**Development of Climate Adaptation and Asphalt Selection Tool (CAAST)**

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# DEVELOPMENT OF CLIMATE ADAPTATION AND ASPHALT SELECTION TOOL


## ABSTRACT

This paper introduces the Climate Adaptation and Asphalt Selection Tool (CAAST), which is a new computer software used to select climate resilient Performance Grade (PG) of asphalt binder for Superior Performing Asphalt Pavements (Superpave) based on extreme high and low pavement temperatures. Developed by National Research Council Canada (NRC), CAAST uses projected climate change temperature data provided by Environment and Climate Change Canada (ECCC) for Canadian cities, obtained from the Canadian Regional Climate Model (CanRCM), version 4, from 1950 to 2100. The CAAST software analyzes the projected temperature data file within a certain time period (i.e.: road design life) to extract and calculate environmental parameters that will be used to assess the impact of climate change and to select the climate resilient asphalt binder performance grade (PG). CAAST incorporated the shortcomings of the existing Long-Term Pavement Performance Bind Online (LTPPBind) such as standing traffic speed, besides slow and fast traffic speed and annual temperature variations in terms of Degree Days (change within a year not only during 6 months).

The paper compares and analyzes Superpave PG results obtained from ECCC's projected temperature data via CAAST against the existing method (LTPPBind) based on Modern-Era Retrospective Analysis for Research and Applications (MERRA-2) temperature data. The study shows that the indices such as Mean Annual Lowest Air Temperature (MALAT) and Mean Annual Degree Days (MADD) for cities in Atlantic, Central, Prairies, Western and Northern Canada are significantly higher when using the new proposed method compared to MERRA-2. The analysis also suggests that climate change can induce higher upgrades in high and low PG grades over the next 25 years than those predicted by MERRA-2 via LTPPBind. Consequently, the use of CAAST with embedded projected air temperature data can provide an effective solution for selecting resilient PG binder types in response to climate change, which is an improvement over traditional approaches that rely on historical climate. Overall, this study highlights the importance of considering climate change projections in pavement design and emphasizes the need for tools like CAAST to ensure pavement performance under changing environmental conditions.


## INTRODUCTION

The performance of an asphalt binder is contingent upon both temperature and load frequency. Elevated temperatures or extreme heat events render the asphalt binder materials used in the Hot Mix Asphalt (HMA) more susceptible to plastic deformations, such as rutting. Climate change projections indicate an acceleration in the rate of climatic alterations over the next few decades. Climatic parameters, frequency, and severity of extreme weather events are anticipated to vary, thus emphasizing the crucial role of appropriate asphalt binder selection. Presently, the selection of Performance Grade (PG) binder is based on the historical climate of the road location, utilizing standalone software known as LTPPBind (FHWA, 2017). However, this selection approach may be inadequate, given the anticipated shifts in future climate and weather patterns, including extreme events, which can affect the functionality of roads in long-term safety.

The current method of PG binder selection generated from the Superpave system (SHRP, 1994) relies on the historical pavement temperature extremes in the intended usage area. This is primarily determined through climate database and embedded models within LTPP software, namely LTPPBind (FHWA, 2017). The commonly used historical temperature data for this purpose is Modern-Era Retrospective Analysis for Research and Applications (MERRA-2), also incorporated in LTPPBind. To address this limitation, the Climate Adaptation and Asphalt Selection Tool (CAAST) was developed using projected data from Environment and Climate Change Canada (2018) to adjust asphalt binder PG type selection. The projected climatic loading files consist of outputs from a large 50-member ensemble of high resolution 0.44º (~50 km) North American simulations run by ECCC, which were sampled hourly. This data was obtained from regional simulations over North America by CanRCM4, driven at the boundaries by global simulations from CanESM2.

The average temperature of the projected data created by the Canadian Centre for Climate Modeling and analysis, under the highest emission scenario (RCP 8.5), is expected to rise by 6º C by the late 21st century (Zhang et al., 2019). To determine the necessary climatic parameters as defined in the most recent PG algorithms, this study will use the projected temperature of road site-specific locations. The temperature projections of future changes underscore the need for a comprehensive tool to adjust to climate change and design grading system tools.

The current procedure for PG selection is predominantly based on MERRA-2 air temperature data, utilizing LTPPBind software to compute the annual maximum and minimum pavement temperature. The maximum pavement temperature in LTPPBind version 3.1 (FHWA, 2017) after September 2018 is determined using Degree Days (DD) of air temperature over 10º C, which is the sum of maximum daily air temperature from April to September above 10º C. The minimum pavement temperature is calculated using the lowest yearly air temperature at the surface. This is also not to mention that the LTPPBind (FHWA, 2017) method for PG grade selection assumes that the pavement will experience an average mix of car and truck traffic moving at slow and high speeds only.

## PROBLEM DEFINITION

The current practice of selecting asphalt binder PG type for Hot Mix Asphalt (HMA) relies on the MERRA-2 climate database and LTPPBind software (FHWA, 2017) or other similar approaches, which all assume stationary climate conditions. However, with the projected increase in temperatures due to climate change, such an assumption may increase the risk of premature failure and reduced service life of asphalt pavements. Moreover, the existing method does not account for traffic speed at standstill conditions. Additionally, the assumption of a fixed warm season in the DD calculation between April and September may no longer hold. Therefore, the need for a comprehensive Climate Adaptation and Asphalt Selection Tool (CAAST) has arisen.

## SCOPE AND OBJECTIVES

The scope of this study revolved around developing and investigating the effectiveness of the CAAST software. The objectives are to analyze the projected temperature data file within a certain time period (i.e.: road design life) to extract and calculate environmental parameters that will be used to assess the impact of climate change and to select the climate resilient performance grade (PG) asphalt binder.

Thirteen cities were chosen to represent different regions in Canada, including capitals and large cities of provinces in Atlantic Canada, Central, Prairies, Western Canada, and Northern Canada. For each city, temperature data was collected from two sources: a projected ECCC data via CAAST and an available historical MERRA 2 data via LTPPBind, spanning from 1995 to 2020. This data was used to compare and determine the environmental parameters and climate-resilient asphalt binder performance grade (PG) for a rut depth of 12.5 mm and a traffic capacity of 3 million Equivalent Single Axial Loads (ESALs).

## METHODOLOGY

This paper highlights the development of a new software application called Climate Adaptation and Asphalt Selection Tool (CAAST) which aims to enable users to perform the following tasks:

- Select and extract temperature records for a particular location from the projected ECCC data file available in the CAAST database.
- Import hourly ambient temperature data file while specifying the latitude and longitude.
- Analyze the temperature data file for a specified time period (corresponding to the road design life) and extract environmental parameters such as Annual Lowest Air Temperature (ALAT), Annual Highest Air Temperature (AHAT), Annual Hottest 7-Day Temperature (AH7DsT), Mean Annual Air Temperature (MAAT), and Annual Degree Days (ADD) over 10°C. These parameters are used to preliminarily assess the impact of climate change and select the appropriate climate-resilient asphalt binder Performance Grade (PG).
- Flexibility to use any data that adheres to a specific format of hourly rate of air temperature for selecting the climate-resilient PG asphalt binder.

## OVERVIEW OF ANALYSIS METHODS

The main assumptions of this study centred around namely the highest Green House Gases (GHG) emission scenario of Representative Concentration Pathway (RCP 8.5) for selected city, specified design life, data sources (MERRA-2 and ECCC), base grade, traffic capacity, traffic speed, layer depth, and rut depth. These components were used to determine the high and low-temperature thresholds for the specific project site and then adjusted for temperature extremes' reliability. Based on the site's temperature conditions, an appropriate climate resilient PG asphalt binder can be eventually determined.

The extreme high pavement temperature performance prediction model is represented by equation 1, which takes into account rut depth (RD), Mean Annual Degree Days (MADT), and latitude (Mohseni et al., 2005). The Degree Days (DD) were calculated from daily hourly ambient temperatures by adding the high ambient temperature above 10° C from April to September, which is considered the heat season (LTPPBind, FHWA, 2017). However, this assumption was discovered to be misleading under global warming. Therefore, in CAAST, the entire year was considered to calculate the Annual Degree Days (ADD) as shown in Equation 2. Equation 3 was also implemented in CAAST for calculating the Mean Annual Degree Days (MADD), representing the change in ADD from year to year along the road design life. It is worth to note that the LTPP model (Equation 4) is also used to calculate the minimum pavement temperature. Equations 1 and 4, are intended to minimize rutting under high temperatures and thermal cracking under low temperatures, respectively. LTPP equations 1 and 4 are adopted in the CAAST software to determine the design pavement maximum and minimum temperatures, respectively.

$$MAHPT = 48.2 + 14MADD - 0.96MADD^2 - 2 * RD + (Z)(48.2 + 14MADD - 0.96MADD^2 - 2RD)\frac{0.000034(Lat-20)^2RD^2}{100} \quad (1)$$

$$ADD = \sum_{i=1}^{k}\left(T_{max_{i,k}} - 10\right) > 0 \quad (2)$$

$$MADD = \frac{\sum_{k=1}^{N} ADD_{k,N}}{N} \quad (3)$$

$$MALPT = -1.56 + 0.72MALAT - 0.004Lat^2 + 6.26Log_{10}(H + 25) - Z(4.4 + 0.52\sigma_{MALAT}^2)^{0.5} \quad (4)$$

Where;

ADD = Annual Degree Days of air temperature over 10$^{o}$ C
MADD = Mean Annul Degree Days of air temperate over 10$^{o}$ C (MADD divided by 1000$^{o}$ C)
MAHPT = Mean Annual Highest Pavement Temperature, $^{o}$ C, at asphalt depth H = 20 mm
MALPT = Mean Annual Lowest Pavement Temperature, $^{o}$ C, at asphalt surface H = 0 mm
MALAT = Mean Annual Lowest Air Temperature, $^{o}$ C
$\sigma_{MALAT}$ = Standard deviation of Mean Annual Lowest Air Temperature, $^{o}$ C
K = year
i = day
N = Road design life, years
RD = Rut Depth, mm
Z = Reliability factor
Lat = Latitude

It was decided to employ the same reliability factors and depth of layer adjustment method, as described in LTPPBind guidelines (FHWA. 2017). That being said, the reliability factors are typically 50 % (median) and 98 % (extreme). The most common one used in here, which account for both extreme weather events (high and low) is 98%. The parameter Z represents the reliability factor in the equations, where Z equals 0 and 2.055 for 50 % and 98 % reliability, respectively. The depth of layer adjustment for high and low temperatures is determined by equations 5 and 6 in both methods.

$$T_{PGhigh-Dadj} = -15.14Log_{10}(H + 25) + 15.14Log_{10}(25) \quad (5)$$

$$T_{PGlow-Dadj} = 6.26Log_{10}(H + 25) - 6.26Log_{10}(25) \quad (6)$$

where H is the depth of layers (0 to 200 mm)

**Existing PG type selection method**

Most existing standards in Canada such as the Ontario Provincial Standard, OPSS1101, 2016, specify the selection of asphalt PG on the basis of historical ambient air temperature data from the MERRA-2 database source when analyzed by LTPPBind version 3.1 (FHWA, 2017) or a later version. In this process, the LTPPBind software accesses climate conditions from NASA's

MERRA-2 and the historical weather database of Long-Term Pavement Performance (LTPP) and converts air temperatures into pavement temperatures followed by adjustments for depth of layers using equations 5 and 6. The impact of maximum temperature is affected by adjustments for base grade, traffic capacity, and speed of traffic, which is referred in this study to as $T_{PGhigh-BTSadj}$. This adjustment is carried out using Table 1, which lists the adjustment factors considered in LTPPBind online (FHWA, 2017). It should be noted that the LTPPBind software's adjustment for speed of traffic is limited to fast and slow traffic, and the standing adjustment is similar to slow traffic, as shown in Table 1.

**Table 1: Adjustment of base grade, traffic capacity and speed in LTPPBind (FHWA, 2017)**

| Speed | Base Grade | Traffic loading ESAL, millions | | | |
|---|---|---|---|---|---|
| | | **<3** | **3 - 10** | **10 - 30** | **30** |
| Fast | 52 | 0.0 | 7.8 | 13.2 | 15.5 |
| | 58 | 0.0 | 7.1 | 12.3 | 14.5 |
| | 64 | 0.0 | 6.5 | 11.3 | 13.4 |
| | 70 | 0.0 | 5.8 | 10.4 | 12.4 |
| Slow | 52 | 2.8 | 10.3 | 15.5 | 17.7 |
| | 58 | 2.7 | 9.5 | 14.5 | 16.6 |
| | 64 | 2.6 | 8.8 | 13.5 | 15.5 |
| | 70 | 2.4 | 8.0 | 12.4 | 14.4 |
| Standing | 52 | 2.8 | 10.3 | 15.5 | 17.7 |
| | 58 | 2.7 | 9.5 | 14.5 | 16.6 |
| | 64 | 2.6 | 8.8 | 13.5 | 15.5 |
| | 70 | 2.4 | 8.0 | 12.4 | 14.4 |

**Development of new Climate Adaptation and Asphalt Selection Tool (CAAST)**

In view of future challenges, it is apparent that above mentioned inherent limitations such as analysing climate data and selecting asphalt binders based on historical data from MERRA-2, not considering standing traffic (i.e., zero speed) and calculating the DD parameter for a limited time period between April and September, despite the extended hot season resulting from climate change are obviously not ideal. In response to these limitations, a new software tool called Climate Adaptation and Asphalt Selection Tool (CAAST) was developed at National

Research Council of Canada (NRC). This tool offers users the ability to analyze the impact of climate on environmental loading parameters, and also serves as a climate-resilient asphalt selection tool by providing the following capabilities:

- Historical and projected temperatures
- Yearly DD parameter
- Standing speed impact

The Climate Adaptation and Asphalt Selection Tool (CAAST) developed in this study includes a temperature database for major Canadian cities provided by ECCC, and it enables users to determine climatic loading parameters and select climate resilient asphalt performance grades using air temperature data files for different road design life. In addition, CAAST has adopted and modified the high-temperature adjustment of base grade, traffic capacity, and traffic speed ($T_{PGhigh\text{-}BTSadj}$) from LTPPBind version 3.1 (FHWA, 2017) to account for extended warming season and traffic speed at standing conditions. To consider the standing speed, CAAST has increased the impact of slow speed by one grade as recommended by the Ontario Provincial Standard Specification (OPSS.MUNI1101, 2016), resulting in an adjustment to PG high temperature ($T_{PGhigh\text{-}BTSadj}$), as shown in Table 2.

**Table 2: Adjustment for base grade, traffic capacity and speed in CAAST**

| Speed | Base Grade | Traffic loading ESAL, millions | | | |
|---|---|---|---|---|---|
| | | <3 | 3 - 10 | 10 - 30 | 30 |
| Fast | 52 | 0.0 | 7.8 | 13.2 | 15.5 |
| | 58 | 0.0 | 7.1 | 12.3 | 14.5 |
| | 64 | 0.0 | 6.5 | 11.3 | 13.4 |
| | 70 | 0.0 | 5.8 | 10.4 | 12.4 |
| Slow | 52 | 2.8 | 10.3 | 15.5 | 17.7 |
| | 58 | 2.7 | 9.5 | 14.5 | 16.6 |
| | 64 | 2.6 | 8.8 | 13.5 | 15.5 |
| | 70 | 2.4 | 8.0 | 12.4 | 14.4 |
| Standing | 52 | 8.8 | 16.3 | 21.5 | 23.7 |
| | 58 | 8.7 | 15.5 | 20.5 | 22.6 |
| | 64 | 8.6 | 14.8 | 19.5 | 21.5 |
| | 70 | 8.4 | 14 | 18.4 | 20.4 |

The CAAST software is designed to use ECCC hourly ambient temperature data for specific road locations in order to calculate climatic loading parameters and select climate-resilient asphalt performance grades. Figure 1 displays list of cities and analysis period selection in the CAAST software, while Figure 2 shows the designer input and selection data, including project name, asphalt information, traffic information, speed information, and base grade selection. The output of the CAAST software provides information on air and pavement temperatures, including the two temperature extremes. From CAAST input data illustrated in Figures 1 and 2, the climate-resilient performance grade can be selected, as shown in Figure 3 snapshot of the CAAST software.

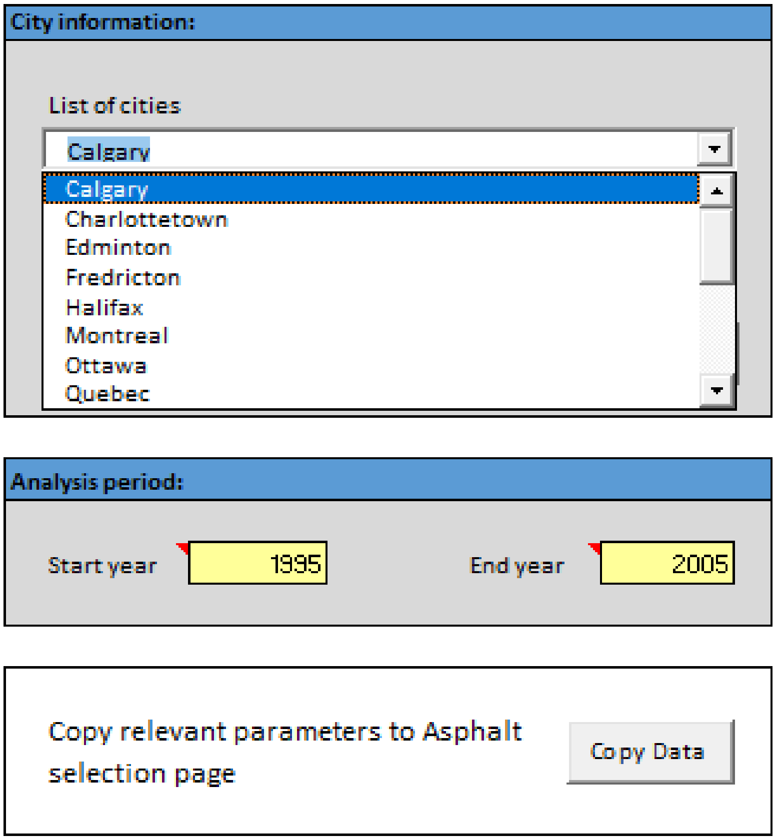
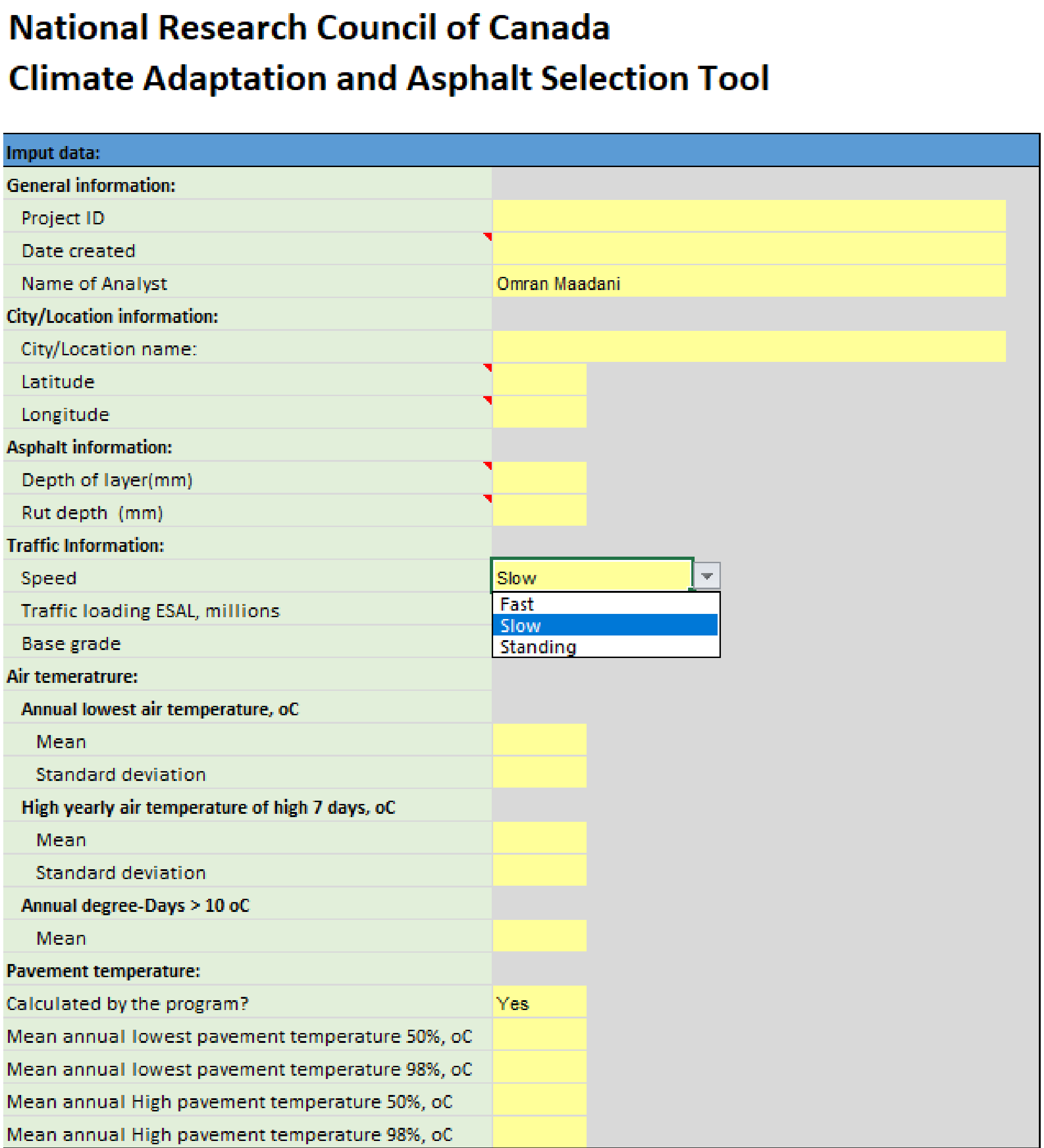



**Figure 1: City information and road design analysis period using CAAST software**



National Research Council of Canada
Climate Adaptation and Asphalt Selection Tool

| Imput data: | |
|---|---|
| **General information:** | |
| Project ID | |
| Date created | |
| Name of Analyst | Omran Maadani |
| **City/Location information:** | |
| City/Location name: | |
| Latitude | |
| Longitude | |
| **Asphalt information:** | |
| Depth of layer(mm) | |
| Rut depth (mm) | |
| **Traffic Information:** | |
| Speed | Slow (Fast / Slow / Standing) |
| Traffic loading ESAL, millions | |
| Base grade | |
| **Air temeratrure:** | |
| **Annual lowest air temperature, oC** | |
| Mean | |
| Standard deviation | |
| **High yearly air temperature of high 7 days, oC** | |
| Mean | |
| Standard deviation | |
| **Annual degree-Days > 10 oC** | |
| Mean | |
| **Pavement temperature:** | |
| Calculated by the program? | Yes |
| Mean annual lowest pavement temperature 50%, oC | |
| Mean annual lowest pavement temperature 98%, oC | |
| Mean annual High pavement temperature 50%, oC | |
| Mean annual High pavement temperature 98%, oC | |

**Figure 2: Input and output of CAAST software**

Calculate    Create report

**Performance graded asphalt binder**

| PG temperature | High | Low |
|---|---|---|
| Performance grad temperature at 50% reliabilty ($MAHPT_{50\%}$ and $MALPT_{50\%}$) | 52.72 | -20.40 |
| Performance grad temperature at 98% reliabilty ($MAHPT_{98\%}$ and $MALPT_{98\%}$) | 56.45 | -29.04 |
| Adjustment for base grade, traffic capacity and speed of trafic ($T_{PGHigh\ BTSadj}$, $T_{PGLow\ BTSadj}$) | 9.50 | |
| Adjustment for depth of layer ($T_{PGHigh\ Dadj}$, $T_{PGLow\ Dadj}$) | 0.00 | 0.00 |
| Adjusted performance grade temperature | 65.95 | -29.04 |
| **Selected PG grade** | 70 | -34 |

| | |
|---|---|
| **PG grade** | PG 70-34 |

**Figure 3: Selection of performance grade asphalt binder using CAAST software**

The asphalt binder PG is determined based on high and low temperature, which are referred in this study to as Mean Annual High Pavement Temperature (MAHPT) and Mean Annual Lowest Pavement Temperature (MALPT). Both LTPPBind and CAAST use equations to estimate $T_{MAHPT}$ and $T_{MALPT}$ based on various factors such as the reliability of extreme temperature events, MADD, rut depth, $T_{MALAT}$, $\sigma_{MALAT}$, and latitude. To adjust for high ($T_{PGhigh\text{-}Dadj}$) and low ($T_{PGlow\text{-}Dadj}$) temperatures, depth of layer adjustment is necessary for both MAHPT and MALPT. For MAHPT, an additional adjustment is required for the base grade, traffic capacity, and traffic speed ($T_{PGhigh\text{-}BTSadj}$). The selection of PG high (PGHH) and PG low (PGLL) temperatures are determined using equations 7 and 8, respectively.

$$PG_{HH} = T_{MAHPT_{98\%}} + T_{PGhigh-Dadj} + T_{PGhigh-BTSadj} \quad (7)$$

$$PG_{LL} = T_{MALPT_{98\%}} + T_{PGlow-Dadj} \quad (8)$$

The asphalt system for the selection of performance grade ($PG_{Design}$) is determined based on the projected temperature of the road's geographic location. The PG binder is denoted using the standard notation $PG_{HH\text{-}LL}$, where HH represents the extreme high pavement design temperature and LL represents the extreme low pavement design temperature, as demonstrated in equation 9:

$$PG_{Design} = PG_{HH} - PG_{LL} \quad (9)$$

## EVALUATION OF DIFFERENT SCENARIONS IN CAAST

The Climate Adaptation and Asphalt Selection Tool (CAAST) is a new software that calculates important climatic parameters and selects binders for pavement performance considering extreme hot and cold temperatures specific to a road's design life. This leads to improved specifications for climate-resilient binders in specific projects and results in longer-lasting, better-performing pavement. The projected temperature data of city of Ottawa has been classified to four road design life cycles named historical term (1993 – 2017), short term (2018 – 2042), intermediate term (2043 – 2067) and long term (2068 – 2092). The ECCC data base of air temperature of city of Ottawa has been used to determine and compare the accuracy of Mean Annual Air Temperature (MAAT) determined by both CAAST and the existing Pavement Mechanistic-Empirical Design (PMED, NCHRP, 2004). Figure 4 shows that the MAAT determined by CAAST and PMED follows an identical trend.

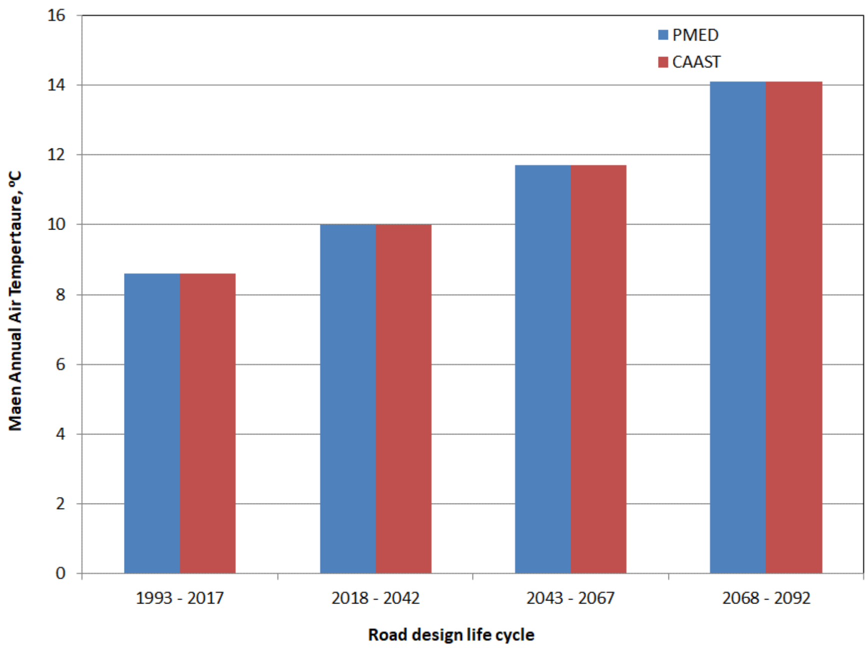



**Figure 4: Comparison of Mean Annual Air Temperature using LTPPBind and CAAST**

Additionally, the CAAST tool has the ability to automatically determine the climate parameters required for the selection of asphalt binder PG, which typically has to be manually input to LTPPBind software. This determination was made using the ECCC projected temperature data for the city of Ottawa from 1995 to 2020, as shown in Figure 5, output of the CAAST software.

**National Research Council of Canada**
**Climate Adaptation and Asphalt Selection Tool**

| Imput data: | |
|---|---|
| **General information:** | |
| Project ID | HYW 417 |
| Date created | 10/11/2020 |
| Name of Analyst | Omran Maadani |
| **City/Location information:** | |
| City/Location name: | Ottawa |
| Latitude | 45.42 |
| Longitude | -75.70 |
| **Asphalt information:** | |
| Depth of layer(mm) | 0.00 |
| Rut depth (mm) | 12.51 |
| **Traffic Information:** | |
| Speed | Slow |
| Traffic loading ESAL, millions | between 3-10 |
| Base grade | 58 |
| **Air temeratrure:** | |
| **Annual lowest air temperature, oC** | |
| Mean | -26.85 |
| Standard deviation | 5.06 |
| **High yearly air temperature of high 7 days, oC** | |
| Mean | 32.68 |
| Standard deviation | 1.77 |
| **Annual degree-Days > 10 oC** | |
| Mean | 2559.29 |
| **Pavement temperature:** | |
| Calculated by the program? | Yes |
| Mean annual lowest pavement temperature 50%, oC | -20.40 |
| Mean annual lowest pavement temperature 98%, oC | -29.04 |
| Mean annual High pavement temperature 50%, oC | 52.72 |
| Mean annual High pavement temperature 98%, oC | 56.45 |

**Figure 5: Environmental parameters output results of CAAST software**

The above climate parameters obtained from CAAST were manually used as an input into LTPPBind software while selecting a traffic capacity of 3.0 million Equivalent Single Axial Loads (ESALs) and slow speed and keeping rut depth at 12.5 mm. The results of asphalt performance grade selection using both CAAST and LTPPBind softwares are presented in Tables 3 and 4, respectively. Both results showed similar PG outcomes.

**Table 3: Performance grade asphalt binder – CAAST**

| PG temperature (°C) | High | Low |
|---|---|---|
| Performance grad temperature at 50% reliability: $MAHPT_{50\%}$ and $MALPT_{50\%}$ | 52.72 | -20.40 |
| Performance grad temperature at 98% reliability: $MAHPT_{98\%}$ and $MALPT_{98\%}$ | 56.45 | -29.04 |
| Adjustment for base grade, traffic capacity and speed of traffic: $T_{PGhigh\text{-}BTSadj}$ | 10.30 | |
| Adjustment for depth of layer: $T_{PGhigh\text{-}Dadj}$ and $T_{PGlow\text{-}Dadj}$ | 0.00 | 0.00 |
| Adjusted performance grade temperature | 66.75 | -29.04 |
| Selected PG grade | 70 | -34 |
| PG grade | PG 70-34 | |

**Table 4: Performance grade asphalt binder – LTPPBind**

| PG temperature (°C) | High | Low |
|---|---|---|
| Performance grad temperature at 50% reliability | 52.70 | -20.40 |
| Performance grad temperature at 98% reliability | 56.00 | -29.00 |
| Adjustment for traffic | 10.30 | |
| Adjustment for depth | 0.00 | 0.00 |
| Adjusted performance grade temperature | 66.30 | -29.00 |
| Selected PG grade | 70 | -34 |
| PG grade | PG 70-34 | |

The results of the climate analysis and asphalt binder selection using CAAST software were found to be in good agreement with those obtained through PMED climate analysis and LTPPBind asphalt binder selection.

## RESULTS AND ANALYSIS

### Climatic loading parameters

As previously described, this study used two different air temperature data files including ECCC projected data and MERRA-2 historical (FHWA, 2017) for the period of 1995 to 2020 for cities in Atlantic Canada (Fredericton); Central Canada (Ottawa); The Prairies (Edmonton); Western Canada (Vancouver) and Northern Canada (Yellowknife). The calculated climate loading parameters for MERRA-2 and ECCC using LTPPBind and CAAST software, respectively, were compared. Results of the comparison in terms of MALAT, MHAAT of seven consecutive days, and MADD are shown in Figures 6, 7, and 8, respectively. Overall, MALAT shows a general higher trend, with an increase of about 4 to 22 %. Mean High Annual Air Temperature of seven consecutive days shows a higher trend in the range of 7 to 20 % increase of air temperature data from ECCC compared to those of MERRA-2. The MADD illustrated in Figure 8 shows an increase in the case of ECCC data compared to MERRA-2, which were about 26, 30, 26, 60, and 38 % in Fredericton, Ottawa, Edmonton, Yellowknife, and Vancouver, respectively. All ECCC trends are in good agreement with general consciences that the temperature trend in Canada has increased more than the global rate (Zhang et al., 2019), as obtained from CAAST.

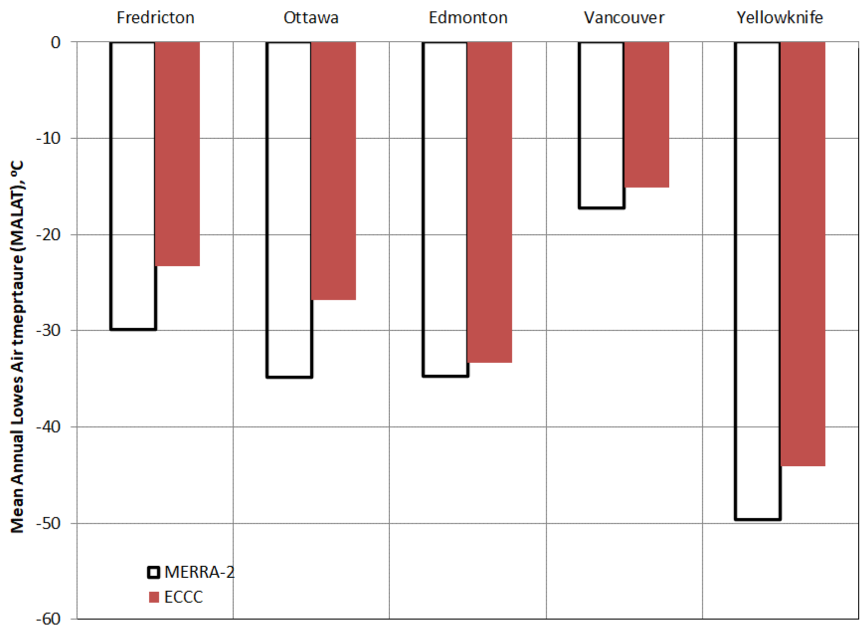



**Figure 6: Mean Annual Lowest Air Temperature for MERRA-2 and ECCC historical climate data files**

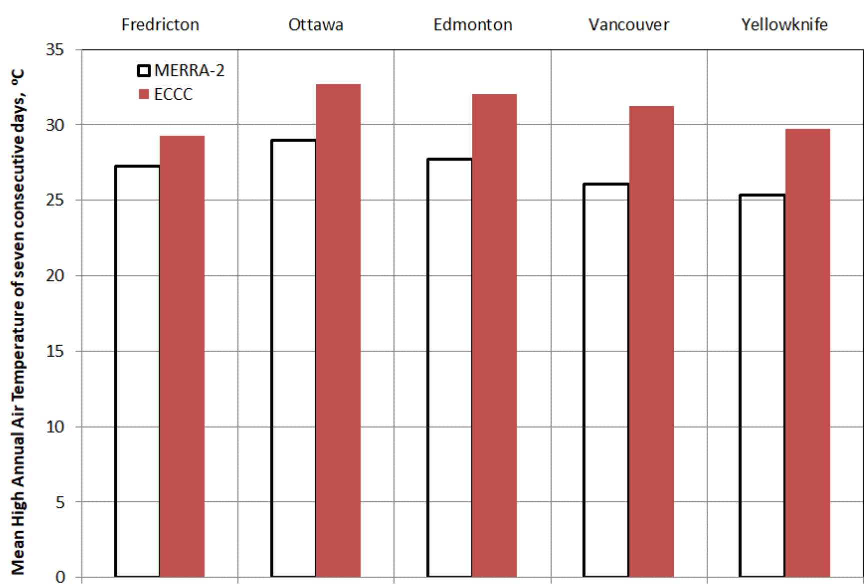



**Figure 7: Comparison of Mean High Annual Air Temperature of seven consecutive days between MERRA-2 and ECCC historical climate data files**

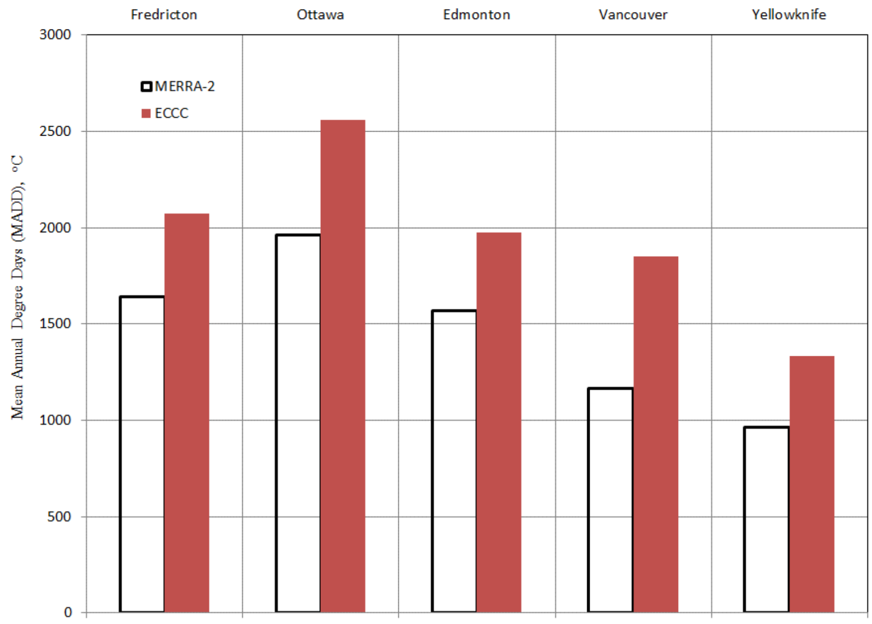



**Figure 8: Comparison of Mean Annual Degree Days (MADD) between MERRA-2 and ECCC historical climate data files**

## ASPHALT BINDER PG SELECTION RESULTS

As emphasized previously, pavement designers around the world have traditionally used LTPPBind (FHWA, 2017) standalone Superpave software to select PG asphalt binder. However, there have been criticisms that the software uses historical MERRA-2 data instead of projected data, does not consider standing speed, and calculates Degree Days (DD) from April to September only. Figure 9 compares the impact of traffic speed on PG asphalt binder selection using MERRA-2 data via LTPPBind and ECCC data via CAAST software for Ottawa and Halifax for the design period of 1995-2020, assuming rut depth of 12.5 mm and traffic capacity of 3 million ESAL. The analysis shows that it is important to consider traffic speed, as changing from slow to standing speed requires at least two grades up to PG asphalt binder selection. The CAAST software accounts for the impact of standing traffic, by interrupting traffic speed so that pavements are subject to significantly slower or stopped traffic, and it recommends using a stiffer asphalt binder than that which would be used for fast-moving traffic.

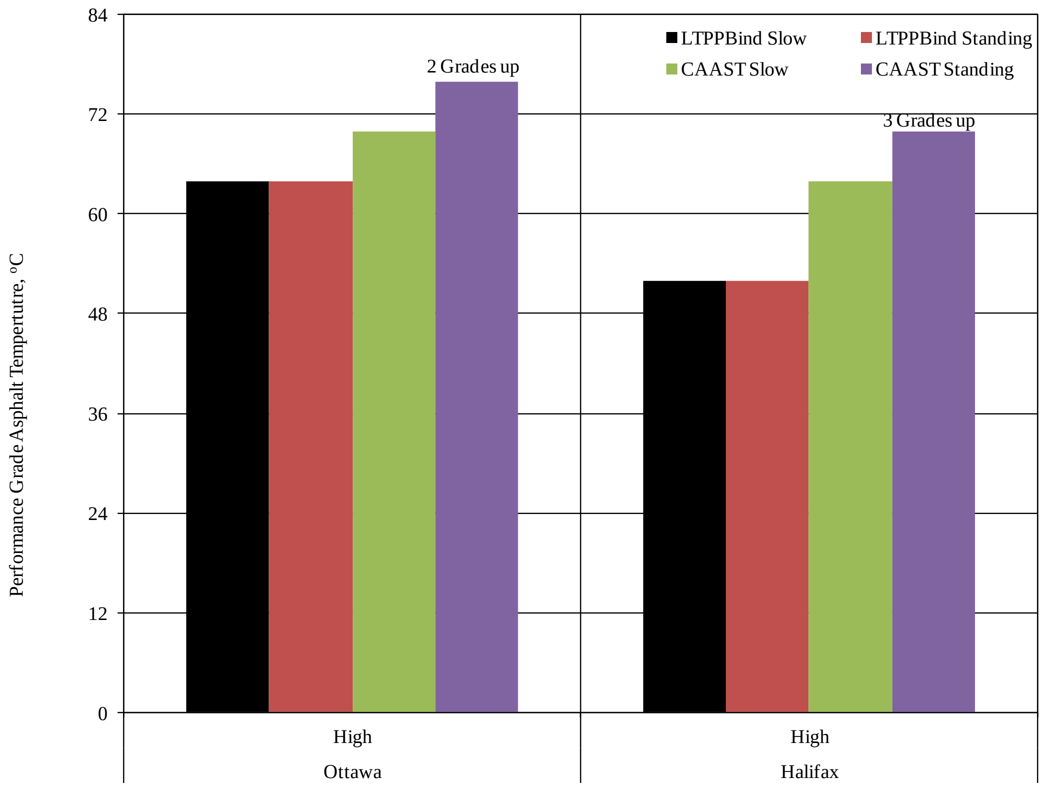



**Figure 9: Speed effect on performance grade high asphalt temperature**

The findings of the climate data analysis in this study indicate a significant and rapid change in Canada's climate, with warming occurring in all seasons, contrary to the simplistic assumption of LTPPBind that only considered the period from April to September. For example, the analysis for the city of Ottawa in this study shows that the hourly air temperature for the years 1995, 2020, and 2045 indicates a trend of longer warm weather starting as early as March and extending until December each year, as depicted in Figure 10. Furthermore, the use of CAAST software for determining the ADD (Equation 1) and MADD (Equation 2) above 10°C for the entire year and road design life, respectively, provides advantages, as demonstrated by Figure 10, in calculating the maximum pavement temperature through air temperature.

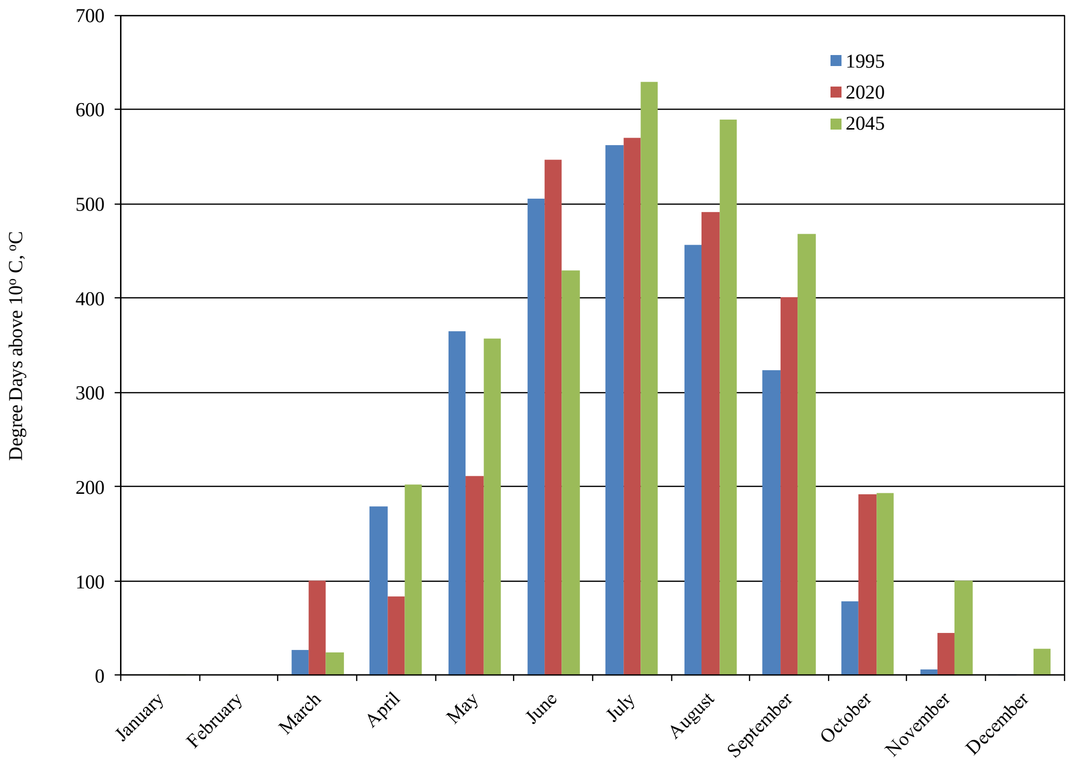



**Figure 10: Degree Days (DD) above 10º C in years 1995, 2020 and 2045 for city of Ottawa**

As previously stated, it is expected that the climate will continue to warm due to future greenhouse gas emissions (Flato et al., 2019). This study compared the impact of historical temperature data files for cities of Ottawa, Halifax, Edmonton, Montreal, Yellowknife and Windsor for a typical road design life between 1995 and 2020, using both MERRA-2 data with LTPPBind and ECCC data with CAAST. Finally, the results, shown in Table 5, indicate an increase of at least two grades and three grades for high and low temperature thresholds, respectively, compared to using MERRA-2 data.

**Table 5: PG asphalt binder selection using both LTPPBind and CAAST**

| | PG selection | | | |
|---|---|---|---|---|
| Grade | High temperature | | Low temperature | |
| Data | MERRA-2 | ECCC | MERRA-2 | ECCC |
| City | | | | |
| Fredericton | 58 | 64 | -40 | -28 |
| Ottawa | 64 | 70 | -46 | -34 |
| Edmonton | 58 | 64 | -46 | -40 |
| Yellowknife | 52 | 58 | -58 | -46 |
| Vancouver | 52 | 64 | -28 | -22 |

## CONCLUSIONS

This study highlights that a comparative study of traditional LTPPBind software for PG selection using historical climate data and the new NRC software, CAAST, which offers several different advantages for pavement designers in Canada, such as using projected ECCC climate data, climate adaptation analysis, consideration of standing traffic speed as well as accounting for year-round climate impacts on Degree Days. The study found that using CAAST resulted in at least two upgrades higher in both high and low temperature thresholds for PG asphalt binder type selection compared to MERRA-2 via LTPPBind. The study concludes that in the next 25 years, high-temperature problems like rutting may become more challenging than low-temperature cracking.

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