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SOLAR PHOTOVOLTAICS FOR ARCTIC COMMUNITY FREEZERS: FEASIBILITY STUDY

Summary

Processing, preservation, storage, and sharing of harvested 'country food' by Indigenous people across the Canadian Arctic has been an essential part of life and survival for millennia. In a modern context, this results in a need for community freezers to support animal harvesting activities. Since these remote communities have isolated electrical systems and rely almost exclusively on diesel generators for electricity, operational costs are extremely high. With a strong interest in renewable energy integration in the Arctic to reduce costs and emissions, solar photovoltaics present a unique opportunity given the alignment of their power output with the energy demands of a refrigeration system in an Arctic climate. The energy performance of integrating solar photovoltaics with an Arctic community freezer were modeled and explored in detail by this study, highlighting great potential for meeting the energy needs and in result, the potential to significantly reduce operating costs.

Keywords: refrigeration, solar PV, traditional food, Canadian Arctic, energy modelling, small wind turbine

Field of application for the findings: technology & engineering, societal & policy impact,

Addressed audience: energy engineering experts, policymakers and policy advocates

1. Introduction

Indigenous people have inhabited the Canadian Arctic for over 5,000 years and for much of this time solely relied on food and other resources that they harvested from the land, water, and air in their territory. This traditional subsistence way of life continues in large part for cultural, resiliency, and financial reasons. Community members work together to harvest food for themselves, family, and share with others in need who are unable or not as able to participate directly in the harvesting. Thus, there is a demand for reliable, cost-effective community freezers in Arctic communities to enable safe storage of country food. Energy costs are very high due to the lack of interconnection to the continental electricity grid. Leading to a high reliance on diesel-generated electricity

As a result of these combined interests expressed by different representatives and individuals across the Canadian north, this work explores a system consisting of a refrigerated container, PV array, small wind turbine, and electric battery using simulations. OpenStudio, a building energy simulation tool, was used to parametrically model the combined system in various configurations to evaluate its feasibility in providing an off-grid refrigerated storage space year-round in the Canadian Arctic. An off-grid configuration was focused on for this work due to specific constraints being considered, but the solar PV modeling is equally relevant to a grid-connected system. The main differences would be no need for battery storage and no need for a backup generator unless desired for energy resiliency.

2. Methods

In this study, the overall system is simulated using OpenStudio, an open-source framework for building performance simulation. The model simulates the performance for each design over a year in Cambridge Bay and accounts for the cross influence of each subsystem. The operational energy gap is the primary metric used to evaluate the performance of the combined system (integration of renewable energy generation, battery and refrigerated container); the gap is the deficit between the energy supplied by the PV (or other renewable source) or battery and the energy demanded by refrigeration unit. To assess the renewable energy and battery capacities required to energize the container (i.e., minimize the energy gap), a hill-climbing approach was used to study a series of designs of the combined system consisting of base components (photovoltaic array, battery, container). The hill-climbing process is an iterative method that:

1. Establishes a design;
2. Improves upon the design by modifying an aspect of the system; and
3. Simulates the design and analyzes the impact of modifications to inform on next iteration.

A series of parametric analyses of the combined system were used to inform the hill-climbing process which established high-performing designs for the combined system. The initial parametric runs highlight the effects of key design parameters (e.g., azimuth angle, surface absorptance, PV tilt, battery storage capacity, etc.) and the ranges that would lead to a high-performance system. This information was used to iteratively establish designs based on a baseline configuration. Battery long-term capacity degradation (LTCD) was incorporated.

2.1 Modeling Inputs

A 40 ft container (11.56 m x 2.29 m x 2.61 m) is shown schematically in Figure 1. The modelled container is assumed to be constructed of polyisocyanurate insulation sandwiched between two layers of steel.

Nominal polyisocyanurate thermal conductivity ranges include:

- 0.018 – 0.024 W/(m·K) according to Berardi (2019);
- 0.022 – 0.025 W/(m·K) according to ASHRAE Handbook – Fundamentals 2021 Chp 26 Table 1 (ASHRAE, 2021).

PV panels are arranged along the length of the container on-grade and on a mounting rack above the container as shown in Figure 2. Note the individual panels are illustrative and do not represent the number of panels in each array.

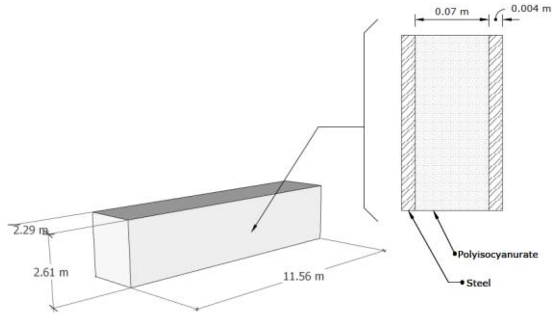

Figure 1. Schematic of the refrigerated container modelled

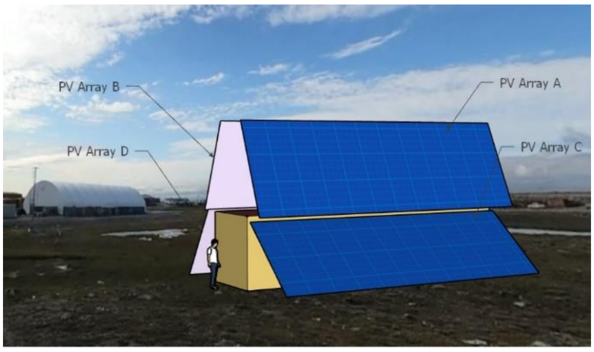

Figure 2. Container with PV arrays (arrays B & D are due north; A & C face south)

The results are highly sensitive to the assumptions of the simulation models employed. Due to limited performance data on refrigerated containers available in the literature, assumptions were made regarding its performance parameters (e.g., compressor performance, insulation level) to provide a conservative estimate (i.e., less efficient) of its performance. The sandia PV model used is empirically based, while the wind turbine model is a combination of kinetic energy equations (physics based) and empirical power correlations. For both power generating systems, the empirical correlations were obtained from the modelling software's component database.

3. Results

Two sets of parametric analyses consisting of 1630 simulations in total were completed. The first set accounts for LTCD and the second set does not; each set explored a range of container, PV, battery parameters and thermostat strategies in 815 (80 + 720 + 15, respectively) simulations. A summary of the annual operational energy gap for each group of parameters for both sets of analyses is provided in Figure 3.

The combined system as modelled experiences periods of insufficient refrigeration during autumn for most years since the simulations were conducted using statistically representative weather data for Cambridge Bay (ECCC, 2024). During September and October, the decline in solar and wind availability results in increasing power deficits, even though refrigeration demand diminishes with cooler temperatures. This is visualized in

Figure 4, which illustrates the performance of the final resulting system configuration from the parametric analysis with a 5 kW wind turbine and including battery LTCD.

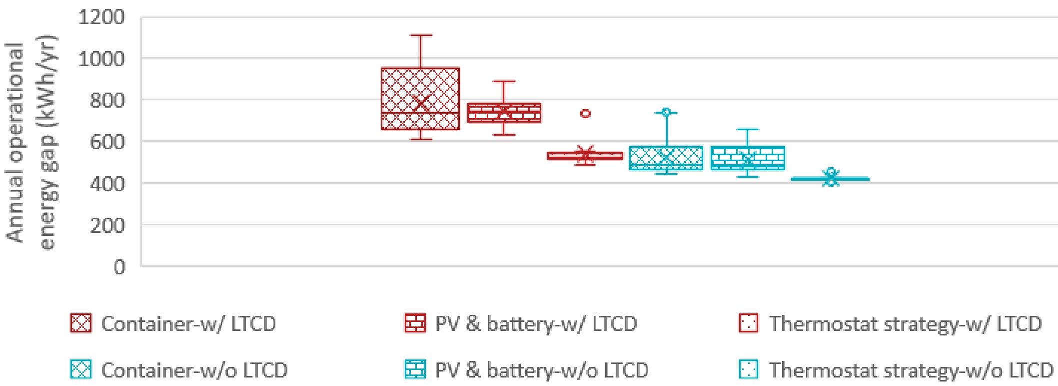

Figure 3. Annual operational energy gap of the parametric analyses, with and without LTCD

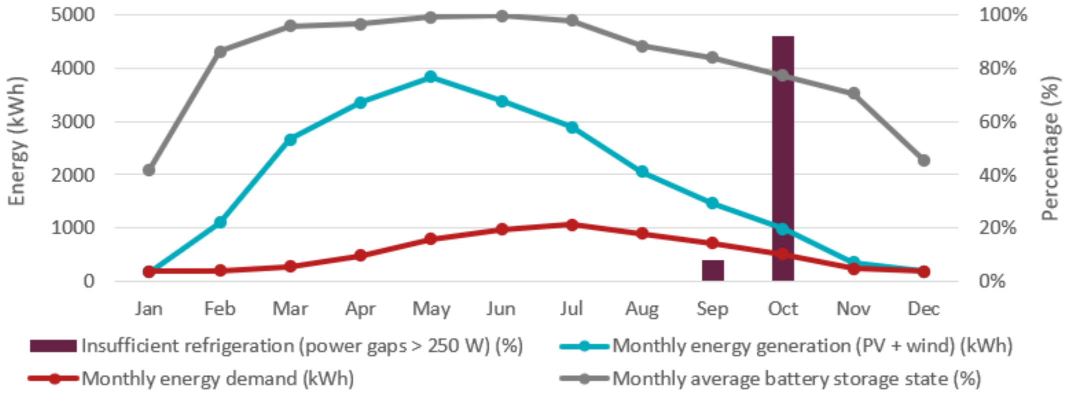

Figure 4. Monthly system trend and energy gaps (with 5 kW wind turbine, with LTCD)

4. Discussion and Conclusions

An evaluation of how well the designs operate off-grid required a review of the duration of the energy gaps, in addition to the magnitude of the gap over the year, because energy gaps translate into refrigeration interruptions. For the highest performing design with the 5 kW wind turbine (with LTCD modelling) shown in Figure 4, the peak power generation (wind plus solar) occurs in May, two months before the peak refrigeration demand in July. During these two months, the battery capacity examined (50 kWh) was large enough to support the system overnight or during less windy conditions until sufficient solar/wind resource was available again to power the refrigeration unit directly and recharge the battery to near full capacity to maintain the daily cycle. However, as autumn approaches, the system was unable to maintain consistent refrigeration. Even though refrigeration demand decreased, declining power generation, coupled with the limited battery capacity to supply energy over longer periods of nighttime, resulted in significant hours of insufficient refrigeration.

The simulation results show the final design of the combined system (with 5 kW wind turbine) is estimated to operate with an energy gap of 28 – 135 kWh/yr (approximately 0.4% – 2.1% of the annual refrigeration energy consumption). Although the system examined is only able to provide quasi-off-grid year-round refrigeration, the energy gap can be easily alleviated using a diesel generator. In this hybrid configuration (renewables in conjunction with diesel generator backup), the combined system can significantly reduce operating emissions and energy costs, compared to a refrigerated container powered solely by diesel electricity generation.

Future work is anticipated to include on-grid modeling for communities throughout the territory of Nunavut.

5. References

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