DESIGN OPTIMIZATION METHODOLOGY FOR A NEAR NET ZERO ENERGY DEMONSTRATION HOME

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Synopsis

This paper applies an energy optimization methodology to identify improvements to an existing near net-zero energy house located south of Montreal, Canada. As many of the design performance parameters are strongly coupled, a hybrid evolutionary algorithm was used to ensure full solution space exploration, and harmonized parameter variation. This paper presents a set of 'lessons learned' to be applied to the design of future net-zero energy homes.

1 ÉcoTerra™, a Near Net Zero Energy Demonstration Home

ÉcoTerra™, located in Eastman Quebec, is one the winners of the Canadian Mortgage and Housing Corporation Equilibrium Net Zero Energy Home competition (see Figure 1a).

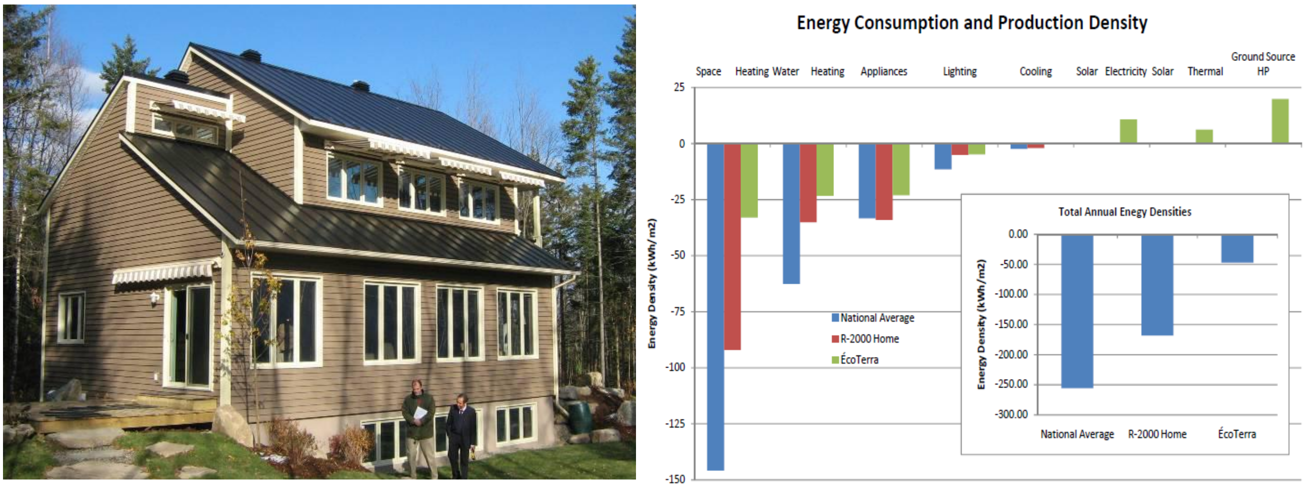

Figure 1: a) Final ÉcoTerra™ Design and b) Energy Usage with respect to national averages

This house represents the first pre-fabricated home design with a customized building integrated photovoltaic-thermal (BIPV/T) roof linked to a hybrid thermal energy storage system [1]. Approximately forty percent of the gross heating demand is met via passive solar gains. Most of the auxiliary heating is provided by a ground source heat pump. The remainder is supplied by the thermal energy contribution of the roof integrated 2.8 kWe BIPV/T system, which can produce up to10 kWp of useful heat. This thermal energy is delivered to a concrete slab in the basement (serving as a passive storage device), and to a domestic hot water pre-heat tank. The yearly energy consumption of the house, of less than 50 kWh/m^2, has been found to be one fifth of the average national energy consumption (see breakdown of power, cooling, heating and hot water consumption, Figure 1b).

Data has been recorded since early 2008 with over fifty temperature sensors distributed within the roof, slab, and thermal zones. In addition, the electrical demand of the home has been monitored. This information permits studying the impact of each design parameter, and offers a unique opportunity to evaluate the present operation as well as to assess the impact of design adjustments in future home design projects.

2 Optimization

The objective of the study is to recommend the optimal solutions for improving the original design to minimize the overall energy usage with the goal of achieving net-zero energy use. To achieve this, annual energy consumption is used as an objective function. Occupant comfort is ensured by constraining solutions to be within ranges of acceptable thermal comfort.

While some design improvements are simple to identify, their repercussions are often not as obvious. This is due to coupling effects across physical domains. For example, slab thickness (passive thermal storage), southern window-wall-ratios, and blind control exhibit physical coupling across thermal, daylighting, and mechanical control domains. The variation to one parameter changes the optimal choice of the other parameter.

Genetic algorithms are ideal as they can handle large solution spaces and allow for simultaneous parametric variation (a prerequisite of highly coupled systems). As genetic algorithms typically have poor local search resolution, the algorithm integrates a deterministic hill-climbing algorithm to improve local optimum identification. The algorithm is based on the Paradiseo optimization framework [2].

2.1 Methodology

The existing design was implemented within a recent version of EnergyPlus which permits the programming of custom models with the EnergyPlus Runtime Language and model integration using the Energy Management System [3].

The variables of optimization, included at this time, are: window-to-wall ratios, number of window panes, insulation level, slab thickness for passive solar storage, active set-point adjustments, and modifications to blind control systems to manage existing active solar collection systems to increase the solar fraction utilization of the home.

Using the commissioned home as a starting point, the set of incremental improvements was identified.

3 Summary

This study utilizes a hybrid evolutionary algorithm and commissioned data from ÉcoTerra™ to identify design improvements. Based on these design improvements lessons learned are presented as a reference for future designers of NZE or near-NZE homes.

4 References

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[2] Paradiseo Homepage, Institut National de Recherche en Informatique et en Automatique (2010), http://paradiseo.gforge.inria.fr

[3] EnergyPlus Homepage, US Department of Energy Building Technologies Program (2010), http://apps1.eere.energy.gov/buildings/energyplus/