Is Your Vehicle Plugged in?
Green Options for Winter Parking at Ayamdigut Campus

Scott Gilbert

Renewable Resources Management Program
Yukon College
Whitehorse, Yukon

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YukonCollege

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Front cover photograph:

Top left: The main staff parking lot provides 76 spaces on a first come – first served basis; on some cold days there is competition for access to plugins. Photo credit: Aja Mason

Bottom left: During December and January the sun is low on the horizon and there is little solar gain during the day. Photo credit: Scott Gilbert

Right: Yukon Energy must run diesel and LNG plants to produce electricity in cold weather when hydro cannot meet the demand from the grid. Picture of the LNG plant running at 6:15 AM on Feb 5, 2018 when the temperature was -34°C. Photo credit: Scott Gilbert

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Executive Summary

Much of the physical plant at the Ayamdigut Campus of Yukon College dates back to 1988 and the expanding body of students and staff is straining capacity in some areas. In most winters some staff complain that during cold spells all the parking stalls with electrical plugins for block heaters are taken. Students commuting to campus have no access to block heater plugins. A 2017 survey of the student population indicated that 2% of students left their vehicles at home on cold days and half of student respondents worried about whether their vehicle would start after being parked in the cold on campus. The goal of this study was to address the concerns of both students and staff by investigating the options to provide improved winter parking. I adopted an environmental lens to evaluate some of the sustainability aspects of the problem by considering the carbon footprint of both the electricity to power block heaters as well as emissions from vehicles that their owners idled to keep the engine warm.

Based on survey results from staff I chose a temperature threshold of -25°C to model when most drivers began plugging in their block heaters. A survey of recommendations from vehicle manufacturers, local vehicle dealerships as well as Alaskan communities (e.g. Fairbanks, Anchorage) turned up a wide range of suggested temperatures when block heaters should start being employed (-7 °C to -30°C). My historical weather analysis focused on the last decade (2007-2016) and showed great temperature variation; the number of days with a minimum temperature < -25°C averaged 28 days per winter (range 6 to 45 days) while the length of the season bounded by those days averaged 85 days (range 26 to 117 days). Using the *Climate Western North America* modelling website I determined that the forecast for the 30 year span centred on 2025 will bring little change in average minimum winter temperatures while the forecast for 43 years in the future (centred on 2055) predicts milder average minimum winter temperatures of about 2 degrees. The overall number of days when block heaters are required will decease but the -25°C threshold is unlikely to disappear.

How should we respond? The options include building increased capacity (at an estimated cost of $800 per parking stall) to help meet demand. I think there is merit in evaluating the current situation where students commuting to campus by vehicle lack any access to plugins and staff, who do avail themselves of the service, do not pay for it. Alternatives such as encouraging the use of public transit and carpooling on cold days could lessen demand for plugins and reduce collective carbon emissions.

There is an excellent opportunity to set up a trial to implement and test energy conservation measures with block heater plugins on campus; this could provide cost savings (and a reduced carbon footprint) for the institution. Changing human behaviour is challenging but the campus population may be a good candidate for a “vehicle idling” reduction study.

Introduction

Winter climates can be hard on combustion engines and most long-time northerners have a series of tricks they use to cope with cold weather. Across the Canadian Prairies and northern territories it is common to find vehicles that are equipped with electric block heaters that can be used to preheat the crankcase oil or engine coolant to reduce friction and make it easier to start the engine. This study teases out a small part of that cold weather problem and investigates the sustainability aspects of a common northern dilemma – how to start a vehicle in cold weather after it has been parked on campus or at the workplace for several hours.

The Ayamdigut Campus of Yukon College was opened in 1988 and after 30 years some of the infrastructure is showing signs of wear and exceeding the capacity limits that it was designed for. One such example is the provision of parking for people who commute by vehicle to the campus. As the number of students and staff who attend campus has increased there have been some incremental additions to parking capacity but during cold weather there are never enough electrical outlets to meet demand. Students who live off campus have no access to electrical outlets as the limited supply is allocated only to staff or people living in student housing. In very cold weather some students will start their vehicles and let the engine idle long enough to warm up so they have some assurance the vehicle will start at the end of the day.

The goal of this study was to explore the sustainability aspects of some practical questions. How many winter days actually necessitate plugging in a block heater? Are the environmental costs of carbon emissions, caused by idling the engine on cold days to warm it up, more or less than the environmental cost of building additional electrical infrastructure (copper wiring, steel conduit, electrical plug-ins, etc.) and providing electricity (which may come from thermal generation)? I tried to define an answer to this question by using a *life cycle costing* approach (slightly modified so we do not have to consider the costs of disposal at the end of the life cycle). Most of the electricity distributed in Whitehorse comes from hydro generation however as temperatures decrease during the winter (when water flows for hydro are limited), and the likelihood of using block heaters increases, the electrical utility is forced to meet increased demand by burning fossil fuels (e.g. diesel, LNG). Therefore I carried out the analysis using both dollars as well as carbon emissions estimated on an annual basis.

The report is divided into four sections and begins by trying to describe the range of cold temperatures when drivers *should* use their block heater compared with some empirical data from Yukon College staff on when they *actually* do so. Combustion engines run poorly when starting in the cold (Cook et al. 2007, Bielaczyc et al. 2014) and I reviewed some of the interesting research done by our Alaskan neighbours on emissions of air pollutants from vehicles during winter. The second section analyzes recent weather data for Whitehorse to generate a baseline description of the number of days per winter when a block heater might be needed. Next I selected a climate model forecast, Climate Western North America developed by Wang et al. (2016), to estimate the number of future days when a block heater might be required. The third section of the report uses a small data set provided by Yukon Energy to try and quantify the relationship between temperature and Yukon Energy's carbon emissions; as the temperature drops below -7°C the utility must burn fossil fuel to meet rising electrical demand. Using that conversion rate I was able to estimate the carbon emissions that would arise from the use of electric block heaters at various temperatures. The final section of the report explores the implications of various "green" scenarios that might be used on campus to reduce the environmental impacts of vehicle operation during winter.

Methodology

Life Cycle Costing This type of accounting exercise is known by many names including *whole life costing, full cost accounting, whole life value* and *total cost of ownership* (Perera et al. 2009). They share a common approach that seeks to register all the costs of a potential product or service including externalities (i.e. costs such as environmental impacts that are not included in market prices). Life cycle costing is most helpful in situations where there are trade-offs that must be weighed over lengthy time periods. For example when deciding whether to install a cheap appliance with a high operating cost versus a more expensive, energy efficient device the most economical decision is determined by the time frame for the analysis; a short period favours the option with the lowest initial capital cost while a longer duration recognizes the benefits of options with lower operating costs.

In its *Design Standards for Government Facilities* document the Yukon Government (2010, p. 1) sets out an objective of designing buildings to meet the functional needs of clients while achieving *"the minimum capital cost consistent with lowest life cycle costs".* When comparing alternatives the guidelines suggest using a 20-year design life.

Carbon Footprint The impacts of carbon emissions on climate change and global warming are one of the most widespread externalities in Canada and only a few provincial jurisdictions have integrated the costs in market prices by implementing a carbon tax. Yukon does not yet set a price for carbon and so our analysis tries to carry through a bottom line denominated in dollars and carbon (CO_2 equivalents). Yukon Energy, the electrical utility, provided estimates of the magnitude of the carbon emissions associated with electrical production during cold winter weather.

Use of Engine Block Heaters I used four approaches to answer the question of what air temperature determines when drivers choose to plug in their engine block heaters. First I carried out an informal survey of local service shops at several car dealerships. Second I tried to measure the decision empirically by monitoring the Yukon College staff parking lots on 21 days between January 19 and March 15, 2017. On each sampling day, about mid-morning, the number of vehicles that were parked in front of electrical plugins, in the main staff parking lot, was recorded and scored as either plugged in or not. On each sampling day 4 weather variables from the Environment and Climate Change Canada's web site for Whitehorse (http://weather.gc.ca/city/pages/yt-16_metric_e.html) were noted (the overnight low temperature, the forecasted high temperature, the ambient temperature and the wind chill). Secondly, I used an anonymous online SurveyMonkey questionnaire that was distributed by email to most Ayamdigut staff members between March 2 and March 7, 2017. The survey (Appendix 1) asked how drivers made their decision about what temperature triggered their use of engine block heater. Thirdly, an informal survey, by telephone, of 7 Whitehorse car dealerships was carried out and asked what advice they would give a new northern resident about when to use an engine block heater. Finally I surveyed the research literature available from studies conducted in Fairbanks and Anchorage, AK regarding air pollution problems in winter. Much of this unpublished research focused on the applied problem of seeking ways to reduce vehicle emissions of key air pollutants during winter and one of the mitigative measures examined the utility of using engine block heaters.

Prevalence of Vehicle Idling Students who lack access to block heater plugins on campus may idle their vehicles to warm up the engine during cold weather. I used an anonymous online SurveyMonkey questionnaire (Appendix 2) that was distributed by email to the student body to obtain estimates of the frequency and duration of this activity.

Weather Records I obtained historical climate data from Environment and Climate Change Canada's web site (http://climate.weather.gc.ca/index_e.html) and chose the Whitehorse A station (Meteorological Service of Canada climate identifier number 2101303). I selected the 30-year climate normal for the period 1981-2010 as well as 11 years of daily records covering the period from 2007 -2017. Where data were unavailable for the Whitehorse A station (n=66 days) I used the data from the nearby Whitehorse Auto station (ID 2101310) as a replacement and in one case (Oct., 25, 2013) both stations had failed and the temperature from the Mayo Road station (ID 2100709) was used.

The 30-year climate normal provides a summary of the number of days on which the minimum temperature was less than -20°C and -30°C and for ease of comparison I adopted these as standard categories. I added a third category for days with a minimum temperature less than -25°C for the analysis of recent weather records. I used the *Climate Western North America* modeling web site developed by Wang et al. (2016) at http://climatewna.com/climatena_map/ to obtain the average minimum winter temperature for various time periods. I entered the latitude and longitude for the location of the Whitehorse station (60.6°N and 135°W) as well as elevation (706 m). I did modelling runs with each of the three different general circulation models developed in the Climate WNA model: (i) the Canadian Centre for Climate Modelling and Analysis model, *CanESM2,* dated 2010, (ii) a European model *CNRM-CM5*, developed by Centre National de Recherches Météorologiques and Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique dated 2010, and (iii) the 2009 UK model developed by the Met Office Hadley (Flato et al. 2013). The Climate WNA model offers a choice of future scenarios based on the predicted greenhouse gas concentrations discussed in the Fifth Assessment Report of the Intergovernmental Panel for Climate Change (Wang et al. 2016). I chose the Representative Concentration Pathway called RCP 4.5, an intermediate scenario, which sees greenhouse gas (GHG) emissions peak in the 2040s and then decline in preference to RCP 8.5 which would see GHG emissions grow throughout the century.

Engine Block Heaters and Temperature Thresholds

It turned out to be surprisingly complicated to answer the simple question of what temperature should be used to model the decision about when to use a block heater. Four approaches were used and provided very different conclusions.

1. Recommendations from Vehicle Manufacturers for Cold Weather Starting

I looked for advice provided by vehicle manufacturers on starting vehicles in cold weather by searching their web sites or owners' manuals for popular models. I was unable to find any explicit guidance on cold weather starting for Hyundai, Kia, Nissan or Toyota vehicles. The advice given by General Motors was to use a heater for the engine coolant at temperatures of -18°C and colder, and further, "Usually, the coolant heater should be plugged in a minimum of four hours prior to starting your vehicle." (General Motors Corporation 2005, p. 2-25). The advice provided by the Ford Motor Company in their owner's manual states, "Use of an engine block heater is strongly recommended if you live in a region where temperatures reach -10°F (-23°C) or below. For best results, plug the heater in at least three hours before starting the vehicle." (Ford Motor Company, 2005, p. 194).

Vehicle technology continues to evolve and starting in 2005, for example, Chevrolet trucks have featured factory installed "engine coolant heaters" that come with a thermostat in the heater cord that prevents operation of the heater when it is warmer than -18°C (General Motors Corporation 2005). While this feature helps save electricity the actual motivation for adding the feature appears to have been to prevent unwanted engine error codes when starting the vehicle.

An informal telephone survey of seven Whitehorse car dealerships in February 2017 found that the service departments at five shops advised plugging in the vehicle when the temperature dropped to -20°C. One shop suggested -15°C and the outlier was a shop that stated -30°C was the threshold when a vehicle should be plugged in.

2. Parking Lot Observations

The vast majority of Ayamdigut staff work a nominal 7.5 hour work day and I had hoped that by surveying the staff parking lot at mid-morning, on work days covering a range of cold days, I could identify a small range of temperatures that triggered the behaviour (of plugging in a vehicle). In fact there was considerable variation (Figure 1) although as the temperature dropped below -16°C the pattern was for increasing numbers of drivers to use the plugins that were available. Using the equation for the regression line predicts 46.5% of vehicles would be plugged in at -25°C and 72% at -30°C[1].

[1] A spot survey in the same staff parking lot a year later, on Feb. 5, 2018, found 75% of vehicles plugged in on a morning when the temperature was -35°C.

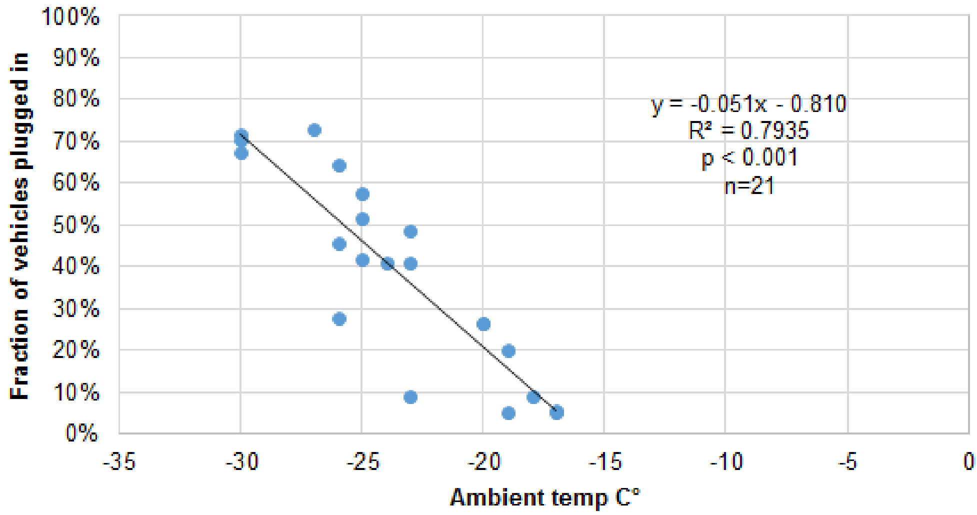

Figure 1. The percentage of cars in the Yukon College staff parking lot that were plugged in is plotted against the ambient temperature based on 21 days of sampling between January and March, 2017. The number of vehicles sampled each day averaged 59 (range 49-67).

3. Survey Results of Staff Use of Parking Plugins

A more definitive answer emerged from the survey of staff members (Table 1) when they were asked how cold it had to be for them to decide to plug in their vehicles. I was able to assign 103 responses to pre-defined temperature categories. Less than 1% of respondents said they started using their block heater when it dropped to -10°C or colder. The largest number of respondents (51%) said they began plugging in their vehicles on days when it was -20°C or colder. When temperatures dropped to -25°C or colder I found that 86% of respondents indicated they would be plugging in their vehicle`s block heater.

Table 1. Results of an **a**nonymous survey of Ayamdigut staff members when asked the question: *How cold does it have to be before you plug in your vehicle*

Temperature	**# responses**	**Percent**	**Cumulative Percent**
-10 C or colder	1	1%	1%
-15 C or colder	14	14%	15%
-20 C or colder	53	51%	66%
-25 C or colder	21	20%	86%
-30 C or colder	14	14%	100%
Total	103	100%	

Is it possible to reconcile the discrepancy between the results obtained from the two survey methods? Based on sampling the actual behaviour of drivers, the regression analysis predicts there would be no one plugging in at a temperature of -16°C or warmer. However when we asked about their *intentions*, 15% of drivers in our anonymous survey reported they would plug in their vehicle when the temperature had dropped to -15°C. It seems very likely that we were sampling the same group of employees so the difference is puzzling. The sample of staff members who volunteered answers to our survey question was 103 and should probably be given more weight because the sample size of the number of vehicles we monitored in the main staff parking lot was smaller and may have included some methodological weaknesses.

Monitoring the fraction of vehicles plugged in during mid-morning may have underestimated the behaviour we were trying to measure for two reasons. First, staff members arriving in the morning who knew they had a meeting or appointment off campus might not have bothered to plug in on cold mornings. We learned from the anonymous surveys that 24% of respondents (23/95) said they decided whether or not to plug in their vehicle at noon or later in the day so we would be misled by assessing their intentions based on whether their vehicles were plugged in or not at mid-morning.

4. Starting Vehicles in Cold Weather and Air Pollution

Should the decision about when to use a block heater be based on the pragmatic question tacitly pondered by drivers during a cold spell, "will my vehicle start?", or should it be based on the vehicle's potential emissions? Two cities in Alaska provide an interesting case history.

Fairbanks, Alaska has a continental climate with cold winters. This, along with the city's topography in a valley, like Whitehorse, makes it vulnerable to a buildup of air pollutants during cold weather when there is a temperature inversion and little air movement. In the United States, the Environmental Protection Agency has a long established set of National Ambient Air Quality Standards; in the past both Fairbanks and Anchorage have triggered Federal government interventions when local air quality deteriorated and exceeded the national limits. For example, in 1991 the EPA declared Fairbanks a "nonattainment" area based on the frequency with which carbon monoxide levels exceeded safe levels (Ward et al. 2012). In 2009 Fairbanks was again declared a "nonattainment" area for concentrations of airborne particular matter, "$PM_{2.5}$" (ADEC 2016)[2].

Anchorage has a warmer winter climate than Fairbanks but has experienced a history of problems with high concentrations of carbon monoxide and exceeded the federal standard every year between 1972 and 1994. The city has also had problems on occasion with fine particle pollutants although some of those cases were traced to releases from nearby volcanoes (Municipality of Anchorage 2011). As a consequence there has been a concerted research effort

[2] $PM_{2.5}$ refers to airborne particulate matter that are particularly small (diameter of 2.5 µm or less) and present a human health risk because of their ability to be drawn deep into the lungs.

in both cities to describe the sources of the air pollutants as well as to identify mitigation strategies to reduce emissions.

The predominant source of both pollutants has been traced to fossil fuel combustion in vehicle engines. Over the years a variety of initiatives to reduce emissions have been explored and included a switch to oxygenated fuels (e.g. ethanol blended gasoline), the adoption of low sulfur gasoline (ADEC 2006), and the use of mandatory "inspection and maintenance" programs to ensure vehicles met emissions standards (ADEC 2008).

The Alaskan research documented that cold engine starts in winter were responsible for a significant fraction (~53%) of the carbon monoxide emissions. As a result both cities embarked on a public education campaign to encourage the use of engine block heaters during winter months to reduce the pollution associated with cold engine starts (Figure 2). For example, in the early 2000s Anchorage ran an *Engine Block Heater Program* that offered 2,000 local motorists substantial subsidies to supply and install block heaters on their vehicles (ADEC 2003). The magnitude of the problem is outlined in this description of the source of carbon monoxide by the Municipality of Anchorage (2011, p.5):

Figure 2. This "Plug @ 20" poster was used in Anchorage to encourage residents to use their block heater starting at -7°C.

> *In Anchorage, CO concentrations are highest in mid-winter. According to the latest inventory compiled for the Anchorage bowl area for the year 2007, an estimated 79% of winter season CO emissions in Anchorage were from motor vehicles. Two-thirds of these emissions occur shortly after start-up, especially if the vehicle is cold.** Cold winter temperatures significantly increase CO emissions during the first few minutes of vehicle operation. In the winter, many Anchorage drivers engage in extended warm-ups, particularly prior to a morning commute. A 1998-99 Anchorage study indicated that the average warm-up period for morning commuters was 12 minutes. As a consequence, some of the highest CO concentrations in Anchorage occur in neighborhood residential areas where cold starts and long warm-ups are prevalent.*
> *** Estimated with the EPA MOVES model for Anchorage on a winter day with an average temperature of 4°F.*

Most vehicles in Fairbanks were already equipped with block heaters because motorists needed the heaters to ensure their cars would start in the colder temperatures experienced in the interior of the state. The campaign to reduce carbon monoxide emissions in Fairbanks took a different turn and focused on providing better access to electrical plugins at workplace parking sites, (ADEC 2016, p. III.D.5.7-14):

> *Engine preheaters are used extensively throughout Fairbanks when ambient temperatures drop below 0° F to ensure that vehicles exposed to these temperatures can be easily started. Local testing programs have confirmed that preheating vehicles, a practice commonly referred to as "plugging-in," provides a substantial reduction in motor vehicle cold start emissions. Recognizing the many benefits of plugging-in (e.g., reduced emissions, lower need for maintenance, fuel economy, startability, etc.), the Borough has a long-standing practice of expanding the number of parking spaces equipped with electrical outlets. This has been achieved by securing funds for retrofitting existing facilities (e.g., school renovations) and including outlets in new public facilities (e.g., the construction of new schools). It has also been achieved by encouraging the private sector to retrofit existing facilities (e.g., hospital expansions) and including outlets in new private facilities (e.g., Home Depot).*

Authorities in Fairbanks also used a public education campaign to encourage motorists to use their engine block heaters when the temperature dropped to 20°F or -7 °C and colder (ADEC 2016). Surveys of the public conducted in Fairbanks in 2000 showed that while, …"86% of people polled listed improved vehicle starting as one of the major reasons for plugging in … only 54–56% listed improved air quality and public health as a major reason." (NRC 2002, p. 94). The technical details behind the choice of -7°C as a cut off for using block heaters is convincing. One study, using a sample of six vehicles, found a large reduction in the amount of carbon monoxide emitted when vehicles were plugged in for 4-8 hours before starting; the cumulative carbon monoxide emissions over a 15 minute start up and idling period were 70% less.

Is there a rationale for adopting the Alaskan temperature of -7°C as the threshold to use an engine block heater in Yukon? Whitehorse has a smaller population with fewer vehicles as well as a different winter climate than Anchorage or Fairbanks. Those cities had to confront serious problems with air pollution in winter, especially carbon monoxide and fine particular matter ($PM_{2.5}$) and had to resort to a variety of mitigation approaches to reduce the concentration of pollutants. The age and composition of the vehicle fleet in the Yukon is probably similar to that in Alaska so there is no reason to expect the Yukon emissions per vehicle to be any different. There is a comparatively rich data source on air pollutants in Alaskan cities that is missing for Whitehorse. Canada's National Air Pollution Surveillance Program (NAPS) has sampling stations in downtown Whitehorse although it is does not currently record carbon monoxide levels (Environment and Climate Change Canada 2017a).

Temperature Threshold Conclusion

I adopted three cut-off temperatures to model when engine block heaters should be used: -20°C, -25°C and -30°C. I did so by giving weight to the questionnaire results from staff and using the two higher cut-offs would have captured 86% and 100% of the sample population respectively. I recognize there are large benefits from reduced vehicle emissions by using block heaters at warmer temperatures such as the -7°C threshold recommended in Fairbanks. However we have scant information about the levels of most air pollutants in the Whitehorse area and it would take a considerable public education campaign to change the entrenched behaviour of the driving public to move to a warmer threshold.

Historical Weather Analysis

I began the temperature analysis by assuming drivers might use their engine block heater between October 1 and March 31. The 30-year climate normal for Whitehorse, covering October-March from 1981-2010, shows there were an average of 47.9 days when the minimum temperature was colder than -20°C and 15.6 days when the minimum temperature was less than -30°C. The more recent weather data from 2007-2016 shows a slight decrease in the average number of days below those thresholds of about 2 days suggesting the winters are getting warmer (Table 2). The range of values over this decade-long period is more informative; in one year (2015-16) there was just one day when the temperature was below -30°C and six days colder than -25°C. This supports the anecdotal stories of some drivers who claimed they did not have to plug in their vehicle once during the warm, El Niño-influenced winter of 2015-16. On the other hand we have had some very cold winters during the last decade with 2008-09 standing out when there were 45 days with a minimum temperature below -25°C. There is no detectable pattern to the number of days with a temperature colder than -25°C during the winter season over this short decade long data set (Figure 3).

Table 2. Number of days between Oct. 1 and March 31 of the following year when the minimum daily temperature was below a certain temperature for the decade from 2007-08 to 2016-17. Year of minima and maxima in brackets.

	<-20°C	**<-25°C**	**<-30°C**
Average	45.9 days	27.9 days	13.5 days
Std. dev.	17.8	12.9	7.5
Median	49.5	31.5	13.5
Min	15 *(2015-16)*	6 *(2015-16)*	1 *(2015-16)*
Max	68 *(2008-09)*	45 *(2008-09)*	25 *(2008-09)*

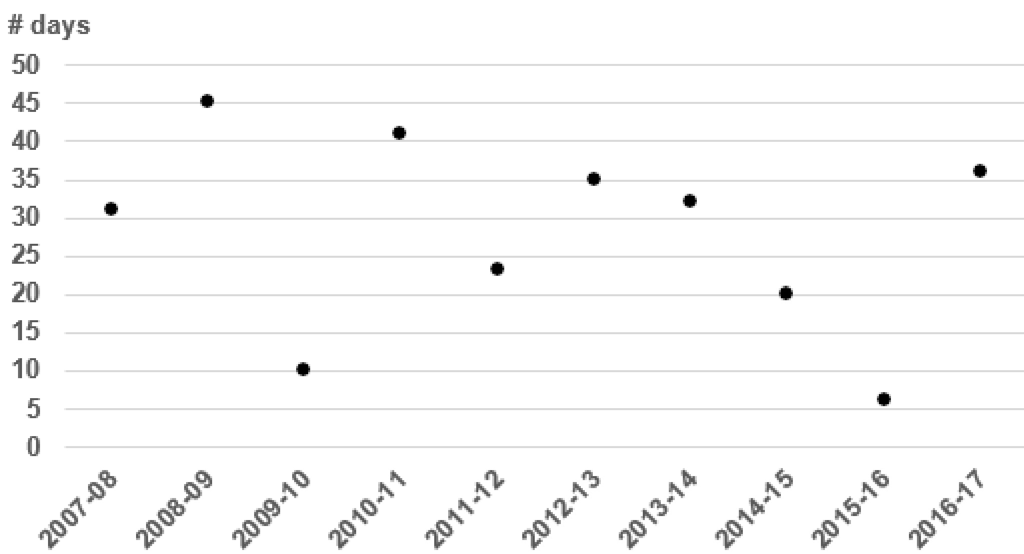

Figure 3. Number of days between October 1 and March 31 of the following year when the minimum daily temperature was below -25°C. There is no trend over time (R^2 = 0.08, prob. = 0.44).

Another way to describe the period when engine block heaters must be used is the season length (Figure 4, Table 3). Between 2007 and 2017 there was an average period of about two months (68 days) between the dates of the first and last days when the temperature was below

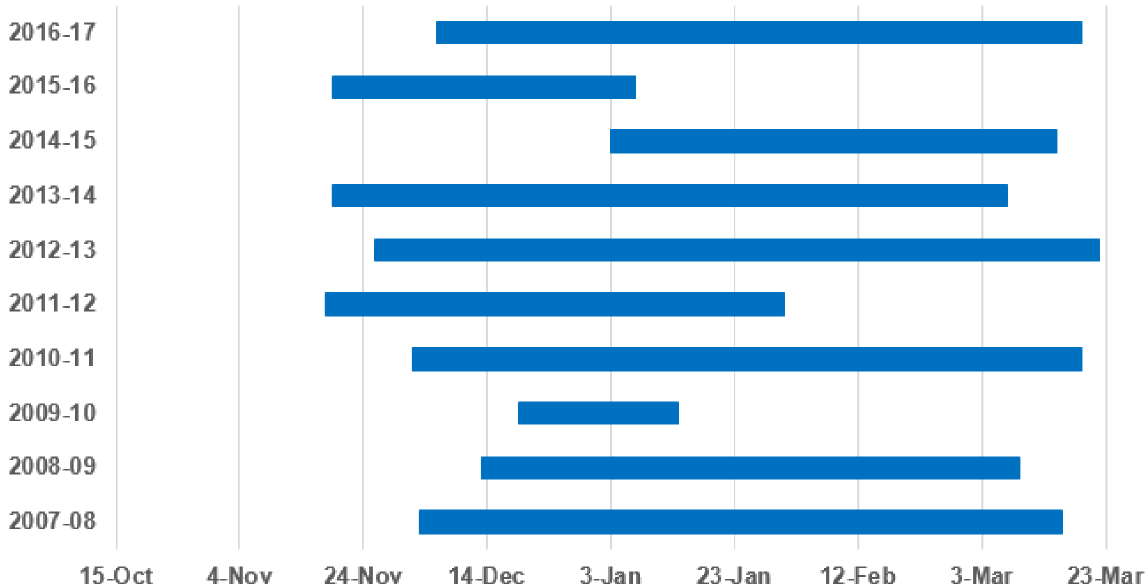

Figure 4. Length of the block heater season using a threshold of -25°C minimum temperature. There is no trend over time in the length of the season (R^2 = 0.00004, prob. = 0.98).

Table 3. Length of the season, in days, measured between the first and last day when a particular temperature threshold was exceeded. Adjustments were made for leap years. Year of minima and maxima in brackets.

	<-20°C	**<-25°C**	**<-30°C**
2007-08	120 days	104 days	69 days
2008-09	144	87	83
2009-10	125	26	12
2010-11	130	108	101
2011-12	128	74	71
2012-13	125	117	107
2013-14	137	109	105
2014-15	108	72	39
2015-16	66	49	1
2016-17	105	104	90
Average	118.8	85.0	67.8
Std. dev.	22.0	29.7	38.2
Median	125.0	95.5	77.0
Min	66 *(2015-16)*	26 *(2009-10)*	1 *(2015-16)*
Max	144 *(2008-09)*	117 *(2012-13)*	107 *(2012-13)*

-30°C. The average first and last day when the temperature was below -30°C was December 9 and February 14 (with a range that spanned dates from November 19 to March 14). The length of the season for milder temperatures thresholds was longer and reached almost four months for -20°C. Again the range of extreme values is of interest. In 2015-16 there was only a single day during the entire season when the temperature fell below -30°; in 2012-13 there was a period of 107 days between the first and last record of a temperature below -30°. Environment and Climate Change Canada (2016) points out the 2015-16 winter season in Canada was a strong El Niño year with unusually warm temperatures.

It seemed pragmatic to choose a time block from October 1 to March 31 to analyze weather records as cold temperatures that may trigger the use of block heaters during this period are possible. Unfortunately that time block does not mirror the seasons used in climate change models and I had to adopt a conventional block using the winter season, defined as December 1 to February 29. Using this shorter winter season as a baseline, the climate normal for 1981-2010 shows there are an average of 12.9 days when the minimum temperature was less than -30°C and 35 when the minimum temperature is below -20°C. My analysis of recent weather records for 2007-2016 (Table 4) lines up closely with the climate normal predictions for the number of days with temperatures below -20°C- and -30°C.

Table 4. Number of days in the winter season (Dec. 1 to Feb. 29 of the following year) when the minimum daily temperature was below a certain temperature for the decade from 2007-08 to 2016-17. Year of minima and maxima in brackets.

	<-20°C	**<-25°C**	**<-30°C**
Average	35.4 days	22.8 days	11.9 days
Std. dev.	13.5	11.1	7.1
Median	39.0	24.0	12.0
Min	12 *(2015-16)*	4 *(2015-16)*	1 *(2015-16)*
Max	56 *(2008-09)*	42 *(2008-09)*	24 *(2008-09)*

Future Predictions from Climate Change Models

It was impossible to find published climate predictions, for Whitehorse, that were broken down into sufficient detail to get a prediction of the number of days with specified minimum temperatures. Most models generate predictions using aggregated averages and not the fine-scale detail I was looking for so I adopted the following strategy. I used the *Climate Western North America* (Climate WNA) modeling web site developed by Wang et al. (2016) to obtain the average minimum winter temperature for their most recent historical decade (2001-2010) as well as predictions for 2025 and 2055. I compared these future predictions with my analysis of the 2007-2016 baseline period (Table 5) and detected relatively small differences. The UK model (HadGEM2-ES) stands out at one extreme with predictions of less future warming for our location; in fact their 2025 prediction would see *cooling* during future winters. The Canadian and European models show closer agreement with little change predicted for the 30 year span centred on the year 2025. The longer range prediction, 43 years in the future, (i.e. a 30 year span centred on 2055) shows significant warming; the Canadian model by 2.3 degrees and less for the European model at 1.1 degrees.

Table 5. Comparison of the average minimum temperature for winter (Dec. 1 to Feb. 29) for the 2007-2016 baseline, 1981-2010 climate normal and several future scenarios based on the Climate WNA model.

2007-2017 This study	Climate normal 1981-2010		Future Scenario	CanESM2 2010 Model	CNRM-CM5 Model	HadGEM2-ES Model
-17.6°C	-17.8°C		**2025** - RCP 4.5	-17.7°C	-17.8°C	-19.3°C
			2055 -RCP 4.5	-15.3	-16.5	-17.3

How many fewer cold nights would a change in the future average minimum winter temperatures lead to? I began by looking at the frequency distribution of the 903 individual minimum temperatures for winter weather records from 2007 to 2016 (Figure 5). The Canadian model prediction for 2055 (Table 5) shows an average winter temperature of -15.3°C, about 2.3 degrees warmer than present. If one assumes that the range of temperature fluctuations (i.e. natural variability) will remain constant in the future then there will be a tendency for the distribution in Figure 3 to shift to warmer temperatures on the right of the graph and result in fewer extreme cold nights. More exact predictions are not possible as these data show a departure from a theoretical normal distribution (Figure 6) as confirmed with a Sapiro-Wilk test (W= 0.983, prob. < 0.0001). As Deser et al. (2012) point out, uncertainly in future climate projects comes, in part, from natural variability. While we can anticipate future warming in northern Canada the underlying natural variation in temperature trends over the next 55 years can be expected to be “substantial” (Deser et al. 2012, p. 777).

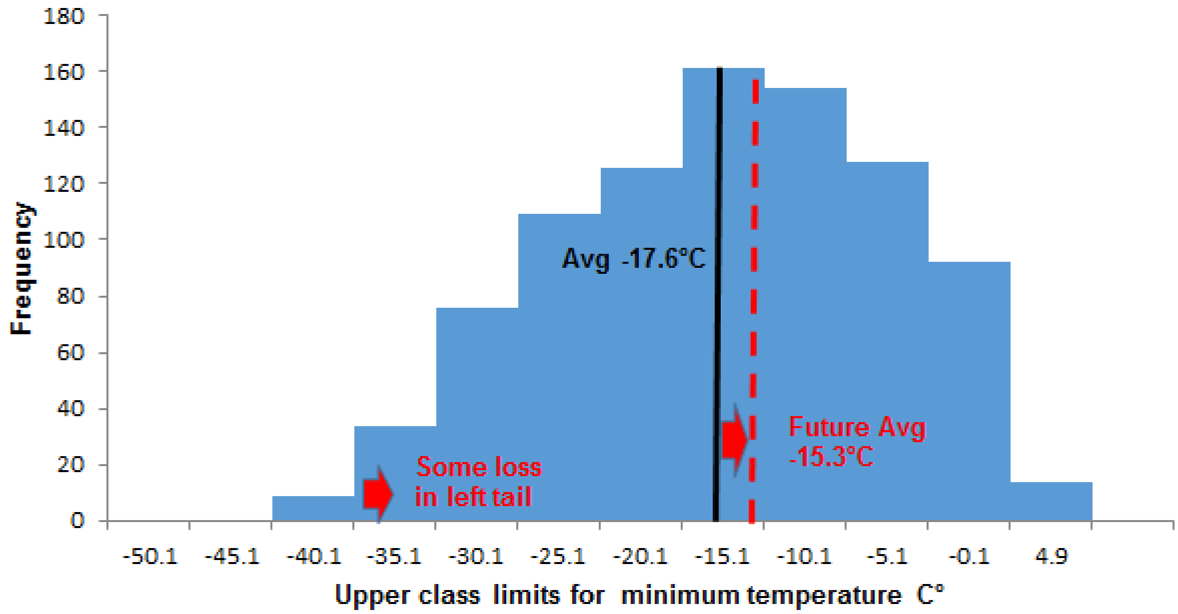

Figure 5. The frequency distribution of the number of days of minimum winter temperatures (2007-2016) showing a current average of -17.6°C. The predicted warming for 2055 under the CanESM2 model would see a new average of -15.3°C and tend to shift the distribution's left tail towards warmer temperatures resulting in fewer cold nights when a block heater might be needed. n= 903

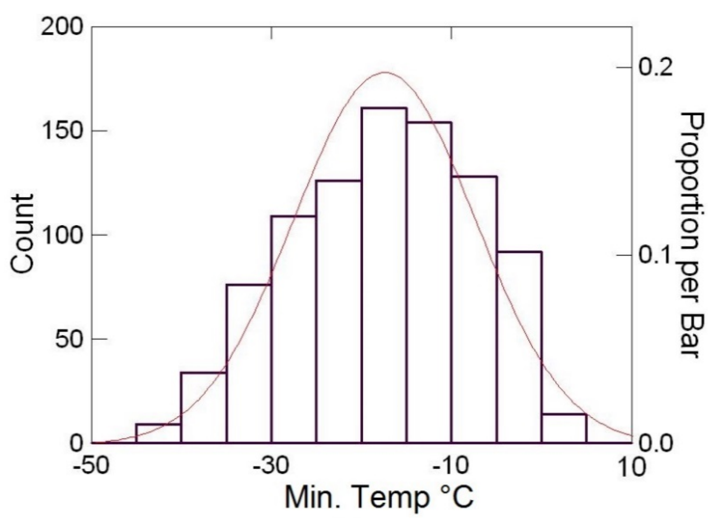

Figure 6. The frequency distribution of minimum winter temperatures (Dec. 1 – Feb. 29 for the period 2007-2017) shows significant departures from a theoretical normal distribution (*thin red line*). n=903

Block Heater Usage: Energy and Carbon Emissions

There was no easy answer to the question of what cold temperature threshold made drivers decide to use their block heater and, it turns out, there is no widely adopted advice on how long a vehicle should be plugged in before starting. In this section I first address the question of how long a vehicle's block heater should be plugged in and then explore some of the implications in terms of energy consumption and carbon emissions from upstream electrical generation.

There are a variety of approaches to keeping an engine and its fluids warm enough to start in cold weather. Two of the popular approaches are to install an inline heater that warms up the engine coolant and (may have a circulating pump) or to install a frost plug heater that heats the engine coolant in the engine block. The power demand of a block heater depends on the size of the engine and varies from 400 watts for an economy sized vehicle up to 600-1,000 watts for large vehicles with 6-8 cylinders (Canadian Automobile Association 2009).

Natural Resources Canada (2016a) states that the optimal amount of time to plug in a block heater before starting the vehicle is 2 hours while Manitoba Hydro (n.d.) through their PowerSmart program suggests a maximum of 3 hours. The local Whitehorse utilities through their website devoted to energy conservation tells consumers they need to plug in their block heater for a maximum of 4 hours (Yukon Energy 2017). Some vehicle manufacturers offer guidance. For example, General Motors suggests the block heater should be turned on for four hours before starting the vehicle when the temperature is below -18°C (General Motors Corporation 2005, p. 2-25) while the Ford Motor Company suggests 3 hours when the threshold temperature is colder than -23°C (Ford Motor Company, 2005, p. 194).

Wiens (1972) used a cold room to empirically measure the change in temperature of the engine coolant in response to block heaters used at a range of different cold room temperatures (from -12°C to -40°C) over time. His experimental design used a 1939 six cylinder engine as well as larger capacity block heaters that may not compare directly to today's smaller engines. His key conclusion would still apply today; after a few hours the engine coolant reaches a constant temperature as the engine block and the heater reach an equilibrium with the ambient temperature. From an energy conservation point of view it makes sense to determine how long the block heater should be plugged in.

Barry Hertz, professor emeritus at University of Saskatchewan, carried out a detailed study in 2008 on the relationship between the temperature and time needed to properly warm a vehicle using a block heater. Although temperature was the main variable he also monitored engine oil viscosity, battery condition and engine type. Sask Power used his unpublished work in 2016 for a blog post titled, "*Mythbusted*" to encourage customers to be more strategic in their use of block heater timers (SaskPower 2016). The article offered guidelines that suggested the time needed to plug in a block heat varied from just 30 minutes at -20°C, 2.5 hours at -30°C and 4 hours at -35°C. The caveat with this advice assumed the vehicle was a car with a gasoline engine, 5W-30 engine oil, a good battery, automatic transmission and parked outside all night.

Carbon Intensity of Electricity

Using an electric block heater to warm a conventional vehicle's engine before starting is an effective way to reduce fuel consumption (and carbon emissions) at start up (Natural Resources Canada 2017). The source of the electricity used to run the block heater may in turn have a carbon footprint and this would vary across Canada reflecting how electricity is produced (e.g. generation from hydro, coal, natural gas, etc.). In 2015, the latest year that figures are available, electrical production for the *territory as a whole* had a carbon intensity of 41 g CO_2 eq /kWh when other GHG were converted to CO_2 equivalents and 46 g CO_2 eq /kWh when transmission line losses were included (Environment and Climate Change Canada 2017b).

Our Yukon situation in winter sees low water flows so hydroelectricity is in limited supply. As a consequence Yukon Energy is compelled to start burning fossil fuel to produce electricity for the Whitehorse grid as the temperature drops below -5°C (Figure 7). From a Whitehorse perspective the thermal generation of electricity can come from a diesel source which has carbon footprint (including fuel transportation to Whitehorse) of 707 g CO_2 eq /kWh, or from a liquid natural gas (LNG) source which has a slightly lower carbon footprint (including transportation to Whitehorse but ignoring any upstream production releases) of 602 g CO_2 eq /kWh (Manuilova et al. 2016). Cold temperatures influence the energy demand by consumers and that determines how much fossil fuel combustion is required to supplement hydroelectricity. At -10°C the carbon footprint is small (11.4 g CO_2 eq /kWh) because hydro makes up 98% of the supply but by -35°C hydro meets only about 90% of the Whitehorse demand and the carbon footprint is higher (65.4 g CO_2 eq /kWh). The key point is that without hydroelectricity the carbon footprint would come from 100% thermal generation and be much higher, in the range of 602-707 g CO_2 eq /kWh.

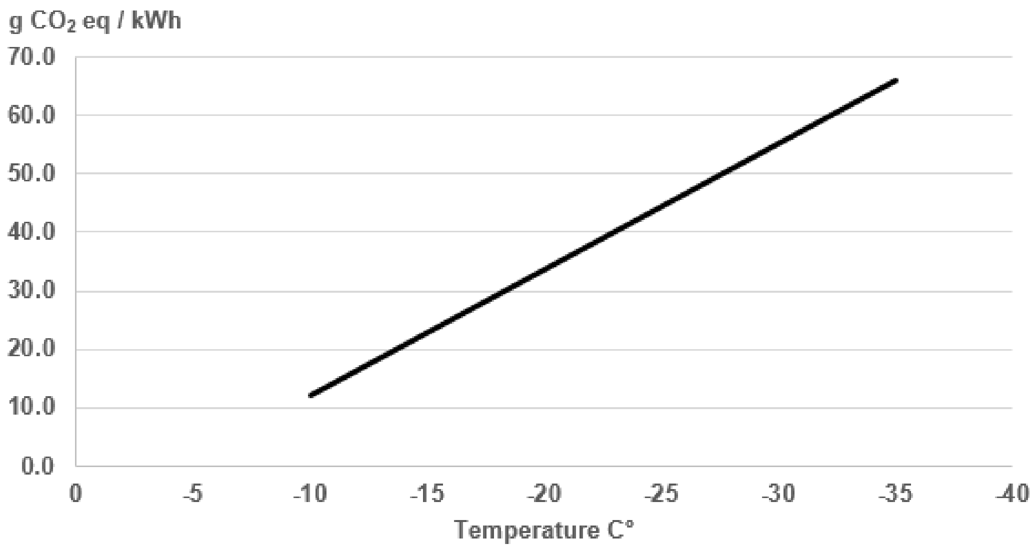

Figure 7. Estimated greenhouse gas emissions per unit of electrical production estimated from the hourly production at various winter temperatures in 2016-17. The exact partition of diesel versus LNG thermal production fluctuates and is estimated as a simple average of the two. Data obtained from Yukon Energy, May 2018.

Using the estimates of the number of days when a block heater might be needed (Table 2) along with an assumption that drivers plug their vehicles in when it drops below -20°C I was able to calculate the amount of energy consumed by one vehicle during the October-March driving season (Table 6). I used the guidelines for best practice to minimize the amount of time needed to plug in the vehicle at various temperatures and predicted it would take about 35 kWh over the season and release about 1.8 kg of CO_2.

Table 6. Estimates of the energy demand and carbon emissions from a single 400 watt block heater for one vehicle over the entire October-March driving season using the number of days with the minimum temperature below -20°C.

Min. Temp. bracket	# days	Hours per day for block heater (best practice)	kWh	g CO_2 eq /kWh	CO_2 eq (g)
-20.1°C to -25°C	18	1	7.2	39.6	285
-25.1°C to -30°C	14	2	11.2	50.2	562
-30.1°C to -35°C	14	3	16.8	60.4	1,015
		Total	**35.2**		**1,862**

Carbon Emissions Estimated from Idling Vehicles

Our North American penchant for fossil-fueled vehicles has a considerable impact on overall greenhouse gas emissions. Carrico et al. (2009) estimated that vehicles with an engine running while stationary ("idling") contributed 93MMt of CO_2 emissions based on the "unnecessary" combustion of 40.1 billion liters of gasoline annually in the United States. Policy analysts would describe the prospect of altering driver behaviour to reduce the amount of vehicle idling as "low hanging fruit" – drivers would save money with no loss of utility or service and the country's carbon footprint would be reduced.

Natural Resources Canada (2017a) has targeted various driving behaviours to reduce the amount of vehicle idling in Canada as a rapid way to reduce carbon dioxide emissions. While they point out that the break-even point for the benefits of turning off a vehicle's engine (when not in traffic) is achieved after 10 seconds of idling the practical threshold they encourage drivers to adopt is 1 minute. The public education message they advocate for winter conditions is more nuanced. Studies in Canada (McKenzie-Mohr Associates 2003) and the United States (Carrico et al. 2009) show most drivers think it is important to warm up a vehicle engine by idling. Natural Resources Canada (2017b) states that the best way to warm up a vehicle is by driving it (when the windshield is clear enough for safety) and that no more than 2-3 minutes is needed to warm up the engine.

Drivers with access to a winter plugin for their vehicle during cold weather have an easier time starting their vehicle and are able to start driving without much of a delay. Students at Ayamdigut who lack access to plugins for their vehicles face a challenge in cold weather starting their vehicle to begin with and tend to idle their vehicles for longer (Table 7). For example, at a temperature below -20°C, 41% of staff respondents said they were able to drive off after about two minutes of idling while only 23% of student respondents said they were able to do so. I calculated a weighted average of the amount of time drivers from each group said they warmed their vehicles[3] and found only a slight overall difference between staff (6.17 minutes) and students (7.0 minutes). By this metric the benefit of providing plugins for engine block heaters provides a very modest improvement of 50 seconds in the time spent warming up vehicles between the two groups.

[3] I used 12.5 minutes for the category of, "I have a remote start and let it run for 10-15 min".

Table 7. Results of an anonymous survey of Ayamdigut staff and students when asked the question: *How long do you let your vehicle warm up before you get going when it's -20 C outside or colder?* There was a significant difference in the frequency of responses between staff and students ($\chi 2 = 8.58$, df=3, prob=0.03).

	Staff		**Student**	
Response category	**# responses**	**Percent**	**# responses**	**Percent**
I let it warm up while I scrape windows - about 2 min	41	41%	12	23%
Long enough to let the windshield clear - about 5 min	24	24%	22	42%
About 10 minutes	12	12%	7	13%
About 20 minutes	1	1%	3	6%
I have a remote start and let it run for 10-15 min	22	22%	8	15%
Total	100		52	

The anonymous survey of students who said they commute to campus by personal vehicle revealed some of the challenges they face to ensure their vehicle starts in cold weather. Just 2% of students said they left their vehicle at home in cold weather and 48% (22 respondents) noted they were on campus for short periods of time, for one or two classes (1.5-3 hours), so they did not have a concern. Half of the student sample population (23 respondents) said they worried whether their vehicle would start and had to start the engine occasionally during the day to let it warm up while idling. Two related questions documented details of this behaviour. Of the 39 students who said they had to start their vehicles between classes during cold weather to ensure they would start at the end of the day I found 26% (10 respondents) did so every 2 hours, 44% (17) did so every 3 hours and 31% (12) did so every 4 hours.

I was able to obtain an estimate of the time students idled their vehicles while warming up the engine between classes by asking a more general question (Table 8). While 13% of students said they never had to warm up their vehicle between classes there were 46 respondents (87%) who said they did idle their vehicles and the duration ranged between 5 and 20 minutes. A weighted average of idling time for the student sample population shown in Table 8, including the 13% that said their idling time was zero, was 11.1 minutes. Note that the purpose of this idling time was solely to give students an increased chance that their vehicle would start at the end of a cold school day.

Table 8. Results of an anonymous survey of Ayamdigut students when asked the question: *On a very cold winter day (say, minus 25 C or colder) if my vehicle is parked at the College (unplugged) for a long time:*

Response category	**# responses**	**Percent**
I never have to start it to warm up to be sure it will start at the end of the day	7	13%
I start the vehicle to warm it up and let it idle for 5 minutes	4	8%
I start the vehicle to warm it up and let it idle for 10 minutes	18	34%
I start the vehicle to warm it up and let it idle for 15 minutes	18	34%
I start the vehicle to warm it up and let it idle for 20 minutes	6	11%
Total	**53**	

Modelling Estimates of the Carbon Footprint of Idling

The survey information I collected from students and staff provided their self-assessments of the amount of time they used to warm up their vehicles in various situations. I was then able to make some estimates of the amount of impact this idling activity would have over an average season (Tables 9 a,b). I did not have a direct count of the number of staff and student vehicles used to commute to campus so I restricted the calculations to an average single vehicle. As a reference baseline I used the Natural Resources Canada (2017b) guideline of taking just 3 minutes to warm up a vehicle in winter and found the CO_2 emissions from vehicles on campus were double that amount (Table 9a). Students who have to warm up their vehicle between classes by idling it make an *additional* contribution, each cold day, of almost 3.7 times the baseline case.[4]

Table 9a. Estimates of the fuel consumption and CO_2 emissions caused by a *single* vehicle idling over the duration of an average cold season (Oct. 1 - March 31). Number of days taken from Table 2 and estimates of idling taken from this study and compared to a reference case using the ideal of 3 minutes of idling.

Scenario	**# days <-25°C**	**Idling (min)**	**Gas (l)**	**CO_2 (kg)**
Baseline using NRCan recommendation of 3 min warmup before driving away slowly	28	3.0	2.5	5.8
Staff with vehicle block heater plugged in	28	6.2	5.2	11.9
Students without access to block heater plugin	28	7.0	5.9	13.5
Students idling vehicles between classes (once per cold day)	28	11.1	9.4	21.4

Table 9b. Description of variables used to estimate impacts from winter idling on campus. A 3-liter engine size was the Canadian average for light-duty vehicles in 2005 according to Natural Resources Canada.

Parameter	**Reference**
Engine size: 3 liter gasoline	Natural Resources Canada (2016b)
Fuel consumption idling: 0.6 l/ hr / liter of engine displacement	Taylor (2003), p. 2-13
Carbon emissions: 2.289 kg CO_2 / l of gasoline	Environment Canada (2008) Annex 12

[4] Students still have to warm up their vehicle's cold engines at the end of the day before driving home.

Campus Parking Infrastructure

The campus has 218 parking stalls with electrical plugins for use in winter distributed around the campus (Figure 8) plus 12 stalls reserved for Yukon Government building maintenance staff. Some of these outlets are located near Student Housing units where they may be used by College staff commuting to work rather than the intended student residents.

Legend	Location	Number plugins	Number vehicles	Comment
1a + 1b	CNIM	11	22	New IPLC pedestal model
2a - YG	Multi-Use Building	8	8	Yukon Government staff parking
2b - YG	Gym – north side	3	4	Yukon Government staff parking
3	510 Student Housing	14	14	
4a	Student Housing - North	14	14	
4b	Student Housing - South	22	22	
5	YRC Visitor House	2	2	
6	YRC Lab Building	8	8	
7	Staff parking	80	76	2 double rows; each row with 2 duplex plugins
8	520 Student Housing - N	32	32	2 double rows; each row with 2 duplex plugins
9a	520 Student Housing - S	4	4	Accessible parking stalls next to building
9b	520 Student Housing - S	48	24	Mismatch – excess of plugins for stalls

Figure 8. Map of the Yukon College Ayamdigut campus (Google Earth image) showing the location of parking stalls with electrical plugins for block heaters.

The power supplied to the Yukon College plugins varies with the vintage of the receptacles. The oldest plugins, for example in the main staff parking lot, (labelled 7a to 7d in Figure 8) have no energy conservation features and are always on. The plugins associated with the 520 Student Building (labelled 8 and 9 in Figure 8) are reported to have a temperature controlled power cycling timer so that whenever the temperature is below -10°C the timer is on for 15 minutes per hour, below -20°C it remains on for 30 minutes per hour, below -30°C it remains on for 45 minutes per hour and at -40°C it remains on for the full hour. The CNIM building, the most recent construction on campus, has a small parking area (labelled 1a and 1b in Figure 8) with plugins designed and manufactured by Vantera Ltd in Manitoba. The unit is called an Intelligent Parking Lot Controller (IPLC) and, in its current configuration, seems ill-suited for our campus setting.

The energy savings features of the IPLC unit are only realized when used with a fleet that must be kept outside in a state of readiness (e.g. service trucks available for a 24 hour call out). At Ayamdigut staff typically show up sometime after 8 AM and leave by 5 PM and follow a very predictable 8 hour schedule. A simple timer attached to the to block heater cord could save much more energy by switching on the unit a few hours before the end of a driver`s work day. The much vaunted energy savings of the IPLC unit are illusory for Yukon College’s purposes. After plugging in to the IPLC the controller switches off power for 2 hours (to allow the vehicle to acclimate to the ambient temperature but still be capable of starting). After two hours the default setting delivers power on a variable basis that depends on the ambient temperature; at -20°C and colder the unit provides constant power. The majority of staff at Ayamdigut do not plug their vehicle in at work until it is colder than -20°C; about 20% of staff actually plug in at milder temperatures and about 15 percent say they would plan to use their block heater before it got down to -20°C. What is the net effect? The majority of our staff gain absolutely no benefit in energy conservation from using the IPLC units installed at the CNIM building (other than the initial 2 hour delay in delivering power) despite the manufacturer’s claim of projected energy savings of up to 65%.

Estimated Cost of Installing New Electrical Outlets

I prepared some approximate costs for adding additional electrical outlets so more vehicles could be plugged in during cold weather. I started by estimating the cost to add 5 duplex receptacles that could service 20 parking stalls (Figure 9) assuming each stall was 2.4m wide (Yukon Government 2000) and the layout allowed two rows of parking to share the plugins.

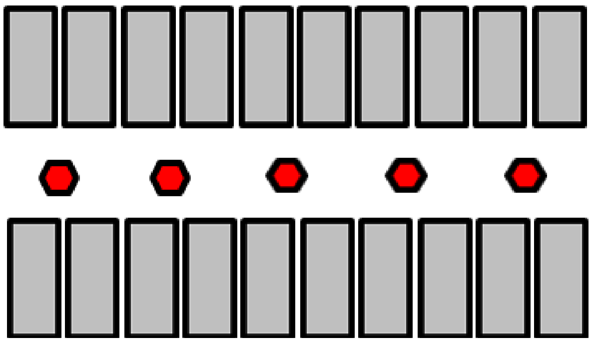

Figure 9a. *(Above)* Layout of 20 parking stalls sharing 5 central electrical receptacles (red hexagons). Standard parking stalls are 2.4 m. (8 ft) apart
Figure 9b. (Right) New parking plugins were installed at the CNIM building in 2016.

Table 10. Estimated cost of installing 5 concrete-mounted electrical receptacles with 20 plugin

Description	**Item / Quantity**	**Estimate**	**Comment**
Service connection to building		$2,000	Costs depends on type of panel or tie in…
Underground run to 1st plugin	Conduit & 10 ga wire	$700	Estimate <100 ft
Underground run to connect 4 remaining plugins	Conduit & 10 ga wire	$600	84 ft
Concrete posts (bollards) to support plugin pedestal	5 columns -12" diameter x 30" high	$2,000	Need to set conduit in place
Plugins - IP3SeriesPedestal	5 @ $817	$4,085	Each unit has 4 plugins
20 15 amp breakers	20 @ $10	$200	
Excavation to 3 ft depth for underground conduit		$1000	Mini-backhoe required ~ 184 lineal ft
Labour	5 days @ $120/hr	$4,880	
	Total	$15,385	~$770 per plugin

The estimated cost of materials and labour to add blocks of 20 parking stalls at the Ayamdigut campus with winter plugins would be about $15,400 or $770 per stall although, this would not include the cost of any pavement resurfacing.

My cost estimate may be an underestimate. For comparison I was able to obtain some costs for two large winter parking projects in Alaska. These projects were funded in part by the United States government to reduce winter air pollution. In 2015 the parking lot for a large government office complex in Fairbanks (Peger Road complex) with 430 parking stalls was retrofitted with winter plugins at a cost (for the electrical plugins, controls and concrete bollards) of $2,417 USD per stall. This did not include the cost of resurfacing the parking area. A total of 932 parking stalls at a high school in North Pole, AK were equipped with winter plugins at a cost of $1,358 USD per stall and again this did not include the cost of building or surfacing the parking lot. It is interesting to note that the winter plugins were provided as a free service to students and employees; the North Pole High school was to receive funding to cover the cost of electricity for an initial three years.

Future Parking Options for the Ayamdigut Campus

In this section I have drawn together some simple cost-benefit analyses using the estimates for various components of the winter parking question identified in this study. Survey results from the student population suggest that their parking options are severely constrained. During cold weather there are also anecdotal complaints from staff members about lack of access to block heater plugins so increased capacity for winter parking could help both groups. Yukon College's transition to a university over the next few years is anticipated to include some new buildings so green parking options could be easily included. The first scenario (Table 11) summarizes the costs and benefits of adding new capacity for winter plugins. I used the marginal price of electricity at $0.1286 per kWh based on the institution's rate class of 2180 for General Service

Table 11. Estimates of the costs and benefits of providing a new winter parking plugin for a single vehicle for one average winter season (October 1-March 31).

Costs	Time	Units	Cost	CO2 (kg)	Comment
Installation of 1 stall			$770.00		Table 10; one time charge
# days <-25°C	28 days				
Electricity for 1 plugin	70 hr	28 kWh	$ 3.60	1.6	Table 6; total for year
Benefits					
# days <-25°C	28 days				
Idle at start	0.8 min	0.68 liters		1.5	Table 9; difference between 7 min and 6.17 min
Idle between classes	11.1 min	9.38 liters		21.4	Table 9; students running vehicles in cold weather

(YEC 2018). It is hard to judge how to incorporate the electrical costs; past practice on campus has been to provide it free to staff using the parking lot although, in theory, it could be recovered by winter parking fees.

The overall savings appear small. The difference in idling time reported by staff members (starting their vehicle with the block heater plugged in) is only 50 seconds less than the time students report when they start a *cold vehicle* so there is very little savings to realize (if these self-reported idling times are accurate). There are more significant savings (and considerable relief) to be found by providing student drivers with access to block heater plugins so they do not have to idle their vehicles one or more times during a cold day when their classes span a lengthy period. Table 11 uses a single vehicle as the estimation unit however the multiplier, the number of vehicles benefiting from new winter parking plugins, is unknown (but would be most economically provided in units of 20 stalls). I did not amortize the capital cost of installing the new plugin infrastructure; with a service life of at least 20 years, the initial cost could be spread over many years.

The existing electrical infrastructure for block heater plugins could be upgraded to obtain increased energy savings and I tried to capture the magnitude of some of the potential savings for the institution by comparing the energy conservation benefits of retrofitting the 76 stalls in the oldest staff parking lot (label 7 in Figure 8). For comparison I calculated the amount of electricity used in the main staff parking lot under the current regime where power is supplied to all the plugins continuously. I then estimated of the amount of electricity needed to run a block heater using the (theoretical) best practices recommended by NRCan (i.e. a timer for a finite period of time) taken from Table 6. To provide some additional realism I calculated the actual number of vehicles that might be plugged in at different temperatures to reflect the practices staff revealed when surveyed about their intentions (Table 12). As expected the "always on" plugin circuits use a great deal of electricity totaling 8,656 kWh over a winter season. Savings of up to 73% could be achieved by retrofitting the circuits with energy conservation in mind. Using a price for electricity of $0.1286 per kWh the savings could be up to $805 per year (assuming average winter temperatures).

Even the newly installed IPLC block heater plugins outside the CNIM building could be programed to deliver more savings in electricity but the amount would be more modest by comparison (but much cheaper to obtain).

Table 12. Estimates of the electrical usage and carbon emissions for the main staff parking lot assuming the use of 400 watt block heaters over the winter season (Oct. 1 to March 31). The number of vehicles equals the 76 stall capacity of the parking lot multiplied by the fraction of staff that indicated they would plug in their vehicle at certain temperatures thresholds (Table 1). The number of days was taken from Table 2 and the carbon intensity estimates are from Yukon Energy (Figure 7). The upper table models the current *status quo* where plugins are always on and the lower table models the best practice of using just sufficient time to warm up the engine block.

Minimum Temp. brackets	**# days**	**% plug-ged in**	**# vehicles**	**Plugin hr / day**	**kWh**	**g CO_2 eq / kWh)**	**CO2 (kg)**
-20.1°C to -25°C	18	66%	50	7.5	2,700	39.6	106.9
-25.1°C to -30°C	14	86%	65	7.5	2,730	50.2	137.0
-30.1°C to -35°C	14	100%	76	7.5	3,192	60.4	192.8
				Total	**8,622**		**436.8**

Minimum Temp. brackets	**# days**	**% plug-ged in**	**# vehicles**	**Plugin hr/day**	**kWh**	**g CO_2 eq / kWh)**	**CO2 (kg)**
-20.1°C to -25°C	18	66%	50	1	360	39.6	14.3
-25.1°C to -30°C	14	86%	65	2	728	50.2	36.5
-30.1°C to -35°C	14	100%	76	3	1,277	60.4	77.1
				Total	**2,365**		**127.9**

Conclusions and Future Research

1. **What's the Weather Forecast?** The detailed analysis of recent weather records and the 1981-2010 climate normal show that the winter climate in Whitehorse has large annual variations and is still subject to periods of very cold weather that necessitate the use of engine block heaters. For example, there were an average of 14 days when the minimum temperature was colder than -30°C during each winter between 2007-08 and 2016-17 but the range stretches from a single day to 25 days (Table 2). We have to live with winters that vary in severity; we can benefit from mild winters but have to be prepared for cold ones. My investigation of one model of future climate projections didn't change the conclusion. Climate change models incorporate predictions that include the range of natural variation so while future winter projections show milder weather on average, the range of temperatures will still include days below the threshold of -25°C.

2. **Increasing Winter Parking Capacity**

   Equity. If winter parking infrastructure is a scarce resource on campus, as seemed to be revealed by the anonymous student survey, then there should be some formal way of opening up the discussion of how to share it. Staff currently have free access to winter plugins by virtue of the *status quo* and not as a result of collective bargaining. The subsidy implicit in free winter parking should not go to just one group of the College community without consideration. Staff who commute to campus by foot, bike or public transit as well as students without access to plugins may question how equitably resources are being shared.

   Stranded Investment? One of the weaknesses of using a cost-benefit analysis approach is their tendency to encourage tunnel vision. Alternative approaches outside the domain of the analysis may be ignored and two of these possibilities merit emphasis in this study. Adopting a business as usual approach to the discussion of transportation to and from a workplace is bound to be eclipsed by technology in a low carbon future (e.g. the 2055 scenario in Table 5). It seems most unlikely that staff and students would be commuting to campus using fossil-fueled vehicles in 40 years so one might question a plan to provide infrastructure for a mode of travel that is unlikely to be present. If the need for additional block heater plugins over the coming two decades is justified (see *Equity* section above) then the cost could be amortized over that period. Surprisingly the results of this study suggest the environmental benefits, in reduced emissions, from using electrical block heaters, are quite modest, at least based on the user groups studied at Ayamdigut Campus. Most users plug in their vehicles when the temperature gets cold enough to threaten trouble with starting the engine while in Alaska, electrical plugins are used at warmer temperatures (from -7C and colder) to reduce air pollution when a vehicle is started.

Public Transit Alternatives The most effective payback may arise from a public, or at least, Ayamdigut workplace, campaign to point out the benefits of reducing the use of vehicles on cold days. In an average year there are about 14 days when the minimum temperature is colder than -30°C; that works out to ~8% of the 182 days between October 1 and March 31. Strategies could focus on encouraging a behaviour change in drivers to leave their vehicles at home on those extreme days by taking public transit or carpooling. Full time Yukon College students already receive free transit passes so it would be easy to "nudge" their participation (French and Oreopoulos 2017). If Yukon College wished to take a leadership role in reducing the institution's collective carbon footprint on cold days a public education campaign could be used to encourage staff to leave their vehicles at home on "cold" days (e.g. when the forecast was for minimum temperatures below -30°C). The concomitant benefit would be less competition for parking stalls with electrical plugins.

3. Handicapped parking stalls are designed for summer use. Due to the location of the plugins at the head of each stall and the nature of snow removal in winter, it is not possible to navigate a wheel chair or move on crutches to the plugin to take advantage of the service. As a result some drivers using these stalls have to revert to idling their vehicles to warm up the engine periodically on cold days.

Future Research

1. There is an excellent opportunity to set up a trial to implement an improved timing regime for the new plugin controllers used outside the new CNIM building. These IPLC units, marketed by Vantera Ltd in Manitoba, are also used by the Yukon Government at some Whitehorse schools so there may be a benefit in expanding the trial as Yukon College only has 22 stalls using these units. The default programming of the UPLC units delivers almost no energy savings to users working a typical 8 hour shift. The units can be readily reprogrammed and Prof. Barry Herz at University of Saskatchewan has unpublished work that could be used to make precise recommendations on how long a block heater needed to be plugged in to allow a vehicle to start in cold weather. The units could be programmed with the calculations provided by Prof. Herz to test the effectiveness of using a plugin timing regime that is more suitable for a cold northern climate and that delivers actual energy conservation.

2. The majority of the existing campus plugins provided for block heaters are old and lack any energy savings features. Retrofitting controls to allow the power to be cycled on and off based on outside temperatures could yield significant savings.
3. The carbon emissions associated with winter parking reveal that the largest and easiest gains in emissions reduction could come from a simple education campaign targeting vehicle idling. The anonymous surveys revealed that some respondents carry significant misunderstandings about the role of block heaters and the role of idling to warm up a vehicle. Natural Resources Canada (2017a, 2017b) makes a strong case that there are easy and immediate gains to be found in reducing drivers' carbon footprint by convincing them to use block heaters and idle their vehicles less. The Ayamdigut "study population" has proven hospitable in the past to students seeking insights to practical aspects of human behaviour (e.g. Heather Ashthorn's 2016 study, *Bear Aware Trail Signs for Yukon College*). A small study using an information campaign could compare the before and after impacts on attitudes of drivers towards idling their vehicle.

References

ADEC (Alaska Department of Environmental Conservation). 2003. Engine Block Heater Program Back by Popular Demand. Press release, January 22, 2003.

ADEC (Alaska Department of Environmental Conservation). 2006. Tier 2 Gasoline Emission Benefits in Alaska. 86 pp.

ADEC (Alaska Department of Environmental Conservation). 2008. State Air Quality Control Plan: Vol. II: Analysis of Problems, Control Actions Section III. A: Statewide Carbon Monoxide Control Program. 44 pp.

ADEC (Alaska Department of Environmental Conservation). 2016. Amendments to: State Air Quality Control Plan, Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan. 232 pp.

Bielaczyc, P., Szczotka, A. and Woodburn, J., 2014. Cold start emissions of spark-ignition engines at low ambient temperatures as an air quality risk. Archives of Environmental Protection 40: 87-100.

Cook, R., Touma, J.S., Fernandez, A., Brzezinski, D., Bailey, C., Scarbro, C., Thurman, J., Strum, M., Ensley, D. and Baldauf, R., 2007. Impact of underestimating the effects of cold temperature on motor vehicle start emissions of air toxics in the United States. Journal of the Air & Waste Management Association, 57: 1469-1479. DOI: 10.3155/1047-3289.57.12.1469

Deser, C., Knutti, R., Soloman, S. and Phillips, A.S. 2012. Communication of the role of natural variability in future North American climate. Nature Climate Change 2: 775-779.

Environment Canada. 2008. National Inventory Report 1990–2006: Greenhouse Gas Sources and Sinks in Canada. [accessed March 24, 2018]. http://publications.gc.ca/collections/collection_2009/ec/En81-4-2006E.pdf

Environment and Climate Change Canada. 2016. El Niño. . [accessed June 12, 2018]. https://www.canada.ca/en/environment-climate-change/services/el-nino.html

Environment and Climate Change Canada. 2017a. NAPS Data Products. [accessed May 27, 2017]. http://maps-cartes.ec.gc.ca/rnspa-naps/data.aspx?lang=en

Environment and Climate Change Canada. 2017b. National Inventory Report 1990–2015: Greenhouse Gas Sources and Sinks in Canada, Part 3, Annex 13. [accessed March 8, 2018.] http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/can-2017-nir-13apr17.zip

Flato, G., J. Marotzke, B. Abiodun, P. Braconnot, S.C. Chou, W. Collins, P. Cox, F. Driouech, S. Emori, V. Eyring, C. Forest, P. Gleckler, E. Guilyardi, C. Jakob, V. Kattsov, C. Reason and M. Rummukainen, 2013: Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M.

Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. [accessed Feb. 2, 2018]. https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter09_FINAL.pdf

Ford Motor Company. 2005. 2005 Ford F-150 Owner Manual. 312 pp. [accessed May 15, 2017]. http://www.fordservicecontent.com/Ford_Content/catalog/owner_guides/05f12og5e.pdf

French, R. and Oreopoulos, P. 2017. Applying behavioural economics to public policy in Canada. Canadian Journal of Economics 50: 599-635.

General Motors Corporation. 2005. 2006 Chevrolet Silverado Owner Manual. 586 pp. [accessed May 13, 2017]. https://assets.gm.com/manuals/chevrolet/2006_chevrolet_silverado_owners.pdf

Manitoba Hydro. No date. Energy saving tips. PowerSmart Guide Booklet #9. 32 pp. [accessed Feb. 18, 2018]. https://www.hydro.mb.ca/your_home/resources/9_energy_saving_tips.pdf

Manuilova, A., Nelson, K., Piewkhaow, L. and Zhou, S. 2016. Lifecycle Assessment for Energy Resource Options In Yukon Territory. Final report prepared for Yukon Energy Corporation by ArticCan Energy Service, 103 pp.

McKenzie-Mohr Associates. 2003. Anti-idling final report. Report Prepared for Earthcare Sudbury. 13 pp. [accessed March 25,2018]. http://www.greatersudbury.ca/content/div_earthcare/documents/sudbury_finalreport.pdf

Municipality of Anchorage. 2011. Air Quality in Anchorage: A Summary of Air Monitoring Data and trends 1980 – 2010. Air Quality Program, Public Health Division, Department of Health and Human Services. 53 pp.

National Research Council. 2002. The ongoing challenge of managing carbon monoxide pollution in Fairbanks, Alaska. National Academies Press. 154 pp.

Natural Resources Canada. 2016a. Learn the facts: Cold weather effects on fuel efficiency. Webpage. [updated Jan. 19, 2016; accessed Feb. 18, 2018]. http://www.nrcan.gc.ca/energy/efficiency/transportation/cars-light-trucks/buying/16748

Natural Resources Canada. 2016b. Arriving at calculations. Webpage. Ottawa (ON): Natural Resources Canada. [updated Jan. 18, 2017; accessed March 24, 2018]. http://www.nrcan.gc.ca/energy/efficiency/communities-infrastructure/transportation/idling/4457

Natural Resources Canada. 2017a. Welcome to the Idle-Free Zone. Webpage. Ottawa (ON): Natural Resources Canada. [updated July 21, 2017; accessed March 25, 2018]. http://www.nrcan.gc.ca/energy/efficiency/communities-infrastructure/transportation/idling/4397

Natural Resources Canada. 2017b. Idling – Frequently Asked Questions. Webpage. Ottawa (ON): Natural Resources Canada. [updated Feb 23, 2017; accessed Feb. 18, 2018]. http://www.nrcan.gc.ca/energy/efficiency/communities-infrastructure/transportation/idling/4463

Perera,O., Morton, B. and Perfrement, T. 2009. Life Cycle Costing in Sustainable Public Procurement: A Question of Value. International Institute for Sustainable Development. [accessed May 21, 2017]. http://www.iisd.org/library/life-cycle-costing-sustainable-public-procurement-question-value

SaskPower 2016. Mythbusted: All cars need to be plugged in at least 4 hours on cold days. Webpage. [accessed Dec. 21, 2017]. http://www.saskpower.com/about-us/blog/mythbusted-all-cars-need-to-be-plugged-in-at-least-4-hours-on-cold-days/

Taylor, G.W.R. 2003. Review of the Incidence, Energy Use and Costs of Passenger Vehicle Idling. Unpublished report prepared for Natural Resources Canada. 40 pp. [accessed March 24, 2018]. http://www.pgairquality.com/uploads/files/pdf/NRCAN2003-Reviewofthe%20ncidence_EnergyUse_CostsofPassengerVehicleIdling.pdf

Tchir, J. 2015. How cold should it be before I plug my car into a block heater? Globe and Mail, Nov, 24, 2015. [accessed February 13, 2017]. http://www.theglobeandmail.com/globe-drive/culture/commuting/what-is-the-benefit-of-plugging-in-my-car-to-a-block-heater-and-when-should-i-do-it/article27446878/

Wang T., Hamann A., Spittlehouse D., Carroll, C. 2016. Locally downscaled and spatially customizable climate data for historical and future periods for North America. PLoS ONE 11(6): e0156720. doi:10.1371/journal.pone.0156720

Ward, T. Trost, B., Conner, J., Flanagan,J. and Jayanty, R.K.M. 2012. Source apportionment of $PM_{2.5}$ in a subarctic airshed - Fairbanks, Alaska. Aerosol and Air Quality Research 12: 536–543.

Wiens, E.H. 1972. Engine block heaters. Canadian Agricultural Engineering 14:15-19. [accessed February 13, 2017]. http://www.csbe-scgab.ca/docs/journal/14/14_1_15_ocr.pdf

Yukon Energy. 2017. inCharge. Whitehorse (YT): Yukon Energy. [accessed Feb. 18, 2018]. http://www.inchargeyukon.ca/

Yukon Energy. 2018. Rate Schedules. Webpage. Whitehorse (YT): Yukon Energy Corporation. [accessed April 6, 2018]. https://yukonenergy.ca/customer-service/accounts-billing/rate-schedules

Yukon Government. 2000. Design Standards for Government Facilities. 370 pp. Available: http://www.hpw.gov.yk.ca/pdf/design_standards.pdf [accessed Feb 20, 2017].

Appendix 1 – Yukon College Staff Parking Questionnaire

Do you plug in your vehicle at Yukon Place?

This is an anonymous survey regarding the use of electrical plugins for block heaters in the staff parking areas around Yukon College and Archives. We are investigating the way that electrical plugins are used for parking in winter and would appreciate your feedback. If you have questions or would like a copy of our eventual report you can contact: Scott Gilbert (sgilbert@yukoncollege.yk.ca) or Aja Mason (aja.mason@yukoncollege.yk.ca)

1. Which of the following applies to you?

- ☐ I drive a vehicle to my work at Yukon Place (YC or Archives) in the winter.
- ☐ I have access to an electrical plugin at Yukon Place for my vehicle in winter.
- ☐ I don't drive a vehicle to the College or Archives: Thank you - no more questions!

2. How cold does it have to be before you plug in your vehicle?

- ◯ -10 C or colder
- ◯ -15 C or colder
- ◯ -20 C or colder
- ◯ -25 C or colder
- ◯ -30 C or colder
- ◯ Other - can you tell us your system for deciding?

3. How long do you usually plugin your vehicle for before you start it?

- ◯ If the forecasted high for the day is colder than what I answered above, I'll plug in my vehicle when I arrive at Yukon Place in the morning. Basically, all day.
- ◯ I'll usually check the weather forecast at lunch and decide whether to plug in my vehicle for the afternoon.
- ◯ Other (please specify)

4. What source do you use to know how cold it is outside?

- [ ] An old fashioned thermometer outside my house
- [ ] An app on my phone - I check it when I arrive at the College/Archives and decide if I'll plug in my vehicle
- [ ] An app on my phone - I check it before I leave the house and decide if I'll plug in my vehicle
- [ ] I hear the weather report on the radio and decide if I'll plug in my vehicle based on that
- [ ] I check the Environment Canada website before I leave my house
- [ ] I have the Weather Network on the TV in the morning
- [ ] Other (please specify)

5. How long do you let your vehicle warm up before you get going when it's -20 C outside or colder?

- ○ I let it warm up while I scrape windows - about 2 minutes
- ○ Long enough to let the wind shield clear - about 5 minutes
- ○ About 10 minutes
- ○ I have a remote start and let it run for 10-15 minutes
- ○ Other (please specify)

6. How did you learn about what temperature you ought to plug in your car at and how long you ought to let your car warm up for?

- [ ] It's common knowledge in the Yukon - everybody kind of just knows
- [ ] I contacted my dealership/manufacturer and asked
- [ ] I did some internet researching and have followed the advice I read
- [ ] I am from here (or some other cold climate) and I was taught by my parents/peers
- [ ] Other (please specify)

Appendix 2 – Yukon College Student Parking Questionnaire

Yukon College Student Parking Survey

This is an anonymous survey regarding winter student parking at Yukon College and we would appreciate your feedback. If you have questions or would like a copy of our eventual report you can contact: Scott Gilbert (sgilbert@yukoncollege.yk.ca) or Aja Mason (aja.mason@yukoncollege.yk.ca)

1. We would like to survey students who occasionally drive a vehicle to the College and park while attending classes

- ◯ I live on campus and have access to Student Housing parking - No further questions - thanks!
- ◯ I take the bus, bike or walk to school - No further questions - thanks!
- ◯ I drive a vehicle to the College - please continue

2. When using the student parking area at the College (i.e. parking lots without electrical plugins for block heaters) have you ever had problems starting your vehicle because of cold weather?

- ◯ Yes
- ◯ No
- ◯ Other (please specify)

3. If you drive to Yukon College on a very cold winter day (say, minus 25 C or colder), how do you ensure that your vehicle will start after it has been parked, unplugged?

- ◯ With my class schedule I am only parked for one or two classes so my vehicle will start
- ◯ I worry about whether my car will start so I leave it at home on very cold days
- ◯ I worry about whether my car will start so I have to go out and start it occasionally and let it warm up
- ◯ Other (please specify)

4. On a very cold winter day (say, minus 25 C or colder) if my vehicle is parked at the College (unplugged) for a long time:

- ◯ I never have to start it to warm up to be sure it will start at the end of the day
- ◯ I start the vehicle every 2 hours or so to let it warm up
- ◯ I start the vehicle every 3 hours or so to let it warm up
- ◯ I start the vehicle every 4 hours or so to let it warm up
- ◯ Depends, I will...

5. On a very cold winter day (say, minus 25 C or colder) if my vehicle is parked at the College (unplugged) for a long time:

- ◯ I never have to start it to warm up to be sure it will start at the end of the day
- ◯ I start the vehicle to warm it up and let it idle for 10 minutes
- ◯ I start the vehicle to warm it up and let it idle for 15 minutes
- ◯ I start the vehicle to warm it up and let it idle for 20 minutes
- ◯ Depends, I will warm it up ...

6. How long do you let your vehicle warm up before you get going when it's -20 C outside or colder?

- ◯ I let it warm up while I scrape windows - about 2 minutes
- ◯ Long enough to let the wind shield clear - about 5 minutes
- ◯ About 10 minutes
- ◯ I have a remote start and let it run for 10-15 minutes
- ◯ Other (please specify)