



## Building design and performance: A comparative longitudinal assessment of a Children's hospital



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### ABSTRACT

The aim of this study was to conduct a whole-building analysis using a host of metrics, including green building metrics, with the goal of providing designers and healthcare providers quantitative data that can be used in their design and operations decisions. The intent was to fill a gap in the research, which previously analyzed only individual rooms, specific design elements, and green building metrics. Therefore, a comparative longitudinal assessment was completed that quantified the effects of building design on performance of a pediatric healthcare facility by comparing a new, LEED-certified hospital relative to its previous, traditional counterpart. This study found statistically significant improvements in productivity, staff satisfaction, and quality of care, including a 19% decrease in actual mortalities despite an 11% increase in expected mortalities (both  $P = 0.005$ ). Children's energy consumption and electricity per square meter decreased over 50%, while water and sewage intensity decreased over 60% (all  $P < 0.001$ ). In their LEED-certified facility, Children's significantly improved their productivity, quality of care, and staff satisfaction, in addition to utility intensity. These improvements can be credited to green building design, mechanical equipment upgrades, and organizational or cultural shifts related to Magnet nursing designation.

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## 1. Introduction

The design and aesthetics of a medical treatment facility impact not only the energy consumption of the hospital but also the performance of the staff and the recovery of the patient receiving treatment within the facility. As a place that serves a vulnerable subset of the population, reports assert that hospitals should be the most rigorous in implementing environmentally sustainable design practices and environmental stewardship [1–5]. Many studies point to Evidence-Based Design (EBD)<sup>1</sup> as a method of improving hospitals' performance and healthcare outcomes. However, continued investigation, especially at the whole-building level, is needed to show the relationship between health and building design and to monitor the actual performance of new building design, especially for green healthcare facilities [6,7].

For the past 7 years, researchers worked with the Children's Hospital of Pittsburgh of UPMC (Children's) staff to quantify the effects of holistic building design on the function and performance of a children's healthcare facility. Using a range of standard hospital reporting metrics in this longitudinal comparative analysis, data was collected to compare the old Children's hospital to their new, LEED-certified facility (Leadership in Energy and Environmental Design) [8]. With metrics of hospital expenses, productivity, quality of care, staff satisfaction, and utilities, researchers show the actual performance of a new hospital including the effects of green building design and managerial practice on the health and safety of the building's occupants.

### 1.1. Research question

Children's 2005 decision to build a brand-new, LEED-certified facility created a unique opportunity to examine the actual performance of a new hospital and the effects of green design on hospital users and occupants. The aim of this study was to conduct a whole-building analysis using a host of metrics, including green building metrics, with the goal of providing designers and

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<sup>1</sup> Children's Hospital of Pittsburgh of UPMC (Children's), Evidence-Based Design (EBD), Leadership in Energy and Environmental Design (LEED), Patient in Bed (PIB), Adverse Drug Event (ADE), Registered Nurse (RN).

healthcare providers quantitative data that can be used in their design and operations decisions [8]. The intent was to fill a gap in the research, which previously analyzed only individual rooms, specific design elements, and green building metrics.

### 1.2. Children's Hospital of Pittsburgh of UPMC case study

Built in 1926, the original Children's Hospital of Pittsburgh of UPMC (Children's) was located in the Oakland neighborhood of Pittsburgh, Pennsylvania. After multiple renovations, it was decided the 260-bed, 37,160 m<sup>2</sup> hospital would be replaced entirely with a new facility in Pittsburgh's Lawrenceville neighborhood [9]. Designed in 2006 and opened in 2009, the new Lawrenceville campus was built using an existing healthcare structure and features nearly 139,000 m<sup>2</sup> of hospital and administrative space, 296 patient beds, and the 27,900 m<sup>2</sup> John G. Rangos Sr. Research Center. The new hospital features daylighting in every room, a green roof and healing garden, a majority of individual and private patient rooms, and mobile nursing stations. With building materials containing recycled content, water-efficient landscaping, and low VOC (Volatile Organic Compounds) interior finishes, the new facility became one of the first LEED-certified (version 2.1) pediatric hospitals in the US and an ideal case study to better understand the impacts of hospital design decisions on the hospital's performance.

### 1.3. Background and theory

A landmark 1984 study found that patients randomly assigned to a corridor with windows overlooking trees were discharged to home about one day earlier than those assigned to rooms with windows overlooking a brick wall [10]. Since then, studies emerged confirming the positive effects of certain design features in medical facilities by analyzing changes in employee and nursing turnover, medication dispensing errors, and hospital acquired infection rates [11–16]. Two design aspects in particular, noise control and natural or appropriate lighting, have been well-studied in hospitals and are associated with increased staff satisfaction and performance, and improved patient outcomes including reduced stress, shorter hospital stays, and reduced pain medication rates [17–25]. This growing field of Evidence-Based Design uses existing research and knowledge to make design decisions in healthcare structures in an effort to improve performance outcomes. These outcomes are monitored, tested, and reported to promote future EBD projects [26]. Most EBD studies, however, focus on specific design decisions such as number of windows or sink orientation and narrow metrics such as length of patient stay or employee turnover [27–29]. Few studies analyze an entire hospital with metrics ranging from staff satisfaction to energy use – metrics that are commonly used by key decision makers.

Such large scoping studies are increasingly important with the adoption of green design within healthcare facilities. Green buildings are designed to be more resource-efficient and environmentally sustainable, and the LEED certification program, which issues formal green building status to structures meeting their design criteria, is considered an indicator of a building's environmental performance. Children's was designed to meet LEED for New Construction version 2.1, which was released in 2002. In 2007, the United States Green Building Council (USGBC) partnered with the Green Guide for Health Care (GGHC) to create a green building standard and certification program specifically for healthcare facilities. The LEED 2009 for Healthcare standards are based on LEED for New Construction and awards points for location and public transportation accessibility, water efficiency, energy performance, the reuse of existing buildings and materials, and reduction in building materials containing certain chemicals to improve indoor

human health [30] LEED for Healthcare aims specifically to provide nurses, doctors, and hospital staff with a safe and comfortable working environment which is “vital both to their health and to the health of their patients” [31–34].

The projected benefits of green buildings – whether hospitals or otherwise – can be difficult to quantify, and it is unknown if green buildings are performing as intended, especially in regards to health concerns associated with the indoor environment [35]. Studies focused on green building performance have analyzed metrics such as worker productivity, developing surveys or analyzing company-collected data such as employee absenteeism or sick leave [6,7,36]. One aspect of green building design in particular, the indoor air and environmental quality (IAQ and IEQ), has been linked to worker health and productivity in multiple studies [37–40]. Other studies have found that natural and sustainable daylighting not only reduces energy demands, but also helps people with perceptual and circadian functions and results in a more positive perception of the work environment [17,41]. As green building design and LEED certification are adopted for use in healthcare facilities, large-scale EBD studies which analyze the entire structure rather than individual design features, may help assess the overall effectiveness and performance of green hospital buildings.

## 2. Methods

In order to perform this comparative longitudinal assessment of the two Children's facilities, metrics were collected, statistically analyzed, and validated with hospital staff via the methods described in this section.

### 2.1. Comparative longitudinal assessment

In 2006, researchers collaborated with Children's executive management team to identify a host of metrics to monitor in the study. Metrics were sorted into the following categories: Expenses, Productivity, Quality of Care, Staff Satisfaction, and Utilities. These metrics, a sample shown in Table 1 and full definitions listed in the Supplementary Material, were chosen for multiple reasons. Children's already collected these data for management and reporting purposes, which minimized time and cost for data collection and retrieval, and enabled retrospective data collection and analyses [42]. The use of standard hospital metrics also makes the study methodology easily replicable in studies at other healthcare facilities. Additionally, these data analyzed the costs and benefits of green building design in a more tangible sense, directly influencing green economic methodology [8].

Children's Hospital generally provided researchers with data in the identified metrics from July 1999 until November 2012. The hospital reported data on a monthly, quarterly, and yearly basis, depending on the metric, as seen in Table 1 of the Supplementary Material. Data prior to May 2009 were considered “pre-move” or old hospital data; data from May 2009 to present were considered “post-move” or new, LEED-certified hospital data.

Some data, due to changes in collection methods or facility size and function, needed to be normalized for comparison. All expenses and monetary data were normalized to the value of the 2009 US dollar. Utility data was collected for functionally equivalent spaces in the two Children's facilities. For example, the main hospital in the pre-move Children's campus contained space for administration, standard hospital care, and testing laboratories. Equivalent space in the new facility and the utilities consumed in that space were included in the comparison.

It must be noted that Children's former facility was not conditioned in every space and was functioning under older

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