve a greater level of design integration and design excellence, daylighting and solar design need to be considered concurrently with other zero-energy carbon-neutral strategies and performance metrics. While this may not seem like a new solar design issue, it is rare that this level of integration is considered in residential design, and even more rare that zero-energy and carbon-neutrality are achieved. Although the Department of Energy (DOE) as well as the National Institute of Home Builders (NIHB) have several excellent zero-energy home initiatives; architects, contractors, and builders in the U.S. are still in need of additional prototypes that have successfully integrated daylighting and passive and active solar strategies which can be easily replicated.

In addition to the excellent work done by the DOE and NIHB, we can also learn from innovative prototype housing in other countries such as the U.K. and Denmark, which have initiated zero-energy and carbon-neutral building standards and research initiatives. Case studies of two recent zero-energy carbon-neutral prototype houses – the Lighthouse in Watford, England, and the SOLTAG Energy Housing in Hørsholm, Denmark – reveal that the integration of daylighting and solar strategies is indeed central to achieving net zero-energy and carbon-neutrality. In exploring the key daylighting strategies of each project, we find diverse means of effectively integrating daylighting with solar strategies, mechanical and renewable energy systems, and high-performance envelope design. The case studies also illustrate the critical role of daylighting in combining zero-energy carbon-neutral goals with issues of health, aesthetics, and design excellence. In addition, both prototype houses are designed to be easily replicated in localities with similar climatic and site conditions.

2. THE LIGHTHOUSE

2.1 Background

Located in the Building Research Establishment’s (BRE’s) Innovation Park in Watford, England, the “Lighthouse” is the first net zero-carbon house in the U.K. This residential
prototype meets the highest net zero-energy carbon-neutral standards in the U.K., Level 6 of the “Code for Sustainable Homes.” Developed as a design-research collaboration between industry and design professions, the project team includes Kingspan Off-Site (manufacturers of varied building and structural systems), Sheppard Robson Architects, and engineers Ove Arup, among others. As the name “Lighthouse” implies, the design focused on the role of daylighting to achieve the highest levels of energy performance and design quality. Architect Alan Shingler of Sheppard Robson explained that quantitative and qualitative issues were addressed from the onset of the design process: “Homes are for people to live in. We did not allow the ‘Code for Sustainable Homes’ to compromise lifestyle and architecture.” The experiential and aesthetic opportunities of daylight and its relationship to thermal comfort, energy performance, and carbon emissions were skillfully resolved in the Lighthouse.

Figure 1: West façade      Figure 2: interior looking west

Figure 3: Kitchen and dining looking south (east to the left)

Sited in a temperate maritime climate at 51º NL, the house has to respond to seasonal heating and cooling loads. With an average high temperature of 73 °F in July and an average low temperate of 41 °F in January, the mild climate easily accommodates natural ventilation strategies for summer cooling; however, the predominantly overcast winter skies makes the climate poorly suited for traditional passive solar design. At first glance one might assume that the Lighthouse is a passive solar home since the linear form is oriented along the east-west axis. On closer inspection, however, one finds that the design team chose instead to achieve the zero-energy and carbon-neutral goals by combining daylighting and natural ventilation with state-of-the-art envelope design, mechanical, and renewable energy systems. Alan Shingler explained that the Level 6 criteria require onsite electric energy generation, which restricts building form and orientation: “Because the electricity is generated on site for all the appliances, lighting, fans, and cooking, the roof has to orient south to accommodate the photovoltaic array and the solar water collectors.” He continued: “If we did not need such a high level of criteria for zero carbon we might have done things differently. We may not have all roofs facing south.” The multi-story house is designed for a site with adjacent neighbors and effective performance is contingent on direct access to solar radiation for the south roof façade, which is used to heat water and generate electricity (rather than to gather passive solar heating). Replication of this prototype house is constrained to sites with south solar roof access and similarly temperate climatic conditions.

2.2 Integrated Daylighting and Solar Design

A particular challenge for the Lighthouse was to meet the strict net zero-carbon code standards for “heating, lighting, hot water and all other energy uses in the home,” while also creating a meaningful home environment and experience. When coupled with the overcast climate of England, the Level 6 standards for net zero-carbon create challenging design constraints, especially for passive solar integration. As a result, daylighting was combined with natural ventilation and a high-performance envelope to minimize seasonal energy loads. The envelope design was driven by the codes, which focus on the building insulation and minimization of windows. As a result, each window was carefully considered to resolve multiple issues simultaneously, such as optimizing daylight, view, solar
control, and natural ventilation during the changing seasons. Shingler underscores that at Level 6, a mandatory heat loss parameter requires a high U-value for windows and walls. In the Lighthouse this was achieved by triple-glazed gas-filled windows and a glazing area of 18% instead of the typical glazing area of 25-30%.4

Contrasting the more traditional approach to passive solar design in the U.K., which often includes the use of buffer spaces (like a “wooly jumper” according to Shingler), the Lighthouse combines daylighting with passive and active solar strategies and systems that operate differently on a seasonal basis. The hybrid thermal design shifts from a predominantly passive mode for cooling and ventilation in the summer and transitional months to an active mechanical mode for heating and ventilation in the winter. Alan Shingler explains that there is not just a single set of zero-energy carbon-neutral rules to consider, but also the client’s brief and the particular location. Shingler cautions that the Lighthouse should not be viewed as a universal design solution that will work in any locale. He argues that the particulars of place matter and that the design has to be assessed for different microclimates and sites.

The Level 6 criteria led to several design decisions that affected the form and massing of the Lighthouse. Given the reduced glazing area and the concern for high quality living spaces with abundant daylight, the team chose to locate the sleeping spaces on the lower level and the living spaces on the upper level where there is greater access to daylight, air, and views. The first floor includes the entry, stairway, utility room, bathroom, and two bedrooms. Daylight is borrowed through the stairwell to mark the vertical passage to the living area above. Open risers and a glass balustrade provide visual and luminous connections between the two floors. High clerestory windows in the lower level bedrooms ensure privacy and security, while enabling soft indirect daylight to wash across the white ceilings and provide illumination throughout the rooms. The upper level living space contains the main living area, centrally located kitchen, and the dining area. A third level mezzanine overlooks the living space. Windows and skylights are located throughout the upper levels to optimize a sense of spaciousness, brightness, and connection to the site. View windows are provided in the dining room, clerestories in the kitchen, and large sliding glass doors in the living room. A stacked row of vertical windows on the west façade washes daylight along the north wall. Two north sidelight windows located on the north wall at the bottom and top of the stair link the living area and the mezzanine. A daylight factor of 1.5-2.0% is provided throughout the house to ensure a high quality luminous environment.

An ingenious “wind catcher/light funnel” is located at the heart of the house to integrate toplighting, passive cooling, and natural ventilation. The ventilation device creates a stack effect by admitting cooler outside air to displace warmer inside air. Operable windows can be coupled with the “wind catcher” to provide additional cross ventilation, connection to the site, and to flush air through the house during overheated periods. Small exterior balconies on the west and east façades extend the living area and the mezzanine workspace to the outside. Even the glass rails around the balconies were designed to admit daylight into the house. Solar control is provided on the west façade by extending the roof plane into slatted eaves to create a shaded south enclosure around the balcony and glazing. Sliding slatted-wooden shutters can be adjusted to shade the western vertical windows while admitting indirect illumination. A sense of enclosure and privacy is created on the ground floor through high clerestory windows. The upper portion of the house has a sense of openness due to the carefully located glazing and abundant direct and reflected daylight. Based on a 40 degree angle, the roof form is shaped to optimize the performance of the photovoltaic panels and solar thermal collectors. Daylighting, shading, ventilation, and passive cooling are adjusted by the homeowner to create the desired quality and character of thermal and luminous comfort during the changing seasons.

Figure 6: Exterior view of the wind catcher/light funnel

Figure 7: Interior view of bedroom to the southeast

Figure 8: Ground level (lower) and first floor plans (above)
2.3 Innovative Systems

Daylighting and natural ventilation strategies in the Lighthouse are combined with active systems to meet varying seasonal needs for lighting, heating, and cooling. Design strategies were the first line of action to reduce the energy demand and to set a low energy budget that could be met with high performance systems and appliances as well as renewable energy systems. Solar hot water heating, a 4.7 kW grid-tied photovoltaic array, mechanical ventilation with heat recovery, a biomass boiler, and efficient electric lighting meet demands throughout the year for hot water, electricity, space heating, and lighting. The design team worked with engineers at Ove Arup to integrate the daylighting, solar design, and energy systems to achieve an estimated energy consumption of 83 kWh/m2/yr (26 kBtu/sq ft/yr). Domestic hot water accounts for an estimated 29 kWh/m2/yr (9 kBtu/sq ft/yr); electric energy 20 kWh/m2/yr (6.2 kBtu/sq ft/yr); space heating 19 kWh/m2/yr (5.9 kBtu/sq ft/yr); lighting 4 kWh/m2/yr (1.25 kBtu/sq ft/yr); and the remaining 11 kWh/m2/yr (3.4 kBtu/sq ft/yr) is consumed by fans, pumps and catering. The operating costs for the Lighthouse are modest, with the following estimate based on the energy analyses: “The energy cost of running the Kingspan Lighthouse would be about £31 per year for the wood pellets, assuming wood pellets cost 1.8 p/kWh. The electricity is free, from the sun! A house of the same size and shape but built to 2006 Building Regulations standards would cost about £500 a year in energy bills.”

The carbon dioxide emissions for space heating and hot water are estimated at 45 kgC02/yr (which are offset by photovoltaic energy exported to the grid).

Design strategies and systems at the Lighthouse are integrated to facilitate ease of use and promote ecologically responsive behavior in the homeowner. As architect Alan Shingler explained: “We wanted the homeowner to have flexibility and control and to make sure it was not too complicated. Occupants adjust the house intuitively.” Despite the strict envelope requirements and minimal window areas of the Level 6 standards, the Lighthouse illustrates how daylighting can be thoughtfully coupled with natural ventilation and the high-performance envelope and systems to achieve zero-energy and carbon-neutral goals. It provides a useful residential precedent for similarly overcast and temperate climates in the U.S. and throughout the world.

3. SOLTAG Energy Housing
3.1 Background

In contrast to the Lighthouse, the SOLTAG Energy Housing combines daylighting with both passive and active heating and cooling design strategies to meet zero-energy carbon-neutral goals. Located in Horsholm, Denmark at the Velux headquarters, the prototype house is a collaborative project between the building industry, researchers, and design professionals, including Velux Danmark, Cenergia, Kuben Byfornyelse Danmark, and Nielsen and Rubow, among others. SOLTAG is one of numerous “Demohouses” designed and built as part of the European Union’s “Sixth Framework Programme,” which focuses on ways to implement EU legislation and directives to reduce energy consumption and carbon emissions in buildings. Designed as a prefabricated house constructed of two modules that are transported separately and joined on-site, SOLTAG is intended as a roof-top housing unit for existing buildings. Given the flexibility of the design, it can also be an autonomous house or clustered into multi-family units.

Figure 9: South façade
Figure 10: Bedroom looking south (left)
Figure 11: Livingroom looking southwest (right)

The prototype house is located at 55º NL in a temperate climate, with an average high temperature of 72 °F in July and an average low temperature of 31 °F in January. The sky conditions in the winter months can be quite variable and at times overcast. Velux team members Anna Dvarsater, Kurt Emil Eriksen, and Per Arnold Andersen explained that daylighting is viewed as an integral aspect of the passive
solar design strategies: “In SOLTAG we focused on optimizing passive solar and active systems, including strategies such as the building and window orientation, passive solar heating, daylighting, reducing cooling, and external shading. We reduce energy consumption by design. The energy that is needed can be from passive design for heat and light and active systems for electricity and hot water.” The quality of light in space was of primary importance and key to successfully realizing the combined lighting, heating, cooling, and health goals. In addition to energy performance, it was equally important to foster a sense of health and well-being that connects the occupants to the rhythms and cycles of nature. As Velux Danmark explains: “SOLTAG is an energy optimized home that lives, breathes and produces quality of life for people. A healthy organism to call home. The house is self-sufficient in terms of energy for heating, and creates CO2-neutral heating through solar energy. The home interacts with nature’s upper air strata via strategically positioned windows, solar panels, solar cells and air ducts. Sun, daylight, and fresh air are brought into the home and transformed into electricity, heat, natural lighting and ventilation.” Zero-energy and carbon-neutral goals are successfully coupled with the highest standards for indoor climate, health, and well-being.

3.2 Integrated Daylighting and Solar Design

As the name suggests, SOLTAG, or “sun-roof,” uses the multi-layered south-facing roof surface to gather sun and air while also integrating the active systems for heating and electric energy generation. The home includes two rectangular prefabricated modules with living spaces, kitchen, and loft in the west module and a bedroom and bath in the east. Daylighting creates a sense of openness and spaciousness in the modest 84 m² [904 ft²] home. As Velux Danmark explains: “In SOLTAG, high-level roof windows are installed to let in as much daylight as possible. A sloping surface lets in twice as much light as a vertical frontage – so the sloping roof areas are ideal sources of light. The roof windows reach right up to the ridge – like bands of light sending daylight down through the house. The roof windows, which run along the inner end walls, send reflections down across the walls which in turn act as one large reflector in the room. The light is passed and reflected out into the room and in under the open loft space, down to the kitchen and dining area, erasing any shadows from the loft space above.”

Figure 12: Floor plan

Figure 13: Exterior of west and south facades

Figure 14: Section looking east

The amount of glazing used for sidelighting and toplighting is equivalent to 28% of the floor area. The loft is set back
from the south façade to avoid blocking daylight and air, while light colored surfaces throughout the home optimize daylight reflection. Skylights include automated blinds that control solar gains during the overheated period of the year and a simple retractable awning covers the southern balcony. Kurt Emil Eriksen and Per Arnold Andersen from Velux emphasized that the team paid great attention to the quality and seasonal control of daylight in the house: “The daylight is amazing. The reason is that instead of a flat ceiling, we sloped the roof. The room feels larger than it is. All windows are positioned to optimize daylight and view. This makes a difference in how people feel in the house.” Daylighting studies of the living spaces revealed an average daylight factor of 12.7% in the living space, 8.7% in the bedroom, and 9.7% in the bathroom. Luminance studies were also used to evaluate potential problems with glare and excessive contrast and to optimize the quantity and quality of daylight on diurnal and seasonal bases.

The SOLTAG design team approached daylighting as a series of dynamic forces that change with the seasons. As Per Arnold Andersen explains: “A window is not just a window. It has to perform in winter, summer, and during the night and day. The role of the windows is to control parameters and not compromise daylight quality. We used dynamic solutions.” With solid walls on the east and west (which form party walls in the multi-unit configuration), the steeply pitched roof and vertical south and north facades contain all of the windows and skylights and present distinct luminous and thermal design opportunities. The vertical slices of operable skylights and windows on the south provide daylighting, natural ventilation, passive solar gains, and site views. The north-facing windows and skylights balance daylight throughout the space and provide supplemental views to the north over the site. Automated shades are integrated into the window envelopes to control heat and light. Velux Danmark summarizes the window placement concept: “The largest window areas in the home face south. These south-facing roof windows are standard products that provide maximum access for sunlight. They provide heat as well as light. The low-energy windows used let energy into the home, but also limit heat loss. Facing north, the passive heat from the sun is limited, so the roof windows are designed to bring light in and retain energy. The north-facing roof windows in the ridge are super low-energy windows – passive house windows with minimum heat loss.”

3.3 Innovative Systems

The daylighting strategies and details at SOLTAG were integrated with other systems, which include a heat pump, ventilation unit, hot water tank, solar thermal panels (to heat water for under-floor heating and domestic hot water), and a double roof with skylights and solar cells. The roof is particularly important in meeting the comfort and energy needs of the house; it supports systems for lighting, heating, ventilation, hot water heating, and electricity. The double-layer roof comprises a zinc surface with alternating skylights and photovoltaic cells, an airspace, and the interior roof structure. Skylights were carefully positioned to meet the illuminance requirements in the space below while optimizing airflow through the double roof. The airspace is used to preheat air for the heat pump, which produces domestic hot water, floor, and air heating. Airflow beneath the photovoltaic cells also helps cool the cells to optimize performance. Amorphous thin-film photovoltaic solar cells covering an area of 17.5 m2 (188 ft2) produce an annual net-zero energy consumption for heating and hot water of 0 kWh/m2/yr (0 kBTU/sq ft/yr). The house uses 60 kWh/m2 (18.8 kBTU/sq ft/yr) for heating and hot water when photovoltaic cells are not used. A solar thermal system (2 m2; 21.5 ft2) heats domestic hot water. As Velux explains, the daylighting, photovoltaic, heating, and renewable energy system designs have to be carefully integrated: “SOLTAG is devised as a home that runs itself and is independent of external heating systems. The independent heating production and maintenance are achieved by harnessing solar energy, which is generated by the windows’ natural propensity to heat up, and by the solar panels that produce domestic hot water and under-floor heating. Solar cells produce the electricity to operate the pumps and ventilators.” A compact, built-in heat-recovery ventilation unit and a mechanical ventilator transfer the heat from the ‘spent’, heated air to new fresh air taken from outside. Ninety percent of the heat recycles.”

The building envelope is described as a “solid climate screen,” using air-tight construction, 350 mm (14”)...
insulation in the walls, and 400 mm (16”) in the roof. An automated solar control system helps keep the house cool in the summer and eliminates the need for air conditioning. The system uses io-homecontrol®, which operates windows, lights, and other components manually, by remote control, or as pre-programmed functions. Airflow and light are regulated by indoor Venetian blinds and ventilation is enhanced by the exchange of air through skylights. Roller shutters on the exterior can also be operated by the control system. The design and integration of the energy systems at SOLTAG demonstrate a simple, straightforward, and off-the-shelf solution to zero-energy and carbon-neutral heating for a northern temperate climate. Daylighting is carefully considered within the context of passive and active energy systems integration, with attention given to strategies that simultaneously support the integration of luminous, thermal, ventilation, and renewable energy goals.

4. CONCLUSIONS
The Lighthouse and SOTAG Energy Housing illustrate the importance of integrating daylighting with solar strategies and systems to elevate both the performance and aesthetics of zero-energy carbon-neutral design. The full integration of daylighting into the solar and systems designs can inform and inspire the next generation of sustainable housing. Emerging zero-energy carbon-neutral daylighting strategies from the Lighthouse and SOTAG include the following:

a. Take a multi-functional approach: To foster carbon-neutrality, the daylight design must provide more than high quality illumination. In the Lighthouse and SOTAG, we find “multi-functional” approaches to daylighting that consider how natural light can support diverse performance, ecological, and aesthetic design goals. The daylighting designs integrate complex sets of considerations ranging from programmatic concerns to climatic response, energy, technology and systems integration, comfort, health and well-being, and aesthetic concerns.

b. Integrate daylighting, thermal, and energy goals: In the Lighthouse and SOTAG, the windows are designed to provide more than illumination. The sections, apertures, and envelope detailing are skillfully oriented, sized, and detailed to meet both luminous and thermal criteria for lighting, solar control, heating, and/or ventilation based on climate and program. With the active solar approach of the Lighthouse, the daylighting design was severely limited by code requirements for the envelope and allowable window area. Each window was precious and needed to be carefully positioned to optimize and integrate luminous criteria with issues of solar control and natural ventilation. At SOTAG, the passive solar design, natural ventilation, and mechanical systems in the south roof needed to be carefully choreographed with the vertical windows and the skylights. We find in both projects that daylighting, thermal, and energy goals are inseparably linked.

c. Work with direct sunlight: In a carbon-neutral approach to daylighting, particularly in cold or temperate climates during the heating season, designers may need to reconcile potential programmatic conflicts between the desires for luminous control and passive solar gains. This is addressed in SOLTAG, where daylighting is carefully integrated with both passive and active solar systems. Both prototype houses admit or control direct sunlight seasonally to address thermal issues while also celebrating the poetics of light. Passive heating and cooling integration may lead to different solutions than would be sought if illumination were the only daylighting priority. With programs and activities that typically require control of light levels and glare, there will be a need for creative solutions that balance the desire for direct solar gain and the mediation of sunlight. A variety of simple strategies can support the integration of daylighting and passive solar design, including fresh approaches to luminous and thermal zoning, spatial planning, controlling direct sunlight at the location of the task, dynamic shading, innovative glazing systems, as well as engaging occupant participation to foster more resource-effective behaviors.

d. Develop dynamic daylighting: To move toward carbon-neutrality, designers must consider how to work more effectively with the dynamic qualities, quantities, and characters of daylight and its relationship to thermal design. Rather than targeting a static daylighting design criteria for all times of the year, the Lighthouse and SOTAG demonstrate how daylighting designs can address changing luminous and thermal conditions on a seasonal and diurnal basis. A matrix of luminous and thermal design considerations can be used to guide daylighting decisions at different scales and across varied programs. Foremost is the importance of explicitly considering diurnal and seasonal flux: What luminous and thermal qualities are desired at different times of day and for differing seasons? How much light is needed at which times of the day and during which seasons? Can the daylighting design be used to provide variability and occupant control? What methods of interior and exterior solar control can be integrated with the daylighting design to enable occupants to tune their luminous and thermal comfort to the particular season and time of day?

e. Use layered envelopes: In addition to the building form, section, and spatial configuration, the design of the building envelope is critical in reducing the carbon emissions. The Lighthouse and SOTAG use the building envelope to most directly foster a “dynamic” or diurnally and seasonally-responsive approach to the
luminous and thermal design. The envelope not only provides comfort and protection, it also shapes the character of the living spaces to inform the occupants’ direct experience and aesthetic of the design. Adjustable interior and exterior layers allow a responsive building envelope to be tuned to provide specific levels and qualities of daylighting, solar heating, shading, ventilation, views, and connections to site. Regardless of the approach, manual or automated, low-tech or high, a “dynamic approach” to design criteria for daylighting, passive integration, and the building envelope is essential to reducing energy and carbon emissions.

f. Deepen Systems Integration: At the Lighthouse and SOLTAG, it is evident that daylighting is fully integrated with passive and active design strategies, innovative mechanical and electrical systems, new envelope technologies, and renewable energy. In both houses, we see that integration enables the design to reach ever greater reductions in carbon emissions and energy consumption. A deeply systemic approach may even move design beyond carbon-neutrality and net-zero energy targets to create regenerative architecture that actually produces rather than consumes energy. Designers will find seemingly unlimited formal, stylistic, and expressive design opportunities through a hybrid approach to integrated daylighting and solar design. The need for sophisticated systems integration challenges design teams to collaborate across areas of design expertise and to investigate methods of design assessment and analysis more rigorously.

g. Create beauty: The poetics of light is perhaps the primary reason that architects throughout history have been fascinated with daylighting design. With carbon-neutral design, we should look even more closely at the relationship between poetic and pragmatic design criteria to consider not only how to foster deeper ecological design performance, but also how to celebrate the beauty of natural light. In the Lighthouse and SOLTAG, we find that the integration of poetic and pragmatic considerations is a distinguishing feature of these innovative and elegant design approaches to zero energy and carbon-neutral architecture; revealing that it is possible to respond to urgent ecological challenges while also fostering design excellence. While the aesthetic expression of carbon-neutral daylighting is yet emerging, the Lighthouse and SOLTAG suggest that the design potential of zero-energy carbon-neutral architecture is limited only by the designer’s imagination.

It is not enough to achieve zero-energy and carbon-neutral targets without taking into account aesthetic and qualitative design intentions. High quality housing must also address broader human and design considerations. The importance of good design should not be underestimated, as Architect Lawrence Scarpa of Pugh+Scarpa Architects emphasized in an interview on the role of solar in the next generation of sustainable design: “An energy hog is better than an energy efficient building that no one loves. Don’t worry about ‘sustainable design,’ focus on design.”13 If people are to care for their buildings, then aesthetics, beauty, human experience, health, and well-being are just as important as are a building’s ecological footprint, energy profile, greenhouse gas emissions, and carbon reductions. A more thoughtful and thorough integration of daylighting and solar design strategies and systems is essential in reaching ever high performance standards while bridging the pragmatic and the poetic opportunities of zero-energy carbon-neutral architecture.

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