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## Net-Zero Energy within Budget: The First Net-Zero Energy Public Library in Indiana

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### ABSTRACT

In 2007, a feasibility study for a new branch library in the small rural community of Chrisney, Indiana (pop. 534) revealed that the branch could only be built if it had virtually no operating costs, due to the limited capacity of the local library district for new operating expenditures. That paramount constraint was countered by the enthusiasm of the citizens, who filled the local gym for several planning meetings. This constraint also led to the conclusion that this would have to be a net-zero-energy building or it could not be built. In 2007, the Town of Chrisney obtained a grant from the Indiana Office of Community and Rural Affairs to construct a branch of the Lincoln Heritage Public Library system. North Spencer County School Corporation donated an acre of land adjacent to the elementary school outdoor nature lab. With the addition of local fundraising, the community secured funds to erect a 2,400 square foot library for approximately \$416,000. The project opened to the public in April 2009. Among a multitude of integrated design systems, certain design features and analyses proved instrumental to achieving the project's ambitious energy goals. In addition to net-zero energy performance (the building actually produced 1,861 more kilowatt-hours than it consumed in its first year), the project proved to be very cost-effective. The building, its mechanical system with geothermal heat pump, its electrical system, the photovoltaics, and all other associated systemic components were constructed and installed for approximately \$155 per square foot – significantly below the projected project cost.

### 1. INTRODUCTION

This article describes a transformation occurring within the architectural/engineering spheres of the building construction industry that allowed this small, but technically challenging project to achieve success on a minimal budget. With the advent of building information modeling (BIM) and increasing demand by clients for high-performance structures, a bridge is being forged between the realms of energy modeling and architectural building modeling. Today, a number of commercial and non-commercial building analysis platforms are becoming accessible to design teams, fostering an unprecedented opportunity for integrated, multi-disciplinary project delivery and a guided design decision making process based on information provided by computer models that take climate data and project information to simulate actual building performance. This project proved that it is possible to achieve net zero energy on a budget and that type of ambitious goal also proved helpful capturing enough interest to obtain the necessary grant funding.

## 2. STRATEGIES TO ACHIEVE NET-ZERO ENERGY

Early in the project, the owner and the project team decided to pursue the goal of net-zero (purchased) energy consumption as the only way to achieve a near-zero operating cost. Among a multitude of integrated design systems, certain design features and analyses proved especially instrumental to achieving the project's ambition energy goals. In general, these elements can be grouped into four broad categories:

- Energy Modeling.
- Mechanical Systems.
- Building Envelope.
- Renewable Energy.

Each of these categories will be expanded upon in turn.

### 2.1 Energy Modeling

With a gross floor area of 2,400 square feet and a meager design budget, the project team did not have the financial resources to hire a specialized energy modeling firm to run a comprehensive energy analysis on the library's design. However, the team was experienced enough to realize that a goal of net-zero energy could only be achieved by taking advantage of every opportunity to optimize all building systems in an integrated manner. Simple design rules-of-thumb would not suffice. The design team looked inward and decided to take advantage of an emerging field of commercial and non-commercial software platforms that have been designed to make detailed analyses more accessible to design professionals than ever before.

The chosen site for the public library is located in a lightly wooded area adjacent to the local elementary school in Chrisney (Figure 2). Modeling of on-site solar resources was analyzed to determine where solar access was most widely available on the site for a proposed photovoltaic array. Going beyond design rules-of-thumb and approximations based on perceived site obstructions from foliage, the design team used devices in the field to determine exactly what portions of the skydome would be obstructed by trees and any other nearby objects. A detailed solar access study revealed that certain locations would allow more direct sun to reach the solar panels than other locations. The goal of the design team was to find the optimal location for the solar panels that would provide the greatest degree of solar access and require the least amount of tree removal to ensure that cast shadows would not short out the on-site power generation from the panels. This led to a strategy to put the solar panels in the sun while siting the building in the shade of 150-year-old oak trees. The armature for the solar PV panels, the Learning Power Pavilion, is an outdoor classroom adjacent to the outdoor learning lab of the elementary school. Bifacial solar panels were used to provide the see-through roof of the pavilion. These panels are designed to utilize reflected as well as direct light and they make for an interesting show and tell for students and visitors.

Energy modeling of the building envelope assisted the design team in determining the most cost effective and energy efficient building system for the project. Specified building material finish selections were integrated into the model in order to accurately simulate interior illuminance. Additionally, computational analyses were used to assess renewable energy potential and minimize heating and cooling loads. Systems design were further determined by the additional constraint that this small rural library would not have the technical staff to deal with any more complexity than normally encountered in a residential HVAC system.

Using long-term climate data made publically available from the U.S. Department of Energy, the design team was able to use computer modeling to simulate the location's actual weather patterns to derive a much more accurate sense of how various top- and side-lighting strategies would perform as opposed to relying on oversimplified design rules-of-thumb. Through such daylight modeling, various strategies were investigated in terms of both interior illumination levels and daylight distribution patterns across the library's interior (Figure 3). The design team was aware that high visual contrast due to improper illumination distribution could be just as detrimental to a project's daylighting strategy as inadequate levels of daylight. The modeling enabled the design team evaluate both issues simultaneously as various design solutions were investigated and compared.

The aggregate effect of the various computational analyses employed for this project was a project with proper system siting, a balanced building envelope, and a calibrated daylighting strategy. These tools allowed the design team to leverage building science, local site conditions, and locally-available building methods to make better informed design decisions about the optimal performance/cost ratio.

## 2.2 Mechanical Systems

Purchased energy use was greatly reduced by employing a ground source heat pump (GSHP). By circulating water in a closed loop through pipes installed in two 400-foot deep wells, energy from the earth was drawn at an efficiency that outperforms most high-efficiency hybrid gas furnace heating / air source heat pump systems. Expected savings over an all-electric system are 60% in heating mode and 40% in cooling mode.

Occupancy sensors were installed to coordinate and maximize the potential of the building's daylighting system with the structure's high performance lighting fixtures.

Albeit less quantitative, in the interest of curbing energy use through the operations and maintenance of the library, the users of the building were trained to best operate the building and minimize plug loads.

## 2.3 Building Envelope

The building envelope consisted of a simple 2,400 SF single-story plan over an insulated concrete slab. The wall assembly consisted of 6-inch wood studs at 24-inches on-center with spray foam wall cavity insulation. The attic contained 14-inches of cellulose insulation. The high-performance window assemblies were fully operable, which permits the patrons to take advantage of cross ventilation during the transitional seasons.

The daylighting strategy is a blend of Carnegie-library-era passive design consisting of 11'-0" ceilings and a strategic use of T-shaped glazing arrangements (Figure 4) with the addition of modern dimmable daylighting tubes. Over the course of the design team's daylighting analyses, it became evident that high strips of windows were most conducive to interior illuminance distribution. The team also realized that views to the outdoors would be desirable to the library's patrons. Such considerations had to be tempered against the knowledge that a greater percentage of building exterior wall area attributed to glazing would correlate to a greater heat transfer through the building envelope. The solution: computational daylighting simulations verified that by keeping to an envelope energy budget (i.e. a maximum square footage of total glazing) and differentiating between high clerestory glazing and vertical slits of view glazing, the design team could achieve both adequate interior illumination and views without forfeiting significant envelope energy performance. To help create an interior with well-distributed interior illumination, a tubular skylight system was installed that consisted of a highly reflective, flexible tubing that could bounce light from a tracking mirror in a dome atop the pitched roof, through the insulated attic to the ceiling of the one-story library. Electrically actuated light dampers in these tubes allow the library to be darkened during daytime for presentations.

## 2.4 Renewable Energy

The project utilizes an on-site 8.9 kilowatt photovoltaic solar panel array mounted atop an exposed wood structure. The result is an outdoor *Learning Power Pavilion* that uses the solar panels as a means of shelter while it produces clean, renewable energy. The photovoltaic solar panels were not located on the roof due to solar access considerations. Rather, the array was showcased via the adjacent *Learning Power Pavilion*. Due to the openness of the wood-framed structure, double-sided solar panels employed that have the ability to generate electricity from both sides. The back side of the panels generates electricity from ambient light that is reflected off of the light concrete slab floor of the pavilion. Thus, more power is generated than if conventional photovoltaic panels were mounted atop the library's roof.

## 3. NET-ZERO ON A BUDGET

In addition to net-zero energy performance, the project proved to be very cost-effective. The building, its mechanical system, its electrical system, the solar panels, and all other associated systemic components were constructed and installed for approximately \$155 per square foot – significantly below the projected cost for the project.

The project was also the beneficiary of a tremendous funding effort. In addition to \$88,000 in funds raised locally by the citizens of Chrisney its surrounding areas (and no local taxes), the Indiana Office of Community and Rural Affairs Federal Block Grant for \$447,000 was awarded to the project. A grant from the Indiana Office of Energy Development provided \$24,000 in funding for the photovoltaic array. The Town of Chrisney is donating free water and sewer service and site maintenance for the life of the building, and 100 volunteers from the community help staff the library branch for the Lincoln Heritage Public Library district. This public library has yet to pay a utility bill after more than a year of operation. That is the only way it could have been feasible to build.

#### 4. BUILDING PERFORMANCE TO DATE

The on-site photovoltaic solar panel installation was installed in March of 2009. From April 1, 2009 through March 31, 2010, the system has produced 12,611 kilowatt-hours (kWh) of renewable energy (Figure 5). This information is publically accessible through an online interface provided by the solar panel supplier/installer.

According to metered data provided by the utility company that services the all-electric library, over the same period of time, the library has consumed 10,785 kilowatt-hours (kWh) of energy (Figure 6). This data verifies that the library produced approximately 1,826 more kilowatt-hours (kWh) of energy than it consumed between April 1, 2009 and March 31, 2010.

#### 5. CONCLUSION

Much of the success of the Chrisney Branch of the Lincoln Heritage Public Library should be attributed to a seemingly impossible set of design and budgetary constraints and the integration of the entire design team from the onset of the design process. Bringing the various disciplines together during the schematic design stage proved invaluable as the team sought economically viable design solutions that could help the project approach its goal of net-zero energy.

Another key factor was the utilization of advanced building simulation modeling during the schematic design stage. No longer do design teams need to rely on broad-based rules-of-thumb. High energy performance necessitates a deeper understanding of building science and analysis-based decision making.

For any project pursuing net-zero energy, it is vital that natural energy flows be leveraged through passive solar design strategies. In the case of the Chrisney branch library, natural shade, natural ventilation and a calibrated daylighting strategy helped greatly reduce energy loads – especially during transitional seasons.

Finally, over the course of this project, both the design team and owner became aware of the virtues of understanding how the building's operable systems work. If mismanaged, such design features as operable windows can become major hindrances to the project's energy performance goals.

#### NOMENCLATURE

The nomenclature should be located at the end of the text using the following format:

BIM	building information modeling
GSHP	ground source heat pump
kWh	kilowatt-hours
SF	square feet

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Lincoln Heritage Public Library District

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Owner - after construction

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Local Match (including donations for books and furnishings)	\$88,000



Figure 1: Exterior photograph of the Chrisney Branch of the Lincoln Heritage Public Library



Figure 2: Satellite imagery of the project site prior to construction.

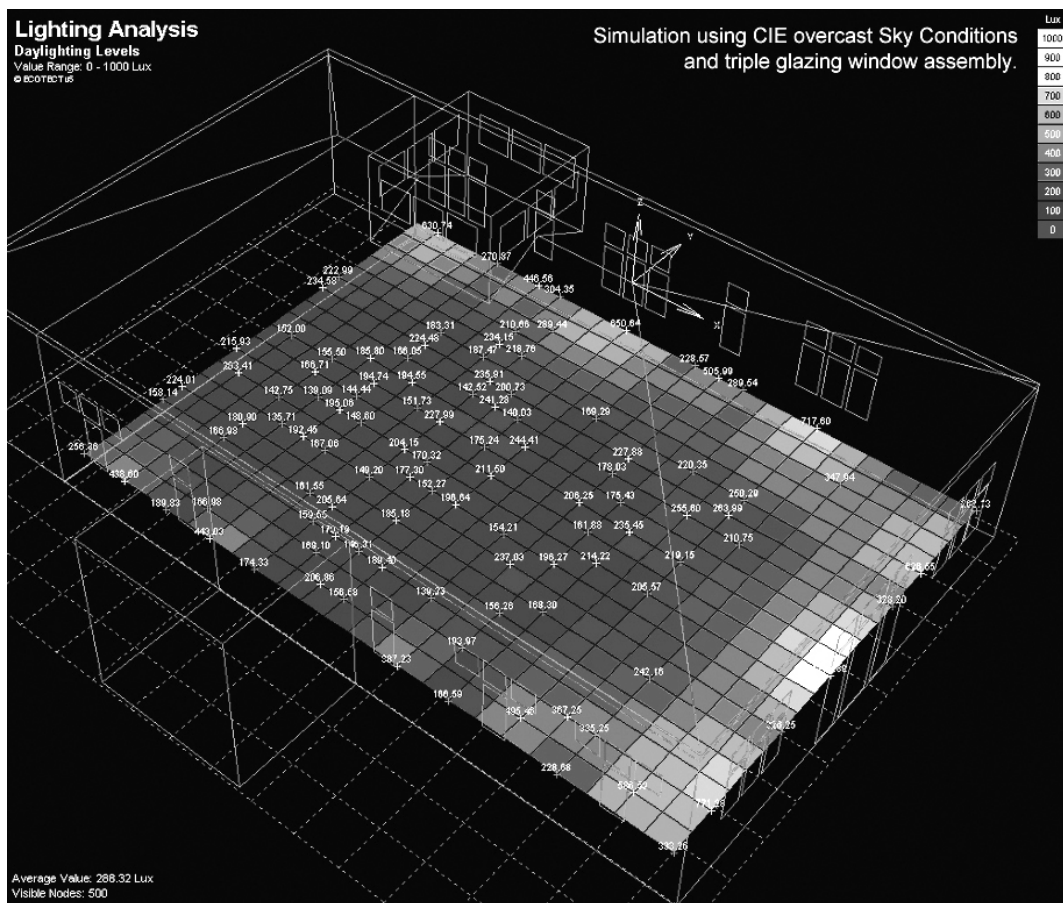


Figure 3: Graphic output from an interior illuminance simulation run.



Figure 4: Interior photograph of the Chrisney Branch of the Lincoln Heritage Public Library.

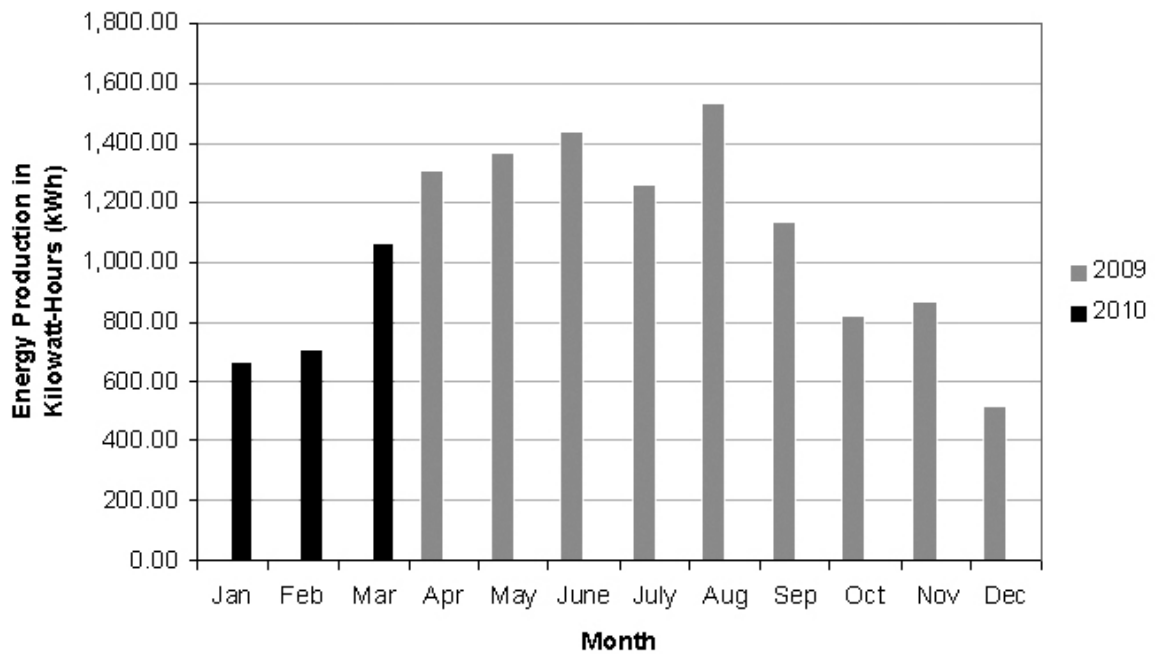


Figure 5: On-site renewable energy production after the first twelve full months of operation.



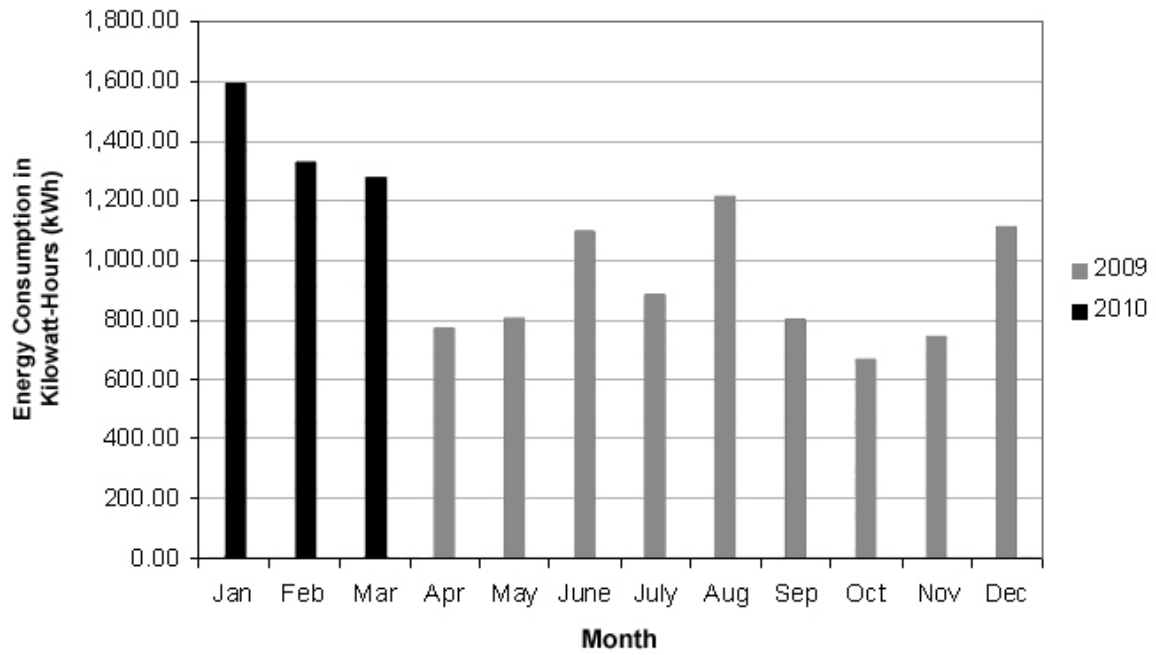


Figure 6: Energy consumption of the library after the first twelve full months of operation.