A Thermal Design Strategy for Net Zero High Glazing Buildings in Temperate Climates

Mariko Thorbecke, Carly Ingrao and Benjamin Linder

Abstract—Green building standards like the Living Building Challenge promote the construction of net-zero energy buildings. In order to meet these standards, alternative heating and cooling methods become necessary, especially for designs with high glazing percentages. The design and analysis of a low cost heating and cooling system with 100% solar fraction is being investigated to address this scenario. Following a literature review and visits to two Living Building Challenge certified buildings, a preliminary building configuration was created for the Living Lab project at Olin College of Engineering. Thermal modeling was conducted on three basic building configurations with different amounts of solar glazing to determine the peak thermal loads for the project's temperate building site. Future analysis will be performed using Green Building Studio and eQuest software to identify energy saving strategies and confirm a final proposed design.

Keywords—Net Zero, Solar Glazing, Green Building, Passive Solar, Seasonal Storage, Geothermal

1 Introduction

Architecture accounts for a large percentage of our energy footprint, with commercial and residential buildings consuming 40% of the total energy United States in 2013 [1]. In particular, heating and cooling accounts for one of the largest energy loads in most buildings [2], especially in environments where temperature and humidity differ significantly from the human comfort zone [3].

Green building design has the potential to address this challenge and green building standards have started to appear that are effective at promoting its use. Popular standards include the Living Building Challenge (LBC) certification program, the Passivhaus energy standard, and the Leadership in Energy and Environmental Design (LEED) rating system. Traditional HVAC (heating, ventilation, and air conditioning) systems account for over 50% of total home energy use [2]. This research focuses on identifying a low cost heating and cooling strategy to meet these standards for buildings with higher glazing percentages in temperate climates.

We report on the preliminary development and analysis of a building configuration based on community engagement at a small New England college located in Zone 6b [4], in the Northeast climate zone [5] in the United States. A variety of solar heating and cooling strategies were explored to enable this configuration to meet LBC certification. An initial computer-based thermal model was created using Revit [6] to determine the thermal loads. The full season performance of the design will be completed in future work using a combination of the Green Building Studio [7] and eQuest [8] software analysis tools.

2 Background

We have chosen to pursue LBC certification for the project associated with this research, which is currently known as the Living Lab at Olin College of Engineering and corresponds to the Campus Zone Transect (L-3) [9]. The LBC approach requires net zero operation while leaving open the approach to achieving that outcome. The Passivhaus approach does not mandate net zero performance but does mandate several specific performance requirements for design components [10]. With the LEED approach, building designs receive points to achieve different levels of certification.

The Living Building Challenge consists of 7 Petals; Site, Water, Energy, Health, Materials, Equity, and Beauty, and a total of 20 associated imperatives [11]. In order to achieve LBC certification, a project must satisfy all of the imperatives and show an occupation period of one year to prove building performance [11]. To date, there are 5 LBC certified buildings worldwide, with approximately 180 registered projects in progress [12]. While LBC addresses several points in sustainable architecture, heating and cooling is not specifically addressed, and is instead included in a general energy category [11].

Net zero energy buildings are now commonly developed through a combination of traditional passive solar [13] [14] and Passivhaus [15] type design practices and the addition of a photovoltaic (PV) array [16] [17], often powering an air-to-air heat exchanger. These designs have relatively low amounts of glazing, and as techniques to manage the building envelope improve, the glazing percentage appears to be decreasing [15].

Higher amounts of glazing lead to larger heating and cooling loads as the effective insulation of the envelope decreases, and while shading and direct ventilation can reduce cooling loads dramatically [16], the winter heating loads become too large to address through diurnal temperature variation alone or supplemental PV systems. In the case of all-solar designs with 100% solar fractions, such techniques also reduce the available solar energy that could be used to address these winter loads.

Large heating and cooling loads can be addressed through seasonal thermal energy storage (STES) [18] of solar energy [19] or with the use of a geothermal heat pump (GHP). The choice between the two systems may be determined by the particular site conditions, occupancy needs, and local costs. For example, a need for higher temperature water could necessitate the use of an air-to-water heat exchanger if the solar glazing is used as a relatively low temperature collector to charge an STES unit. Conversely, the on-site coefficient of performance of a GHP including circulation pump energy can be so low that the required PV array would be unreasonably large.

The total cost of either system (STES or GHP) can easily climb without careful consideration of the overall system requirements and design options. For example, a cost reduction may be possible by sizing the main system for base load and using a subsystem for peak loads. Similarly, the space may be divided zonally to match a more limited capacity system to occupants needs, if a spatial configuration of needs can be arranged. The objective of this research is to investigate how high glazing levels in net zero energy homes influence design choices and total cost.

3 METHODOLOGY

A preliminary literature review was performed, which was followed by tours of two LBC certified buildings, the Hawaii Preparatory Academy Energy Lab in Waimea, HI, and the Smith Bechtel Environmental Classroom in Northampton, MA, providing a source of first-hand knowledge and inspiration. The visits prompted general insights about green building design and revealed specific strategies for meeting LBC requirements, such as materials sourcing options.

The expected outcome of this research is a design of a living building and an analysis that together satisfy all of the LBC imperatives and demonstrate an approach to achieving high glazing ratios in net zero energy buildings. The hope is that this building will be constructed on the Olin College campus, however approval for this project has not been solicited from the College at this time.

The Olin campus is located in Needham, MA (42° 21′ 29″ N and 71° 3′ 37″ W) near Boston. The Boston area annual heating degree days (HDD) average 5 641 [20], while cooling degree days (CDD) average at just 678 [20]. For comparison, Barrow, Alaska has on average 20 370 HDD, and 0 CDD, whereas Hilo, Hawaii had 0 HDD, and 3 134 CDD [21]. Heating and cooling degree days give a sense of the energy necessary for heating or cooling buildings [21]; the greater the number of heating degree days, the greater the amount of energy that will be needed to heat a building.

Initial design requirements and potential building configurations for the Living Lab were created using input from Olin students, faculty, and staff on potential vision, siting, programming, contracting, operation, and maintenance. To get an initial understanding of the heating and cooling loads that would be encountered at the site, a thermal analysis was performed with three basic thermal configurations to determine the peak heating and cooling loads at three different levels of glazing.

Several holistic building configurations will be modeled and compared using Autodesk Green Building Studio and eQuest software. Green Building Studio is an energy analysis software with a focus on whole building energy analysis. Design configurations can be easily compared and alternative designs explored to maximize energy savings. Building orientation, design for daylighting and natural ventilation potential can all be analyzed using Autodesk GBS. While Autodesk GBS offers a more general picture of maximizing energy savings, eQuest offers the ability to simulate more advanced heating and cooling scenarios, including ground source heat pumps and natural ventilation.

4 PRELIMINARY RESULTS

A preliminary design was created that consists of a 1 200 ft^2 classroom space and an attached greenhouse space (Fig. 2) located on the backside of the Olin campus (Fig. 1) at 42° 21′ 29″ N and 71° 3′ 37″ W and oriented south. Collectively these spaces meet a variety of stakeholder needs including supporting sustainability projects. For example, the greenhouse would enable plant-based experiments in biology and materials science classes.

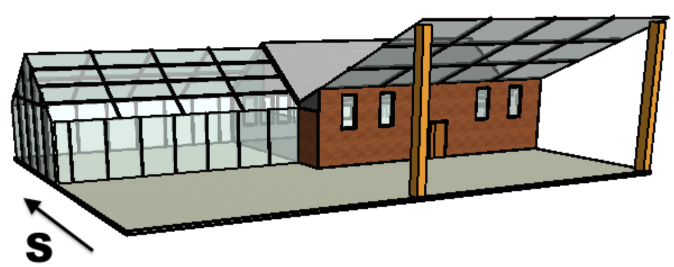

Fig. 1: A preliminary Olin Living Lab building configuration consists of a 1 200 ft^2 classroom space and an adjacent greenhouse. Both components of the design provide space for sustainability projects.

Fig. 2: The site is located on the north-most edge of the Olin College campus in Needham, MA, at 42° 21′ 29″ N and 71° 3′ 37″ W

A sloped roof allows for rainwater catchment in order to fulfill the net-zero water requirement. Natural daylighting plays an important role in minimizing electricity use. A south facing solar array plays a double role as both natural shading for an outdoor deck area, as well as the sole source of electricity. The heating and cooling system is expected to be a water tank based season energy store driven by an air-to-water heat exchanger. In this scenario the water tank would be installed below grade. High insulation values combined with a tight building envelope will help to reduce the size of this system. While materials have not been specified in the model, LBC requires that materials be locally sourced and not contain any chemicals on a red list. Once ideal R-values and U-values have been established, materials that meet those criteria can be sourced.

In order to estimate the thermal load necessary to maintain a comfortable temperature in the space, a thermal analysis was conducted. A simpler building configuration was modeled in Revit, and three different design configurations were compared for the site.

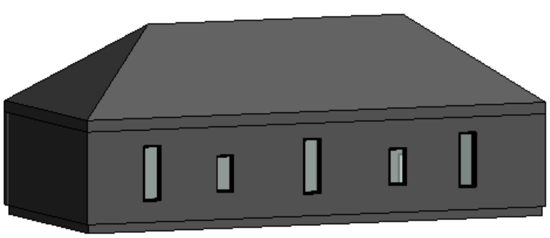

Fig. 3: Thermal Configuration 1

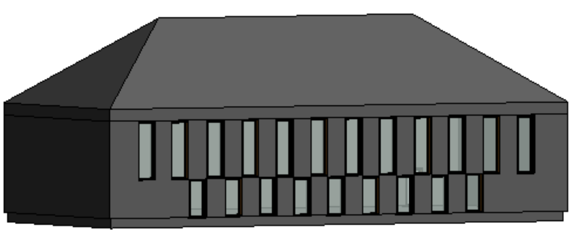

Fig. 4: Thermal Configuration 2

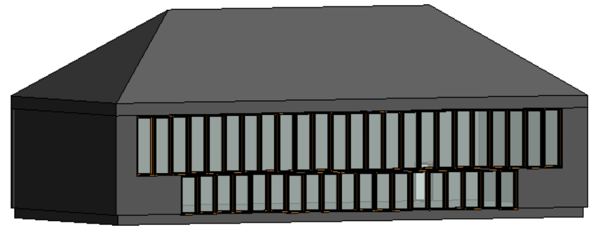

Fig. 5: Thermal Configuration 3

The most basic of the three configurations (config. 1) consisted of a 112 m^2 (1 205 ft^2) rectangular structure with a 3 m (10 ft) high ceiling and 10% solar glazing. Configuration 2 was comprised of the same shell but with 40% solar glazing, and Configuration 3 doubled the solar glazing to 80%. In the high insulation simulations, the R-value for the roof was set to 52, and the walls to R-38. The U-value for the windows was set to 0.27, with a low e value at 0.2, and a SHGC of 0.6. For a low insulation configuration, the wall and roof R-values were set to 11, while the window U-value was set to 0.35, with an e value of 0.2 and a SHGC of 0.65. The resulting peak heating and cooling values are listed in Table 1.

TABLE 1: Peak loads for three building configurations with different levels of glazing and insulation as modeled in Revit.

Config.	Solar Glazing	Insulation	Peak Heating (BTU/h)	Peak Cooling (BTU/h)
1	10%	low	9 700	30 000
		high	3 500	26 000
2	40%	low	12 000	54 000
		high	6 000	49 000
3	80%	low	16 000	88 000
		high	9 300	82 000

As expected, higher insulation values correlated to lower peak heating and cooling loads and increased glazing correlated to increased heating and cooling loads. The glazing is oriented to maximize winter gain at the expense of summer gain, so these loads already account for higher direct winter solar gain. The greenhouse should collect sufficient energy to balance these loads, although this outcome depends on the extent of natural ventilation used [22] [23].

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