

HIGH PERFORMANCE HOSPITAL PARTNERSHIPS: REACHING THE 2030 CHALLENGE AND IMPROVING THE HEALTH AND HEALING ENVIRONMENT

Heather Burpee, Research Associate of Architecture; University of Washington's College of Built Environments; Health Design Specialist, Integrated Design Lab, Seattle, Washington with BetterBricks.

Joel Loveland, Professor of Architecture; University of Washington's College of Built Environments; Director, Integrated Design Lab, Seattle, Washington with BetterBricks

Michael Hatten, Principal Engineer, Solarc Architecture and Engineering, Eugene, Oregon with BetterBricks

Stan Price, Principal, Putnam Price Group, Inc., Seattle, Washington with BetterBricks

Abstract

This paper documents that new hospitals in the United States can greatly increase their value to their owners by reducing energy by 75% and increased environmental quality for patients and staff. It identifies: 1) the energy use characteristics for common and higher performing US hospital energy efficiency strategies; 2) the rationale, goals, strategies and metrics for innovative daylighting and ventilation strategies for the broadest range of hospital space types; 3) the de-evolution of the performance of hospital prototypes related to these energy performance and interior environmental quality metrics during the 20th century; 4) Scandinavian hospital case study examples that exemplify the highest quality and energy performance characteristics, and interior environmental qualities; and 5) describes the business case for making these design and operational changes, and detailing what goals should be set for hospital design and operations that model continuous process improvement.

Section I: Energy Use in Hospitals

Introduction

Funded by BetterBricks of the Northwest Energy Efficiency Alliance, in collaboration with the University of Washington's Integrated Design Lab, Solarc Architecture and Engineering, The Putnam Price Group, Mahlum Architects and NBBJ, this group has developed a body of work that encompasses: 1) knowledge about the actual operational energy-use characteristics of hospitals in the Pacific Northwest and abroad 2) developing strategies for significantly reducing energy use for this building type, and 3) working with planning, design, construction and ownership teams to implement integrated high performance hospital projects. As part of this work, this group has developed strategies for reducing energy in hospitals by more than 50% in the Pacific Northwest and these strategies provide a road-map to even greater energy savings in the newest breed of hospitals being designed and built in Northern Europe. Scandinavian case studies illustrate that achieving these energy goals is possible while simultaneously creating superior interior environmental qualities for patients and staff.

Reducing energy use in hospitals is a low risk and high yield investment that offers greater cost control throughout the life-span of the building. Integral to owning and operating a high-performance, high-value hospital is using a better integrated interdisciplinary "project ownership" process that includes the hospital ownership, design and construction team members in a goal and metric setting and testing process. This process tests and verifies performance via modeling throughout the design, construction, and operations of the building.

Characterizing Hospital Energy Use

With growing attention on climate change and a developing focus on sustainability, it is important to address the energy use of buildings. The US Department of Energy estimates that buildings use approximately 50% of the total energy consumed in the United States today and produce a similar proportion of greenhouse gases. Hospitals contribute significantly to this figure. They exhibit the second highest energy use intensity in the building sector, just behind fast-food restaurants.

One of the first steps in addressing energy use in hospitals is to characterize the patterns of energy use for typical US hospitals. This involves developing expectations for the amount of energy used, the type of fuel used, and the breakdown of energy end use categories: lighting, cooling, fans, etc. One could consider this as "taking the temperature of the hospital." To evaluate the amount of energy used by a building, it is conventional practice to estimate an Energy Use Index (EUI), expressed in KBtu/SF•year (thousands of British Thermal Units per square foot per year). The EUI is estimated fairly simply by summing the annual energy use of all fuels (typically electricity and one or more fossil fuels), converting to a common energy unit (typically the Btu or KBtu in the US), and dividing by the applicable conditioned area of the facility. Once estimated, an EUI can be interpreted by comparison to a database of energy use statistics for similar facilities, a process called benchmarking. Two hospital energy databases were referenced for use in this project.

One reference database that was consulted is a developing database of hospitals that have started working with the Northwest Energy Efficiency Alliance's building operations program. This database consists of eleven existing acute care hospitals, ranging in size from 190,000 SF to 1.4 million SF, and located in Montana, Idaho, Oregon, and Washington. Hospitals in this database consume approximately 260 KBtu/SF•year in total energy. A second database, the Commercial Buildings Energy Consumption Survey (CBECS) is a national database of hospitals, which indicates that hospitals use on about 280 KBtu/SF•year. While both databases were used as points of reference, the Pacific Northwest regional data was assumed to be a more robust and reliable dataset because project team members had actually collected much of the information contained in the dataset.

For regional hospitals, the fuel use split tends to be about 60% fossil fuel and 40% electric. The majority of this energy is used for heating, with about 40% of the total energy used for space heating. Of that amount, reheat coils within ducted air cooling systems accounts for most of the load. Other major loads are domestic hot water, at about 15%, and building fans and pumps, at about 16%. In typical hospitals, energy used by the heating, ventilating, and air conditioning (HVAC) systems represents over 70% of the total annual energy use. Significant energy reduction in US hospitals must focus attention on the design and operation of HVAC systems. For new hospitals, this focus should occur within a context of design integration that includes a profound understanding of the loads being served by hospital HVAC.

While the energy problem in hospitals, at least those located in temperate climate zones, can safely be described as heating, the loads problem is actually related to cooling, i.e. getting rid of heat. It is common for large hospital central plants to be enabled when outside air temperatures are quite low (44°F to 48°F, and sometimes lower). Monitored facility-level electric loads range from 2.5 to 3 watts/SF during the peak heating season, and tend to be quite flat over a 24 hour cycle. Much of this electric load is converted into heat. In short, US hospitals are an internally load driven facility. With modern envelopes, driven by energy code requirements, it is not unusual for hospitals to have a greater need for heat rejection than heat addition, even when outside air temperatures drop well below freezing. Calibrated energy and loads modeling performed on a conventional, core dominated prototype hospital design supports this observation. For most climates, these load patterns suggest that hospitals should never really need to add heat if the design would accommodate moving heat from those zones that need to get rid of it to those that need it. It is no small irony that the load problem imposed on the HVAC systems by the modern hospital program and its corresponding architecture involves cooling while the energy problem created by the typical hospital HVAC system is all about heating. This certainly underscores the importance of focusing attention on the HVAC systems, and especially on the reheat system's components and functionality.

The typical HVAC system type found in modern hospitals is a multi-zone overhead ducted air system. It may be variable air volume (VAV) or constant volume. It may be return air capable or designed as a '100% outside air' system. In all cases, these systems will be equipped with reheat capability. Reheat is the energy transfer process where heat energy is added to air that has already been cooled. In hospital HVAC systems, the air is cooled at the air handling unit, either with a cooling coil or by mixing cool outside air with warmer return air. In either case, the temperature of the air delivered to the ductwork is determined by the space calling for the most cooling. Much of the time, this will have the tendency of over-cooling all other spaces on the same HVAC system. Reheat is used to compensate for this overcooling effect. Both steps of this process require energy. Extra cooling energy is used at the air handling unit and extra heating energy is used at the reheat coil. An appropriate analogy might be driving with the accelerator constantly engaged and using the brake to adjust the speed.

While reheat can be a consequential energy issue for many building types, it has particularly significant energy implications for hospitals. This is because of the hospital specific code requirements that can limit minimum air flow as well as emerging functional protocols that translate to exceptionally low supply air temperatures for certain spaces, i.e. operating rooms. In Washington, Oregon, and Idaho, the state codes to which design teams must comply require that patient rooms have a minimum air circulation rate of six Air Changes per Hour (6 ACH.) For conventional room geometry, this is equivalent to about 1 CFM/SF, and represents a severe limitation to the ability of a VAV terminal unit device to turn down during low load conditions. Many hours throughout the year could be expected to have cooling loads that require significantly less than 1 CFM/SF, yet a patient room terminal unit cannot deliver lower air flows. The magnitude of reheat is directly related to the minimum air flow setpoint at the VAV terminal unit. By way of comparison, non-regulated buildings are allowed, and even encouraged by energy codes and incentive programs, to turn down to flow rates as low as 0.1 CFM/SF.

Sustainable Healthcare Energy Challenge: Meeting the 2030 Challenge

The 2030 Challenge is a design directive to the architectural community that takes its cue from the increasing concern about carbon driven climate change. It is a challenge that includes energy and carbon emission performance targets, starting with targets that are logically consistent with the current global emissions protocols. The 2030 Challenge states: "All new buildings, developments and major renovations shall be designed to meet a fossil fuel, Green House Gas-emitting, energy consumption performance standard of 50% of the regional (or country) average for that building type." This performance standard increases in five-year increments until 2030 when buildings shall be designed to use no carbon-emitting energy. A simplification of the 2030 Challenge goal is typically summarized as a 50% reduction in overall energy consumption in 2008-2009, and a 60% reduction in 2010. Thus, for new hospitals, the 2030 challenge could imply an EUI of 130 KBtu/SF•year, which is a 50% reduction of the average Pacific Northwest hospital energy performance. The lowest EUI in the regional database was verified to be 199 KBtu/SF•year, for a hospital that is generally acknowledged as one of the regional leaders in energy efficient design and operation. (Note that a significant effort has been made to validate the regional database EUI information so that it represents performance of acute care program areas, and does not include a significant amount of medical office building area. This has been a point of some confusion when some hospital EUIs have been computed for energy benchmarking systems like Energy Star.) The 2030 Challenge in its current form represents energy goals for hospitals that are very aggressive, especially considering the current documented range of performance. It is a performance goal, that honestly, has not been embraced with much enthusiasm by many hospital facility managers or design team leaders for this very reason. Many health care design and operations experts in the US are at somewhat of a loss about how to respond to such an aggressive goal, one that seems impossible to achieve for many.

One of a growing number of architectural firms that is undertaking an exploration of the implications of the 2030 Challenge is NBBJ, an internationally-based firm with significant health care design studios. In 2007, NBBJ formed a research project team, The Sustainable Healthcare Energy Challenge (SHEC), led by Duncan Griffin, to address meeting the 2030 Challenge for a hypothetical hospital. Architects, engineers, contractors, and owners met once a week with a goal of how to design a hospital that reduces the energy use of a "typical" hospital by 50% in 2008, and 60% in 2010. By the end of the year the SHEC team identified a series of design strategies that appeared to have potential to significantly reduce energy use for a new hospital, and were ready to be tested using a series of hourly energy simulations.

As part of ongoing work at the University of Washington's Integrated Design Lab (IDL) related to high performance hospital designs, detailed hourly energy simulations (using DOE2.2 as embodied in EQuest) were already under development at the time that NBBJ approached the IDL with the suggestion of dovetailing with the SHEC work. Working together, NBBJ and IDL refined the SHEC strategies into the following strategy sets, which would be subjected to iterative hourly loads and energy simulation testing, as well as construction cost modeling. Initial energy modeling and supporting energy calculations have been completed to identify potential energy performance of the strategy sets. Note that the cost modeling work and refinements to the energy models and the strategy sets themselves are ongoing, with that work anticipated to be completed in 2009.

Strategies Considered in the SHEC Research Project

Continuous Commissioning: The first energy use reduction strategy is continuous commissioning. Its performance prediction is based on extensive observation, testing, and monitoring in existing hospitals. Energy assessments conducted for all of the hospitals in the regional database indicate that a comprehensive effort of system tune-ups, repairs, and targeted retrofit commissioning can reduce energy consumption in existing hospitals by at least 10 to 15%. This is associated primarily with HVAC and light systems, and is evidenced by any number of suboptimal real-world conditions, i.e. excessive operating hours, poor set-points, plugged coils or intakes, leaky ductwork and piping, broken damper actuators, incorrectly mapped control points, and excessive light levels, among numerous basic maintenance issues. Hospital systems are inherently complex and challenging from a maintenance perspective. Without a process of continuous tune-up and commissioning, a reasonable expectation is that a new hospital would exhibit 10 to 15% greater energy use than that predicted by an energy model. That is, a reasonable expectation is that a savings of 10-15% can be achieved for

a facility that is built to today's code and is subjected to regular on-going energy performance review and evaluation and implementation of issues management.

Green Guide for Healthcare (GGHC) Strategies: The next bundle of energy saving strategies selected for testing and evaluation was a set of design recommendations included within The Green Guide for Healthcare as a prescriptive path to reducing energy use in hospitals. Key recommendations in this bundle include:

- High Performance Glazing. This is defined defined by GGHC as having a maximum center of glass U-value of 0.4 Btu/hr-SF-F. The glazing analyzed in this model represents the emerging industry-standard double pane clear glass with spectrally selective low-emissivity coating (U=0.29, solar heat gain coefficient of 0.29, visible transmittance greater than 60%).
- High Efficiency Condensing Boilers and Water Heaters. This strategy represents a significant departure in central heating plant design approach for many hospitals – essentially moving away from central steam generation to a distributed and/or modular heating plant. The plant would use condenser modulating boilers to serve a low temperature hot water for hydronic heating loops, dedicated condensing semi-instantaneous water heaters for potable water heating, and significantly downsized central steam generators to meet process steam loads. Process steam could also be served by point-of-use steam generation. Fuel conversion efficiencies for the condensing heaters can range between 90% to 95%. Preferred back-up fuel for the heating plant would be propane rather than diesel fuel.
- Central VAV Air Systems. Most contemporary hospitals routinely incorporate VAV system functionality into their secondary HVAC systems. There may not be much actual turn-down in many systems for a variety of reasons, including applicable codes. Energy modeling assumptions included central VAV systems in the baseline model as a starting point, based on field observation at the hospitals in the regional database. Thus, this element of the GGHC strategies did not result in additional efficiency performance beyond what was already assumed for a new code-compliant hospital.
- HVAC System Turn-down Ratio of 30% Where Allowed by Code. As discussed above, there are many functional areas within acute care hospitals where applicable state codes will not allow VAV systems to implement this degree of minimum flow. Energy modeling assumptions included this recommendation in non-regulated areas such as lobbies, waiting areas, and administration areas. This recommendation also applies to variable flow hydronic systems – both chilled water and heating water.
- High efficiency Variable Speed Chillers. Most large chiller plants in today's hospitals are specified with machines that exhibit excellent full load efficiency. This recommendation suggests a modest additional improvement in full load efficiency (modeled at 0.52 kW/ per ton) and chiller capacity control using variable frequency drives (VFDs).
- Reduced Fan Power Requirements. A focus on reducing fan system pressure requirements during design can translate to reduced velocity through filter and coil sections within the air handler, reduced average air velocities in the external ductwork, and improved aerodynamics at duct fittings and take-offs. The goal is to reduce fan power requirements by 10% relative to applicable energy code requirements. This would also include specification of premium efficiency motors for all AC motor applications. This was represented in the prototype models as an overall reduction of about 75 kW (100 bhp) in total fan power throughout the facility.
- Reduced Exterior Lighting System Load. As a prescriptive recommendation, the goal is to reduce exterior lighting power requirements by 20% relative to applicable energy code requirements. This was represented in the prototype models as an overall reduction of 4 kW.

As a package, the prescriptive recommendations of GGHC are predicted to reduce the energy consumption of a modern code-compliant hospital by about 20% (See Figure 2.0). This is a significant reduction, however, it remains well short of the implied performance of the 2030 challenge, and highlights the need to identify design strategies beyond the basic systems efficiency thinking. Subsequent

strategies sets, or “bundles,” that have been analyzed begin to view the energy performance issue from an integrated design perspective, and are logically organized with an initial emphasis on loads.

Load Reduction Strategies: A set of load reduction strategies were identified as a next logical set of additional design strategies to layer into the GGHC bundle. These included:

- Optimized orientation, siting and fenestration location. Optimized orientation and siting often translates to creating dominant north and south-facing façades that facilitate cost-effective solar control strategies related to fenestration design. Initial energy modeling assumptions included optimized orientation and reasonable glazing in the baseline model as a starting point. Thus, this element of the load reduction strategies did not result in additional efficiency performance beyond what was already assumed for a new code-compliant hospital.
- Operable windows in public areas and patient rooms, as allowed by code. From an energy perspective, operable windows are assumed to support a simple natural ventilation strategy, where windows can be opened during days with mild outdoor conditions and provide ventilation and cooling functionality. Controls interlocks with perimeter HVAC systems would allow fan systems to turn down, resulting in reduced fan energy use and cooling/heating energy use. Various State codes place limitations on the use of operable windows in patient rooms, although in Europe it is commonplace. For purposes of initial energy modeling, very limited energy “credit” was allowed for this component of the load reduction strategy set.
- Perimeter zone daylighting. All perimeter zones equipped with significant windows can be outfitted with electric lighting controls that respond appropriately to light levels within the daylit spaces. This was predicted to reduce electric lighting energy use in these spaces by about 20% annually.
- Energy Star equipment. This is an opportunity for energy efficiency in hospitals that remains to be developed in depth. There is general lack of knowledge about the market choices for general and specialty energy using equipment that is commonly located in hospitals, particularly in the diagnostics and treatment areas. Today’s micro-computer electronic equipment market does offer such choices, and a 2.5% reduction in miscellaneous equipment energy use was assumed to be associated with this element of the load reduction strategy set.

As a package, the load reduction strategies were predicted to reduce the energy consumption of a modern code-compliant hospital by only about 22% (an additional 2% improvement over the GGHC set). This is a not a significant reduction, however, there are several strategies in this set that were not subjected to analysis in the initial round of energy modeling work, i.e. optimized orientation and siting. In addition, a strategy set element related to overall interior electric lighting design warrants future inclusion in an expanded load reduction set, but was not part of the set of strategies initially identified within this work to date. It is anticipated that potential energy use reduction associated with a refined set of load reduction strategies (to be developed in future work) could exhibit predicted energy use reduction of 4% to 6% relative to the GGHC set.

Alternative Mechanical Systems: Identification of a number of potential alternative HVAC system concepts was collected under the heading of alternative mechanical systems. These included:

- Solar thermal water heating sufficient in design to provide at least half of the required thermal energy for potable water heating over the course of a year.
- Use of 100% outside air (OSA) VAV systems that are equipped with air-to-air heat recovery. Minimum heat recovery effectiveness was established at 50%.
- Radiant heating and cooling with dedicated OSA ventilation systems.
- Displacement ventilation systems.
- Zonal HVAC systems, i.e. 4-pipe fan coil units.

The design implications associated with the concepts in this strategy set are profound. These ideas represent fundamental changes in design approach for the mechanical systems, and would be expected to exhibit a degree of mutual exclusion, i.e., if one concept is chosen others may no longer be applicable. Many of these concepts are not able to be comprehensively modeled by today’s energy

simulation tools. For the initial work, performance of these alternative concepts were developed using supplementary engineering calculations that used energy modeling results as calculation inputs. A simple average of the predicted EUIs for each alternative was calculated as an initial projection of the estimated performance associated with implementation of code-compliant alternative mechanical systems. The resultant average represents a overall energy use reduction 32% below the baseline (an additional 10% beyond the load reduction set).

Central Energy Plant Strategies: Implementation of alternative HVAC system concepts is expected to be inherently limited by current code requirements. Thus, reheat energy is still expected to be the significant energy end use (See Figure 2.0, next page). Central plant heat pumping concepts offer the potential to dramatically reduce the site energy requirements associated with the space heat and re-heat loads. Performance associated with a combination of condenser heat recovery and a ground-coupled central heater-chiller plant was estimated. Energy use reduction was predicted to be about 52% below the current average energy use of Pacific Northwest hospitals. This is a performance threshold that meets the current 2030 challenge goal.

Innovative Control Strategies: This strategy set assumes comprehensive application of occupancy sensor control for lighting and HVAC system, where allowed by code and functional requirements. Energy end uses associated with lighting, fans and pumps, heating, and cooling were assumed to be reduced by an additional 5%, bringing the overall energy use reduction to 55% below the current average energy use of Pacific Northwest hospitals.

On-Site Energy Generation: On-site energy generation was defined as photovoltaic (PV) systems applied comprehensively to rooftop and parking area. PV capacity of about 2200 kWdc, modeled within the climate context of the baseline model (Boise Idaho weather) results in an overall EUI just below 100 kBtu/SF•year.

Initial Energy Performance Results

A series of energy models, in combination with supplemental energy calculations, were developed to parametrically analyze the different strategy sets describe above. The energy modeling was based on a typical 225 bed acute care program enclosing about 480,000 SF of space with fairly conventional massing (Figure 1.0). A base diagnostic and treatment platform has two levels with a 5-floor patient tower stacked on top and a small medical office building (40,000 SF) located adjacent to the hospital. Boise, Idaho weather was used for the modeling.

Energy consumption was predicted, in total and by the end use to identify the savings impact of each strategy set. The strategy sets were modeled using a “rolling baseline” approach starting with a code-compliant prototype baseline that was extensively reviewed and calibrated to represent a reasonable match to measured and observed energy performance in actual hospitals. Each strategy set was sequentially added to the overall building model so that the results show the incremental improvements associated with each strategy set. In some cases, particularly for alternative mechanical systems that are not explicitly supported by the DOE2 system mathematics, supporting calculations were used to supplement the energy modeling predictions.

Design integration in hospital design implies a complete re-evaluation of the system concepts that have evolved over the past 30 to 40 years as accepted design solutions. It also requires a re-examination of common design practice where iterative assessment of loads and associated system solutions must start at the onset of a project and occur in close coordination with the ownership group, entire as well as the design and construction team. A substantial cultural shift for both client and design team may be required to achieve this kind of energy use performance. First, design goals and directives

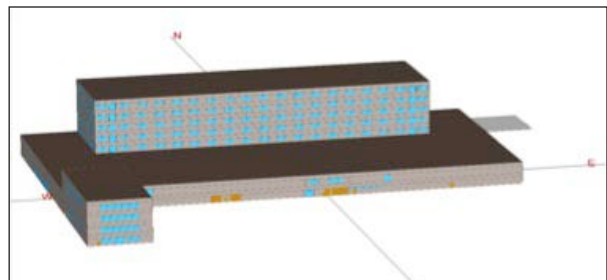


Figure 1.0: EQuest representation of theoretical hospital simulated through this research effort. The energy modeling was based on a typical 225 bed acute care program enclosing about 480,000 SF of space with a 2 level base diagnostic and treatment platform and a 5-floor patient tower stacked on top; a small medical office building is (40,000 SF) located adjacent to the hospital.

Sustainable Healthcare Energy Challenge: Approaching the 2030 Challenge

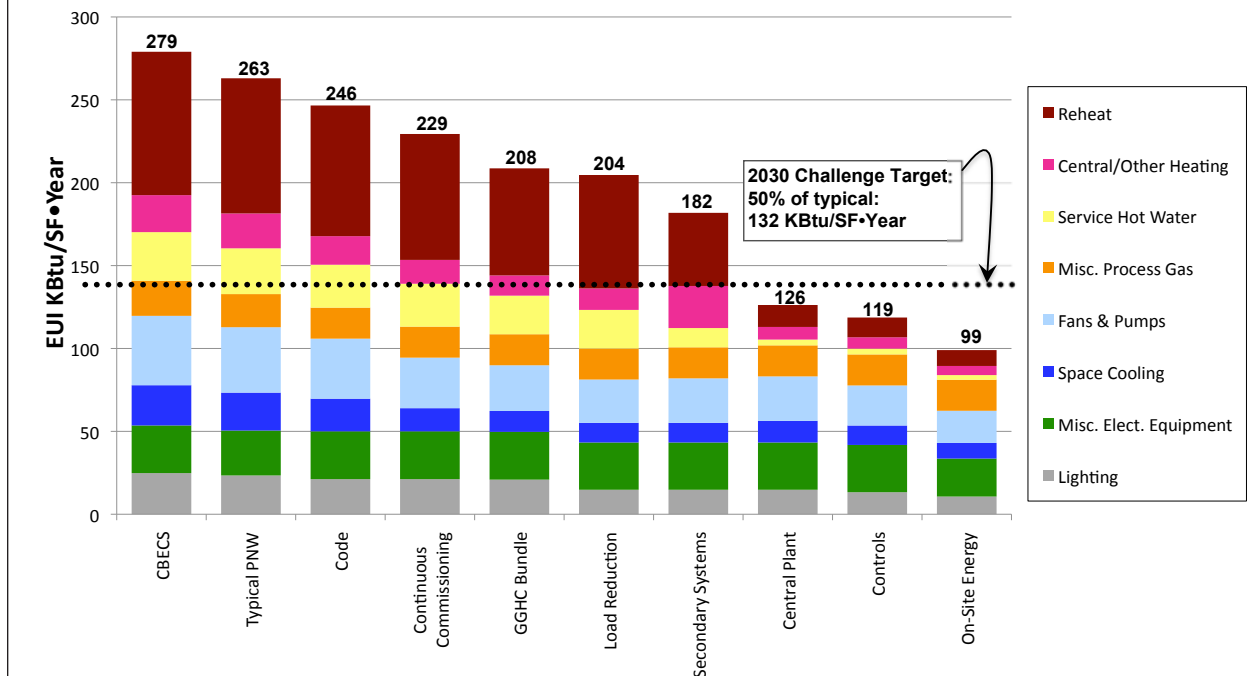


Figure 2.0: Summary of the energy use characterization developed from actual hospital observation and strategy set simulation. Colors represent the energy predicted to be required for different end-uses from heating to lighting. The first two bars represent typical performance for existing hospitals, using information from the Commercial Buildings Energy Consumption Survey (CBECS) database and from the regional database for Pacific Northwest, representing specific hospitals in Montana, Idaho, Oregon, and Washington. The third bar represents simulated performance for an energy and healthcare code compliant hospital, located in a climate similar to Boise, Idaho. Its EUI is predicted to be about 245 KBTu/SF-year, with the largest end use associated with re-heat.

The remaining bars show the sequential energy use predictions associated with each of the design strategy sets discussed above. The horizontal dashed line identifies the 2008 energy performance threshold associated with the 2030 Challenge. Initial results show that compliance with the 2030 Challenge is possible for new hospital design in the United States. While the potential for this performance appears to exist, it is important to emphasize that there are no currently identified hospitals in the US that are actually performing at this energy use level. Designs that achieve this performance will do so by integrating a number of strategies focusing on mechanical systems, but will not be exclusively limited to those systems. An integrated design approach is likely to be required to achieve the most successful result.

for energy must be established. Then performance targets that establish a path to those goals need to be developed. Computer modeling and simulations are necessary design tools for the team to use in order to test the energy and comfort performance of the emergent design against the stated goals. This is an iterative process that requires constant check-in, reiteration, and interaction within the project team. The healthcare organization must maintain a vision of energy efficiency that is communicated from the onset of the project. The design team must work together to implement strategies to achieve the energy goals. Ultimately, a substantial commitment must be made on the part of the organization to adopt a maintenance and operations philosophy that focuses on energy efficient performance as one of the important goals and use continuous commissioning as one of the integral strategies. Thus, the design's energy efficiency potential will be fully realized in actual operation.

Lessons Learned

Several big ideas have become apparent from the research and evaluation work completed to date. They are lessons learned from direct observations on the operations side of hospitals and from the evaluation of the initial simulation data.

- Avoid or minimize re-heat needs. For hospitals in temperate climates reheat represents the largest energy end use, with much of the energy use caused by the inherent over-cooling nature of ducted air systems. Reheat energy can be reduced by creative zoning and control strategies, or large-scale adoption of alternative system concepts such as fan coil units that do not rely on reheat.
- Identify all sources of waste heat and implement heat recovery strategies. Waste heat is being rejected in the exhaust air stream, waste water stream, from cooling system condensers, from oil coolers and after-coolers in the compressed air and vacuum pump systems, and from basic equipment in heating plants, laundries, kitchens, and laboratories. Most of the energy in these waste heat streams is not recovered. New and creative heat recovery solutions, such as heat recovery chillers and modular ground-coupled heat pumping offer the potential to meet most if not all of a hospital's space and potable water heating needs with recovered heat instead of imported fossil fuel.
- Focus attention on reducing or eliminating other systems-imposed loads. In addition to reheat, fan heat represents a significant component of the overall cooling load for a conventional hospital system design. Ventilation represents another significant load component, for both heating and cooling systems. Both of those load categories should be addressed by design solutions, either alternative systems or separate ventilation pre-tempering solutions.
- Address excessive zone-level loads with architecture solutions. While the system-level and facility-level load issues in today's hospitals are about systems choices, the zone level loads are often about architectural choices particularly in perimeter zones such as patient rooms. Refined architectural design solutions addressing fenestration are one of the key envelope design opportunities to avoid creating peak hourly load conditions that drive zone level peak air flow rates (and zone level air system component sizes) significantly above code-required minimums.
- Work with applicable state agencies to undertake a review of air flow related code requirements. A systematic effort by design teams to address the issues listed above, will likely result in spaces where the peak cooling loads translate to peak air flow rates that are lower than code-required minimums. Codes appear to be in need of comprehensive review that considers infection control issues, modern energy code-driven envelope designs, and the emerging societal focus on energy use reduction.

Energy use in hospitals: High Performance Examples

To this point, the considered strategies and their resulting energy performance were merely schematically simulated numbers. In practice each of these concepts reduces energy, but there are few, if any, built examples in the US demonstrating actual performance of integrated, high performance systems that greatly reduce energy consumption below the Pacific NW average energy use.

When embarking on new methods for designing systems, it is helpful to look to others who have already been successful in implementing these strategies. Scandinavia is a leader in sustainability and has focused on increasing building energy efficiency for far longer than the US. Scandinavian hospitals can serve as a useful resource to evaluate for achieving energy reductions in our hospitals.

The Integrated Design Lab (IDL) began an analysis of actual energy use in Scandinavian hospitals in conjunction to the research that was being undertaken to achieve significant theoretical energy reductions in US hospitals. During this research, a presentation was given by White Arkitekter at HealthDesign 2007. They showed their design for the New Karolinska Solna project, and presented the overall energy strategies for the project, including a projected overall EUI of 50 KBtu/SF•year. To put this in perspective, that is 1/5th the amount of energy used for an average operational Pacific NW hospital.

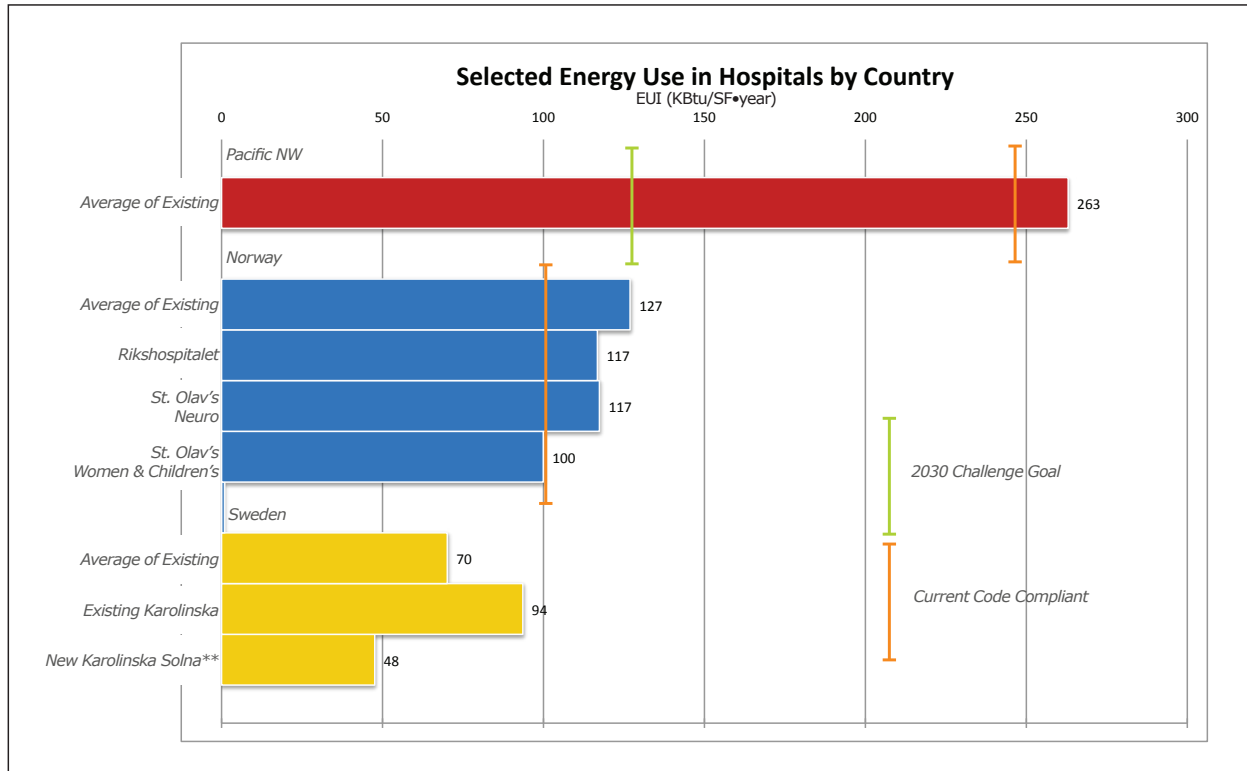


Figure 3.0: A representation of the average energy use of hospitals in Scandinavia compared the Pacific NW. This data shows that Norway (blue) uses about half the amount of energy for hospitals than the Pacific Northwest average (red), and Sweden uses about a quarter (yellow).

The drastically reduced energy use for the proposed New Karolinska Solna project prompted the IDL to realize the importance in understanding the energy use in operational hospitals throughout Scandinavia and understand how those hospitals compare to US hospitals. Figure 3.0 compares the energy use of Pacific NW hospitals (red bar) to Norway (blue) and Sweden (yellow). Norwegian hospitals use about half the amount of energy as Pacific NW examples and Swedish hospitals use about one quarter the energy. In each group, the top bar represents the country's average energy use for hospitals and the lower bars represent specific examples: In Norway, Rikshospitalet and St. Olav's; in Sweden, the existing Karolinska. The New Karolinska Solna modeled projection is also represented as the final bar on the graph. These hospitals are not only energy efficient, but embody high indoor environmental qualities that make them high quality places to heal, work, and visit. The hospitals represented in this paper will be described in more detail later in the Case Study section of this paper.

Understanding how these operational hospitals, and the design for the New Karolinska project, are able to reduce energy use by such a substantial factor is a key component to solving the energy equation in US hospitals. While the US is trying to decrease energy consumption by one-half, Scandinavian countries have proven that this is possible. Simultaneous to our efforts of reducing energy by 50%, these countries are working on similar conservation efforts, but starting from an already reduced operational benchmark. Thus, projections for new hospitals in Scandinavia show overall energy reductions that will surpass ours by over five times.

The reduced energy use in these Scandinavian projects is remarkable, especially the Karolinska Solna model. To create a clearer picture of how energy conservation is undertaken in Scandinavia, the IDL forged an in-depth relationship with the design team at White Arkitekter and at the MEP firm ÅF. The first step to understanding the fundamental differences between Scandinavian hospitals and Pacific NW hospitals was to compare the energy end uses between the two. These energy end use estimates are compared in Figure 4.0, where the New Karolinska Solna energy model is compared to the most aggressive energy reduction model that the SHEC group identified (meeting the 2030 challenge) and the Pacific NW code baseline. Overall, The New Karolinska Solna model estimates that the new

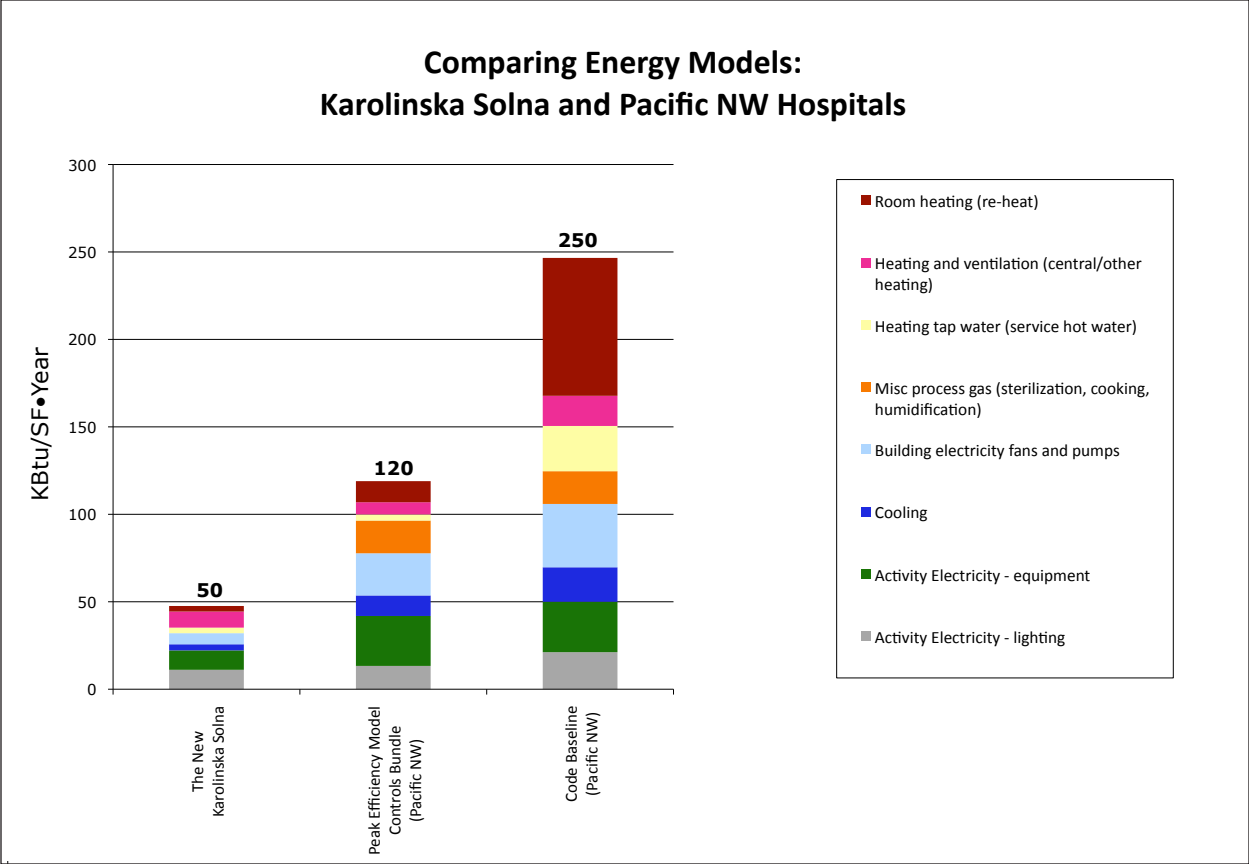


Figure 4.0: Comparison between the New Karolinska Solna energy simulation model, Sustainability Healthcare Energy Challenge most aggressive efficiency model and Pacific NW baseline.

hospital will use half the amount of energy from even the most aggressive model that was identified in the SHEC research project. The biggest differences in energy use between these models are in room heating, re-heat, heating tap water, and electricity for fans and pumps. Ultimately, in the Swedish model, it becomes clear that the thermodynamics of the building are being maximized to their fullest potential. The US is not reaching full capacity in thermodynamic utilization, and is paying a penalty in energy consumption. Another difference that emerges in this analysis between the Swedish and Pacific NW models is the “activity electricity” figure, that is, plug load. This is a number that is affected by the number of machines, computers, and equipment that are being used in the facility. One hypothesis for why the difference is so great between the two models is possible cultural differences between the care delivery systems. The number of scans and tests may be accelerated in the US because of the care delivery system. The number of computers, equipment, and number of hours that they are operated are also potentially very different between the two systems.

Projects like The New Karolinska and others highlighted in this paper use a variety of strategies to radically reduce energy loads. These Scandinavian examples provide a roadmap for improved energy performance in the US. Most importantly, in order to maintain such a low energy profile, a complete re-envisioning of the overall system configuration must be undertaken. The following strategies are specific approaches that The New Karolinska Solna and other Scandinavian hospitals have adopted to significantly effect lower energy use. Since our building standards and codes are different than in Scandinavia, some of these approaches would require code variations in order to be utilized in the US.

Key Energy Concepts:

- Re-formulating the Building Envelope Geometry & Thermal Performance
- Daylighting
- Reformulating the HVAC Systems:
 - Severely limiting use of re-heat
 - Reduced Air Change Rates (two liters/second/meter³ for patient rooms typ.)
 - Displacement Ventilation with Radiant Heating & Cooling
 - Heat recovery from ALL internally generated heat sources
 - Ground Source Heat Pumping for majority of heating and cooling

New regulations in Sweden are driving lower energy use in buildings, including hospitals. Southern Sweden's maximum energy use, "building energy use" regulation for any new commercial building is 100 kWh/SM•year (32 kBtu/SF•year). Thus, any energy used for building systems, heating, cooling, and ventilation must fall below that number or must be produced by alternative sources. For buildings like hospitals with high ventilation rates (above 0.35 l/s,m²), a provision is allowed to increase energy use based on increased air flow rate. In Southern Sweden the additional allowed energy is calculated by $70(q-0.35)$ where q is the average flow of external air during the entire heating season. "Activity electricity," electricity used for plug load and lighting is not included in this figure and can be in excess to these energy provisions.

There is also a new European Union directive that will require energy labeling of all new and remodeled buildings for their energy use. There are definitions of how this energy must be metered and which conditioned areas should be included in the calculations. Energy use will be easily traceable for all of these buildings, for everyone. This will make benchmarking and creating comparisons between projects much easier. It will also create awareness about the amount of energy that buildings produce in an open, direct way.

Section II: Environmental Quality in Hospitals

Indoor Environmental Quality

While the primary focus here has been on energy and reducing energy consumption, high quality environments for patients, visitors, and especially staff are equally important in the healthcare setting. High quality healing environments have been well recognized and established for patients and continue to be critical part of design parameters. For staff, however, there is vast room for improvement to create more supportive workplaces. The hospital workforce is a chronically stressed population making life-or-death decisions working 12+ hour shifts. They often work without a glimpse of daylight, a view from a window or a place of respite away from this chaotic environment. There is vast room for improvement in our hospitals. Scandinavian examples that provide a roadmap to energy efficiency also present examples for incorporating high quality indoor environmental quality into the hospital environment.

High quality attributes such as daylight, view, green space, and fresh air are imperative components to high performance hospitals. Light is necessary for visual performance, and daylight is critical for human health; this is even more so than we recognized even five years ago. Views and green space provide visual, mental, and physical places of respite. Fresh air provided by an operable window, natural ventilation, or alternative mechanical systems can provide fresher, cleaner air, potentially at lower energy costs. Thus, all of these quality drivers can contribute to better healing, working, and visiting environments for those that use the facility. Figures 5.1 – 5.3 on the following page illustrate daylight, view and fresh air in a staff area, visitor waiting lounge and in a patient room. These spaces, in European examples, demonstrate how quality drivers can be incorporated in hospitals providing more comfortable environments for patients, visitors, and staff.



Figure 3.1: Nursing Station at Meyer Children's Hospital, Florence Italy. Natural light is brought in from two sides to this workstation; from one side, a small lightwell brings daylight deep within the building to a space that is essentially underground. From the other side, light comes in from a children's play-area, also providing a view outside.



Figure 3.2: Waiting Area at Radium Hospital, Oslo Norway. This space has a view to the natural landscape of the site, opening to the view with a generous two story volume. The juxtaposition of art, nature, and daylight create a soothing waiting environment for this oncology treatment waiting area.



Figure 3.3: Patient Room at St. Olav's Women and Children's Centre, Trondheim Norway. This patient room has generous windows for daylight. The windows are automatically controlled with exterior louver blinds that can be adjusted from the bedside. There is also a small deck that can be accessed directly from the patient room, providing fresh air and the opportunity to be outside. This example also shows the shift to single patient rooms in Scandinavia. Scandinavian designers look to the US for our approach to patient centered design, while we look to their design for attention for staff and energy efficiency creating an opportunity for cross-cultural exchange.

Light, Daylight and Health

Light has a significant impact on our quality of life, and impacts our perception of a quality environment. Most research to date has focused on our visual response to light and its effect on our functional vision and task performance. Recent discoveries in photobiology highlight the fact that daylight also has a significant impact on health, productivity, and learning. This research underscores the importance of incorporating natural light into the built environment, especially in healthcare facilities. Significant to these findings, is the importance of the cyclical nature of light, the specific spectrum of light and the intensity of light that people are exposed to.

For millennia, people worked in the day and slept at night. With the advent of the industrial age and "night" lighting, we have slowly taken over the night as a time of wakefulness, and therefore work. As our wakeful hours shift deeper into the night, or similarly as we work farther and farther from daylight during the day, we are seeing that there are photobiological implications for our health and wellness. There are two dimensions to the relationship between light and health; the role of vision with visible light and "what we commonly see", and the effects non-visible light on "what we don't see." This non-visual aspect may not be "seen," but it greatly affects human chronobiology and the endocrine system.

Light and the "non-visual": In 2002 a novel, non-visual, photoreceptor was discovered in the human eye (Berson 2002). This receptor is essential for mediating bodily rhythms and systems and is regulated primarily by light and dark cycles. Thus, our eye is responding to two parallel responses to light; one for vision and one for physiological regulation. This newly discovered non-optical receptor is connected through its own pathway through the superchiasmatic nucleus in the brain, and triggers a multi-synaptic light induced pathway that communicates to other non-visual parts of the nervous system. This process acts as a clock, oscillating on daily (circadian) and seasonal (circannual) rhythms.

Many physiological responses are activated and regulated by light entering the eye and triggering this non-visual photoreceptor. For example, body temperature, and the hormones cortisol and melatonin are regulated by this process. These two hormones play important roles in governing alertness, sleep, regulating blood sugar, and maintaining the immune system. An imbalance in these hormones over a long period exhausts the system causing fatigue, stress, and loss in the body's homeostatic balance.

In a natural setting, where we have access to natural light, the body synchronizes its internal clock to the changing nature of sunlight. In environments where we have less access to natural light, these biological systems can be significantly disrupted. In a recent study of nurses, night shift work has been associated with increased risk for cancer (Dimich-Ward, 2007). This suggests that exposure to light at times of day that we have not adapted to over thousands of years can have a significant negative effect on our health and is potentially very deleterious over a long period of time.

Scientists have also discovered that the color of light that stimulates the circadian clock is slightly different than the color that is used for the visual system. The maximum visual sensitivity lies in the yellow-green region of the light spectrum, whereas the non-visual system perceives light that is shifted into the blue spectrum. Thus, blue light is more potent for stimulating physiological responses through the non-visual system. Human beings evolved with different colors of light shifting throughout the course of the day. The sky ranges in color from blue in the morning to red in the evening. Similar patterns are necessary for our non-visual response to light. For optimal health, the human eye would receive blue light during the day, warm light in the afternoon (without high intensity blue light), and red light or no light at night.

The amount of light that is necessary for human health is a research topic that is currently under investigation. Although dose response and daylight have not been fully quantified, the relationship between daylight and its positive effect on human health has been well documented. As Daniel Kripke M.D. at UCSD points out in his research, most people, even in a very sunny climate, do not have enough access to natural light on a daily basis.

Light and the "visual": We are dominantly visual beings; as much as 80% of our perception of the world around us occurs through our sight. Providing the most appropriate quantity and the best quality of light are keys to a productive, well perceived, and healthy environment. An electric light fixture mounted on the ceiling of a patient room, nursing station, or in a break room can commonly provide the same amount of light as a window with a view. If lighting is considered only within the dimension of the quantity of light provided, electric and natural sources of light might compare equally. If

considered more appropriately, there are multiple dimensions to visual and non-visual perception of light, and therefore, quality lighting. For example:

- Natural light sources can provide views and visual relief as well as environmental information. Sources of light provide environmental information such as the spectral quality of the light and the variation of the light source over time and across a space.
- Quality lighting should enhance seeing and provide views of nature in all patient rooms and nursing stations, and spaces where staff work for more than several hours. Seeing a view to nature reduces chronic stress, thus is critical in a hospital.
- Windows and their immediate surrounding spaces should be designed as critical interior spatial light sources and access portals to the exterior environment. In this way, the interior and exterior space fuse and the exterior space becomes part of the hospital. Achieving this goal will provide views of the outdoors that link patients and staff to outside environmental information through observations of the day's weather and daily or seasonal variability in the rich landscape of plants and changing daylight.
- The varying tasks within the hospital should be expressed appropriately for the functional program. Distinctions for the variable needs of light need to be expressed in a quality lighting design for a healthy, productive work and healing environment.

The discovery of a non-visual light responsive receptor that regulates physiological processes highlights the fact that light must be thoughtfully examined in the built environment. The biggest architectural implication for light and human health is designing a building that creates as much opportunity for accessing daylight as possible. Our non-visual system has evolved to respond to natural light, thus it is critical to provide spaces that work with the natural rhythms of the environment and allow occupants access to natural light. To achieve this relationship, the building form will be thinner and have more surface area, thus more opportunity for natural light. Spaces that have been traditionally thought of as 'dark' spaces can even have windows incorporated to include natural light. This thinner plan building can then be complemented with an electric lighting scheme that takes into account the importance of limiting the amount of blue light exposure in the evening and allows complete darkness at night including rooms that are free from light "leaking" from corridors, computer monitors, and equipment at night. Many of these instruments have blue wavelength displays; it is critical that these are filtered or eliminated from patient rooms, and care is taken to provide the staff with the most adequate wavelengths of light for their chronobiological adaptation.

Daylight, View, and Green Space

Many of the attributes that we associate with daylight are also commonly attributed to view. It has been very difficult in the real world, however, to separate the effects of daylight from the effects of a view. Views help provide information about place, time, and weather and give visual relief from interior surroundings. But, information such as the spectral quality, variability, and the photobiological aspects of light are not necessarily linked with view. However, we do know that people prefer to have a view (DiLouie, 1996), and in some studies a natural view has been attributed to faster healing times, reduced stress, and use of less analgesic medication use (Ulrich, 1984, Ulrich 2002 and Edwards, 2002). Places to access the outdoors are also important, not only for patients, but also for staff. Often times referred to as "healing gardens" in hospitals, these spaces can take many forms. Creating green space within urban sites can also have a positive ecological effect, creating permeable surfaces and decreasing the overall heat gain of the facility. Thus, green space that is integrated throughout the exterior of the hospital creates an opportunity for places to see from the interior, and places to be outside for staff and for patients while also softening the ecological footprint of the overall facility.

Fresh Air and Personal Control

The aspects of fresh air can range from an operable window to alternative mechanical ventilation systems. In Europe, nearly all hospital windows are operable, providing occupants with a sense of control over their interior environment, a connection with outside, and a more home-like atmosphere. This level of control has been shown to increase the typical thermal comfort range, which if capitalized on can save a significant amount of energy (Brager, 2004). The psychological aspects of having a connection to one's surroundings and the greater world are also beneficial in the healing environment, or any environment. Beyond having an open window, aspects of fresh air can include re-thinking

traditional ventilation strategies such as adopting natural ventilation or displacement ventilation. Natural ventilation is used for common spaces in several of the case study examples in this paper, and ongoing research efforts in the UK strive to incorporate natural ventilation into more aspects of the hospital. Displacement ventilation is also used in several of these case study examples, in patient rooms and even in operating rooms. All of these aspects of “fresh air” point out that there are alternative approaches for thinking about the configuration of hospital architecture and ventilation that can accommodate a more comfortable experience, as well as energy efficiency.

Section III: 20th Century Hospital Prototypes

Historical Progression of Hospitals in the US

To understand the context of contemporary hospital examples in Scandinavia, it is important to look at a historical context and evaluate how the typology of hospitals has evolved through time to become the building typology that we know today. In the Victorian Era, Florence Nightingale was a very influential figure in hospital design. Nightingale’s passion for creating a better healing environment for patients prompted her to write *Notes on Hospitals* in 1863 outlining her priorities for designing hospitals. Her approach to creating ideal healing environments for patients not only looked at the physical surroundings, but also looked at the social welfare of her patients. She focused on providing patients with access to natural light, air, landscape, attention to diet, as well as a clean, sanitary environment. Nightingale’s principles were first implemented in H. Currey’s design of St. Thomas’s Hospital in London, which was built between 1861 and 1865. Nightingale’s observational approach led her to understand the qualitative aspect of light, view, and fresh air that we are just beginning to acknowledge as so critical in the healthcare design field today. St. Thomas’s and other pavilion type hospitals reflect a form that embodies the humanistic principles that she outlined as being so important for patient health and healing. These pavilion ward hospitals were influential for decades, including in the US until the beginning of World War II.

With the growth of medical practice and technology it was necessary to move to a new hospital typology. In the hospital boom following World War II, Nightingale’s original concept of hospitals with fresh air, light, and views was replaced by deep plan hospitals that prioritized functional efficiency over human comfort and healing. The hospital form began to shift from a pavilion style to what is referred to as a “podium on a platform” typology. A typical hospital configuration became a deep span, multi-floor block (or platform) with a patient tower placed on top (as a podium). Building technology aided in this transformation with a new ability to create long span structures, mechanically ventilate interior spaces, and move people vertically with elevators. It is estimated that at the peak of this typology nurses spent 40% of their time in patient transport logistics (Jones, 1995). Circulation patterns were confusing, without any external cues of directionality, setting or hierarchy. Ultimately, the attitude of the hospital as a well-tuned machine took precedent over more human factors for the patients, staff, and visitors to these facilities. Designers and builders maximized the machine-like efficiency of hospitals without evaluating how these changes in form related to human health, stress, and comfort. In the United States we have maintained a similar hospital typology since the first major hospital building boom after World War II. We are still building hospitals with very deep floor plates and subterranean spaces with little or no relationship to the outside environment.

Historical Progression of Hospitals in Scandinavia

A re-examination of the typical block hospital form, the podium on a platform typology, occurred in Northern Europe as early as the 1980s. A changed form of the hospital created more human scale facilities that allowed more access to daylight, outdoor space, fresh air and ultimately are very energy efficient facilities. This re-examination of form began with the design of a Norrköping Hospital in Northern Sweden. The design of this hospital was carried out for over a decade with numerous re-designs through the process. Initially, a fairly typical hospital was designed. However, through time the design transformed into a new conceptualization of departmental relationships in the hospital. Ultimately, a horizontal relationship between diagnostic and treatment facilities with patient wards was established. This opened the possibility to allow light, air, and view into traditionally “dark” spaces and also decreased the restrictions that occur with vertical transportation of patients.

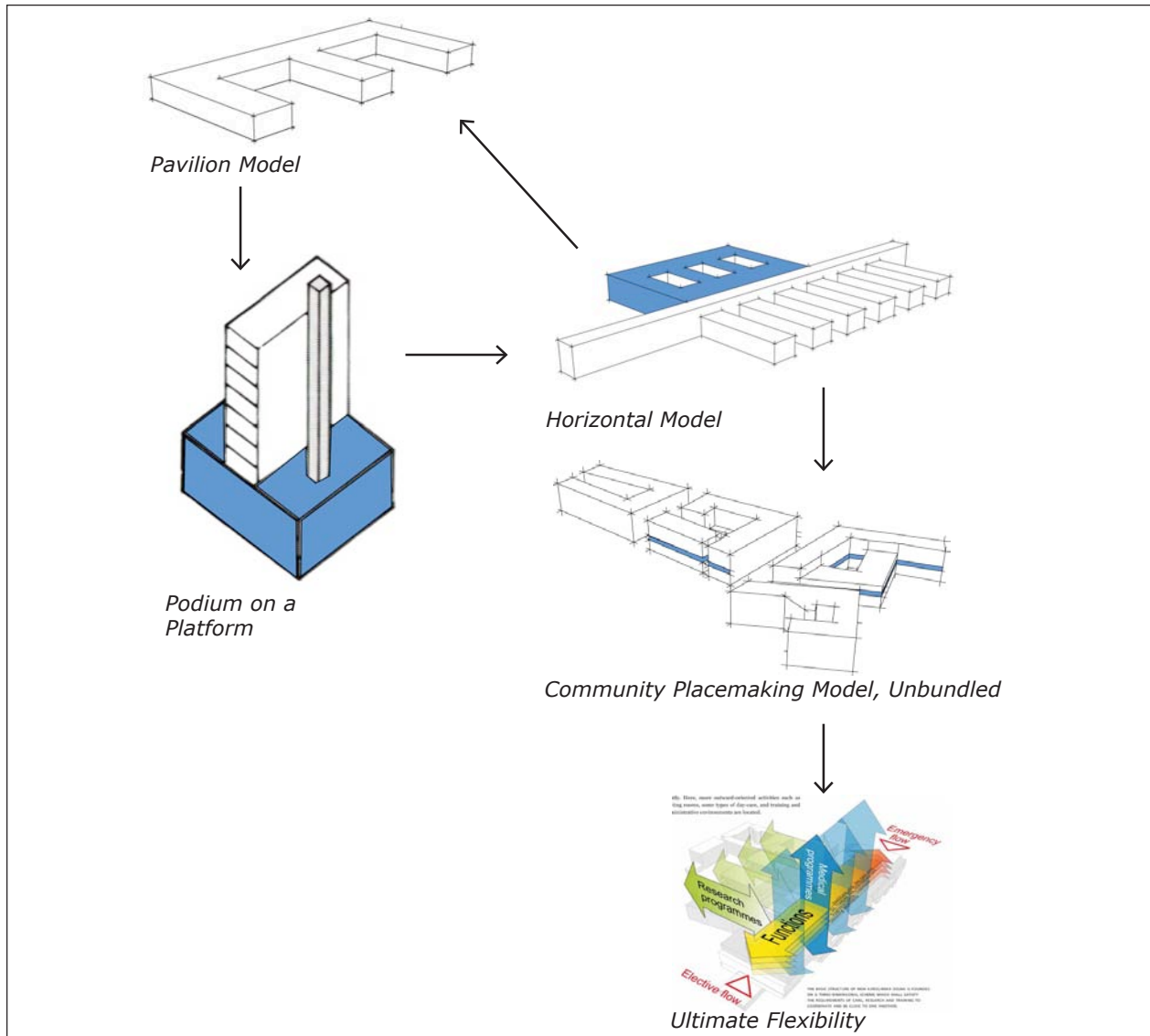


Figure 5.0: Historical progression of hospital form in the US and in Scandinavia. From the Pavilion model to the Podium on a Platform typology. In Scandinavia, a change in form has emerged. Horizontal pavilion hospitals and unbundled hospitals are being built and the newest concept is a hospital that provides ultimate flexibility in function for change through time.

The design of Norrköping hospital began a sea change in hospital design that continues to change and grow in Northern Europe. The horizontal typology then evolved into a layering approach, where the hospital is more integrated into the urban landscape. This idea of “community placemaking” is an urban design concept that frames the hospital as an enterprise that plays a greater role in its surrounding community. These designs incorporate an unbundled approach where several buildings serve as clinical centers of excellence, clustering together to form the overall hospital. This decentralized approach combines the ideas of the block hospital and the horizontal typology with imaging, surgery, and bed floors located in each block of these centers of excellence forming small hospitals within the larger hospital facility. The final approach that is taking hold in Northern Europe is ultimate flexibility in programmatic distribution. This concept combines the urban placemaking typology and layering approach, and incorporates mechanical and structural design that allows any programmatic function to reside in any place within the building. This eliminates the problematic floor-to-floor height variations and organizational and programmatic changes that are inevitable over the life span of a hospital.

Section IV: Case Studies

Case Study I – Rikshospitalet



Figure 6.0: Interior “street” at Rikshospitalet, Oslo Norway.

Location: Oslo, Norway
Architect: MedPlan AS
Mechanical Engineer: Techno Consult and IGP
Opened: 2001
Beds: 585
Energy Consumption: 117 KBtu/SF•year

Rikshospitalet showcases the shift in typology from a predominantly vertical distribution to a horizontal distribution. This contemporary pavilion hospital draws its inspiration from Victorian hospital models, adapted to today’s contemporary practice. Rikshospitalet is the large National University research hospital that serves specialized patients from all over Norway. The whole hospital is designed with the human scale in mind, and this philosophy permeates the design. Its functional areas are organized as if the building is a town unto itself. The four main zones are: town (public areas, streets and entrance areas), city block (auditoria, staff canteens, libraries), workplace (examination rooms, treatment areas, laboratories), and home (wards, common rooms) help to break down the scale of this large hospital. The main circulation occurs on an interior “street” that serves as the main conduit through the hospital. This interior street is daylight and naturally ventilated and the long distances that this horizontal distribution creates is overcome with staff using tricycles and scooters for transport on this level. These attributes make this space truly feel like an active “streetscape.”

The wards and diagnostic and treatment areas in this hospital are horizontally opposed, and circulation between the two occurs on sky bridges that span the interior street. This shift in form creates the opportunity for plan-enclosed courtyards in the diagnostic and treatment area of the hospital, allowing daylight and views into spaces such as surgery and imaging. While these traditionally dark spaces have windows, opening the envelope for daylight and view, they are also very well controlled with three levels of shading that can be operated by the occupants as necessary. Every opportunity for daylight is capitalized on here; recovery rooms that are not on the perimeter have operable skylights creating natural illumination in the space as well as natural ventilation. For staff, the nursing stations all have access to a perimeter window.

This pavilion form incites a challenge in the floor-to-floor height variation between the treatment building and patient wings. In this example, the treatment floors are layered with interstitial floors so that they match up in section with the patient wing floors. This challenge becomes a benefit for the hospital. These interstitial floors allow for easy maintenance of systems, fast re-construction, and limit the disruption that occurs on the clinical floors.

Windows are operable throughout the hospital. There are also opportunities throughout the hospital to go outside on balconies, and many patient rooms on the ground floor have doors that open directly onto grassy courtyard patios. Patient rooms use displacement ventilation rather than a traditional overhead mixing system to deliver fresh air to the room. Radiant panels provide most of the heat in the room and there is little cooling in patient rooms. Thus, room tempering has been separated from the ventilation system. Typical overhead mixing systems rely on dilution of the air; therefore, more air changes per hour are required to provide increased ventilation in the room. Displacement ventilation supplies cool fresh air low in the space and as the air heats up the natural buoyancy of

warm air causes it to rise, ideally in a laminar piston effect. The goal of displacement ventilation is to condition the space at a lower air change rate, and to carry contaminants directly up away from the occupants and exhaust them as quickly as possible. It is hypothesized that displacement ventilation is equal or better than overhead mixing systems for comfort, ventilation effectiveness, and airborne particle control. Substantial research efforts by Mazzetti and Stantec are being undertaken in the US to determine the validity of these hypotheses and the viability of displacement ventilation systems for hospitals. Displacement ventilation can provide substantial energy savings since ventilation is largely separated from room tempering and fewer air changes per hour are required. In this example, the air change rate is equivalent to two Air Changes per Hour (ACH). In Washington State the minimum ventilation requirement for patient rooms is four ACH if ventilation is separated from tempering and 100% outside air is used. Typically, however, a minimum of six ACH is used and as high as 12 ACH depending on the zone, cooling loads, and if VAV boxes are installed and operational. Thus, displacement ventilation (here at a rate equivalent to 2ACH), has the potential to save a substantial amount of energy, but would require either change in code, or exceptions in code, in order to be implemented in the US in acute care facilities.

In 2007, Rikshospitalet used 117 KBtu/SF•year total energy. This is approximately 50% of the typical Pacific NW energy use for similar acute care facilities. Thus, Rikshospitalet provides an operational example of achieving a 50% reduction in energy use, while providing high quality environments for patients, for staff, and for visitors.

Case Study II – Akershus



Figure 7.0: Interior “street” at Akershus, Oslo Norway.

Location:	Oslo, Norway
Architect:	CF Møller
Mechanical Engineer:	AF Statkraft Grøner/ Theorells
Opened:	2008
Beds:	735
Energy Consumption:	Est. 60 KBtu/SF•year

Akershus was completed in the Fall of 2008 and is a very recent example of the contemporary pavilion style hospital. It was designed by CF Møller and displays their Danish design roots in its clean, straight lines in comparison to the more organic nature of Rikshospitalet. This hospital demonstrates that this form with horizontal adjacency between treatment block and patient wings is still relevant for the Norwegian hospital system.

The hospital form is similar to Rikshospitalet, but the systems approach is even more contemporary in this example. 40% of the heating and cooling for the hospital is renewable energy using a combination of ground source heat pumping and seasonal energy storage. The state-of-the-art systems include a closed loop ground source heat pump with 350, 200 Meter bore holes. The project also re-captures waste heat from systems equipment, medical equipment, lighting, people, and other heat generators. In this sense, this project has solved the thermodynamic equation, saving a substantial amount of wasted heat and energy in the process. The estimated energy use for this hospital (60 KBtu/SF•year) is 77% below the Pacific NW average energy use in hospitals (260 KBtu/SF•year).

Case Study III – St. Olav’s



Figure 8.0: Central Courtyard at St. Olav's Women and Children's Centre, Trondheim Norway. This hospital maximizes places to be, and places to see outside even in an urban setting.

Location:	Trondheim, Norway
Architect:	MedPlan AS, Frisk Arkitekt AS (Phase I) and Narud Stokke Wiig (Phase II)
Mechanical Engineer:	COWI, Gunnar Karlsen
Opened:	Phase I, 2004-2006; Phase II, 2009-2015
Beds:	802
Energy Consump.:	100-117 KBtu/SF•year

St. Olav's Hospital in Trondheim Norway is an example of a contemporary hospital designed with "community placemaking" in mind. Here the horizontal concept is pushed even further, with buildings spread apart into separate distinct centers of care that act as individual hospitals. Connectivity between the campus is maintained at the second level via sky

bridges and underground through service functions. Each of the buildings preserves its own unique architectural character allowing the buildings to be recognized and distinguished from one another while softening the potential overwhelming institutional rhythm that might otherwise be created in such a large facility. This unbundling of the building into separate centers of care allows each building to be built at the standard that is appropriate for the building type. For example, the laboratory is much different than the Women and Children's Hospital, which is in turn much different than the on-site Hotel. Ultimately, this saves on the total construction of the building and creates a campus-like atmosphere, rather than one homogeneous institutional building. The development of the hospital campus, on the same site as the original hospital, is being carried out over several phases. The first clinical centers were completed in Phase I: the research laboratory centre (fall 2005), and the women and children's centre (March 2006); the neuro centre (June 2006); and the hotel St Olav (Sept 2004). Construction for phase II is currently underway, which includes: gastro centre (fall 2009), knowledge centre (summer 2013), heart and lung centre with emergency (January 2010), and a mobility centre (fall 2009). Additionally, construction is currently underway for a new gerontology hospital and nursing home. The entire project is slated for completion in 2015.

The Women and Children's Centre is a great example of providing outdoor space and views within an urban setting. Every opportunity is taken to create spaces to be outside, throughout the hospital. The hospital is a thin plan building that wraps around a large central courtyard. Patient rooms have doors that step directly onto upper terraces on the courtyard side, which are planted and have play equipment. Rooms on the street side of the corridor have small one-person balconies. There are also rooftop terraces adjacent to staff areas and throughout the rest of the hospital so that outdoor space is successfully incorporated throughout the hospital. Generous windows daylight the patient rooms and provide light in the surgery suites. Daylight is controlled on all of the façades (except the north façade) with automated exterior louver blinds that move with the movement of the sun. Micro-adjustments of the shading system can be varied so that occupants can have control over their environment.

St. Olav's monitors their energy use separately for each centre of care. the laboratory building uses more energy (142 KBtu/SF•year) than the Neuro Centre (117 KBtu/SF•year), which in turn uses more energy than the Women and Children's Centre (100 KBtu/SF•year). For Phase II, the energy target is estimated to be 100 KBtu/SF•year.

Case Study IV – The New Karolinska Solna



Figure 9.0: Rendering by White Arkitekter of the New Karolinska Solna project in Stockholm, Sweden. This hospital will revitalize this area of Stockholm and is the most contemporary example of indoor environmental quality and energy use in a hospital to-date.

Location: Stockholm, Sweden
Architect: White Arkitekter
Mechanical Engineer: ÅF Consult
Opened: Projected 2016
Beds: 600
Energy Consumption: 50 KBtu/SF•year

The New Karolinska Solna was presented earlier in this paper as being very innovative in how it is reducing energy use lower than any other hospital project to date. Overall, the energy model for Karolinska Solna shows a 30% reduction in energy use from the average Swedish hospital that is operational today and it shows an 80% reduction in energy use from typical Pacific Northwest hospitals are in operation today. It is also architecturally the most contemporary hospital project that is being designed in the world today. White Arkitekter's approach incorporates the ideas of commu-

nity placemaking that is used in St. Olav's and combines that with a more compact, general, flexible approach. The building is designed with a general floor-to-floor height, load bearing capacity, and service installations enabling any programmatic function to reside in any place within the building. Like in the St. Olav's model, there are separate "lanterns" of care that create distinct hospitals within the larger hospital. Within this distribution, each floor has been planned with stacking program of support, clinic, surgery, diagnostics, and wards. The concept is that there is a gradation in the intensity of care from most urgent to elective functions. However, the building's generalist design for structure, mechanical system, and services allow for ultimate flexibility. That is, if the hospital decides that this programmatic organization should shift, it can. Thus, surgery and imaging can reside anywhere within the building. An interstitial "activity core" provides space for mechanical equipment and service installations and creates a space where equipment can be updated or repaired without disrupting the clinical functionality of the floors. Redundancies have also been designed into the systems of the building. ÅF Consult in Stockholm serves as the mechanical, electrical and systems engineer on the project. Each of the building cores has a service loop system that is served from four points. If one point is taken out, the other three are sufficient for fully serving the area in need. This redundancy and loop system allows for flexibility, redundancy, and robustness in all of the systems for the hospital. The hospital floorplate is designed on a nine meter square modular grid with space for two patient rooms or one operating suite to be placed within that 9M² module. The central core of the building is 12 meters wide and allows space for light wells that drive down through the building creating the opportunity for light and air even in the central part of the floorplate.

The hospital buildings are adjacent to a large research facility that is accessed across an exterior "academic mall" via skybridges, similar to the pavilion concepts of Rikshospitalet and Akershus; here the "street" is exterior space weaving together the academic and clinical environments. The hospital is sited in a very dense, urban part of northern Stockholm and the city of Solna. The project will recreate the urban street grid at the surface level, and bury a major transportation artery that exists on the surface today, simultaneously creating a new mass transit stop. The hospital will not just be an institution, but will revitalize this part of Stockholm, creating new shopping, jobs, a transportation hub and hotel rooms. In this way this project becomes much more than just about the hospital and what happens inside its walls. It is about reclaiming the community and making it a better place. White Arkitekter describes the project as, "...one of Sweden's most comprehensive hospital projects ever, and a decisive venture in the realization of the vision of Stockholm and the Mälardalen area as the world's premier life science region." Sustainability, flexibility, and high architectural integrity supporting patients and staff are all top priorities for this huge hospital venture in the central part of Stockholm.

Section V: Energy Management Planning

The Business Case

When carefully considered, lower energy use can be the hallmark of improvements in the quality of the healthcare delivery environment; less energy use can produce more, and at an improved quality.

In working with hospitals and hospital systems to put energy into a strategic planning perspective, conversations with executives and ownership teams show that energy is often not even considered, and these groups are often unaware of the high energy implications in hospitals. This is of course not new information for facility managers, who manage the facility's operating budget that pays \$2-3M in utility bills annually. But CEO's and CFO's are much less aware of energy and the role that it is playing in relationship to the overall financial health of the institution; 2% of an overall operating budget for energy seems to be a small piece of the total investment for the hospital. When CEOs were surveyed at the end of 2008 about the things that were most on their mind, issues in relationship to the status of the hemorrhaging economy and their overall investment portfolios were first and foremost on their minds. That is, their job is first and foremost about cost control.

Even though energy is not on many executive teams' minds, cost control and reduction is something that they care about a lot. But, hospital executives don't necessarily see energy conservation as a cost reduction issue. Improving patient outcomes, attracting patients, healing times, staff retention and quality issues that we see so clearly in the Scandinavian hospitals can all be really important issues for cost reductions. So can reducing energy use. In not-for-profit typical net-operating income (NOI) hospital environments, it can take \$20 in gross income to produce \$1 in net-profit. A typical hospital can easily require an excess of \$2,000,000 for natural gas and electricity in a typical year (at current fuel costs). Thus, a targeted 50% reduction in annual energy end use in a 5% NOI business environment has the effect of adding approximately \$20,000,000 in revenue generating services. The CEO or CFO of a hospital does not typically think of money being saved in energy as equivalent to other opportunities for income, or what other kinds of net revenue the hospital would have to generate in order to attribute that same amount of bottom-line profitability for the institution. This is where executives start to slow down and think for a minute; they have never had energy efficiency projects pitched to them where it wasn't just talked about in terms of pay-back, break-evens, or cost-recovery.

Instead of simple pay-back, energy efficiency can be thought of an on-going revenue stream over the lifetime of that investment that actually exceeds what they can get in relationship to making investments in other medical related practices and disciplines that they might bring to the hospital. Since the executive team is interested in cost control, there is potential to resonate the very attractive high yield low risk investment in energy efficiency and it proves to them that there is a significant opportunity here for actual returns on their investment. This is true if they consider the tried and true technologies for their existing facilities or start to think about the more cutting edge technologies in relationship to new hospital facilities they might be building in the future. Getting this business case message into the executive level is important so that they will be more responsive to ideas that are brought to them not only by their facilities managers, but also by design teams for new construction when they present ideas that dramatically reduce the typical cost of energy. This prepares them to be thinking from a different perspective; from a simple pay-back mentality where this kind of investment might be considered high risk and low yield to a point of view that is more strategic: low risk and high yield.

Strategic Energy Management Plans

The Putnam Price Group has worked with specific hospital systems in Washington State to develop strategic energy management plans. Making the plans, formalizing those plans, and getting an executive commitment to those plans started with benchmarking the organizations' existing facilities. You cannot manage what you don't measure. Thus, the first step was to create baselines of the performance of the hospitals; how is energy being used in these facilities today, what are the energy related business practices, and what are the performance metrics in relationship to how well the institution is operating today. Based on that data, the institution can think strategically to set realistic energy performance goals based on their current practice. For example for an existing facility it is very reasonable to think about an energy savings of 15-20% over time, if the existing institution uses 250-275

KBtu/SF•year. The next step is to help the organization set up an energy accounting and reporting system to make sure that they attain that number and persist that energy savings over time. This strategic energy management plan might also be setting goals in relationship to what new facilities might want to achieve. For new facilities, 250-275 KBtu/SF•year should not be the goal anymore; perhaps 100-150 KBtu/SF•year should be the new goal for new design and construction of hospitals since there is demonstrable evidence to show that this is achievable. Without having a measurable performance target to hold facility managers and design teams (who are hopefully working in an integrated, collaborative design process) accountable to from the owner's side, energy performance will likely not reach the potential that is hoped for. "Give it your best shot" is not going to put the strength and passion behind the design process that is necessary to meet the aggressive goals that the executive teams have agreed to in the strategic energy management plans. If executive teams benchmark their facilities, commit to a performance goal, and hold design teams responsible for energy performance then it challenges everyone to actually make changes in the design process to meet those goals. Through work with executive teams, successful strategic energy management plans have been initiated with a number of hospitals in Washington State, and progress is being made on meeting the goals set forth for existing facilities, and also for new construction. These plans begin to pave the way for reduced energy use, measurable results, and cost control for the hospital systems.

Measurement and Verification; during design and after construction

"You can't manage what you don't measure..." to paraphrase Edwards Deming, the father of continuous quality process improvement. Deming was asked during World War II to assess the fast changing and immense manufacturing processes for American military equipment. Total quality process improvement was founded in that assessment, now 70 years ago. It is well known that after the war he volunteered his expertise to the American automobile industry so as to improve quality and reduce costs in the American automobile manufacturing processes. His expertise was shunned. In the 1950's Deming left for Japan where he consulted with their auto industry and founded the continuous quality management movement within industrial engineering, largely the basis of LEAN process improvements today.

One of many strengths of Deming's innovative industrial engineering system was periodic monitoring and verification during the manufacturing process of a product's ability to meet its authors' design expectations. For Deming, what comes out of an assembly process should never be a surprise, because its goals were clear and the assembly process was measured, verified, and perfected during a highly integrated design and manufacturing process.

The building industry operates in a very similar fashion today in relation to its automobile cousin from the 1950's. Goals are set for performance during the programming process, and with minor exceptions few tests are made of its potential performance during design, or construction. The high-performance integrated design (id) process we are advocating requires objective energy and interior environmental quality goals setting during the pre-design and master planning process. At this point, the methods and timing for early periodic assessments, simulations, of progress towards those goals are established. The scope of work for each team member in the id process is defined and funded.

This work will provide all the members of the design team the assurances that they need as to how the work is progressing towards meeting its various process goals, including energy and interior environmental quality performance. The team is setting goals and managing the course of project development by continuously measuring the quality of the process outcomes. The development of a high-performance hospital requires significant improvements in our expectations for building value and improved skills in managing the project outcome so that we can 1) test the viability of a variety of design and construction strategies and 2) give dependable progress results to owners when they are concerned with measuring and verifying performance. This will lead to better design and resources that are well spent by all members of the healthcare building industry.

References

- Architecture 2030. "The 2030 Challenge". http://www.architecture2030.org/2030_challenge/index.html
- Berson, D., Dunn, F., Takao, M. "Phototransduction by Retinal Ganglion Cells That Set the Circadian Clock." *Science*. 295 (2002): 1070-1073.
- Brager, G., Paliaga, G., de Dear, R. 2004. "Operable Windows, Personal Control and Occupant Comfort." *ASHRAE Transactions*, 110 (2004), 17-35.
- Dimich-Ward, H., Lororenczi, M., Teschke, K., et. al. "Mortality and Cancer Incidence in a Cohort of Registered Nurses from British Columbia, Canada." *American Journal of Industrial Medicine* 50 (2007): 892-900.
- Dilani, Alan. *Design and Care in Hospital Planning*. Stockholm: Karolinska Institute, 1999.
- DiLouie, C. "Quality Metrics." *Architectural lighting*. 10(1996) 50-53.
- Edwards, L., Torcellini, P. *A Literature Review of the Effects of Natural Light on Building Occupants*. Golden: National Renewable Energy Laboratory, 2002.
- EIA, 2006 Energy Information Administration (EIA), *Commercial Buildings Energy Consumption Survey (CBECS)*. US Department of Energy, 2006., 2003.
- . "Energianvändning i vårdlokaler: Förbättrad statistik för lokaler, STIL 2." ER 2008:09. Energimyndighetens publikationsservice, Sweden, 2008.
- The Green Guide for Health Care. <http://www.gghc.org/>.
- Gulick, R. "Displacement Ventilation In Hospitals." *Engineered Systems*. July 1, 2007.
- Jones, W. "Acute Care Design: Emerging Trends." In *Innovations in Healthcare Design: Selected Presentations from the First Five Symposia on Healthcare Design*, edited by S. O. Marberry, 12-20. New York: John Wiley & Sons, Inc., 1995.
- Joseph, A. "The Impact of Light on Outcomes in Healthcare Settings" Concord: The Center for Health Design, 2006.
- Ulrich, R. "Health Benefits of Gardens in Hospitals." Plants for People International Exhibition Floriade, 2002.
- Ulrich, R. "View Through a Window May Influence Recovery from Surgery." *Science* 224 (1984): 420-321.
- Van Bommel, WJM and van den Beld, GJ. "Lighting For Work: A Review of Visual and Biological Effects." *Lighting Res. Techol.* 36.4 (2004): 255-269.
- Verderber, Stephen. *Healthcare Architecture In an Era of Radical Transformation*. New Haven: Yale University Press, 2000.
- White Arkitekter. *New Karolinska Solna University Hospital, Project Programme*. Stockholm City Council, November 2007.

Citation:

Burpee, Heather, Hatten, M., Loveland, J., and Price, S. "High Performance Hospital Partnerships: Reaching the 2030 Challenge and Improving the Health and Healing Environment." Paper presented at the annual American Society for Healthcare Engineering (ASHE) Conference on Health Facility Planning, Design and Construction (PDC). Phoenix, AZ, March 8-11, 2009.