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VIA E-MAIL **rkidd@twp.beckwith.on.ca**

Reeve Richard Kidd
Corporation of the Township of Beckwith
1702 9th Line Beckwith
Carleton Place, ON K7C 3P2

Dear Reeve Kidd:

Re: Township New Building Net Zero Energy Feasibility Study

The Township has requested that the design of their new municipal building achieves net zero energy. The following letter is to provide a feasibility study of the design options in adherence to this request.

BACKGROUND

The Corporation of the Township of Beckwith (the Township) has requested that JLR undertake a feasibility study to outline a pathway to net zero energy (NZE) for the design and construction of a new 15,000[1] square foot municipal building in the Beckwith Park site. It is the Township's hope that the construction of their new facility will serve as an example for all moving forward as they opt for a facility that will be highly energy efficient, produce its own power, and that will be low in maintenance and operation costs.

The Township further intends to use the report from this feasibility study to apply to the Federation of Canadian Municipalities (FCM) for Green Municipal Fund Capital Projects support for the construction of this facility. This fund requires a net zero energy design target and further requires that a feasibility study has been undertaken.

The Township has already engaged a construction contractor, Cavanagh Construction, who also has architects engaged for the project (Cavanagh Team). The hope is to have construction started in spring of 2021. As the building is at the early stages of design, this is an ideal time to evaluate the feasibility and implications of implementing NZE design. Though there are added upfront costs in design and construction, the upgrades will reduce overall lifecycle costs and contribute to the Township's plan to reduce emissions by 8 percent of 2011 levels. NZE design also has many other advantages such as building integrity, future resiliency against fuel cost increases, building asset value, branding, and occupant comfort.

[1] Including semi-basement

SCOPE OF WORK

The purpose of this study is to provide a clear pathway for achieving a NZE design prior to the detailed design of the building. Energy modeling of a NZE design option was undertaken in order to determine energy savings and greenhouse gas (GHG) savings compared with a baseline or 'business-as-usual' building design. The intent of the study is to consider alternatives to a baseline building envelope, energy supply, and mechanical heating, ventilation, and air conditioning (HVAC) equipment in order to identify high efficiency design options that allow for NZE building. Note that the Township has requested the area available for a photovoltaic (PV) array be limited to the back half of the roof to limit visibility and reduce the aesthetic effect of the panels on the architecture. For this reason, an aggressive approach to NZE design was undertaken, such that the amount of energy consumed on site was minimized enough to be offset by a PV array on the back half of the building.

NZE DESIGN TARGET

It is possible and suitable to develop a building to a NZE design target without seeking any formalized certification standard; the calculus is such that all energy consumed on site must be equivalently generated on-site by a renewable source. The pathway to NZE typically involves a high-performance building envelope (ex. enhanced insulation, window glazing and airtightness) at its base, with efficient HVAC equipment (ex. heat pump and energy recovery) in conjunction with a building automation system (BAS). These features significantly reduce the amount of energy consumed on site, as they decrease the space heating and cooling demand along with ventilation air heating, which together typically account for two-thirds of the energy consumed in a similar building. Once energy demand has been sufficiently reduced, the remaining building energy consumption can be offset by a photovoltaic array, either rooftop or otherwise. This is the approach taken in this study.

Note that space and ventilation heating is electricity-based; there is no natural gas supply to this building. There will be a back-up diesel-based generator used in case of emergency. The building will use and feed into the electrical grid; there are no plans for battery energy storage. The heating and cooling system intended is a ground-source heat pump (GSHP), either with a horizontal or a vertical loop design.

Procedure

The first step of the analysis involved developing an energy model of a base building designed based on JLR best practices and the Ontario Building Code. *Trace 700*, a building energy modeling software by TRANE, was used for the building energy modeling. The base building energy model was developed to act as a relative measure to compare to the NZE design. Once the base building model was complete, NZE design options were incorporated into the energy model to quantify their effects. Various NZE design options were considered such as increased insulation in the walls, roof and slab, high performance window glazing, reduced window area, window shades, demand control ventilation, energy recovery, and rooftop photovoltaic (PV) system. The modeled energy consumption of the NZE design options were analyzed relative to the base building.

Base Building Model Description

The base building design is a hypothetical building, developed to represent the business-as-usual approach. A number of energy efficient measures, which are JLR best practices, are included in the base building design as follows:

- Exhaust air energy recovery to pre-heat ventilation air
- High efficiency LED lighting with smart lighting controls (occupant sensors, lighting schedules, etc.)
- Smart building automation system controls (temperature set-back, ventilation scheduling and occupancy sensors, etc.)
- Variable flow drives for fans and pumps
- High efficiency electric motors for fans and pumps

Design choices that remain identical between the baseline and NZE designs include:

- Gross floor area
- Building occupancy schedule
- Plug loads
- Internal heat gains
- Weather file
- Quantity of workstations and office equipment (assuming use of Energy Star appliances)
- Heating and cooling setpoint and driftpoint temperatures
- Minimum ventilation rates (as required by ASHRAE 62.1)
- Infiltration schedule
- Door types
- Domestic hot water demand

The fundamental design differences between the baseline and NZE proposed design are in the building envelope and the HVAC system. The baseline building implements a code-minimum standard for the envelope, with double glazed windows, basic insulation (min. required by OBC), 5% higher window-to-wall ratio, and comparatively less airtightness. The NZE proposed design preferences a high-performance envelope with improvements to insulation, airtightness, and window glazing, while decreasing the total glazing area. The mechanical equipment for the base building includes electric hydronic heating and cooling with a packaged rooftop unit (VAV with reheat and minimum required energy recovery as per ASHRAE 64.1) for ventilation; the NZE proposed design, uses a GSHP for space and ventilation air heating and cooling as well as domestic hot water. Table 1 below summarizes the main differences in design choices.

Table 1: Differences between baseline design and NZE proposed design

	Baseline Design	**NZE Design**
Wall insulation	R-23	R-40
Roof insulation	R-30	R-50
Slab-on-grade insulation	R-10	R-23
Window-to-wall ratio	30%	25%
Glazing	Double pane	Triple pane

Infiltration	0.6 airchanges/hr	0.3 airchanges/hr
Ventilation	Packaged RTU	VAV w/ baseboard
Heat or energy recovery	Min. energy recovery	High performance ERV
Heating and cooling	Electric boiler, unitary AC	GSHP

NZE Proposed Design

Envelope

At the foundation of any NZE design is a high-performance building envelope. This NZE modelled design includes:

- Enhanced insulation using structural insulated panels (SIP)
  - Wall thermal transmittance: 0.023 Btu/h·ft²·°F (Effective[2] R-40)
  - Roof thermal transmittance: 0.018 Btu/h·ft²·°F (Effective R-50)
  - Slab[3] thermal transmittance: 0.035 Btu/h·ft²·°F (Effective R-23)
- Reduced window-to-wall ratio
  - Windows, doors and skylight (decorative tower) encompass 25% of wall area
- Triple glazed windows (with argon)
  - U-value (imperial): 0.14
  - Visible transmittance: 0.48
  - Solar heat gain coefficient: 0.28
- Low infiltration
  - Airtightness of 0.3 airchanges/hr

Minimizing infiltration is a key component of a high-performance envelope as it is central to preventing heat loss, which lowers the space and ventilation air heating demand. Airtightness is a difficult factor to predict because it is largely dependent on the builder's commitment to properly sealing the building during construction. Achieving a tight envelope requires special attention be paid to areas that are susceptible to air leakage; these areas include any junctions or corners between window frames, doors, walls, floors, roof or other envelope penetrations. This also applies to mechanical or electrical equipment that connects between the inside and outside of the building; these conduits must be sealed with spray foam insulation (ex. gap filler) to prevent air leakage.

Another important feature of a robust envelope involves reducing thermal bridging, which is when a conductive material (ex. metal building materials) creates a path for heat to leave or enter the building. One strategy to mitigate this effect is to add thermal clips to the wall assembly to reduce thermal bridging that results from the steel girts that are between the insulation[4]. Thermal bridging significantly reduces the effective insulation properties of the wall assembly. Transition areas between balconies and indoors, such as the lunchroom patio in the south-east corner, should be

[2] Effective R-value includes a marginal reduction from rated to account for losses in effectiveness after installation due to thermal bridging. Refer to the Building Envelope Thermal Bridging (BETB) Guide or ISO 14683
[3] Slab insulation is essential at slab-edge and is higher for in-slab heating
[4] SIP panels will require product-specific strategies to minimize thermal bridging between panels

designed to avoid creating a thermal bridge with cantilevered concrete. Concrete has a low thermal resistance, so any continuous slab edge exposed to ambient conditions that is uninsulated will form a significant thermal bridge, essentially bypassing wall insulation and significantly reducing the effective R-value of the entire wall. Moreover, increased heat loss at the slab results in colder indoor floors, can increase the likelihood of condensation and mould. Manufactured (cast-in-place) slab edge thermal breaks should be used to create a barrier separating interior from exterior.

Other areas where thermal bridging is common include roof-to-wall transition, corners, point penetrations, spandrels, assembly joints, glazing transition and foundation/grade. Failure to properly reduce thermal bridges will diminish the effects of added insulation, which will not only increase energy consumption but also costs.

An additional benefit of improved envelope that is difficult to quantify is the benefit to occupant comfort. People tend to be more comfortable as drafts are minimized and temperatures are easier to regulate with improved envelopes. This is especially true with triple pane windows, which have also shown to significantly reduce noise.

Ground Source Heat Pump

A key component of NZE design is employing high efficiency HVAC equipment; one of the most efficient forms of heating and cooling a building is through heat pump technology. An air conditioner is an example of a one-way heat pump, which draws heat from the inside of the building and rejects it to the outside air. An air-source heat pump is an air conditioner that can be run in either direction; in winter it draws heat from the outside air to heat the building. Ground source heat pumps are similar, but include heat exchange piping in the ground to draw heat and reject heat therein. Though heat pumps consume electricity, they use significantly less energy when compared to electric resistance heating since the primary heat source is the ground or air, not electricity.

While air source heat pumps face lower efficiency in cold climates, and require auxiliary backup system, Ground Source Heat Pumps (GSHP) are a viable and effective technology in most climates, including the Ottawa area. In terms of efficiency, GSHPs generally have a high coefficient of performance[5] (COP) between three and five, meaning they output three to five times as much heat energy as the electrical energy input. The highest efficiency gas boilers on the market, under ideal conditions, fail to achieve a COP of one, while the average boiler typically operates at 20 percent lower than that. Though GSHP systems are high in capital cost, they are low in operation and maintenance, reliable, and have a long operation life. They are an excellent option for reducing energy use while minimizing operational cost.

The proposed NZE design implements a GSHP system to supply all heating and cooling loads, in addition to domestic hot water. Note that space heating is to be provided by radiant in floor heating, while space cooling will be administered through via air handler units. While the decision to use a horizontal or vertical loop (closed or open) is contingent on the results of soil/rock testing on site, the model assumes a horizontal loop. Closed loop systems use a series of buried pipes

[5] COP is a measure of useful heating provided per energy input

acting as a heat exchanger, drawing heat to and from the ground. Horizontal systems must be installed below the frost line and the water table to allow for heat dissipation to be effective. For vertical systems, piping is grouted within vertically drilled boreholes, and must be pressure tested as part of the installation process. The installation of the buried pipes is regulated and must be installed by licensed drillers. The performance of horizontal systems is generally lower than vertical systems since vertical ground loops are drilled deep enough that the ground is not affected by seasonal temperature variations.

Another important question regarding the use of horizontal versus vertical systems is whether or not a backup heating system is required, and if it is, what portion of heat will be supplied by the heat pump and what portion will need to be supplied by an auxiliary electric resistance coil. This question will be answered by the soil conditions available for a horizontal system; if the ground is not conducive to effective heat transfer, the loop will not be able to provide sufficient heating, so an auxiliary/backup system will be required. If the horizontal system relies too much on the auxiliary system, it may become more economical to choose a costlier but more effective vertical system, which will not require auxiliary heating.

Ventilation

The final essential component of this NZE design is minimizing the demand for ventilation air heating and dehumidification through use of a high-performance energy recovery ventilator (ERV). These units capture waste energy by transferring heat and humidity from conditioned exhaust air into fresh outdoor air. As ventilation can be one of the largest loads in an office building, choosing a high-performance ERV is crucial to the NZE design. High-performance models are capable of transferring up to 89 percent of the exhausted heat and 60 percent of the exhausted humidity to the incoming fresh air stream. Pairing this ERV with demand control ventilation, which uses carbon dioxide sensors to determine the required amount of ventilation air to be supplied to a room, will drastically reduce the amount of energy required to ventilate the building.

Table 2 below summarizes the energy model results of the two design options complete with preliminary PV costing and GHG emissions estimates. The table includes two metrics for energy efficiency: Energy Use Intensity (EUI) and Thermal Energy Demand Intensity (TEDI), both of which are based on energy consumption (kWh) per unit of floor area (m^2). EUI is a measure of whole building energy use and is expected to be below 100 for a well performing office building, while TEDI is a measure of space and ventilation heating output and should be under 20.

Dismissed NZE design options:

- Solar wall air pre-heating
  - This is a good option if high ventilation rates are required and energy recovery ventilation is not an option. Energy recovery ventilation is more reliable than solar air heating and has become more effective and less costly.
- Heat recovery from the nearby hockey arena was considered, but the ground source heat pump, in combination with local energy recovery, are expected to meet space and ventilation air heating requirements efficiently without need for supplementary pre-heating.

Table 2: Energy Modeling Results with PV Costing and GHG Emissions

	Base Building	NZE Design
Annual Electricity (kWh)	161,030	55,250
Annual Gas (kWh)	0	0
TEDI (kWh/m²) (target of 34)	64	12
EUI (kWh/m²)	113	39
Year 1 GHG Emissions (tCO2e)	32	0
Required PV Production (kWh)	n/a	55,250
Required PV Capacity (kW)	n/a	55
PV Capital Cost	n/a	$113,000
Annual Energy* Costs, Excluding PV Generation	$20,611	$7,072
Annual Energy Costs, Including PV Generation**	n/a	$0
Annual GHG Emissions (tCO2e)	32	0

* Electricity: $0.128/ kWh

**Annual energy costs will equate to zero, but there will still be fixed utility costs such as delivery costs.

Reeve Richard Kidd, Township of Beckwith

As shown in the report, achieving NZE is technically feasible. Note that a financial analysis has not yet been undertaken for this study, though it will be addressed once the mechanical and electrical design has been finalized and true costing is available. There are higher upfront capital costs associated with the high energy efficiency choices, as well as the on-site energy generation, but a positive return on investment over the life of the building. The return period can be somewhat long, which can challenge the cash flow and financing for municipalities. However, additional funding support for highly energy efficient construction, such as the FCM fund, has the effect of markedly improving the investment in NZE design.

While modelling demonstrates it is possible to achieve the NZE design target, there will be natural variations in terms of as-built performance due to numerous factors, including airtightness of the envelope and minimized thermal bridging during construction. A revision of the model with final components, or after constructed and employing a blower door test and thermal imaging, can be considered for final sizing of the PV array to achieve the optimal match of consumption verses supply. That said, some further influences on energy consumption during operation, including weather variations and change in occupancy or occupant behavior, may continue to affect the balance on a year-to-year basis.

Carbon Reduction

While NZE does not account for carbon emissions directly, it is worth noting that this building will also achieve zero carbon performance. This is because the building is designed to be all electric, as such, there is no fossil fuel combustion on site. The building will generate all the electricity it consumes using renewable zero-carbon generation in the form of PV an annual basis. This is accomplished by a net-metering arrangement with the utility, where electricity is fed into the grid when PV production exceeds consumption within the building; credits with the utility are accumulated and used during periods when PV production is low.

Furthermore, there are camps of thought, including within the Canadian Green Building Council (CaGBC) and Zero Carbon Building standard, that allow for a carbon advantage (or higher emissions avoidance factor) for PV production because it is generally produces new energy into the grid during peak hours, thus reducing the use of other "marginal" or peak electrical generation, which are natural gas generators in Ontario. This marginal value is 400 gCO2e/kWh for Ontario versus its average grid emissions rate of 30 gCO2e/kWh. Thus, the Beckwith Municipal Building will, on average, provide carbon abatement of 22.5 tCO2e per year.

SUMMARY AND RECOMMENDATIONS

In order to achieve NZE with a limitation on available roof area, this study analysed and presented an ambitious but technically feasible pathway, and compared it to an alternative, business-as-usual design scenario. The outcome of this study is a useful gate point to help secure FCM funding.

Beckwith's new municipal building is well suited to meet the NZE design target. It has a large, unobstructed roof area that is well suited for rooftop PV, and an expansive site area ideal for either a horizontal or vertical GSHP. In addition, the building is largely unoccupied, with regular occupancy of less than 10 on a regular basis, translating to minimal heating and electrical demands in sparsely occupied rooms, minimising the energy use intensity metrics (TEDI and EUI). By implementing the energy saving measures described above, the building can fully meet the NZE design target.

We have presented a design package that reduces GHG emissions from 32 tons of CO_2 per year to zero when compared to the baseline building. The sustainable options presented in this package also provides other advantages such as occupant comfort, building integrity, future resilience against fuel cost increases, building asset value, and branding.

Reeve Richard Kidd, Township of Beckwith

LIMITATIONS

This report has been prepared for the exclusive use of the Township of Beckwith, for the stated purpose, for the named facility. Its discussions and conclusions are summary in nature and cannot be properly used, interpreted or extended to other purposes without a detailed understanding and discussions with the client as to its mandated purpose, scope and limitations. This report was prepared for the sole benefit and use of the Township of Beckwith and may not be used or relied on by any other party without the express written consent of J.L. Richards & Associates Limited.

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Reeve Richard Kidd, Township of Beckwith

Please advise when you are available for a follow-up meeting at your earliest convenience.

Yours very truly,

J.L. RICHARDS & ASSOCIATES LIMITED

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