How U.S. hospitals can realize net-zero energy

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Hospitals can reduce energy use with the aim of achieving net-zero energy (NZE). Insights from hospitals that are on the path to NZE and other buildings that have realized this goal help identify barriers and help identify next steps for the healthcare sector to design-toward and achieve NZE.

Keywords: Hospital, Healthcare, Energy Efficiency, Net Zero Energy

Abstract

In the United States hospitals use nearly 4% of national energy, emit over 8% of U.S. commercial building greenhouse gas emissions, and exceed $9 billion in annual energy costs. Recognizing buildings' impacts on atmospheric health as well as their connection to community health and economic viability, more hospitals are evaluating their energy impacts. Concurrent efforts are being made to improve codes, strengthen standards, and accelerate deeper energy savings across the building sector. This paper will explore how hospitals can reduce energy use with the aim of achieving net-zero energy (NZE). First, it will contextualize hospital energy use in the U.S., discussing common design practice, and define the scope and scale of NZE for commercial building projects. It will then highlight programs such as Targeting 100! and case study examples of forward-thinking hospitals that are leaders in deep energy savings and are on the path toward NZE. It will also explore an example of a non-hospital building that has achieved NZE, providing insights into achieving this goal in practice. Insights from hospitals that are on the path to NZE and other building types that have realized this goal help identify barriers unique to NZE and hospitals and help identify next steps for the healthcare sector to design-toward and achieve NZE.

Average energy use in U.S. hospitals

Hospitals in the United States (U.S.) use nearly 8% of all national energy (1), emitting an equivalent amount of greenhouse gasses, and exceed $9 billion in annual energy costs (2). In 2016 the private and public healthcare markets combined spent $464 billion nationally on new construction (3). Most of this construction occurs at code minimum energy standards, missing large opportunities for energy savings. With such large infrastructural investments, a focus on energy and environment could bolster positive environmental and economic impacts. Concerted efforts are being made to improve codes, strengthen standards, and accelerate deeper energy savings across the building sector. Hospitals can reduce energy use with the aim of achieving net-zero energy (NZE), though it would be a heavy lift requiring a shift in typical hospital design.

Understanding how typical hospitals use energy is pivotal to informing NZE design. On average, U.S. hospitals consume 231 kBtu/ft^2-yr (729 kWh/m^2-yr), ranging from 110 kBtu/ft^2-yr (347 kWh/m^2-yr) to 450 kBtu/ft^2-yr (1420 kWh/m^2-yr). For comparison, typical office buildings use 78 kBtu/ft^2-yr (246 kWh/m^2-yr) on average (4), and international examples use about 50% less energy than typical U.S. hospitals.

Data shown in **Figure 1** highlights the U.S. national average for hospital energy use as it compares to several specific examples of hospitals in Norway and Denmark (5). These data are corroborated in an older study compiled by the Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), which shows the U.S. as one of the largest energy users for healthcare, second only to Canada (6).

Defining Net Zero Energy (NZE)

In 2015, the U.S. Department of Energy published A Common Definition for Zero Energy Buildings, providing common definitions for Net Zero Energy buildings (7). Their definition for a "Zero Energy Building", which this paper refers to as a "Net Zero Energy" building, is "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy." To simplify this concept, many teams use a site-based only definition that does not consider the energy source. The New Buildings Institute has simplified this definition to only include site energy implications, stating "Zero net energy (ZNE) buildings are ultra-efficient new construction and deep energy retrofit projects that consume only as much energy as they produce from clean, renewable resources (8)." This paper applies this definition.

Net Zero Energy "ready" refers to a building with an energy profile that can realistically be accommodated by a clean, renewable energy source, which may be purchased after construction of the building. For example, the building may be built and operate reliably with a low energy profile and later, when funds are available, a photovoltaic array is installed, which produces as much energy as the building consumes on a net-annual basis.

Approaches for significantly reducing energy in hospitals

Programs such as Targeting 100! (9), ASHRAE's 50% Advance Energy Design Guide for Large Hospitals (AEDG) (10) provide a roadmap for significant energy reductions in hospitals, presenting a path toward 60%

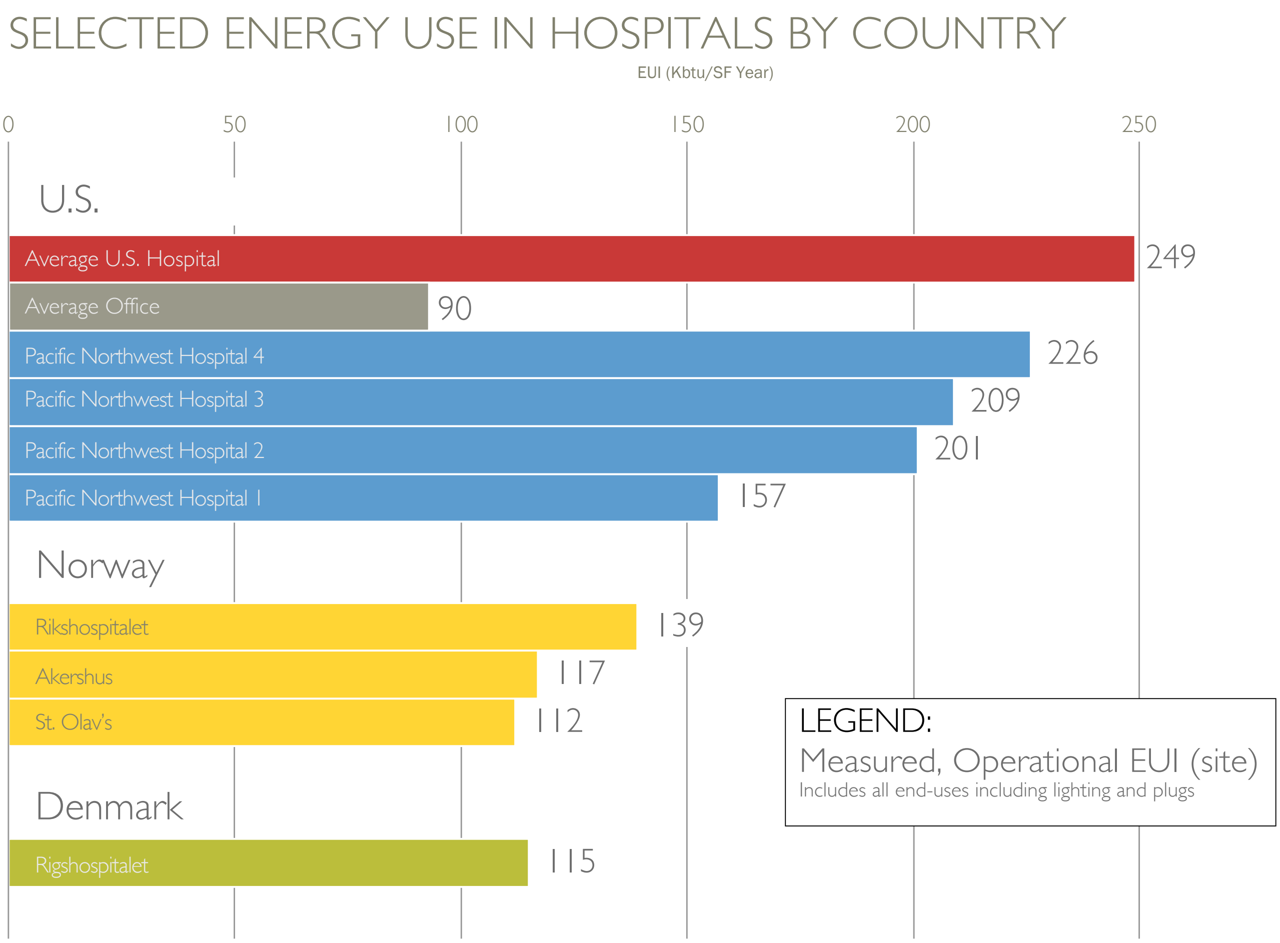

Figure 1. Hospital energy use in the U.S. vs. Norway and Denmark (100 Kbtu/SF-yr = 315 kWh/m^2-yr).

energy savings at little-to-no additional capital cost. These roadmaps outline what is achievable utilizing current codes and standards, and represent a starting point for NZE or NZE-ready hospital design. Insights from recently built hospitals also showcase that lower energy hospitals are possible. For example, the Swedish Issaquah Hospital in the U.S. Pacific Northwest. operates below 120 KBtu/SF-yr (380 kWh/m²-yr), and the Peace Island Medical Center operates under 100 KBtu/SF-yr (315 kWh/m²-yr). International examples show that there is consistent achievement of similar or better results (11).

The major points for Targeting 100!, the AEDG, and recent built examples include:

1. Hospitals are large energy consumers for somewhat surprising reasons: Minimum requirements for ventilation mean that a large portion of the energy consumed in a hospital is being used to transport and condition ventilation air. Re-heat energy is the single largest energy consumer, representing 40-50% of the total energy consumed in a typical facility. Hospitals' internal requirements dictate that air be very cool in some hospital areas; spaces needing the coolest air (such as surgery suites) determine the air temperature traveling through an entire zone. All spaces needing warmer air (e.g. offices, exam rooms, patient rooms) require air to be re-heated at the delivery point. Additionally, hospitals are densely occupied, operate 24 hours per day, seven days a week, and house a lot of energy consuming equipment.
2. To reach low energy targets, designs should:
   a. **Prioritize Load Reduction through Architectural Systems**. Energy reductions start by aggressively reducing external climate dependent loads and activity dependent internal loads. A simultaneous focus on peak loads and whole building annual energy loads is important for solving the energy and cost equation. Smaller peak loads mean smaller plant equipment which translates to lower capital cost investments; lower overall load profiles provide flexibility in ventilation system choice and mean significantly reduced annual energy use profiles for heating and cooling, and thereby, annualized energy savings. Highly coordinated architectural and building mechanical systems are required to meet large load reduction goals. For example, exterior shading on the envelope significantly reduces solar heat gain enabling a de-coupled approach to building heating, cooling, and ventilation systems. De-coupling heating and cooling from ventilation of rooms enables much lower whole building load profiles and significantly reduced peak loads.
   b. **Re-Heat Energy Reduction through Building Mechanical Systems**. Strategies for reducing or eliminating re-heat include de-coupling space tempering and ventilation for most spaces; fluid rather than air-transport of heat and cooling for peak conditions; and the final distribution of heating and cooling to each space via a bundle of de-coupled systems such as radiant heating and cooling panels. These systems require a limited load profile and thus, require prioritizing load reduction strategies. Optimized heat recovery from space heat and large internal equipment sources also reduces the overall energy demand as does including advanced HVAC and lighting controls: turn off what is not in use.
   c. **Efficient Plant-Level Equipment**. Provide the ability to capture heat in the most efficient way. Utilize advanced heat recovery at the central plant and implement heat pumping, or enhanced heat recovery chillers paired with highly efficient boilers.

Implication for on-site energy production

Targeting 100!, the AEDG for Large Hospitals, and recent built examples show that achieving an Energy Use index (EUI) of 100 KBtu/SF-yr is possible alongside current codes and standards. Even though these examples utilize significantly less energy than their typical counterparts, they still use too much energy to achieve NZE by simply adding renewables. The total energy use for a 250,000 SF hospital operating at 100 KBtu/SF-yr would require a 6850 kW photovoltaic array, measuring nearly 500,000 SF (in Seattle, WA, U.S.), or a slightly smaller, 4500 kW, 300,000 SF of PV array (in sunnier Los Angeles, U.S.) to produce enough energy to offset the total energy demand in an average year (12). The site area size and cost of PV equipment is not realistic to achieve NZE. If these examples reduced their energy demand to 50 KBtu/SF-yr (158 kWh/m²-yr), that implies a much smaller array, 3400 kW (Seattle) or 2250 kW (Los Angeles), using just under 250,000 SF and 160,000 SF respectively (13). An even lower EUI, more efficient array, or sunnier climate would imply an even smaller and more affordable array to achieve NZE. These calculations highlight that in order to approach NZE, or become NZE ready, a hospital must reduce its energy footprint significantly beyond what has been achieved to date in the U.S.

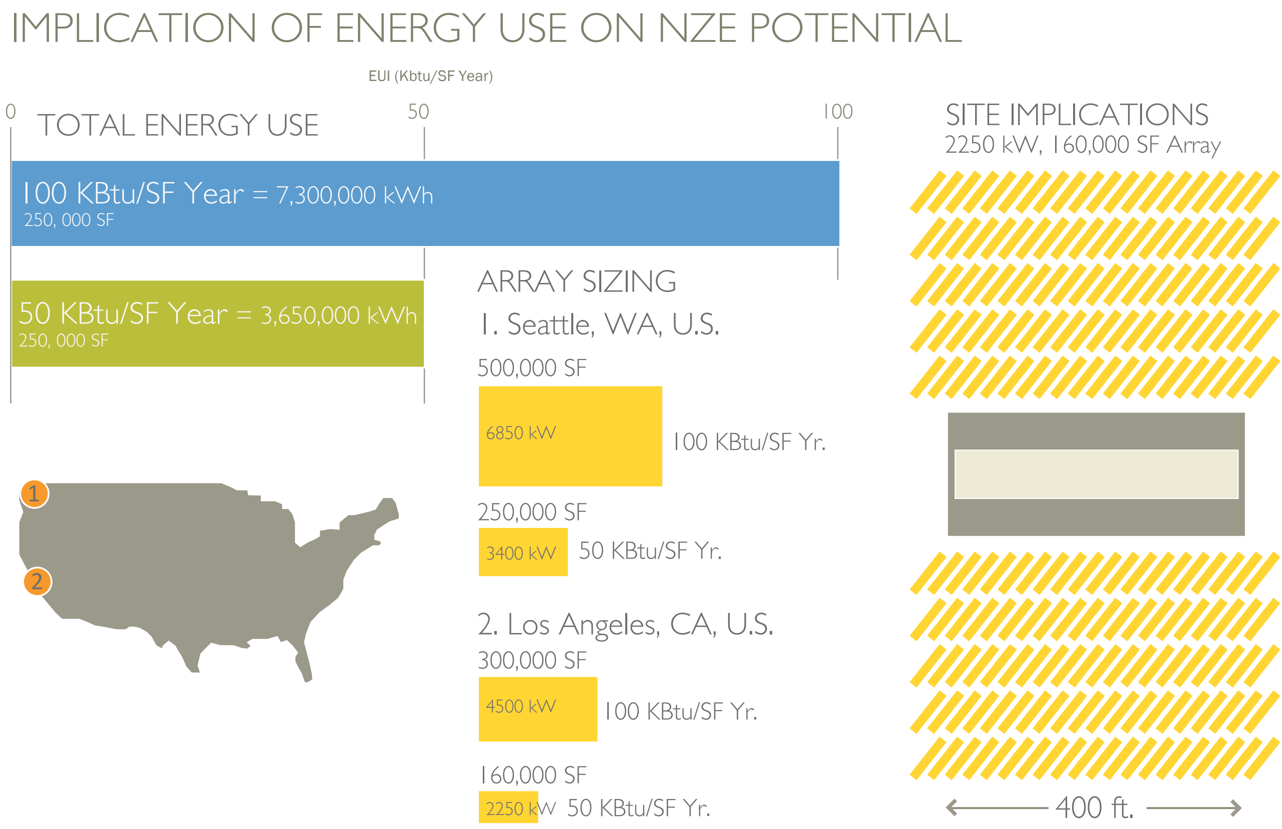

Figure 2. Implication of energy use on net-zero ready potential including relative PV array sizing and relative coverage of site area (100 Kbtu/SF-yr = 315 kWh/m^2-yr).

What is needed to achieve NZE

Roadmaps and built examples show how to significantly reduce energy in hospitals usually through the natural gas systems, implying a fuel switch from predominantly gas-fired plants to all-electric plants. This presents opportunity to move closer toward NZE and carbon neutrality through strategies that achieve deeper electricity savings. Major opportunities that have not been fully addressed in healthcare are miscellaneous equipment loads (MELs) and plug loads. MELs include fan power energy both at the plant level and in distributed systems. Plug loads capture all energy connected equipment including computers, TVs, imaging equipment, and rolling devices such as IVs, beds, etc. As has been done with the hospital building as a whole, a coordinated research effort is needed to first understand the energy profiles of this equipment, then reduce energy demand where there is the most opportunity. This will likely start with choosing the most energy efficient devices, then turning off equipment not in use from full-power mode through more sophisticated controls. Re-designing devices to include energy efficiency as an important criterion will help move this area forward without negatively impacting the quality of patient experience or patient care. Efforts such as Energy Star for commercial and residential equipment show a similar path for commercial and residential equipment, and can effectively rate equipment and achieve energy savings. Energy Star has initiated partnerships that will lead to ratings for some large healthcare equipment, such as MRI machines. Once Energy Star equipment is available, a reliable energy attribute can become a specification criterion for designers involved in acquiring new healthcare equipment. Beyond MELs and plugs, careful analysis and research is needed to determine the necessity of codes and standards that impact energy-using systems in hospitals. Specifically, a concerted effort to understand effective and necessary air-change rates throughout hospitals will help re-define minimums, potentially significantly decreasing energy demands, while not compromising (or potentially improving) quality.

Learning from other NZE buildings

Current NZE buildings provide insight into how hospitals can achieve similar energy targets. The Bullitt Center in Seattle, WA U.S. is one example of a 50,000 SF commercial office building that has operated at NZE since 2013. In fact, this building has produced more energy than it consumed (making it Net Positive Energy) in its first three years of operation (14). Insights from this building include: 1. First reduce loads through the envelope, 2. Use water-based heat pumping systems for heating and cooling, 3. Provide minimum ventilation for fresh air using 100% Out Side Air (OSA) with high-efficiency heat recovery, 4. Utilize the outdoor environment as much as possible for natural ventilation and passive cooling, 5. Install very low lighting power and using comprehensive control systems to turn off lights when not needed, 5. Implement sophisticated building controls that guide users in energy-using systems, 6. Gain comprehensive understanding and control of plug loads, 7. Measure and verify energy use patterns at a granular level to understand what is working and where improvements can be made, 8. Since plug-loads and patterns of use become a bigger part of the energy picture, partner with building occupants to participate in energy efficiency strategies and utilization, and 9. Partner with utilities to ensure a transaction structure that is sustainable and economically viable for public and private entities as more buildings approach NZE.

Hospitals are often more complex and sophisticated than typical commercial buildings. However, there is a path toward energy and carbon neutrality that is achievable. A comprehensive re-visioning of how a typical hospital is designed and operated must be part of the solution for meeting and achieving aggressive energy targets that are outlined by city, state, and governmental leaders. ■

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