5 Steps to Net Zero Multi-family Residence Renovation: Toronto

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Introduction

Renovating multi-family residences for net zero capable operation is a process. This report presents a 5 step net zero energy renovation process for a multi-family residence in Toronto consisting of window replacement, infiltration sealing, smart ventilation, cold weather comfort conditioning heat pump, and heat pump water heater.

The energy, economic and financial analyses follow a renovation strategy proposed by engineer Rob Blakeney. Rob's vision is a process that improves energy efficiency with minimal disruption to building residents. Ideally, within a 1 to 2 day renovation period, apartment residents are reside in temporary quarters while interior infiltration sealing and window replacement occurs. The process does not include the addition of exterior/interior insulation to walls and roof in order to expedite the renovation process. An exterior, stackable set of all-electric mechanicals would be erected adjacent to the building's exterior. The "mechanicals' compartment consists of smart ventilation, comfort conditioning and hot water supply to each residence. CERV2 distributed, wireless sensor technologies are placed in the residence for ventilation and comfort control, and residence energy monitoring. An online dashboard provides building management and maintenance an efficient means for managing residence IAQ, comfort and energy usage.

ZEROs Case Studies

We present 6 cases that follow the 5 step process that converts the example multi-family residence to a high performance residence. The renovation process steps are modeled using ZEROs (free-to-use, online software by Build Equinox). ZEROs has been validated using US DOE's "bestest" simulation results and has been validated against an extensive set of field data.

We use ZEROs to answer the following questions:

1) What energy savings can be achieved?
2) What is the renovation cost?
3) What is the lifetime cost (aka, Life Cycle Cost) for net zero renovation and how does it compare to conventional (do nothing) operation?
4) How do monthly expenditures (amortization, real estate taxes, insurance and utilities) for a net zero renovation compare with conventional (do nothing) operation?
5) How do Life Cycle Cost, capital cost and monthly expenditures for renovations that include local (rooftop) solar PV installation compare to energy efficiency renovations without solar PV?
6) How large is a solar PV array for a net zero capable residence?
7) What are indirect benefits of multi-family renovation?

Note that ZEROs incorporates energy, moisture (humidity), IAQ (indoor air quality), solar PV array sizing, Life Cycle Cost economics, and finance (monthly expenditures) into a simple-to-use, integrated design package. "Sensitivity" factors in ZEROs help guide users to economically optimized solutions.

The example residence is a 1000sqft apartment with 2 occupants located in Toronto. The apartment has 400sqft of external wall (200sqft facing south and 200sqft facing north) and 100sqft of conventional double glazed windows (50sqft facing south and 50sqft facing north). The apartment has “as is” infiltration of 6ACH50. Residents are assumed to use 18 gallons of hot water per person per day. “As is” heating is electric resistance and cooling is a 14SEER air conditioning system. The apartment is assumed to have a base plug load of 200W per apartment with 50W per occupant additional plug loads.

Six cases describe a transition from current energy usage to high performance consisting of the following cases:

Case 1: As Is condition as described above

Case 2: Windows improved to “good” (half conventional U value)

Case 3: Apartment sealed with Aerobarrier to 2ACH50 (unacceptable air quality without ventilation)

Case 4: Smart (CERV2) ventilation system added for automated air quality management and energy recovery

Case 5: Electric resistance space heat and 14 SEER AC replaced with high performance (10HSPF/24SEER) heat pump

Case 6: Electric resistance water heating replaced with Heat Pump Water Heater (COP=3)

Economic factors assumed for the 6 cases are the following:

Case 1: Conventional windows are replaced with conventional windows ($25 per sqft) replaced every 30 years

Case 2: Conventional windows are upgraded with more energy efficient windows ($50 per sqft) replaced every 30 years

Case 3: Apartment is sealed to 2ACH50 (fixed cost for set up, clean up, and sealing estimated to be $1500 per residence)

Case 4: Smart (CERV2) ventilation is added with $6000 capital cost with replacement every 20 years

Case 5: High performance heat pump replaces electric resistance heating with $500 per kW heating and $500 per kW cooling capacity cost. Heat pump is replaced every 20 years.

Case 6: Heat pump water heater cost assumed to be $1500 (versus $400 for conventional) replaced every 15 years

Results

Successive energy improvements to the example apartment with 2 occupants located in Toronto reduces annual energy consumption from 11,000kWh to less than 5000kWh over the course of the 5 step process. Figure 1 shows annual energy consumption due to improved windows, decreased infiltration, smart ventilation, efficient heat pump heating and cooling, and heat pump water. All 5 steps result in significant contributions to improved energy performance. Annual energy savings of 7000kWh per year per residence is sufficient for providing 20,000 miles per year of EV (Electric Vehicle) transportation. In effect, these energy improvements allow transition to EV transportation without increasing electric grid capacity above current levels.

Figure 2 shows indoor carbon dioxide concentration for each case. Case 3 illustrates how sealing a residence below 6ACH50 without adding ventilation results in poor indoor air quality. An average 2500ppm of carbon dioxide impairs cognition, degrades sleep, and increases transmission of colds, flu and other airborne contagions. Adding CERV2 smart ventilation (Case 4) supplements heating and cooling requirements while automatically maintaining excellent air quality and reducing annual energy usage. CERV2 energy reduction is due to two effects: first, energy recovery from the exhaust air stream and second, heat pump contribution to residence comfort conditioning requirements.

Figure 3 shows a comparison of design day heating and cooling requirements. Heating and cooling capacities vary between 2 and 3kW (slightly less than 1 ton or 12,000Btu/h). We note that our field studies of similarly sized residences in a cold climate (Vermont, see Build Equinox Vermod report) indicate that residents frequently operate their heating and cooling systems during times when outdoor temperatures are comfortable, and that 2 to 3kW is our recommended minimum comfort conditioning capacity for any residence even when an “average” design model (Model J, Remrate, PHPP, Wufi Passive, etc) indicates zero comfort conditioning load. The reason why residents want heating and cooling during comfortable outdoor conditions is their desire to move their house to a new comfort setting. The energy impact of periodic movements of indoor comfort conditions is not significant in terms of annual energy usage, but is very significant in terms of resident satisfaction with their residence.

Figure 4 shows changes of the Life Cycle Cost (100 year basis) for each case. Case 6 with all improvements displays the lowest LCC, indicating that all improvements contribute to reduction of both residence energy requirements and cost. If LCC increased while energy decreased for a particular renovation step, a decision as to the value (and uncertainty) of energy reduction with a cost increase must be made. We note that a broader view of energy value may also help the decision process for cases with opposing trends in LCC and energy usage. We discuss these effects in our section on “indirect” factors.

Figure 5 shows trends in renovation capital cost requirements. Renovations that include sufficient solar PV for net zero energy residences are compared to renovations that do not include solar PV cost. Apartment capital cost for Case 6 is $15,000, with an additional $15,000 for sufficient solar PV for net zero capability. Note that $9000 of renovation capital for energy efficiency improvements reduces net zero solar PV capital cost by $7000.

Figure 6 compares monthly cost estimates for each case. Monthly costs include a 30 year mortgage for the capital cost (30 year amortization at 4.5% interest), real estate taxes (assumed to be 2.5% of assessed capital improvements), insurance (assumed to be 0.3% of improvement value), and utility cost ($10 per month of customer service fee with 12 cents per kWh energy cost are assumed). For Case 6, the estimated monthly cost difference for the no solar and net zero solar PV cases is $25 per month. Monthly costs are greater for renovated apartments in comparison to the “do nothing” Case 1 during the loan repayment period. After loan repayment, monthly costs are lower for Case 6, and as noted previously, Case 6 has a lower LCC than Case 1 indicating an overall economically favorable situation.

Figure 7 compares apartment monthly utility cost for each case. Note that solar PV cases eliminate utility bills for tenants. The utility cost shown assumes a monthly customer service fee. Without solar PV, monthly utility bills are successively reduced from $125 per month to $60 per month. Reduction of tenant utility bills helps stabilize tenants financial situation. Adding solar PV further reduces tenant utility bills. Building owners could recover the cost for solar PV through $25 per month rent surcharge.

Monthly finance costs do not include any tax credits or rebates for solar PV or energy efficient mechanical systems. Also, depreciation impacts on a building owner investments are not included. Although tax credits, tax rebates, and depreciation can significantly alter (and benefit) renovation improvements, displaying a comparison of basic renovation costs allows one to determine how the improvements compare to conventional system operation. That is, can sustainable energy improvements stand on their own against unsustainable energy-based living. And the answer is in every North American region and climate that a sensible approach to sustainable, fossil-fuel free living is also the most economical path.

Figures 7 and 8 provide additional description of solar PV array power and size for achieving net zero capable residences in Toronto. Figure 7 shows a successive reduction of solar PV array nominal power from more than 9kW for Case 2 to less than half that power for Case 6. Solar PV array size decreases from somewhat greater than 700sqft to approximately 350sqft for the 1000sqft residence. These results indicate that a 3 story multi-family apartment can be designed for net zero operation. Multi-family buildings greater than 3 stories in Toronto may be able to achieve net zero if BIPV (Build Integrate PV) strategies are used to incorporate solar PV panels into the building's exterior façade. The example building is assumed to have 400sqft of exterior wall, which can provide significant additional renewable energy contributions while potentially acting as an exterior cladding.

Indirect Benefits

The cost differences between cases in terms of Life Cycle Cost and monthly expenditures are not significantly different. The 5 step renovation process for this example apartment indicates a favorable reduction of LCC each time an improvement is made, however, depending on costs, interest rates, climate, and other factors, Life Cycle Cost will not necessarily decrease with each "improvement".

Let's assume that the LCC for the conventional (do nothing) case is the same as the improved, net zero case for a multi-family building renovation project. Why should one bother reducing the energy impact for no lifetime cost benefit in the building's operation? Multiple "indirect" reasons provide motivation for reducing energy usage and shifting from conventional energy resources to renewable energy. Although the impact of these factors is indirect (that is, they do not show up in the balance sheet of an individual project) indirect cost benefits are real and important.

1) Carbon reduction: The most obvious benefit to reduced energy usage is reduction of carbon dioxide released to the atmosphere. Based on 0.92pounds CO2 released per kWh electricity generation (EIA faq), without solar PV, the 7000kWh energy usage reduction from "as is" to energy renovated residence eliminates 322tons per apartment of CO2 released into the

atmosphere over 100 years of building operation. Conversion to renewable energy for net zero operation eliminates 506tons of CO2 per apartment released over 100 years operation.

2) Every dollar shifted from conventional energy to more efficient products and building construction produces a significant increase in employment opportunities. Conventional energy companies typically create 1 job for every $2,000,000 of corporate revenue in comparison to manufacturing and construction companies that create 10 jobs for every $2,000,000 of corporate revenue. Therefore, a shift from energy-dominated building operation to efficient mechanical and building system design (heat pump water heaters, heat pump comfort conditioning and ventilation systems, and solar PV) creates new job opportunities. The indirect benefit of shifting to more efficient systems is job creation that results in more income generation with significant expenditures occurring within the local region for renovation labor.
3) Conversion to renewable energy powered electric transportation is very dependent on electric grid infrastructure. This multi-family renovation example shows that energy efficiency improvements yielding 7000kWh of energy usage reduction provides 20,000miles of EV transportation potential, or more that would be expected for an average apartment resident's annual transportation requirement. Adding rooftop solar PV for an additional 4000kWh per residence frees up another 12,000miles of EV transportation potential. Therefore, renovation of multi-family residences is an effective way to free up grid capacity for immediate growth of EV transportation.

Summary

Significant energy usage reduction in multi-family residences in Toronto's climate can be achieved with a streamlined 5 step renovation process. The renovation process described reduces both energy and Life Cycle Cost, indicating an economic situation that favors renovation. Estimated monthly expenditures for an improved building are similar but higher than the "do nothing" case during amortization of renovation capital cost. Tax incentives (credits, deductions, rebates, and depreciation) may reduce monthly renovation costs below the do nothing case. After amortization, monthly expenditures for the improved building decrease below a conventional building's expense.

We note that exterior wall and roof (for top floor residences) have been excluded because exterior surface area per apartment is less significant than in individual residence of the same size. The present study does not preclude consideration of adding additional insulation. For the present example, an increase of wall insulation thermal resistance from R10 to R25 results in 10% (approximately 450kWh per year) additional electrical energy consumption. Depending on insulation material and labor cost, improved insulation may or may not improve the Life Cycle Cost. We note, however, that an important aspect of the proposed streamlined renovation process is an expedient displacement of building residents, and the selected steps are ones that could be accomplished within a 1 to 2 day time period for minimal tenant disruption.

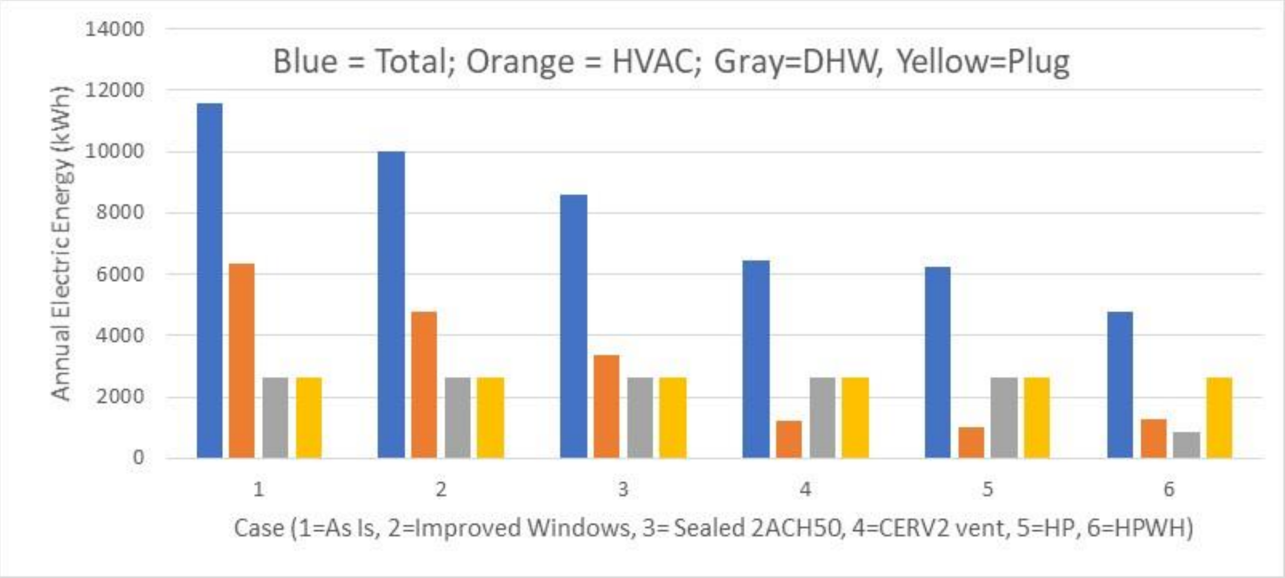

Figure 1 Annual electric energy usage for 6 cases.

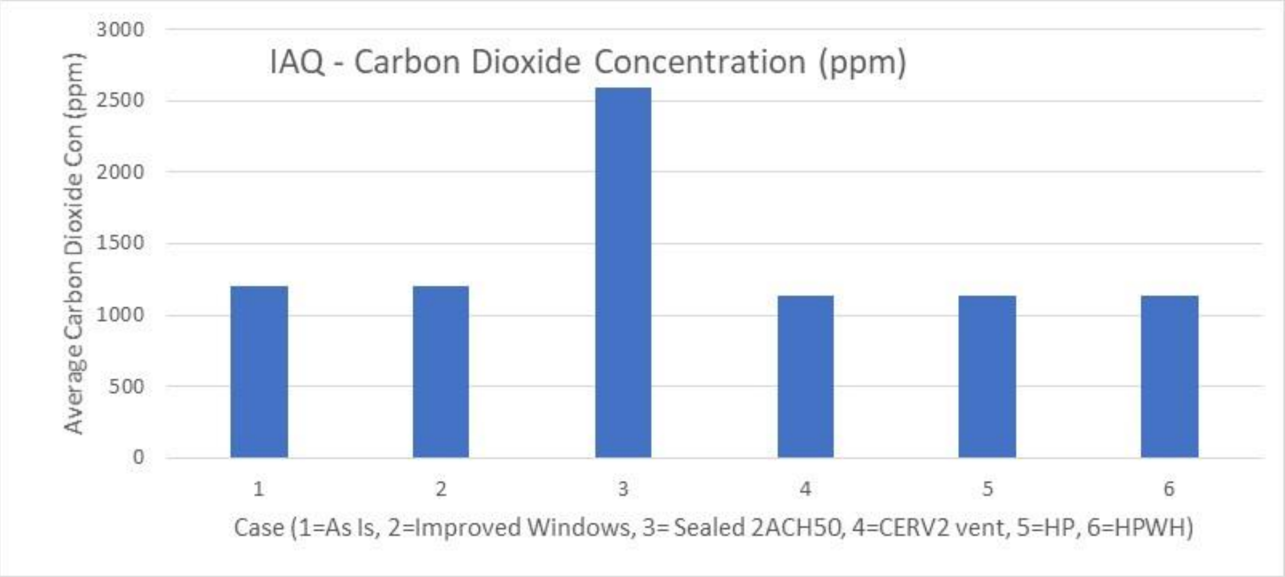

Figure 2 Average carbon dioxide concentration for each case.

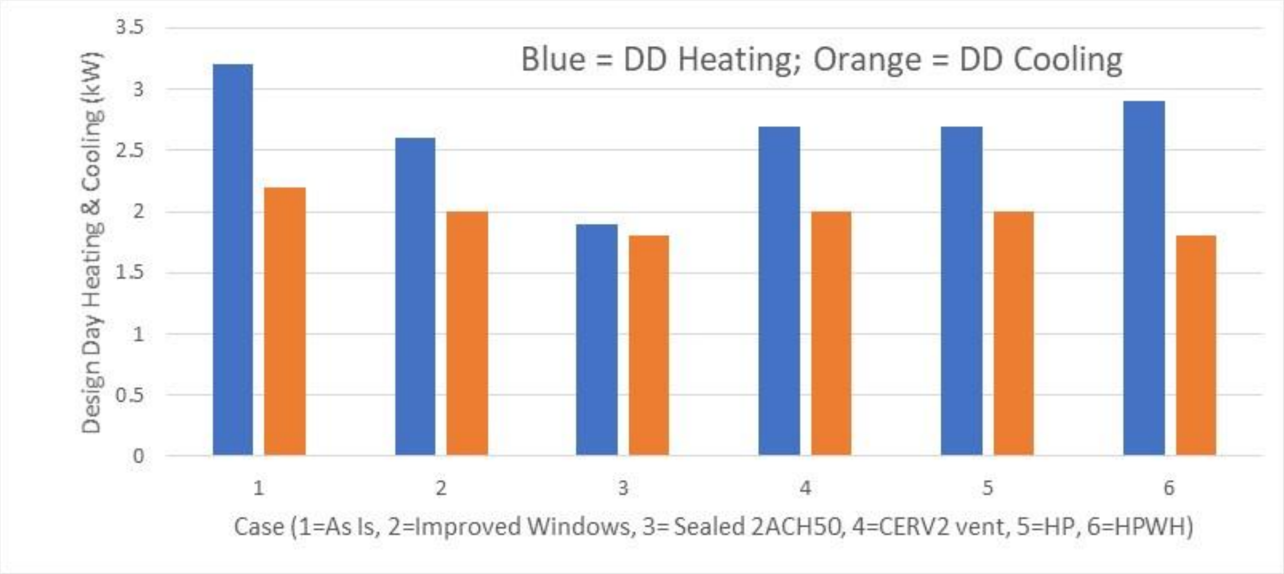

Figure 3 Design Day heating and cooling capacities for 6 example cases.

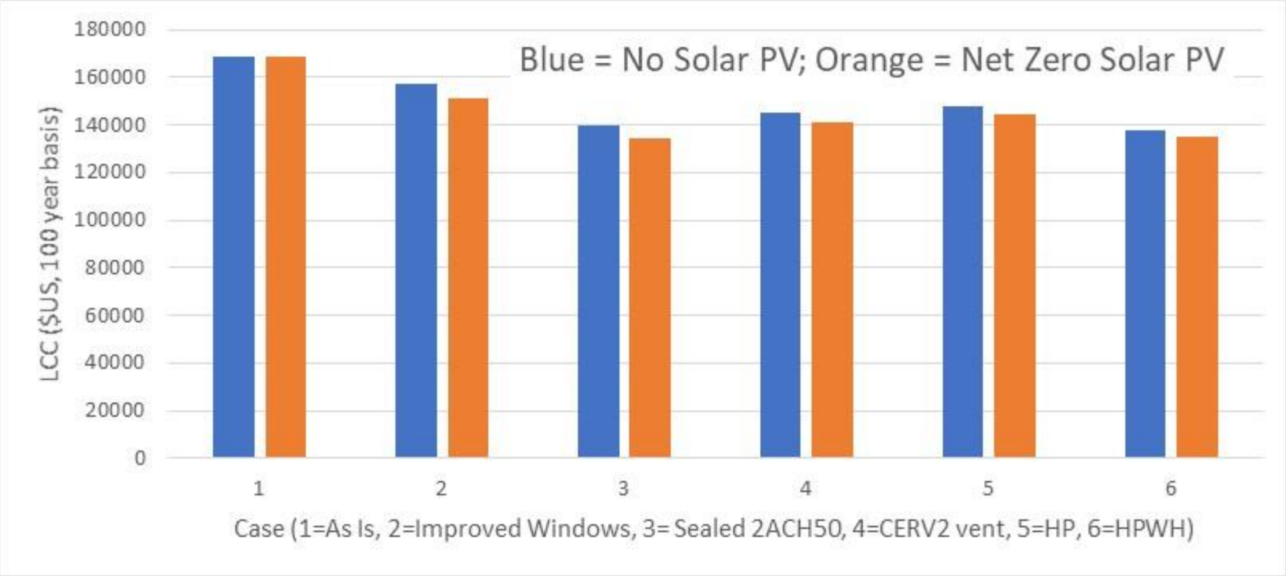

Figure 4 Life Cycle Cost for 6 cases without solar and with net zero solar PV.

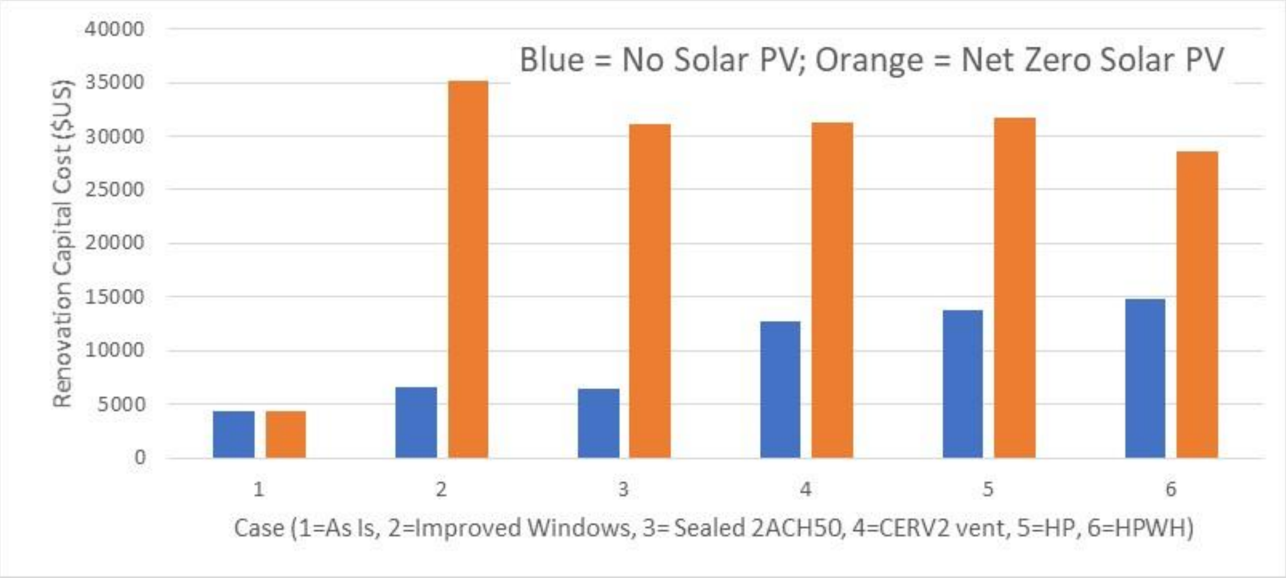

Figure 5 Renovation capital cost for 6 cases without and with net zero solar PV.

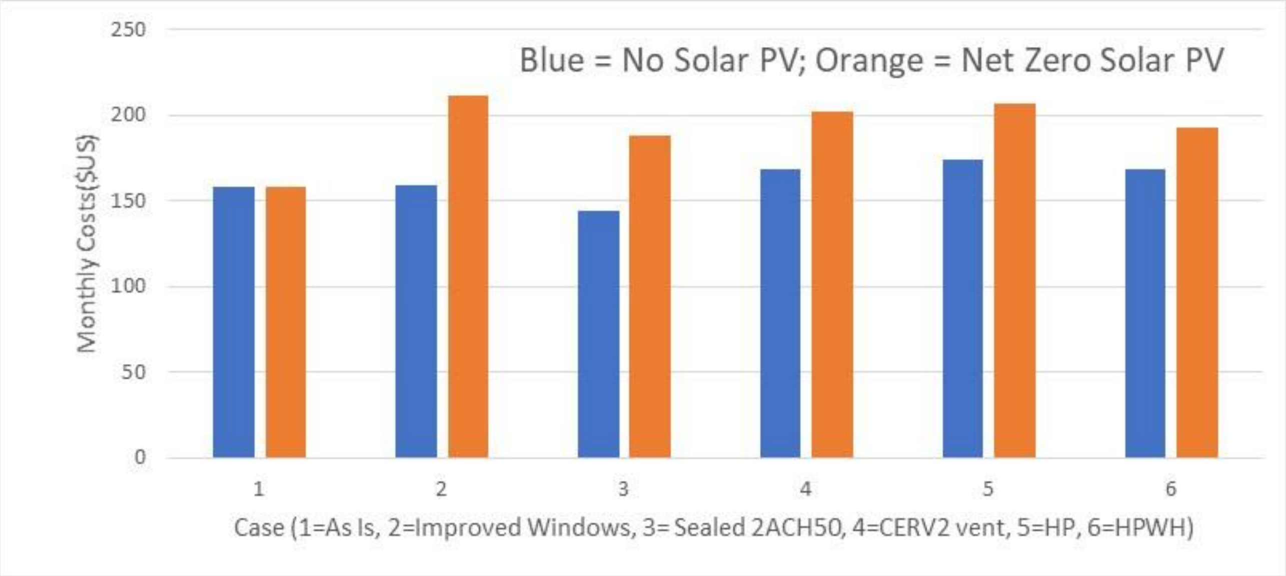

Figure 6 Total monthly costs (amortization, real estate tax, insurance, and utility) for 6 cases without and with net zero solar PV.

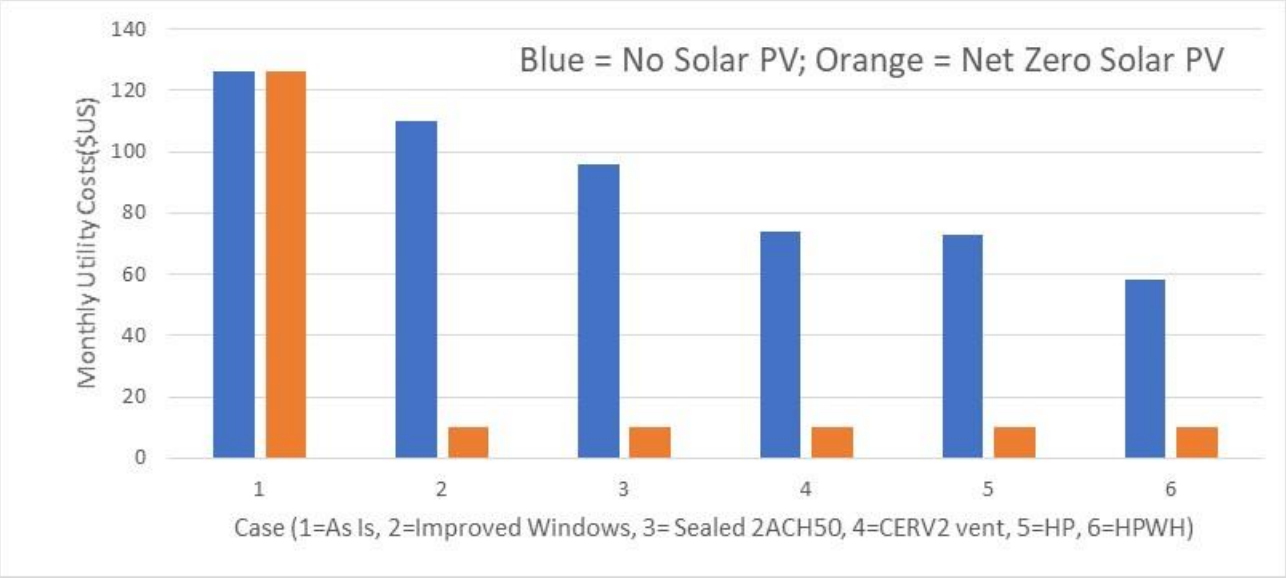

Figure 7 Monthly utility cost for 6 cases without solar and with net zero solar PV.

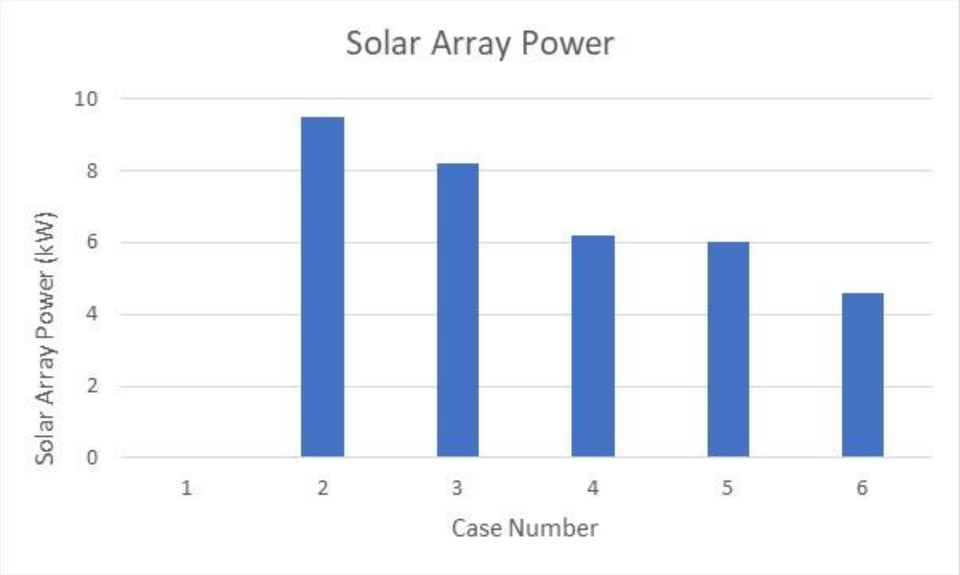

Figure 8 Solar array power variation for net zero operation.

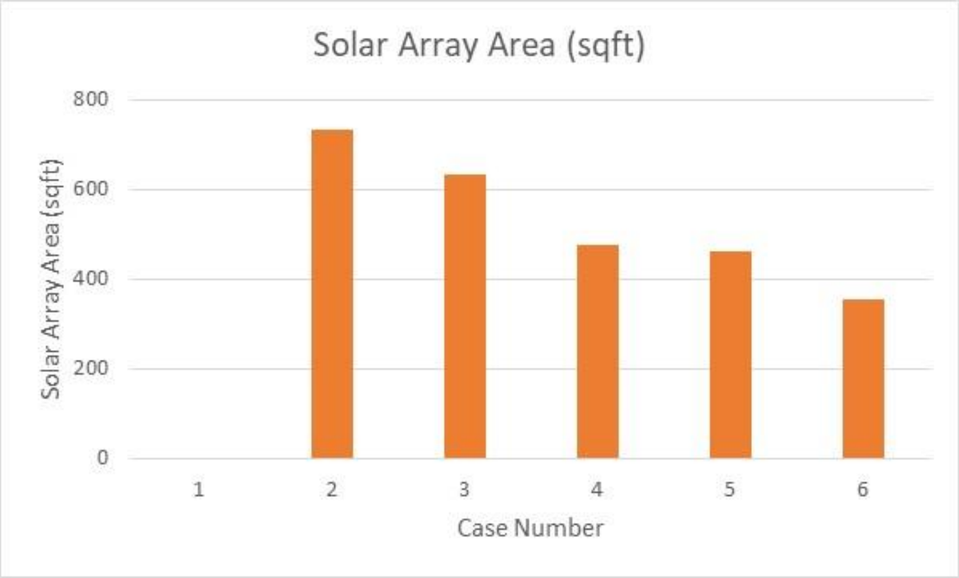

Figure 8 Solar array area variation for net zero operation.