TOWARDS BIM-BASED PARAMETRIC BUILDING ENERGY PERFORMANCE OPTIMIZATION

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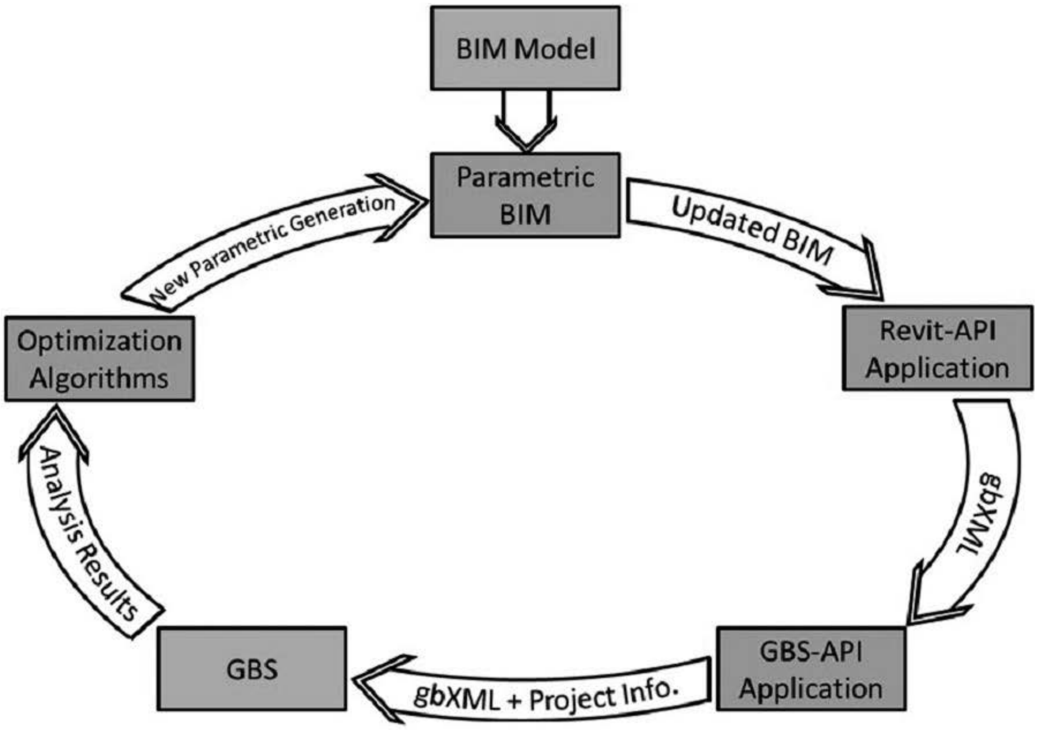


1 BIM-based Parametric Energy Optimization

ABSTRACT

The demand for sustainable buildings with minimal environmental impact and efficient energy use is increasing. The most effective design decisions for sustainable design can be made in the early design phases, but appropriate tools to explore design alternatives and understand their impacts on building energy performance are not available at this stage of the project. The integration of Building Information Modeling (BIM) and parametric modeling is the new trend of building modeling, which can greatly benefit sustainable building design. This research introduces an innovative tool to facilitate integrated parametric BIM and to enhance its applications towards creative, sustainable building design through simulation and optimization. The created tool, Revit2GBSOpt, integrates parametric BIM and building energy performance simulation and enables designers to generate alternative options in BIM to explore the energy performance simulation results automatically. Finding the optimized solution, the BIM model will be updated.

1 INTRODUCTION

As a result of the rising awareness of environmental issues and the increase in the cost of energy, building professionals increasingly have to consider the sustainability and energy performance of their designs. Sustainable building design is a highly complex, labor intensive and expensive process. With this level of complexity, design mistakes are very common (Jesus, Almeida, and Pereira 2005) and in many cases significant mismatches exist between the predicted performances and the actual performances of these buildings (Majumdar 2009). On the other hand, design practitioners typically create and explore very few design alternatives before choosing a final design which leads to underperforming designs. There is a lack of efficient tools to explore design alternatives and understand their impacts on building energy performance. Therefore, any automatic process that gives the designer options to explore various alternatives and make decisions based on building performance is in high demand.

As a major shortcoming of current energy modeling, there are no parametric relations among building objects in energy models, for example in EnergyPlus developed by the US Department of Energy (DOE). For instance, if a wall is transformed in an energy model, all objects including windows, shading devices, rooms, zones, roofs and floors that are connected to the wall should be updated automatically, but they are not updated in the energy model. In other words, design intents that are embedded in parametric Building Information Modeling (BIM) are not embedded in the energy models. As a result, manual update of model data is needed before running the simulations, which is tedious and prone to errors.

The integration of BIM and parametric modeling can significantly benefit simulation and optimization of building energy performance. Parametric modeling enables the creative exploration of a design space by varying parameters and their relationships in the early design stage, when the most effective design decisions for sustainable buildings can be made (Azhar and MBC 2009). However, designers mainly use parametric modeling to enhance visual qualities. BIM allows semantically-rich and object-based building data to be created and managed for the building lifecycle across the building's design, simulation, construction and operation (Schlueter and Thesseling 2009; Krygiel and Nies 2008). BIM contains most of the data needed for energy performance analysis and if used appropriately can save a significant amount of time and effort on one hand, and reduce mismatches and errors on the other hand. This research introduces an application that integrates building energy simulation process into BIM and parametric modeling systems to enable performance-based design in the early stage of the design process.

2 LITERATURE REVIEW

Building energy performance assessment processes are complex multi-criteria problems and architects mostly do not have enough expertise and knowledge to deal with them (Bazjanac 2008; Schlueter and Thesseling 2009). However, they need to have access to the results of conceptual energy simulation and the ability to interpret these results to improve the building performance. In traditional architectural design workflow, building performance analysis is mostly done at the latest stages of design. With energy-efficiency becoming more important than ever, designers may want to narrow down their design alternatives to those that are more promising to save energy. Shifting the building performance assessment phase back into the conceptual design stage can determine energy efficient solutions, which improve building performance drastically.

2.1 PARAMETRIC MODELING

Performance-based design requires designers to explore the potential design alternatives which are available to them parametrically, and choose the best alternative for the project (Mourshed, Kelliher, and Keane 2003; Welle, Haymaker, and Rogers 2011). Parametric modeling enables generative form-making through the use of parameters and rules based on aesthetic and performance metrics of buildings, and allows objects to automatically update based on changed contexts (Aish and Woodbury 2005; Qian 2007; Stocking 2009). Current parametric design tools provide rapid design iteration and visualization. While most of the current parametric modeling-based designs are focused on the aesthetic form generation, the significant potential lies in the field of performance-based design by using the parameters and design intelligence to respond to climatic considerations, structural limitations, energy saving requirements and ecosystem balancing (Caplan 2011; Kensek 2011).

The application of parametric modeling in performance-based design enables the designer to explore design alternatives and make decisions based on the performance of the building. Parametric modeling can be integrated into the process of performance analysis in different fields of building design including structural analysis, energy simulation and acoustic simulation. As an example, a preliminary generative structural design system and an associative modeling system is developed in the field of structural engineering (Shea, Aish and Gourtovaia 2005). Parametric studies show more potential contributions to optimize the building energy performance (Naboni et al. 2013, Pratt and Bosworth 2011). Despite the potential benefits of parametric energy simulation, they are rarely used because of the difficulty of energy model preparation and long simulation run time. In order to solve this problem, either computational algorithms must be developed to reduce the number of runs (Coley and Schukat 2002; Wetter and Wright 2004), or increase the computational power using parallelization and cloud-based simulation (Garg et al. 2010; Zhang and Korolija 2010; Zhang 2009). Cloud computing is an emerging style of computing in which services to users are provided over the web by managing large numbers of virtualized resources (Iorio and Snowdon 2011, 119). However, the use of cloud infrastructures is still a novel approach (Iorio and Snowdon 2011; Naboni et al. 2013).

2.2 BIM AND ENERGY MODELING

The integration of BIM with performance analysis tools has the potential to greatly facilitate the often cumbersome and difficult energy simulation process (Azhar, Brown, and Farooqui 2009). BIM represents the building as an integrated database of coordinated information about building topology and objects. Performance-based design supported by BIM is growing in building design disciplines, allowing practitioners to efficiently generate and modify building models (Fischer 2006; Welle, Haymaker, and Rogers 2011). To simulate building performance in the early design stage, architects need to access the information of the building such as geometry, materials, construction and technical systems as the design of the project proceeds (Schlueter and Thesseling 2009).

The process of building energy performance analysis and optimization can be much more effective if integrated with BIM with automated parametric changes. Existing studies that consider BIM as the central data model to automate this process, can be classified into three main categories:

- Towards automated BIM-based building energy performance analysis: this group focuses on automatic preparation of the energy simulation input data and execution of energy simulation (Schlueter and Thesseling 2009; Azhar, Brown, and Farooqui 2009; Azhar et al. 2011; Laine, Karola, and Oy 2007; Yan et al. 2013). The main approach in this type of research is to use Industry Foundation Classes (IFC) to reach BIM data and solve interoperability issues and automate the process (Morrissey et al. 2004; Bazjanac 2008; O'Sullivan and Keane 2005). Creating the automatic link between BIM authoring tools and building performance analysis is the main focus of these research studies, and the use of the parametric modeling approach to optimize the building performance is out of their scope.

- Towards parametric design optimization: the second category of research is scoped to explore a solution that optimizes the building performance by utilizing a methodology that is composed of parametric modeling and optimization algorithms as can be seen in the work of Gerber et al. (2012). This group of research uses CAD software tools or only BIM mass models rather than the information modeling data that is non-graphical and embedded inside building models.

- Towards BIM-based parametric energy performance optimization: the third group of research studies provides automated BIM-based parametric modeling to optimize the building energy performance, as can be seen in the works of Welle et al (Welle et al. 2011). The researchers have created a thermal optimization methodology (ThermalOpt) to enable designers to pre-process, configure, execute and analyze the energy performance of their design during the early stage of the project by automating the whole process. ThermalOpt is faster, more accurate, and more consistent than conventional methods, which enables a larger number of design alternatives to be explored. The main issue is that ThermalOpt has a very complex process. The whole process of integration is controlled by ModelCenter® (Phoenix Integration 2013) which is difficult to setup and needs a lot of expertise and training, therefore beyond the access of architects.

The present study falls into the third category and aims to optimize the energy performance of building design using BIM-based parametric modeling in a significantly more simplified approach for architects. It introduces a new approach to improve the shortcomings of the existing tools on BIM-based parametric building energy performance optimization. Using Application Programing Interface (API) of BIM and energy simulation tools, we have created a prototypical system interface between BIM and energy simulation tools. The prototype utilizes a BIM authoring tool—Autodesk® Revit®, which designers use to create building information models. Architects can develop BIM-based parametric models and explore parametric simulation using Green Building StudioTM (GBS) automatically through its newly-released API. The parametric runs of the simulation enable the finding of the optimum that fits the project multi-objectives. Most importantly, all the operations from BIM to parametric simulations are inside a single software user interface—a Revit Plug-In. In addition, our approach provides a method that can overcome the scalability barrier and explore the building performance using cloud computing of GBS.

3 METHODOLOGY

Revit to Green Building Studio Optimization (Revit2GBSOpt) is an application that provides the automatic link between Autodesk Revit and Autodesk Green Building Studio and enables architects to optimize building energy performance at the early phase of design parametrically. It provides a user interface inside Revit, which enables designers to create a large number of parametrically generated design options based on the BIM model. It interacts with the GBS in the cloud through the web to perform the energy performance analysis and chooses the optimized solution for the project. At the end, it updates the BIM model to the optimized solution and provides a report of the process to the architects. The overall architecture of the application is illustrated in (Figure 1).

In order to integrate parametric BIM and energy simulation, Revit2GBSOpt has been developed using Autodesk Revit's Application Programming Interface (API) and the newly released Green Building Studio (GBS) API (Kfouri and Kennedy 2013) to enable the interaction between Revit and GBS. This application is able to automatically propagate the user defined parameters and generate new models inside Revit. It uses Green Building eXtended Markup Language (gbXML 2013) format, which has the necessary information for GBS to perform energy analysis. Revit2GBSOpt creates gbXML files for parametric runs and uploads these files for energy analysis to GBS cloud through the web. It retrieves the energy simulation results and finds the optimum solution for the project. At the last step, it updates the BIM model to the selected solution and reports the results to the architect.

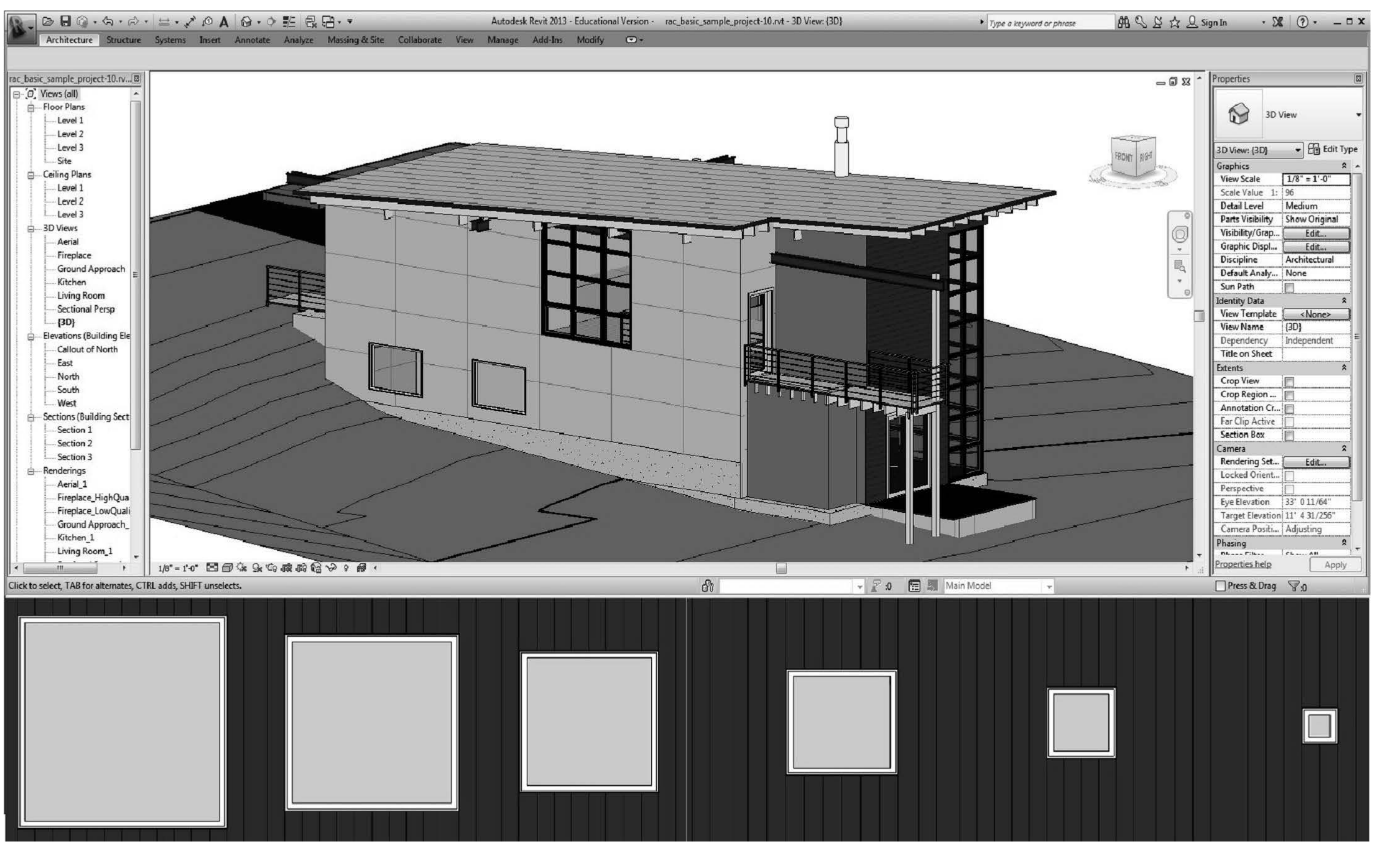
Therefore, Revit2GBSOpt provides a user interface inside Revit in which architects can interact with the GBS website in real-time and explore the impact of different design options on the building's performance profile. The following case study elaborates the use of Revit2GBSOpt to optimize energy performance of a residential building.

4 CASE STUDY

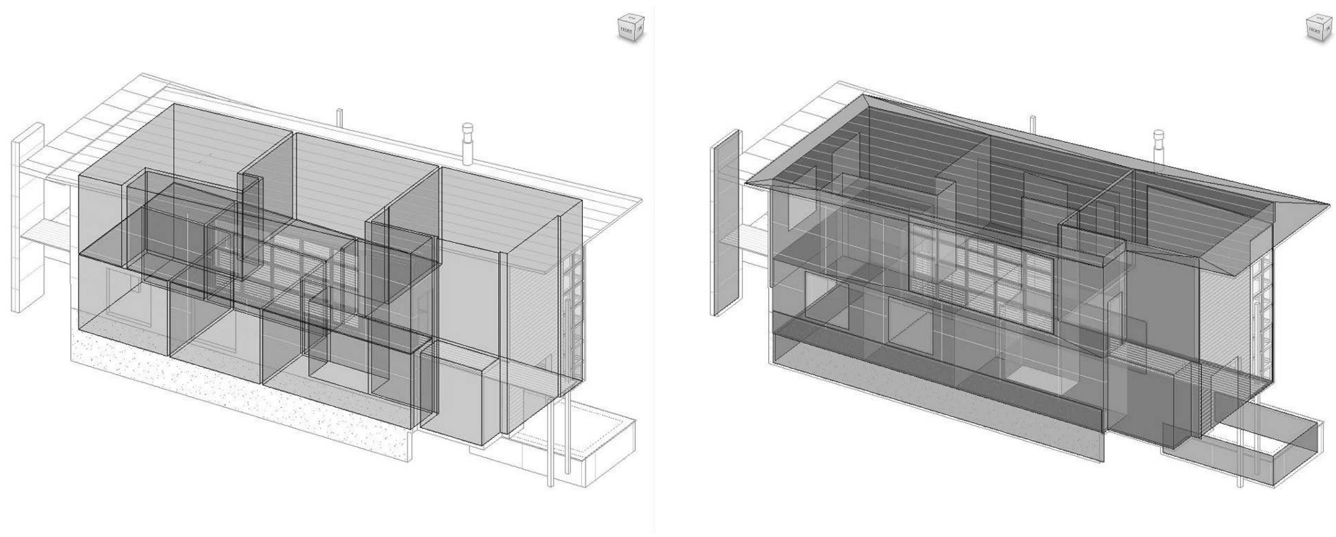
In order to evaluate the performance of Revit2GBSOpt, a case study has been developed to demonstrate the capability of creating BIM-based parametric runs and accessing the building performance analysis results inside Revit in a tightly coupled feedback loop. This case shows how the tool enables design professionals to optimize the building performance.

In this case study, a sample model of Autodesk Revit 2013 is used (Figure 2). For multi-objective optimization including daylighting and whole-building energy performances as sample objectives, the goal of this study is to find the optimized window size which results in minimizing the building energy consumption and at the same time achieving the LEED daylight credit. LEED requires the project to achieve a minimum glazing factor of 2 per cent in a minimum of 75 per cent of all regularly occupied areas of the building.

BIM-based simulation requires some forethought, as to specific modeling requirements to adhere to, in order to successfully transfer the BIM data for the downstream analysis (Bazjanac and Kiviniemi 2007). Any failure in doing the required process results in an interoperability issue which makes the designer go back to the BIM



2 The BIM model of the case study with different window sizes that can be parametrically changed by Revit2GBSOpt



3 Building zoning (Left) and building analytical surfaces-gbXML (Right)

tool, troubleshoot and redo the process to solve the issue (Bazjanac 2008). Therefore, designers must follow some specific yet simple rules to be able to use Revit2GBSOpt.

As the first step of building energy simulation, the building is divided into a few thermal zones based on their functionalities and conditions. In order to define thermal zones for GBS "Rooms" must be used in Revit and volume computations for "Room & Area" needs to be set to calculate room volumes. The user can change the wall properties to be either room bounding or not room bounding in order to achieve desired zones. Room separator lines can also be used to separate zones. Figure 3 shows zones and analytical surfaces created for this step.

In order to create design alternatives, a parametric window family is created with "Width" and "Height" instance parameters. Revit2GBSOpt takes a range of values for each of these two parameters based on user input and creates various alternative designs. In this case, by changing these two parameters of the window, fifty-four design options have been created.

Revit2GBSOpt created the gbXML files for all of the design alternatives. A new project is created in GBS with the project information gathered from the BIM model such as building location, building type, etc. For each alternative design option, a base run is created on GBS and its gbXML file is uploaded. Revit2GBSOpt retrieved the results of building energy analysis from GBS website and Revit. The results, including window areas and building energy simulation output for the parametric runs, are exported to a comma-separated values (CSV) file.

Using the building energy costs and LEED daylight results the optimum size of the window is calculated (Figure 4). In this case, with the increase in the windows area the building energy cost increases. Therefore, the design option with minimum window size that gets the LEED credit is the desired solution. The BIM model will be updated with the optimum window size automatically. The user can access the energy analysis results directly inside a single user interface (Revit) to explore the other available options. Also, the impact of any small change on the building performance profile during the design phase can be explored.

5 CONCLUSION AND FUTURE WORK

The traditional process of building energy performance analysis is ineffective and must be improved. Design practitioners typically create and explore very few design alternatives before choosing a final design, which leads to underperforming buildings. Parameterizing design and developing automated methods to evaluate the performance of design open an opportunity to search for optimized solutions. The current study shows that maximum efficiency in energy consumption could be achieved using parametric BIM and utilizing optimization algorithms. This case study also shows that highly complex tasks, which architects have to perform in order to evaluate the sustainability of their designs, can also be significantly simplified. Though simple, the case study demonstrated the great potential of making complex parametric simulation and optimization seamlessly integrated with architectural modeling.

In the design process designers are occasionally equipped with evolutional processes that are complex and convoluted. Energy performance analysis is an example of this kind. To design a building, however, we need to make suggestions rather than evaluating potential alternatives. When utilizing optimization algorithms the evaluation processes will transform to suggestion processes. Evidently, the new parametric BIM technology coupled with optimization algorithms can tackle the boundaries of sustainable design and design in the general sense. The application of optimization algorithms in parametric BIM, on the other hand, poses new challenges. When a BIM model is optimized to reach maximum efficiency for instance in energy consumption, it might not be efficient in safety or visually pleasant. In future, multidisciplinary design optimization methods are required to serve a series of different purposes simultaneously.

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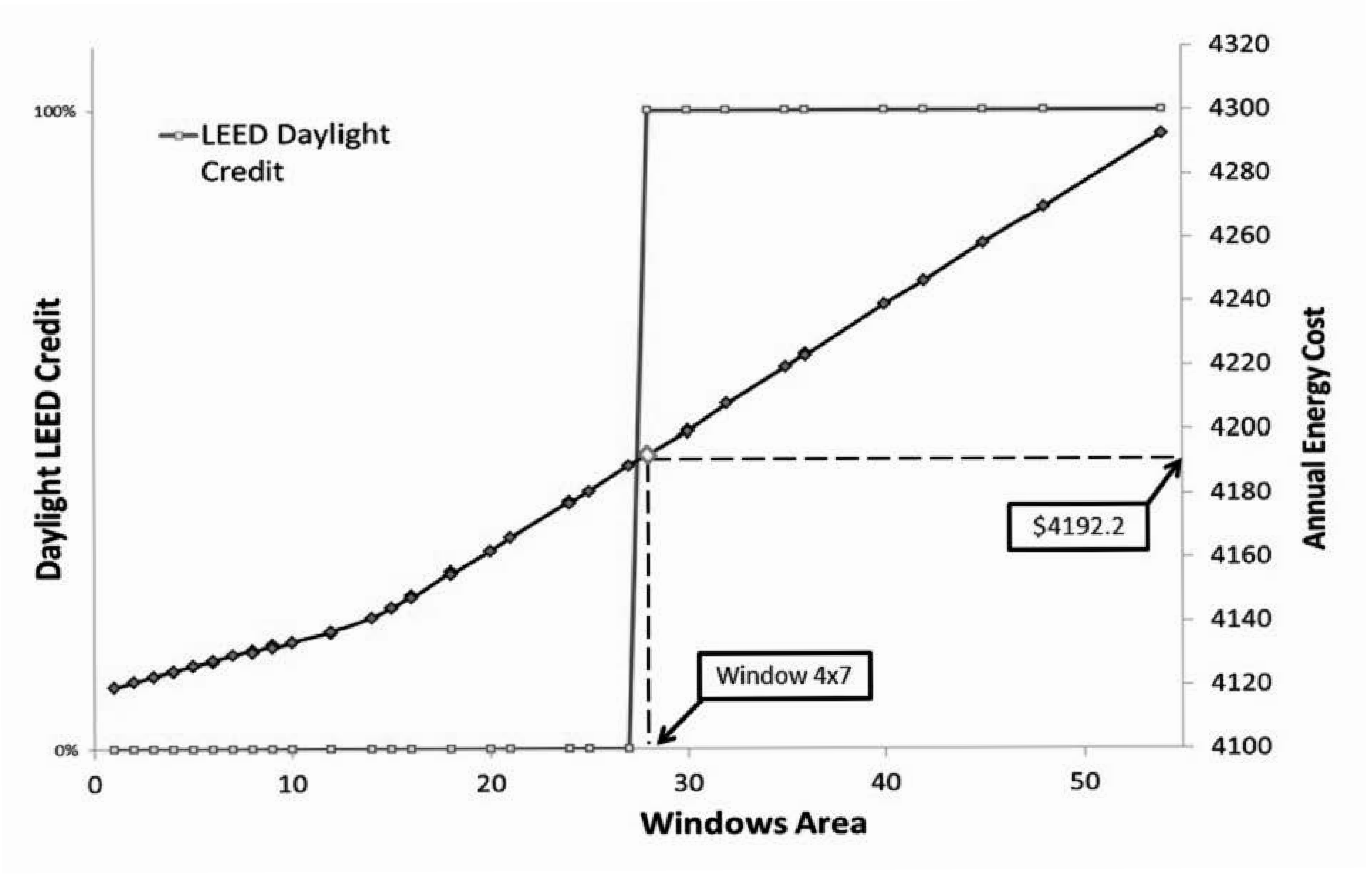

4 Parametric optimization of windows sizes to get LEED credit and minimized energy use

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