Design of a **Net Zero** Home

Francesca Cuda, Navindra Budhwa, Phi Fors, Noeline Tharshan
and Prof. Ramani Ramakrishnan
Department of Architectural Science, Ryerson University

Introduction

A net-zero home is designed and built to be highly energy efficient so as to produce, at least, as much energy as it consumes annually through renewable resources. In addition, factors such as massing, envelope design, HVAC systems, and water systems need to be considered in order to achieve a successful net-zero home. All of the above factors must be designed to work efficiently to reduce the total energy consumption of the house. If the net-zero number is 100, the designed house will be totally self-sufficient. The focus of the current investigation was the design of a 2000 sq. ft. residential dwelling, as an in-fill development that satisfied net-zero requirements.

The site is located in North York, one of the suburban regions in the City of Toronto. Given the existing nature of the site with its moderate density, the house was designed strategically to utilize the maximum potential for shading and daylighting, as well as to minimize the impact of the site. The existing south-facing residential home will be demolished and redesigned. The proposed house will be a two storey home with an open concept basement, a driveway to connect to the frame garage in the backyard, and a decent amount of glazing to the backyard. The only design constraint to the site was the five-foot minimum separation requirement from the property line on the west side.

The design process involved the following steps:

a) Resolving the site issues and building massing.
b) Design of the envelope.
c) Application of renewable energy sources.
d) Evaluation of net-zero numbers.

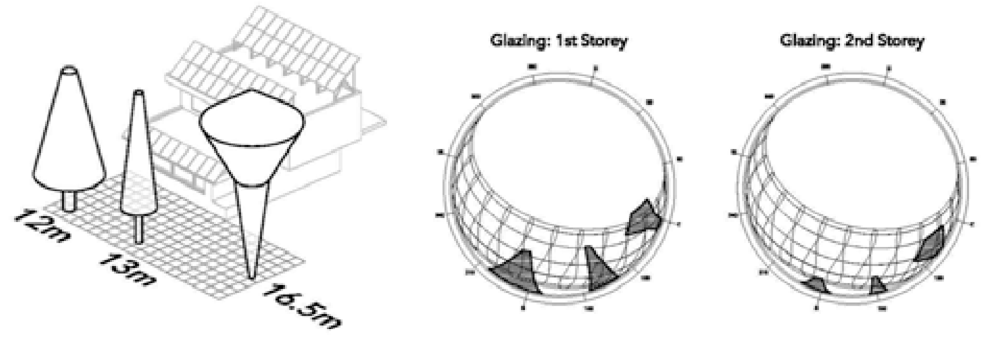
The following tools were used in the design:

a) To determine the net-zero number through an energy model simulation software, HOT2000.
b) Evaluations conducted with THERM 6.0, Rhino, Grasshopper, Ladybug, and Excel to create an efficient design.

Site Conditions and Building Massing

The most important features on the site are the trees. The challenge for daylighting was the two trees in front of the south facade. A basic shading study was conducted to determine the total amount of solar radiation. There are two coniferous trees directly to the south and one deciduous tree to the south east on the adjacent site. It is important to note that the coniferous trees will retain the majority of their pines all year round and will provide consistent shading. The deciduous tree will lose its leaves in the fall, which means it will have a minimal effect in the cold winter months when solar radiation is required the most. A simplified massing of the trees was assumed and used to generate shading mask diagrams. The trees are displayed on a 1x1 meter grid in Figure 1 below. Setbacks were imposed on the southern facade to allow for deeper solar penetrations into the interior, to maximize the amount of solar gain during the winter. It can be seen that pushing the second storey facade back (north) reduces the shading on those second storey glazing units.

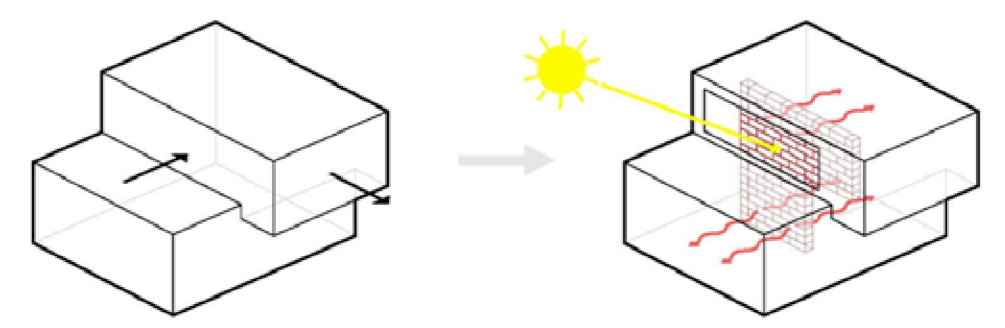
Figure 1. Schematic Details of Shading Study.



***a)** Representation of the 3 trees* ***b)** Impact of shading*

The building massing was the next factor considered in the design, as it has a significant effect on the passive heating potential and the successful application of the photovoltaic system. In the massing design process it was important to orient the building to respond to the sun path, and to develop a form that would allow optimal window placement as well as good roof areas for photovoltaic array. Two main gestures were made to fulfill these requirements. As seen in Figure 2, the south facade of the second story was pushed closer to the centre of the building so that solar radiation could heat up a thermal mass and the heat then can radiate in all directions. Further, energy loss through the envelope is reduced. The second major decision was to extend the second story east over the driveway to increase the roof area to accommodate 18% more PV modules.

Figure 2. Evolution of Building Massing

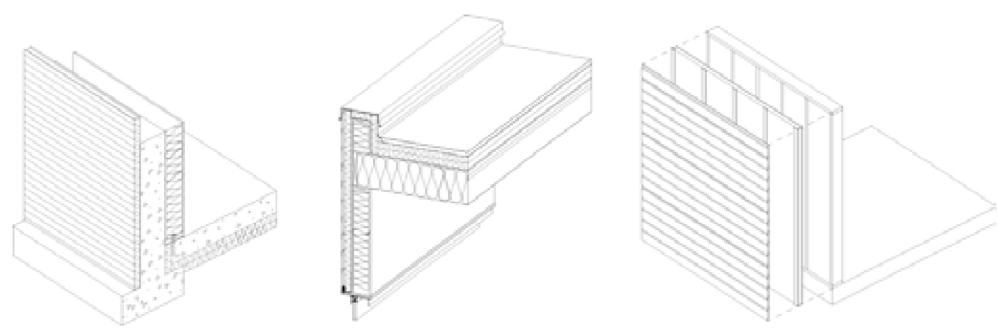


Envelope Design

The next step was to create a thermally efficient envelope that minimizes any thermal bridging. In order to achieve this, three specific locations were analyzed including the foundation wall, above grade wall, and roof. In addition, the junctions were detailed to wrap the envelope in a layer of continuous insulation.

The best assembly for the house was chosen after performing an analysis of different wall types. A combination of 50 mm exterior XPS insulation, 140 mm interior insulation, and 100 mm under slab XPS insulation was chosen as the best alternative for the foundation wall. XPS insulation was chosen due to its high ‘R” value per inch and low relative embodied energy. The upper wall consisted of 100 mm exterior XPS insulation, with 140 mm interior mineral wool framed. Mineral wool was chosen for the same reasons as the XPS. Closed cell spray foam was not chosen because of its negative environmental impact. Wood siding was used as a way to lower the embodied energy of the cladding. The roof consists of traditional framed 2 x10 wood construction with mineral wool between rafters and 115 mm of XPS insulation on the exterior. The envelope details are The insulation values for each portion are as follows: a) foundation- R-31 (RSI 5.5); b) above grade wall- R-45 (RSI 7.9); and c) roof- R-68 (RSI 12)

Figure 3. The basic composition of the foundation, roof and above grade wall.



As part of this study, the roof/parapet, the house footing to foundation wall, and second floor junction were tested in THERM to check for any thermal bridging with the indoor temperature of 21° C and exterior temperature of -18° C. The calculated ψ values confirmed that each connection performed with minimal thermal bridging. In addition, ATHENA was used to calculate the lifecycle analysis of the envelope.

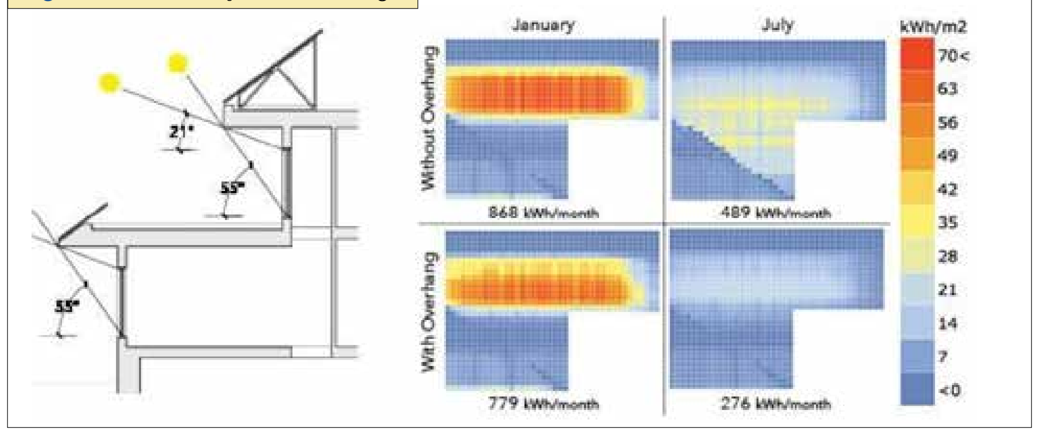
The selected envelope provided a tight thermal seal to minimize any heat loss and allowed the heating and cooling systems to operate effectively. Energy use can thus be reduced and allow the home to reach the goal of net zero.

Renewable Energy

In order for a building to meet the criteria of Net Zero operation, it is very important that the building has systems in place to utilize renewable energy resources. Solar energy is the most easily available resource in a suburban site. Solar radiation can offer a significant energy supply but is only available for a few hours of the day. Heating however is required throughout the winter. A thermal mass, such as a Trombe Wall will absorb and retain solar energy and slowly distribute it throughout the hours when the sun is down. Concrete is the most common material used for a thermal mass in buildings, but due to its extremely high carbon foot print, alternate materials were explored. It was decided that the thermal mass could be built out of recovered brick from the existing house demolition.

The sun-angle was used to establish specific geometric and dimensional relationship between windows and the overhang, in order to allow sufficient solar gain during the heating season, and reduce radiation gain as much as possible during the cooling season. Based on the approximate time of year when the heating season and cooling season switches (May 1st and September 15th), the value of 55 degrees is determined to be the highest angle at which sun may enter the facade. This value defines the window and overhang design, as seen in Figure 4 below.

Figure 4. South Façade Overhangs



“In order for a building to meet the criteria of **Net Zero** operation, it is very important that the building has systems in place to utilize **renewable energy resources**.”

Figure 4b represents the radiation (in kWh) per square meter hitting the surface of the Trombe Wall with and without an overhang. The radiation gain in January for the two instances are similar, but in July the peak radiation gain on the non-overhang variant is 1.5 times greater, and the surface area of significant radiation gain is much greater than the design with an overhang. With the optimized shading design, solar radiation gain is greatly reduced during the cooling months, but the Trombe wall is still gaining approximately 1000 kWh of heat energy during summer due to indirect sky radiation. This is one reason that an active shading system is used to optimize the performance of the passive system. A mechanical interior shading system can support the passive system in three major ways such as additional shading during atypical temperature conditions; block radiation from exiting the space when sun is not present; and provide additional insulation to reduce conduction and convection heat loss during winter

The final major component of designing for solar energy use is implementation of photovoltaic system to supply the house with adequate electricity. The major design elements for the optimization of the system include: tilt angle, rack spacing, module efficiency, and total PV surface area. The current investigation showed that 37 degrees is the optimal tilt angle for electricity generation. Using the tilt angle of 37 degrees, rack spacing was designed such that the panels don’t shade each other during December and January when the sun angle is very low. With these considerations, the current design accommodated approximately 88 m2 of PV surface. The energy calculation accounting for shading of trees resulted in a the value of 13889 kWh per year with a module efficiency of 15%. If module efficiency was increased to 22.8%, the highest in the industry, showed that 21111 kWh per year can be generated.

Net Zero Number

Throughout the design process, HOT2000 was used as a way to benchmark and improve upon the energy usage of the house. HOT2000 was able to simulate the construction and systems designed for the home and determine whether the photovoltaic panels are able to provide enough electricity to achieve net zero consumption on an annual basis. With the EnerGuide addition in HOT2000, the design achieved a value of 98. The design did not achieve 100, however it is important to acknowledge some of the deficiencies of HOT2000.

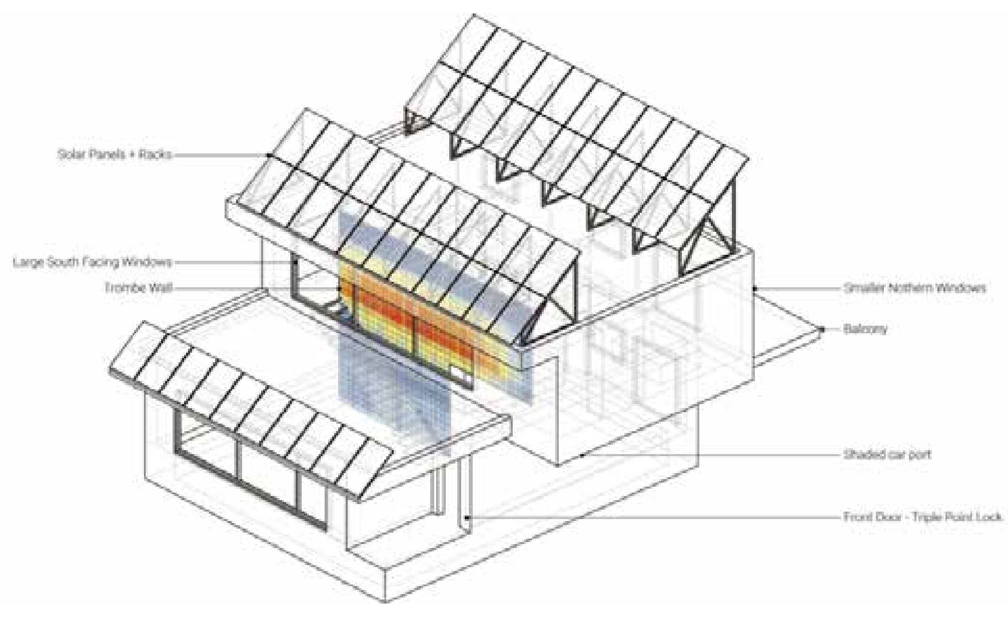
The current HOT2000 model of the project calculates a total energy consumption (including natural gas converted to ekWh) of 16485 ekWh. The actual energy consumption of the house is a significantly less than 16485 ekWh, because of the implementation of advanced systems that HOT2000 was unable to account for. Hence, a 15% module efficiency would be sufficient and is a much more economically efficient panel than the modules of higher efficiency.

In addition, one could not input many of the designed envelope details and advanced systems in HOT2000. Some examples are: a) advance PV modules; b) better window designs; c) air-to-water heat pumps; d) advanced water usage designs; and e) rain water harvesting systems.

Design Sketches

Major design features seen from the exterior are highlighted in Figure 5 and a rendering of the house is shown in Figure 6. These included - solar panel spacing, window sizing, and specifications of the home owner. The windows were designed and selected to minimize the amount of frame. Finally, the triple point locking system on the front door minimized air leakage and would keep the house airtight.

Figure 5. Major design features seen from the exterior.



Conclusions

An infill site in North York, Ontario was used to implement a 2000 sq. ft. home to achieve NET ZERO efficiency. Preliminary design of the house involved the resolution of the site and orientation issues. Passive heating and cooling strategies were integrated into the design and aided in reducing the overall energy consumption. Energy modelling software, HOT2000, was used during different stages of the design process. The implementation of renewable energy sources also contributed to the efficiency of the house. The iterative process of the various design strategies and systems for residential home aided in achieving the Net Zero status. Even though HOT2000 evaluated a Net Zero number of 98, the actual result would be higher since HOT2000 was unable to incorporate advanced systems in its evaluation.