Assessing the Thermal Comfort and Peak-Shifting Capabilities of Electric Thermal Storage Technology in the Yukon

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PROJECT OVERVIEW

Project Overview – Introduction

- The Yukon's Electric Thermal Storage (ETS) demonstration project involves over 40 participants and nearly 100 ETS units, sourced from two manufacturers, being studied to assess the viability of ETS technology in the Yukon.
- The project is primarily funded by Natural Resources Canada.
- The Yukon Conservation Society is responsible for managing the installation, operation, and data collection of ETS units.
- The Northern Energy Innovation team at Yukon University is responsible for data analysis.
- ETS units studied in the project include space heaters, central furnaces, and hydronic heaters.

Project Overview – How ETS works

- The fundamental concept of ETS is the separation of heat production and heat delivery.
- Heat is produced and stored via electric coils embedded within material with good heat retention, often ceramic bricks.
- Heat production is controlled to occur during specific periods, for example when grid electricity demand is low or when there is a surplus of electricity from a renewable resource.
- Typically, the stored heat is released passively through natural convection or actively with a fan or pump.

ETS furnace unit – Credit Yukon Conservation Society

http://www.storageheaters.com/how-storage-heaters-work.htm

Project Overview – The case for ETS in the Yukon

- ETS systems have the potential to reduce the peak demand on the Yukon grid through the shifting of electric heating loads from on-peak to off-peak times.
- The Yukon grid experiences winter peaks which cannot be met with existing hydro resources.
- Both fixed and rented fossil fuel generators are needed to meet the excess winter load.
- Through the reduction of winter peaking with ETS technology, greenhouse gas emissions could be reduced.
- Economic benefits could be realized, costs for fuel and rented generation for the utility are ultimately borne by Yukon residents.

Project Overview – Assessing ETS performance

- Data from the 2021-2022 heating season (September – April) was used to assess ETS performance.
- The power drawn by ETS units is analyzed with respect to the time of day that power was drawn to determine the unit's ability to meet a pre-determined "charging" schedule.
- For occupants, the most important function for an ETS unit is the ability to provide heat responsively and reliably.
- A mixture of survey and sensor data are used to determine the thermal comfort ETS units can provide.
- Assessing ETS' thermal comfort abilities in conjunction with ETS' adherence to a charging schedule provides an informative look at the technology's potential to be more widely adopted in the Yukon.

METHODOLOGY

Methodology – Assessing thermal Comfort

- Temperature and relative humidity sensors were installed in participant homes to gather quantitative data on thermal comfort, whereas surveys were circulated to participants to assess qualitative experiences.
- Hourly quantitative data was fed into the well known Predicted Mean Vote (PMV) model, and the 2-Node PMV model.
- The 2-Node PMV is more sensitive to changes in humidity and may better reflect occupant sensations.
- PMV models take inputs like temperature and humidity to generate an expected response from an average occupant on a 7-point thermal comfort survey scale.

Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
+3	+2	+1	0	-1	-2	-3

The PMV scale

- Results falling within [-0.5,+0.5] are considered best.

Methodology – Assessing peak-shifting

- The pre-determined times ETS units were set to charge were set to match the local grid's off-peak periods, where the non-charging times correspond to on-peak periods.

ETS Manufacturer	Charging times (hrs)
1	1100-1600 and 2200-0600
2	1100-1500 and 2200-0600

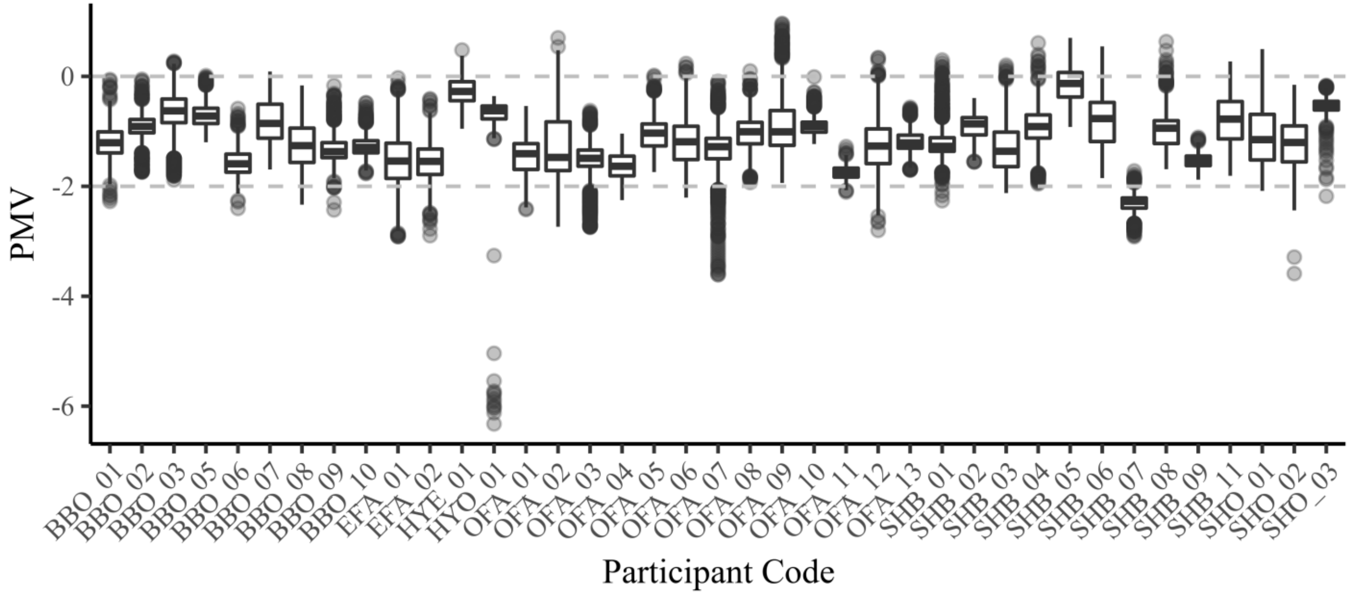
Charging times for ETS systems

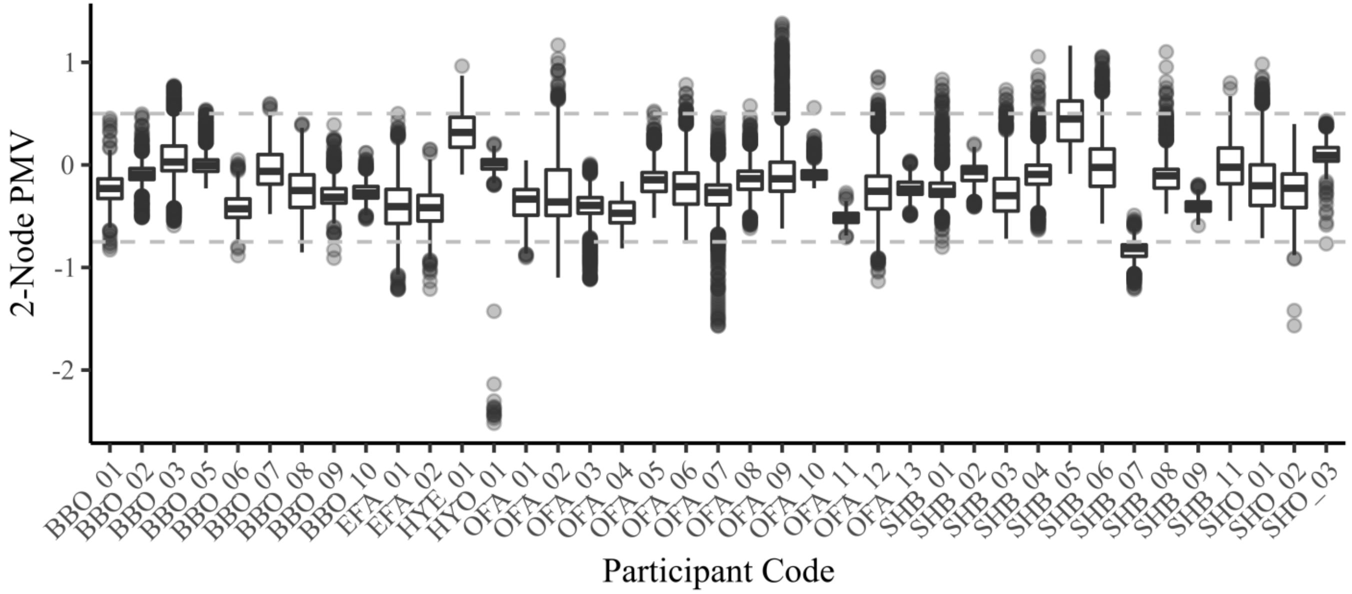
- A variable was needed to capture each ETS unit's adherence to scheduled charging times.
- The amount of power drawn by each ETS unit was summed with respect to the on and off-peak charging periods, then the proportion of the total power consumed during on and off-peak periods calculated.
- A higher resolution of this variable was created through calculating the proportion of power draw during on and off-peak times day-by-day instead of across the entire heating season.

RESULTS

PMV model results

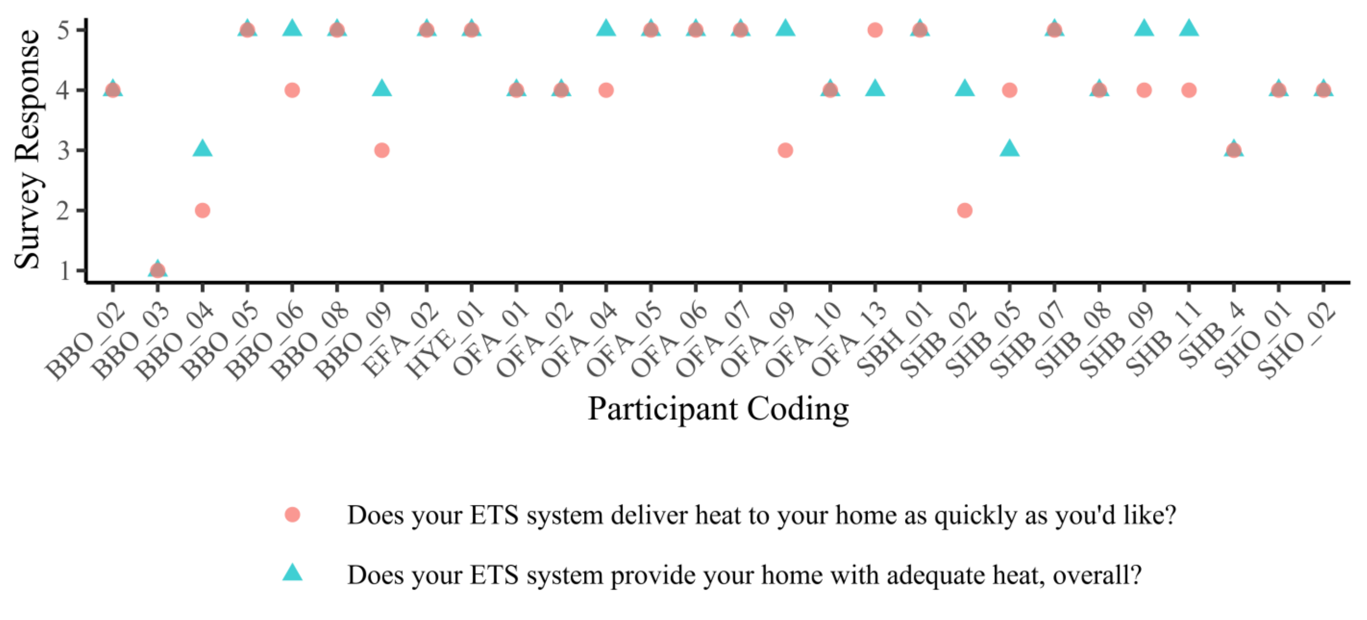
- The 2-Node PMV and regular PMV model results are shown through a boxplot in the right-hand figure.
- The x-axis displays each participant home coded by the primary heating source each ETS unit replaced (OFA = oil furnace, BBO = baseboard, etc.).
- The regular PMV model shows that across all participants, the majority of the expected thermal sensations fall between neutral (0) and cool (-2).
- In contrast, the 2-Node PMV shows that across all participants most of the expected thermal sensations fall between +0.5 and -0.75, close to the optimal range of [-0.5,+0.5].





Survey results

- The survey responses are given in the right-hand figure.
- Participant codings are displayed on the x-axis, whereas participant responses on a five-point scale are given on the y-axis.
- A response of “1” corresponds to the most negative response while a response of “5” corresponds to the most positive.
- It is clear a majority of ETS participants who answered the survey, responded positively to the thermal comfort related survey questions.
- 46 of 56 (82%) participants answered with a 4 or a 5.
- The high proportion of positive responses indicate that the 2-Node PMV is the more appropriate model to use than the regular PMV, and supports the conclusion that the thermal comfort needs of occupants were met.



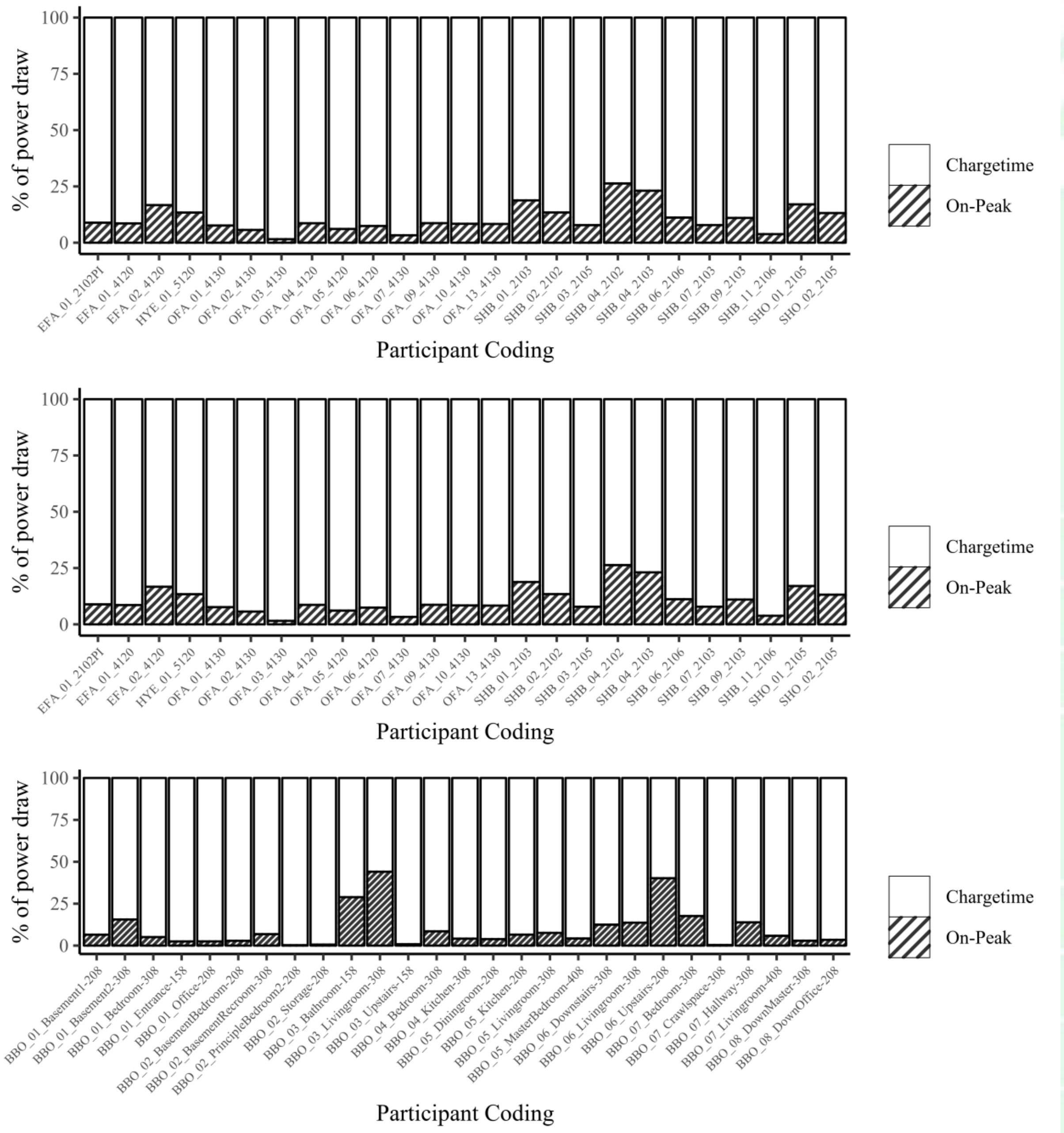
Adherence to scheduled charging times

- The proportion of charging that occurs during on-peak and off-peak times is given in the right-hand figures for project participants.
- The x-axis is broken down by participant coding and individual unit, as some participants have multiple ETS units in one home.
- Figure (a) shows results for manufacturer 1 units, figure (b) and (c) for manufacturer 2.
- Across all units it is apparent the majority of ETS charging took place during scheduled periods.
- 15 of 25 ETS units (60%) from manufacturer 1 drew over 90% of their power during scheduled charging times.
- 33 of 45 ETS units (73%) from manufacturer 2 drew over 90% of their power during scheduled charging times.

(a)

(b)

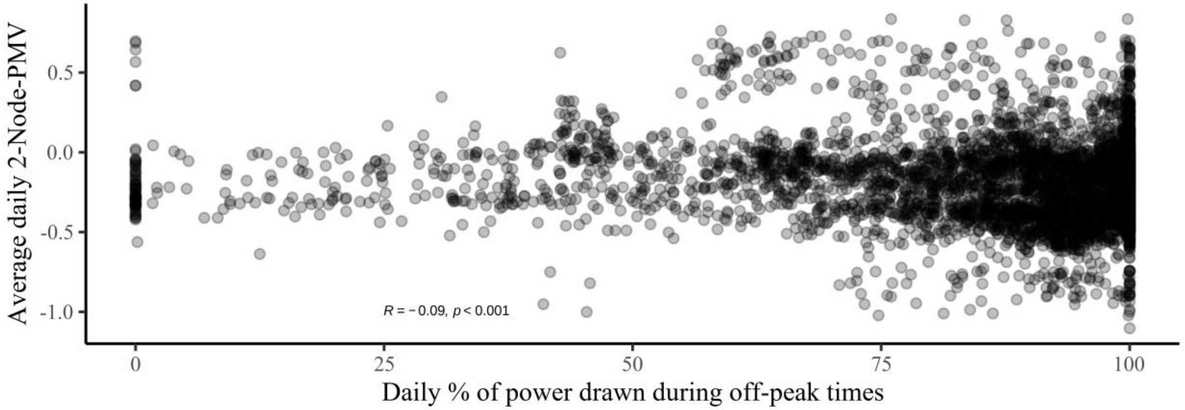
(c)



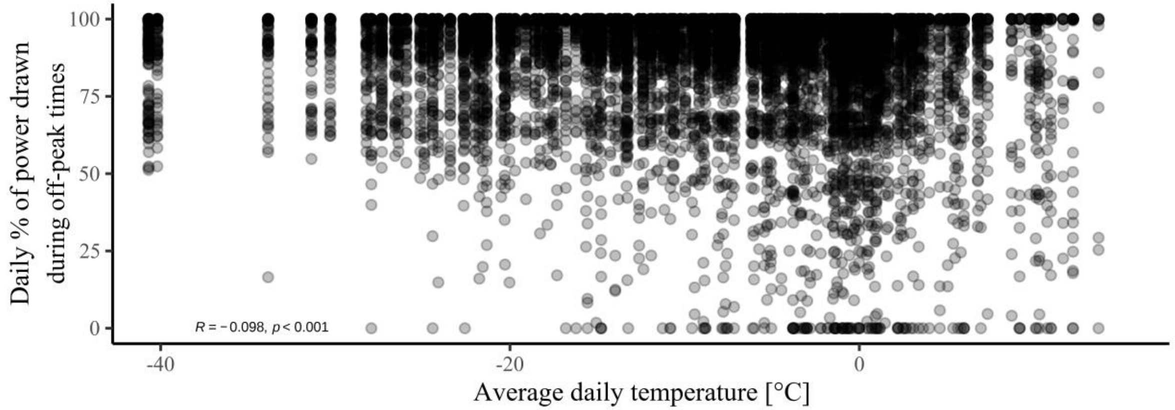
Relationships between thermal comfort, adherence to scheduled charging, and outdoor temperature

- It is useful to investigate the relationship between thermal comfort and charging schedule adherence to identify any correlations, as well as outdoor temperature to identify any effect the harsh Yukon winters may have on either variable.
- These relationships are plotted in the right-hand figure, along with a correlation value R and associated p-value.
- In (a) there is a slightly negative relationship between off-peak power draw and the 2-Node-PMV outputs, possibly indicating a cooling effect when units are charging.
- In (b) there is a slightly negative relationship between off-peak power draw and outdoor temperature, as temperature increases less power is drawn during off-peak times.
- In (c) there is a slightly positive relationship between outdoor temperature and the 2-Node-PMV outputs, indicating that as temperature increases thermal sensations are warmer.
- The weakness of the correlations between outdoor temperature, thermal comfort, and charging adherence are encouraging, the Yukon's harsh winter do not appear to have a problematic effect on ETS performance.

(a)



(b)



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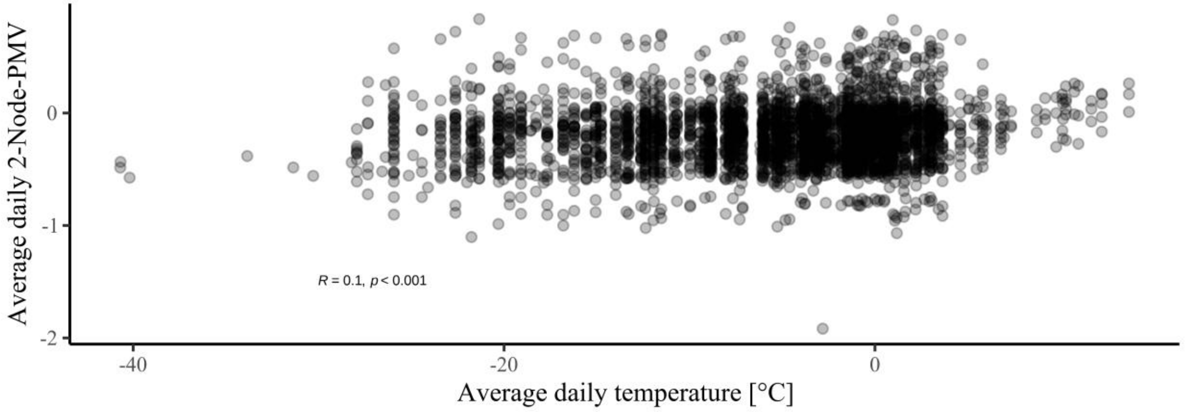

CONCLUSIONS

Conclusions

- The analysis of ETS project data for the 2021-2022 heating season found compelling evidence ETS units can reliably adhere to a predetermined charging schedule while maintaining a satisfactory level of thermal comfort.
- The majority of ETS systems drew over 90% of their power during off-peak periods, while the majority of project participants gave positive responses to survey questions regarding ETS thermal comfort.
- An empirical thermal comfort model used sensor data to confirm the survey results and indicated optimal levels of thermal comfort for the majority of the time across all participants.
- An analysis of the relationship between thermal comfort, charging schedule adherence, and outdoor temperature found evidence of minor correlations.
- The weak correlations between the two performance variables and outdoor temperature are an important result, indicating the Yukon's harsh winter had no serious effect on ETS performance for the 2021-2022 heating season.
- These results show ETS has potential to effectively shift peaks in electricity demand while satisfying occupants in the Yukon.

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