

Emission Adjustments for Temperature, Humidity, Air Conditioning and Inspection and Maintenance for Onroad Vehicles in MOVES3

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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List of Acronyms

A/C	air conditioning
ACCF	air conditioning correction factor
ASM	Acceleration Simulation Mode
CO	Carbon Monoxide
CDB	county database
CF	critical flow factor coefficient
CFR	Code of Federal Regulations
CNG	Compressed Natural Gas
CV	coefficients of variation
DPF	diesel particulate filter
EPA	U.S. Environmental Protection Agency
E85	gasoline containing 70-85 percent ethanol by volume
F	Fahrenheit
FTP	Federal Test Procedure
GDI	Gasoline Direct Injection
GHG	Greenhouse Gases
GVWR	Gross Vehicle Weight Rating
HC	hydrocarbons
HP	horsepower
I/M	Inspection and Maintenance program
IM240	Inspection and Maintenance roadside vehicle driving schedule
KCVES	Kansas City Light-Duty Vehicle Emissions Study
kW	Kilowatt
LA-92	California dynamometer driving schedule for light-duty vehicles
LDT	Light-Duty Truck
LDV	Light-Duty Vehicle
LHDT	Light Heavy-Duty Truck
LLDT	Light Light-Duty Truck
MDPV	Medium-Duty Passenger Vehicle
MOBILE6	EPA Highway Vehicle Emission Factor Model, Version 6
MOVES	Motor Vehicle Emission Simulator Model
MSAT	Mobile Source Air Toxics rules
MSOD	Mobile Source Observation Database
NEI	National Emission Inventory
NMHC	Non-Methane Hydrocarbons
NMIM	National Mobile Inventory Model
NO _x	Oxides of Nitrogen
OBD	On-Board Diagnostics
ORD	Office of Research and Development
OTAQ	Office of Transportation and Air Quality
PFI	Port Fuel Injection

PM	Particulate Matter
RIA	Regulatory Impact Analysis
SFTP	Supplemental Federal Test Procedure
SIP	state implementation plan
SRC	selective reduction catalysts
STP	scaled tractive power
SwRI	Southwest Research Institute
THC	Total Hydrocarbons
US06	A drive cycle that is part of the SFTP
VIN	Vehicle Identification Number
VOC	Volatile Organic Compound
VSP	vehicle specific power

1. Introduction

The United States Environmental Protection Agency's Motor Vehicle Emission Simulator—commonly referred to as MOVES—is a set of modeling tools for estimating air pollution emissions produced by onroad (highway) and nonroad mobile sources. MOVES estimates the emissions of greenhouse gases (GHGs), criteria pollutants, and selected air toxics. The MOVES model is currently the official model for use for state implementation plan (SIP) submissions to EPA and for transportation conformity analyses outside of California. The model is also the primary modeling tool to estimate the impact of mobile source regulations on emission inventories.

MOVES calculates emission inventories by multiplying emission rates by the appropriate emission-related activity, applying correction and adjustment factors as needed to simulate specific situations, and then adding up the emissions from all sources and regions. The highway vehicle emission rates in the MOVES model represent emissions under a single (base) scenario of conditions for temperature, humidity, air conditioning load and fuel properties. MOVES is designed to adjust these base emission rates to reflect the conditions for the location and time specified by the user. MOVES also includes the flexibility to adjust the base emission rates to reflect the effects of local Inspection and Maintenance (I/M) programs. This report describes how these adjustments for temperature, humidity, I/M, and air conditioning were derived. Adjustments for fuel properties are addressed in a separate report.¹

This report describes MOVES3 adjustments that affect running exhaust, start exhaust, and extended idling exhaust emissions for Total Hydrocarbons (THC), carbon monoxide (CO), nitrogen oxides (NO_x), fine particulate matter (PM_{2.5}) and energy consumption. The temperature effects that impact these pollutants, also affect the pollutants that are calculated from these pollutants in MOVES, such as volatile organic compounds (VOC)² and individual toxics such as benzene³ (chained to THC), NO₂ (chained to NO_x)^{10,11}, elemental carbon (chained to PM_{2.5})², and CO₂ emissions (chained to energy)⁴. The definitions of these pollutants and the relationship to the primary pollutants are discussed in the cited MOVES reports. The crankcase emission processes^{10,11} are chained to running exhaust, engine start, and extended idling exhaust emissions, and thus are similarly affected by the temperature adjustments described in this report. The impact of fuels, temperatures, and I/M programs on vapor venting, permeation, and liquid leaks is addressed in a separate report on evaporative emissions.⁵

This report replaces the MOVES2014 adjustment report.⁶ Updates for MOVES3 were minor. They include removing the running exhaust temperature effect for particulate matter and correcting an error in the I/M adjustments. The updates to the running temperature effect was included in peer-review of MOVES updates conducted in 2017, and comments and responses are located on the EPA Science Inventory webpage.⁷ This report also includes a new appendix describing temperature and humidity in MOVES defaults.

2. Temperature Adjustments

Emission rates in MOVES are adjusted by the ambient temperature to account for temperature effects that impact emissions such as inefficient oxidation of emissions at cool catalyst temperatures and additional fuel needed to start an engine at cold temperatures. In MOVES, exhaust emissions are adjusted relative to their base rates at 75 degrees Fahrenheit based on two considerations:

1. Ambient temperature⁸
2. The latent engine heat from a previous trip, applied as an adjustment based on the length of time the vehicle has parked since operating (soak time)^{9,10}

This report describes the adjustment based on ambient temperature. Soak time and start emissions are addressed in the light-duty¹⁰ and heavy-duty¹¹ emission rates reports.

This report addresses temperature sensitivity of emissions from gasoline vehicles in Sections 2.1 through 2.3. Although the gasoline temperature effects are developed based on emissions data from light-duty gasoline vehicles, they are applied to all gasoline vehicles in MOVES, including motorcycles, heavy-duty gasoline vehicles, and light-duty vehicles fueled on ethanol-gasoline blends.

Section 2.4 discusses the temperature effects derived for diesel vehicles. The data used to derive diesel temperature effects is based on light-duty diesel vehicles but are applied to all diesel vehicles in MOVES due to a lack of temperature effect data on heavy-duty diesel vehicles. The diesel temperature effects are also applied to CNG buses as discussed in Section 2.5.

Section 2.6 discusses the temperature effects for energy consumption for all vehicle types in MOVES. These effects are applied only to vehicle starts.

2.1 Data Sources for Gasoline Temperature Effects for THC, CO, and NO_x emissions

To determine the impact of ambient temperature on running emissions, our analysis included the Bag 2 emissions of Federal Test Procedure (FTP) tests as well as US06 tests (without engine starts).

For start emissions, measurements from both the Federal FTP and California Unified Cycle (3-phase / 3-bag tests) were used. Within each test cycle, the first and third phases are identical driving cycles, but the first phase begins with a cold-start (cold engine and emission control equipment) while the third phase begins with a hot-start (relatively warm engine and control equipment). The difference between Bag 1 and Bag 3 (in grams) are the emissions attributed to the cold start of the vehicle.

The data used in these analyses are from the following sources:

Table 2-1 Summary of Data Sources

Data Source	Test	Temperatures Tested (deg. F)	# of Vehicles	MY Range
MSOD	FTP +	15-110	Hundreds	Pre-2005
ORD	FTP, IM240	-20, 0, 20, 40, 75	5	1987-2001
MSAT	FTP	0, 20, 75	4	2005
OTAQ	FTP, US06	0, 20, 75	9	2006, 2010

- **MSOD** - EPA's Mobile Source Observation Database (MSOD) as of April 27, 2005. EPA has acquired data representing emissions measurements over various cycles (often the FTP) on tens of thousands of vehicles under various conditions. EPA has stored those test results in its Mobile Source Observational Database (MSOD).¹²

For the data stored in MSOD, we limited our analysis to those tests for which vehicles were tested at two or more temperatures. The subset of tests meeting this criterion covered a temperature range from 15 to 110°F. Note that the results acquired from MSOD were collected in aggregate or “bag” modes.

Information on EPA's MSOD is available on EPA's website:

<https://www.epa.gov/moves/mobile-source-observation-database-msod>

- **ORD Program** - EPA's Office of Research and Development (ORD) contracted (through the Clean Air Vehicle Technology Center, Inc.) the testing of five cars (model years 1987 through 2001). Those vehicles were tested using both the FTP and the IM240 cycles under controlled conditions at temperatures of: 75, 40, 20, 0 and –20°F.¹³
- **MSAT Program** - Under a contract with EPA, the Southwest Research Institute (SwRI) tested four Tier 2 vehicles (2005 model year car and light-duty trucks) over the FTP under controlled conditions at temperatures of: 75, 20, and 0°F. This program was used in the Regulatory Impact Analysis of Final Rule: Control of Hazardous Air Pollutants from Mobile Sources¹⁴, which is referred to as MSAT-2 in this report to distinguish it from an earlier mobile source air toxics (MSAT) rulemaking.¹⁵ The MSAT-2 rule required Tier 2 vehicles to meet a non-methane hydrocarbon (NMHC) standard on the FTP cycle of 0.3 g/mile for light-duty vehicles (<6,000 lbs) beginning phase-in for model year 2010 vehicles.¹⁶

OTAQ Cold Temperature Program - EPA's Office of Transportation and Air Quality (OTAQ) contracted the testing of nine Tier 2 vehicles (2006 and 2010 model year car and light-duty trucks). Eight of the nine vehicles were Mobile Source Air Toxics (MSAT-2) rule compliant. Vehicles were tested on the FTP and US06 under controlled conditions 75, 20, and 0°F. Information on the tested vehicles is summarized in Appendix B. Note that for the estimation of the THC and CO cold start effects the two GDI vehicles were excluded from the analysis.

2.2 Temperature Effects on Gasoline Start Emissions

When a vehicle engine is started, emissions can be higher than during normal operation due to the relatively cold temperature of the emissions control system. As these systems warm up to their ideal operating temperature, emissions from the vehicle can be dramatically reduced. The cold start effect can vary by pollutant, temperature, and vehicle technology.

The effects of ambient temperature on THC, CO, and NO_x start emissions were developed using the following approach:

- No adjustment for temperatures higher than 75°F. 75°F is the midpoint of the allowable temperature range (68°F-86°F) per the FTP.
- Additive adjustments for temperatures below 75°F. These adjustments are added to the emissions that would occur at 75°F.
- Calculate the adjustments as either polynomial (Equation 2-1) or log-linear (Equation 2-2) functions, depending on model year group and pollutant:

$$\text{Additive Grams} = A * (\text{Temp} - 75) + B * (\text{Temp} - 75)^2 \quad \text{Equation 2-1}$$

$$\text{Additive Grams} = B e^{A * (\text{Temp} - 75)} + C \quad \text{Equation 2-2}$$

This approach provides a value of zero change for the additive adjustment at 75°F (i.e., the temperature of the federal FTP test). The coefficients, A and B, for the adjustment equations are stored in the StartTempAdjustment table. This table contains temperature effect coefficients for each model year group, operating mode, and pollutant.

In MOVES, the temperature effects for older model year groups use polynomial function (Equation 2-1) and more recent model year vehicles use log-linear function (Equation 2-2). The data processing and the model fitting process differed for the polynomial and log-linear fits and each is described separately below. Temperature effects in MOVES3 were retained from earlier versions of MOVES.

THC and CO Start Emissions for Gasoline-Fueled Vehicles

In developing temperature adjustments for THC and CO start emissions, both polynomial and log-linear regression models were used to fit the data. Data anomalies were resolved by combining two or more model year groups to obtain a larger dataset, or by removing anomalous data points. We also distinguish temperature effects between pre-MSAT-2 (Mobile Source Air Toxics) and MSAT-2 compliant vehicles, which began phase-in starting in 2010. The MSAT-2 rule included the first regulation on low temperature (20°F) non-methane hydrocarbon (NMHC) emissions for light-duty and some medium-duty gasoline vehicles.¹⁶

Polynomial Fits

The coefficients for THC emissions for pre-2006 gasoline vehicles and CO emissions for pre-2001 gasoline vehicles were calculated with polynomial fits to data processed in the following steps. First, the cold start emissions (grams/start) were calculated as the difference between Bag 1 and Bag 3 emissions

for each relevant vehicle test in the MSOD, ORD and MSAT data. Next, the cold start emissions were stratified by model year groups. The data was initially grouped according to the following model year groups:

- 1960 to 1980
- 1981 to 1982
- 1983 to 1985
- 1986 to 1989
- 1990 to 1993
- 1994 to 1999
- 2000 to 2005

Then, the mean emissions at 75°F were subtracted from the mean emissions at the other temperatures to determine the change in emissions as functions of ambient temperature. Then, we modeled the changes in cold-start emissions as a polynomial function of temperature minus 75°F. The additive adjustments are set equal to zero for temperatures higher than 75°F. Thus, we did not use the changes in emissions from temperature above the FTP temperature range (68° to 86°F). The model year groups were aggregated to larger intervals when the less aggregated groups yielded non-intuitive results (e.g., older model year group had lower cold start emissions). Table 2-2 summarizes the coefficients used with Equation 2-1 (polynomial) to estimate additive start temperature adjustments for older model year gasoline vehicles.

Table 2-2 Polynomial Model Coefficients for CO Temperature Effects for 2000 Model Year and Earlier Gasoline Vehicles and THC Temperature Effects for 2005 and Earlier Gasoline Vehicles

Model Year Group	CO		THC	
	A	B	A	B
Pre-1981	-4.677		-0.631	
1981-1982	-4.631		-0.414	
1983-1985	-4.244		-0.361	
1986-1989				0.002
1986-2000		0.023		
1990-2005				0.003

The THC test data for the 1986-1989, and 1990-2005 model year groups included the ORD program vehicles that were tested at an ambient temperature of -20°F. However, when this ultra-low temperature data was included, the "best fit" THC regression curves (linear, quadratic and cubic) all exhibited poor fits for temperatures from zero through 20°F. We removed the five ORD vehicle tests conducted at -20°F, which improved the estimate of the cold-start THC emissions in the more common 0° F to 20°F range. Therefore, the coefficients in MOVES are based on the changes in cold-start emissions for temperatures from zero through 75°. However, these coefficients are applied to all ambient temperatures below 75°F in MOVES.

For CO, the temperature effect developed based on the 1994-2000 model year vehicles was applied to all model years from 1986-2000, because including 1986-1993 model year vehicles in the analysis resulted

in cases where older model years were modeled with substantially lower CO emissions than newer model years. Note that the base CO emission rates still vary across this model year range.

To adapt the additive ambient temperature adjustments to account for intermediate soak times, the A and B coefficients for start operating modes other than cold starts were reduced by multiplying by a factor equal to the ratio between emissions at the desired soak time and the cold start emissions for catalyst equipped vehicles as used in MOBILE6.⁹ These factors are summarized in Table 2-3.

Table 2-3 Soak Time Multipliers for Additive Start Temperature Effects

Operating Mode ID	Nominal Soak Time (min)	THC	CO	NOx
108	720	1	1	1
107	540	0.908778	0.91377	1.053118
106	240	0.733962	0.79137	1.117624
105	105	0.64496	0.72996	1.128799
104	75	0.599625	0.6285	1.129778
103	45	0.444825	0.44136	1.02786
102	18	0.208548	0.199678	0.58398
101	3	0.037593	0.035422	0.20508

Log-linear Fits

In estimating the THC temperature effect for model years 2006 and later and the CO temperature effect for model years 2001 and later^a, data from ORD, MSAT and OTAQ cold temperature programs^b were used to fit regression models. We used linear mixed models, with both continuous and categorical variables, to fit to the logarithm of the start emissions. Second-order polynomial models exhibited non-intuitive behaviors (e.g., negative values, non-monotonically increasing emissions). Thus, we chose to fit the data with log-linear models because they provide monotonically increasing emissions at colder temperatures and can model the strong curvature evident in the cold start data (See Figure 2-1 and Figure 2-2).

The model parameters were fit using linear mixed models using the function *lme* within the R statistical package *nlme*.¹⁷ Using random effects for vehicle, and the test temperature as a fixed effect, we accounted for the paired test design of the data set, yielding robust temperature effect estimates for the entire data set (e.g., not all vehicles were tested at the same set of temperatures which is evident at -20°F in Figure 2-1).

The linear mixed model had the following form:

^aThe CO temperature effects for 2001-2005 model years were estimated using the log-linear fit because the temperature correction for these model years in previous versions of MOVES caused the model to estimate cold start CO emissions that were unrealistically high relative to older model year vehicles.

^b We excluded the two GDI vehicles from the OTAQ cold temperature program from the model fit because they were not deemed representative of the predominate technology in the 2010 vehicle fleet. In addition, they were believed to be transitional GDI technologies that were not necessarily representative of future GDI technology.

$$\log(y) = \alpha + \beta_1 \cdot Temp + Veh \quad \text{Equation 2-3}$$

Where: y = start emissions (grams), Temp = temperature in Fahrenheit, Veh = random effect for each individual vehicle.

The mean model simply removes the random vehicle effects:

$$\log(y) = \alpha + \beta_1 \cdot Temp \quad \text{Equation 2-4}$$

We then converted the mean logarithmic model to real-space, yielding:

$$y = e^{\alpha + \beta_1 Temp} \quad \text{Equation 2-5}$$

We then normalized to degrees below 75°F, by setting $T' = 75 - Temp$, and substituting $Temp = 75 - T'$ into the above equation and rearranging. This yields the equations:

$$y = e^{\alpha + \beta_1(75 - T')} \quad \text{Equation 2-6}$$

$$y = e^{\alpha + 75 \cdot \beta_1} e^{\beta_1(-T')} \quad \text{Equation 2-7}$$

$$y = e^{\alpha + 75 \cdot \beta_1} e^{\beta_1(Temp - 75)} \quad \text{Equation 2-8}$$

Then setting $A = \beta_1$, and $B = e^{\alpha + 75 \cdot \beta_1}$, B is essentially the ‘Base Cold Start’ at 75°F, with units of (g/start). The $e^{A(Temp - 75)}$ term is a multiplier which increases the cold start at temperatures below 75°F.

To convert the model to an additive adjustment, we calculated the additive difference from the cold start: $y - y(75) = B e^{A(Temp - 75)} - B$. This model form can be used in the current MOVES temperature calculator for THC and CO, by setting $C = -B$, yielding Equation 2-2:

$$Additive\ Grams = B e^{A(Temp - 75)} + C \quad \text{Equation 2-2}$$

The initial estimated fixed effects (including p-values) for the linear model fit for CO are displayed in Table 2-4. The model estimates that the Portable Fuel Injection (PFI) MSAT-2 compliant vehicles (Model year 2010) tested in the OTAQ 2012 test program have consistently lower CO start emissions than the pre-MSAT-2 vehicles (pre-2010), as shown by the positive pre-MSAT coefficient (α_2). However, no statistically significant difference in the log-linear impact of temperature (coefficient β) was found between the 2001-2009 and the 2010 model year groups for CO emissions, as shown in Table 2-4 (p-value of the Temperature \times pre-MSAT effect is >0.90).

Table 2-4 Fixed Effects for the Initial CO Model Fit to Data from 2001+ Model Year Vehicles from the ORD, MSAT and Cold Temperature Programs (13 vehicles, 95 observations)

	Value	Std.Error	DF	t-value	p-value
Intercept (α_1)	3.5502	0.1433	80	24.8	2.8E-39
Temperature (β_1)	-0.0380	0.0022	80	-17.5	4.3E-29
pre-MSAT (α_2)	0.7378	0.2066	11	3.6	0.0044
Temperature (β_1) \times pre-MSAT (α_2)	-0.0003	0.0032	80	-0.1	0.9225

Because there was not a significant temperature effect between the pre- and post-MSAT-2 vehicles, we estimated the temperature effect (β_1) from a model fit where the pre-MSAT-2 and post-MSAT-2 vehicles are pooled together as shown in Table 2-5.

Table 2-5 Fixed Effects for the Final CO Model Fit to Data from 2001+ Model Year Vehicles from the ORD, MSAT and Cold Temperature Programs (13 vehicles, 95 observations)

	Value	Std.Error	DF	t-value	p-value
Intercept (α_1)	0.6914	0.1400	81	4.94	4.1E-06
Temperature (β_1)	-0.038	0.0016	81	-24.08	1.1E-38
pre-MSAT (α_2)	0.7284	0.1815	11	4.01	0.0020

The data along with the final model fits are displayed in Figure 2-1. The MSAT-2 compliant group (2010+) has significantly lower base cold start (coefficient α), which causes the emissions to be lower across all temperatures for the newer model year vehicles. The CO model coefficients in the form of Equation 2-2 for use in MOVES are provided in Table 2-8. The 2009 and 2013 model year B values are derived from the linear mixed model for the pre-MSAT-2 and the MSAT-2 compliant groups, respectively. The 2010 through 2012 model year B values are derived by linearly interpolating the 2009 and 2013 values.

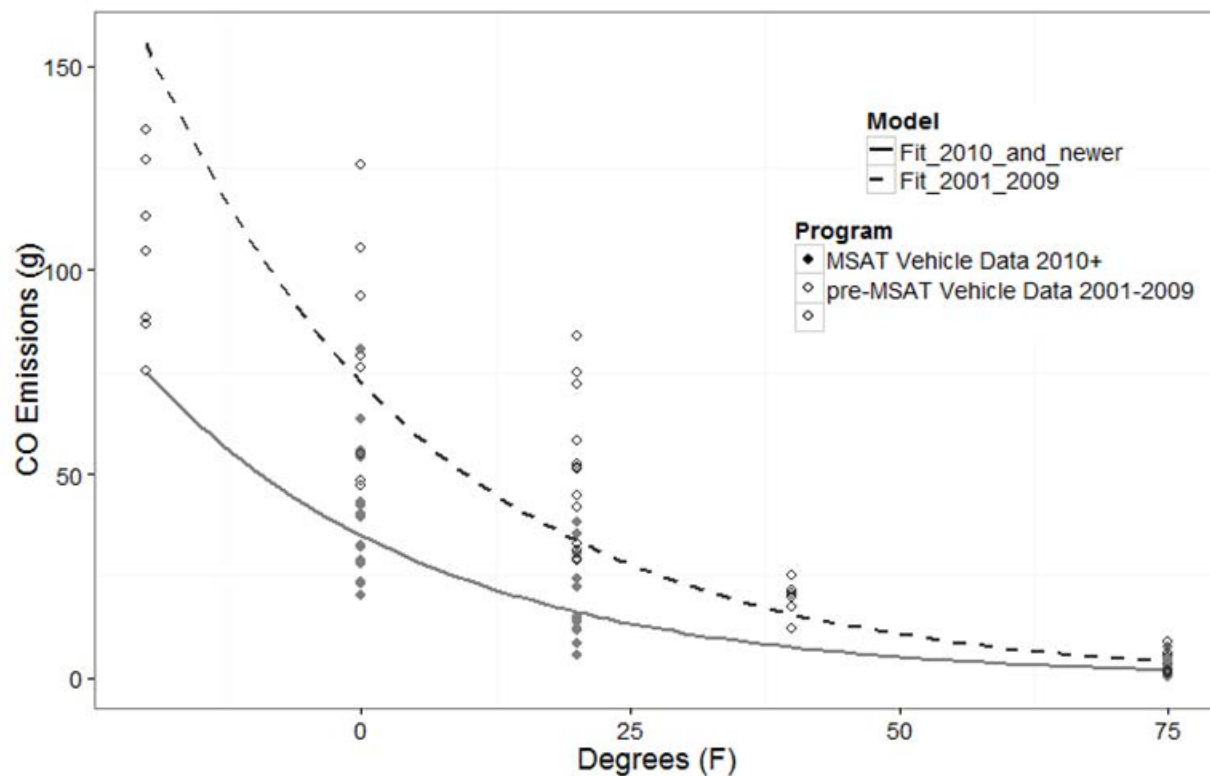


Figure 2-1 FTP CO Start Emissions with Log-linear Model Fit

For THC emissions, a statistically significant difference was detected in the log-linear temperature effect (β_1) between the pre-MSAT-2 and MSAT-2 compliant vehicles as shown in Table 2-6 (p-value of the Temperature \times pre-MSAT term is much smaller than 0.05).

Table 2-6. Fixed Effects for the Final THC Model Fit to Data from 2006+ Model Year Vehicles from the MSAT Program and the Cold Temperature Program (11 vehicles, 69 observations)

	Value	Std.Error	DF	t-value	p-value
Intercept (α_1)	1.8613	0.1321	56	14.1	4.6E-20
Temperature (β_1)	-0.0394	0.0011	56	-34.6	1.7E-39
pre-MSAT (α_2)	0.7503	0.2254	9	3.3	0.0088
Temperature (β_1) \times pre-MSAT (α_2)	-0.0111	0.0021	56	-5.2	2.7E-06

The THC model fit to the cold start emissions data is graphed in Figure 2-2. As shown, the pre-MSAT-2 cold start emissions for THC are much more sensitive to cold temperature than the MSAT-2 compliant vehicles.

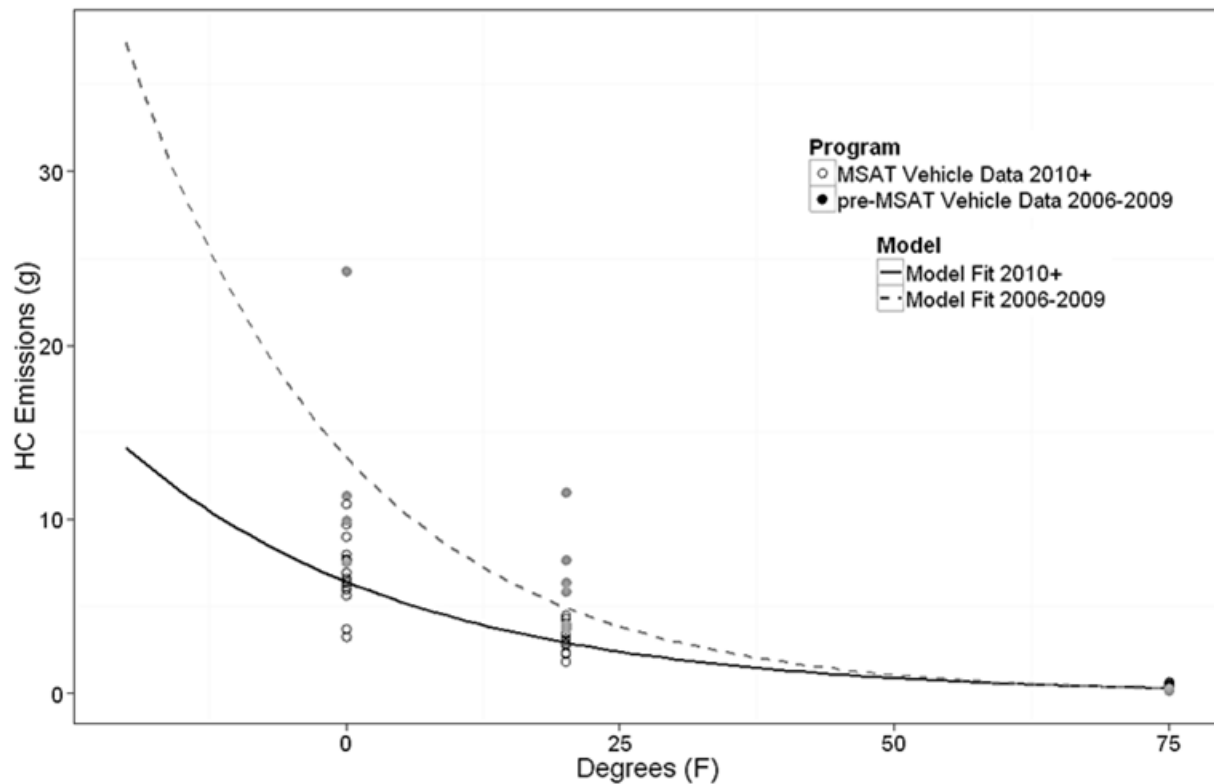


Figure 2-2 FTP THC Start Emissions with Log-linear Model Fit

The differences in the THC cold start temperature effect represent the impact of the Mobile Source Air Toxic (MSAT-2) rule. The MSAT-2 rule included a limit on low temperature (20°F) non-methane hydrocarbon (NMHC) emissions for light-duty and some medium-duty gasoline-fueled vehicles.¹⁶ Specifically:

- For passenger cars (LDVs) and for the light light-duty trucks (LLDTs) (i.e., those with GVWR up to 6,000 pounds), the composite (combined cold start and hot running) FTP NMHC emissions should not exceed 0.3 grams per mile.
- For light heavy-duty trucks (LHDTs) (those with GVWR from 6,001 up to 8,500 pounds) and for medium-duty passenger vehicles (MDPVs), the composite FTP NMHC emissions should not exceed 0.5 grams per mile.

These cold weather standards are phased-in beginning with the 2010 model year, as shown in Table 2-7.

Table 2-7 Phase-in of Vehicles Meeting Cold Weather THC Standard

Model Year	LDVs / LLDTs	LHDTs / MDPVs
2010	25%	0%
2011	50%	0%
2012	75%	25%
2013	100%	50%
2014	100%	75%
2015	100%	100%

For the phase-in years, the coefficients for the THC temperature effect equation in the startTempAdjustment table were adjusted linearly according to the light-duty vehicle phase-in. Equation 2-9 shows how the temperature effect is calculated for a model year 2010 LDV, where A_{2010} is the 2010 emissions rate:

$$A_{2010} = A_{2009}(1 - 0.25) + A_{2013}(0.25) \quad \text{Equation 2-9}$$

With this approach, the log-linear temperature effect (coefficient A) for THC emissions is reduced from 2009 to 2013 while the base 75° F THC cold start (coefficient B) is relatively constant.

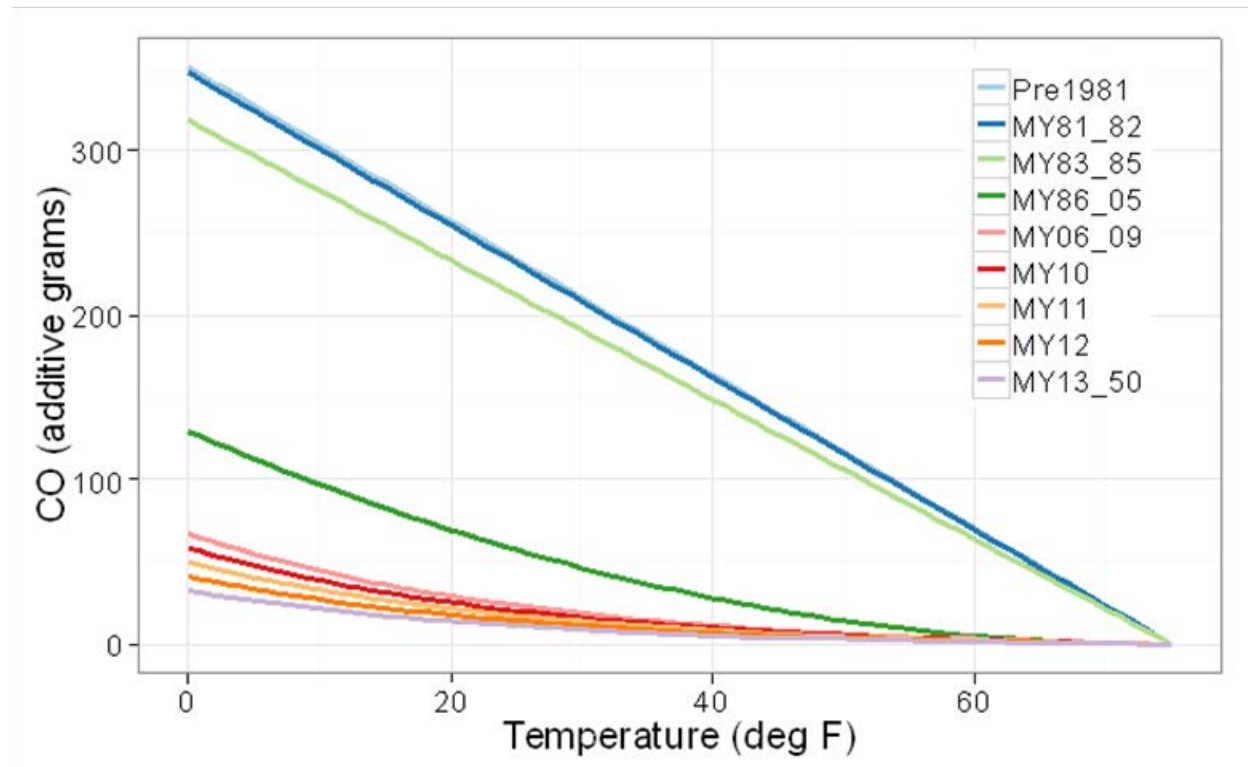
Within the current MOVES design, temperature effects are applied by fuel types and model year vehicles, but not by regulatory class (e.g., LHDTs/MDPVs). As such, the light-duty rates, including the light-duty MSAT-2 phase in are applied to all the gasoline-fueled vehicles in MOVES. No data on LHDTs/MDPVs or heavy-duty temperature effects were available to assess this approach.

Table 2-8 summarizes the coefficients used with Equation 2-2 (log-linear) to estimate additive start temperature adjustments for more recent model year gasoline vehicles.

Table 2-8. Coefficients Used for Log-linear Temperature Effect Equation for All Gasoline Source Types

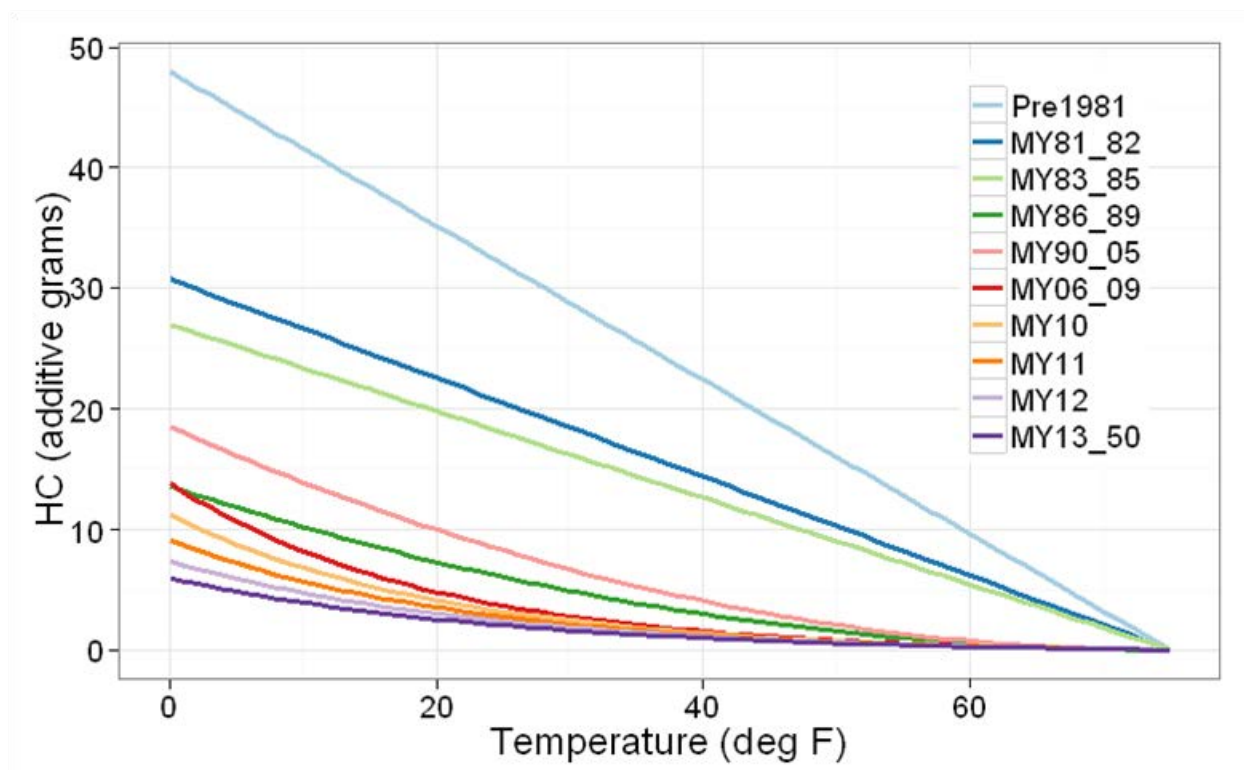
Model Year Group	CO			THC		
	A	B	C	A	B	C
2001-2009	-0.038	4.136	-4.136			
2006-2009				-0.051	0.308	-0.308
2010	-0.038	3.601	-3.601	-0.048	0.315	-0.315
2011	-0.038	3.066	-3.066	-0.045	0.322	-0.322
2012	-0.038	2.531	-2.531	-0.042	0.329	-0.329
2013 & Later	-0.038	1.996	-1.996	-0.039	0.336	-0.336

Figure 2-3 and Figure 2-4 graphically compare all the cold start temperature effects for gasoline vehicles by model year groups in MOVES for CO and THC, respectively. These include both the polynomial fits and the log-linear curve fits to the data.



Note: In MOVES3, "MY13_50" applies to all model years 2013-2060.

Figure 2-3 CO Additive Cold Start Temperature Effects for Gasoline Vehicles by Model Year Groups



Note: In MOVES3, "MY13_50" applies to all model years 2013-2060.

Figure 2-4 THC Additive Cold Start Temperature Effects for Gasoline Vehicles by Model Year Groups

To adapt the additive adjustments for intermediate soak times, the B and C coefficients for start operating modes other than cold starts were reduced by multiplying by a factor equal to the ratio between emissions at the desired soak time and the cold start emissions for catalyst equipped vehicles as used in MOBILE6 as summarized in Table 2-3.⁹

Temperature Effects on Gasoline NO_x Start Emissions

Cold-start NO_x emissions are not as sensitive to ambient temperature changes as THC and CO emissions, because the fuel-rich conditions at engine start favor incomplete combustion of fuel, forming CO and THC; NO_x is favored under the lean burn, high temperature engine operation more typical of running emissions. However, NO_x emissions are impacted by the inefficiencies of the three-way catalyst at low temperatures and a small cold start temperature sensitivity is expected.

Due to the small temperature effects and the variability of the data, the NO_x temperature effect was calculated in MOVES by averaging all the available NO_x results (i.e., the 2005-and-earlier model year data) together across model year groups and then performing regression. Table 2-9 lists the average incremental cold start NO_x emissions, compared to 76.3°F, from the MSOD, ORD, and MSAT programs.

Table 2-9. Average Incremental Cold Start NO_x Emissions by Temperature for Gasoline Vehicles Calculated from the MSOD, ORD and MSAT Programs

Temp F	Delta NO _x (grams)
-20	1.201
0	1.227
19.4	0.202
20.7	0.089
22.4	-0.155
31	-0.007
40	0.876
48.8	0.127
49.8	0.333
51	0.325
54.2	0.438
76.3	0
95.3	0.225
97.1	0.37
105.8	0.543

Using the data above, we fit a linear regression to the emission averages for temperatures of 76.3°F and lower and obtained the following fit:

$$\text{NO}_x \text{ temperature additive adjustment} = A * (\text{Temp} - 75) \quad \text{Equation 2-10}$$

$$\text{where: } A = -0.009$$

$$R^2 = 0.61$$

Although the value of R^2 is not as high as for the THC and CO regression equations, the fit is statistically significant.

Note that Equation 2-10 predicts a decrease in cold-start NO_x emissions for temperatures greater than 75°F, while the data in Table 2-9 indicates an increase in cold-start NO_x emissions as the ambient temperature rises above 90°F. The increase is small and may be an artifact of how these data were analyzed, since only a subset of vehicles were measured above 75°F. Therefore, as with the other temperature adjustments, we have set the NO_x additive adjustment to zero in MOVES for temperatures higher than 75°F.

In addition, we investigated whether different NO_x temperature correction is needed for vehicles subject to the MSAT-2 rule. Figure 2-5 shows a comparison between NO_x start emissions data from OTAQ Cold Temperature Program, including both the port-fuel injection (PFI) and gasoline-direct injection (GDI) 2006-2010 model year vehicles, and the emissions predicted using temperature effects calculated from the MY2005-and-earlier vehicles. Because start emissions compose such a small percentage of total NO_x emissions, the differences between the MOVES temperature effects and the NO_x data from the OTAQ Cold Temperature Program were considered negligible. Thus, we applied the NO_x temperature adjustment estimated in Equation 2-10 for all model years.

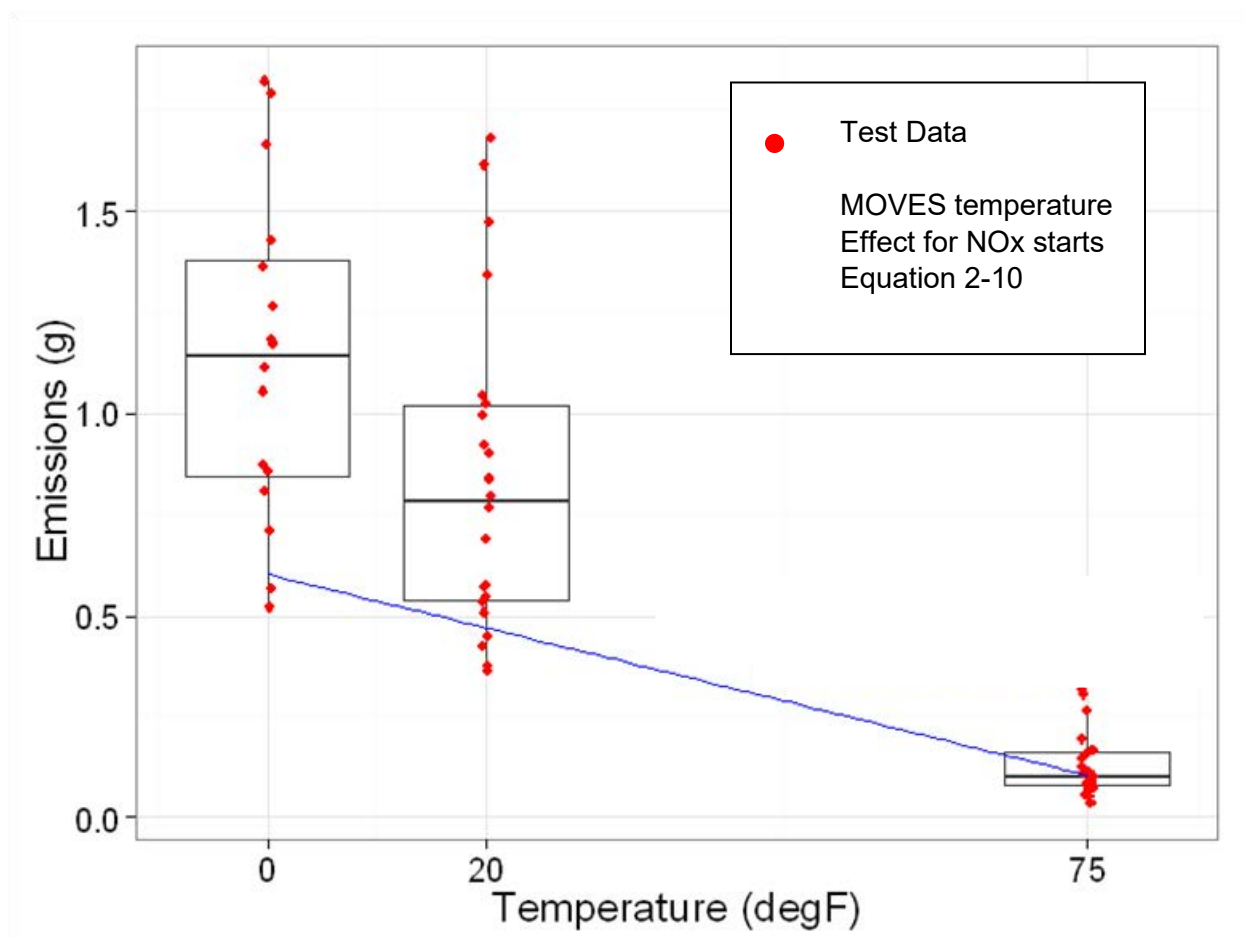


Figure 2-5 FTP Start NO_x Emissions, Bag 1 – Bag 3, Model Years 2006-2010

To adapt the additive adjustments for intermediate soak times, the A coefficients for start operating modes other than cold starts were adjusted by multiplying by a factor equal to the ratio between emissions at the desired soak time and the cold start emissions for catalyst equipped vehicles as used in MOBILE6 and summarized in Table 2-3.

Temperature Effects on Gasoline PM_{2.5} Start Emissions

The temperature effects for particulate matter emissions from gasoline engines were obtained from the Kansas City Light-Duty Vehicle Emissions Study (KCVES)¹⁸, conducted between 2004

and 2005. The KCVES measured emissions from 496 vehicles collected in the full sample, with 42 vehicles sampled in both the winter and summer phases of the program. The EPA conducted an analysis of the temperature effects of gasoline vehicles from the KCVES by estimating the temperature effect on PM emissions from 34 paired vehicle tests that were sampled in both winter and summer ambient conditions (10 paired vehicle tests were removed due to missing values and/or too small temperature differences between the phases) as described in the EPA report¹⁸ and Nam et al.¹⁹

The analysis of the KCVES data indicated that ambient temperature affects for start PM emissions is best modeled by (log-linear) multiplicative adjustments of the form:

$$\text{Multiplicative Factor} = e^{A \cdot (72 - \text{Temp})}$$

Equation 2-11

Where

Temp = Temperature

A = log-linear temperature effect. *A* = 0.0463 for cold starts from the KCVES analysis^{18,19}

The log-linear temperature effect of 0.0463 is used in MOVES for gasoline vehicles of model year 2009 and earlier (i.e., vehicles not affected by the MSAT-2 requirements).

The MSAT-2 rule (signed February 9, 2007) does not explicitly limit cold weather emissions of particulate matter (PM). However, the Regulatory Impact Analysis (RIA) document¹⁴ that accompanied the rule noted there is a strong linear correlation between NMHC and PM_{2.5} emissions based on the MSAT program discussed in Section 2.1. That correlation is illustrated in Figure 2-6 (reproduced from that RIA) as the logarithm of the Bag-1 PM_{2.5} versus the logarithm of the Bag-1 NMHC (for various Tier-2 vehicles).

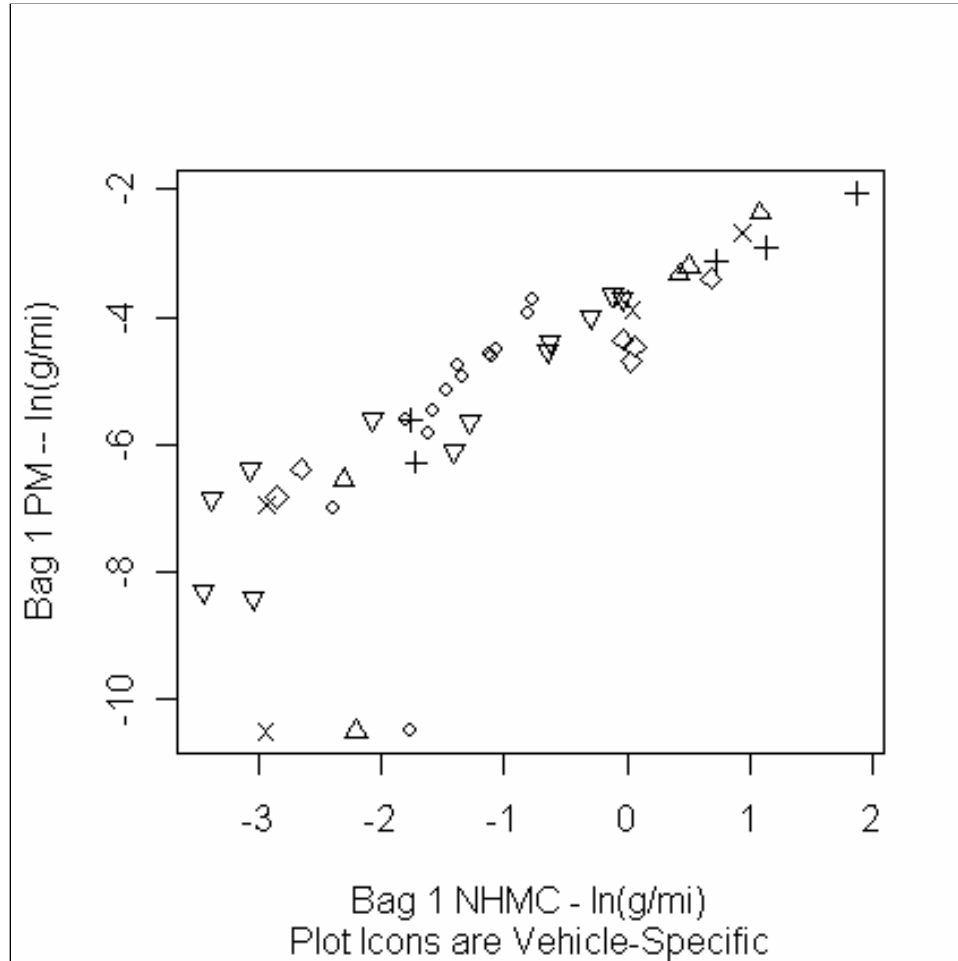


Figure 2-6 FTP Bag 1 PM and FTP Bag 1 NMHC for Tier 2 Vehicles

Therefore, the limitation on cold weather THC (or NMHC) emissions is expected to result in a proportional reduction in cold weather PM_{2.5} emissions. In the MSAT-2 RIA (Table 2.1.-9), EPA estimated that this requirement would result in a 30 percent reduction of VOC emissions at 20°F. Applying the same analytical approach that was used in the RIA means that a 30 percent reduction in VOC emissions would correspond to a 30 percent reduction in PM emissions at 20°F (for Tier 2 cars and trucks).

Applying the 30 percent reduction for vehicles affected by the MSAT-2 requirements to the temperature effects calculated for the fully phased-in (2015+) MSAT-2 vehicles implies a PM increase as the temperature decreases from 72° to 20°F of:

$$\begin{aligned} \text{Multiplicative Factor at } 20^\circ \text{ F for MSAT-2 Vehicles} &= 0.7 * e^{0.0463 * (72 - 20)} \\ &= 7.8 \end{aligned} \quad \text{Equation 2-12}$$

Using Equation 2-12 with the MSAT-2 phase-in schedule from Table 2-7 leads to the following (multiplicative) increases as the temperature decreases from 72° to 20° F:

Table 2-10 Multiplicative Increase in Cold Start PM_{2.5} from 72° to 20° Fahrenheit for Gasoline Vehicles

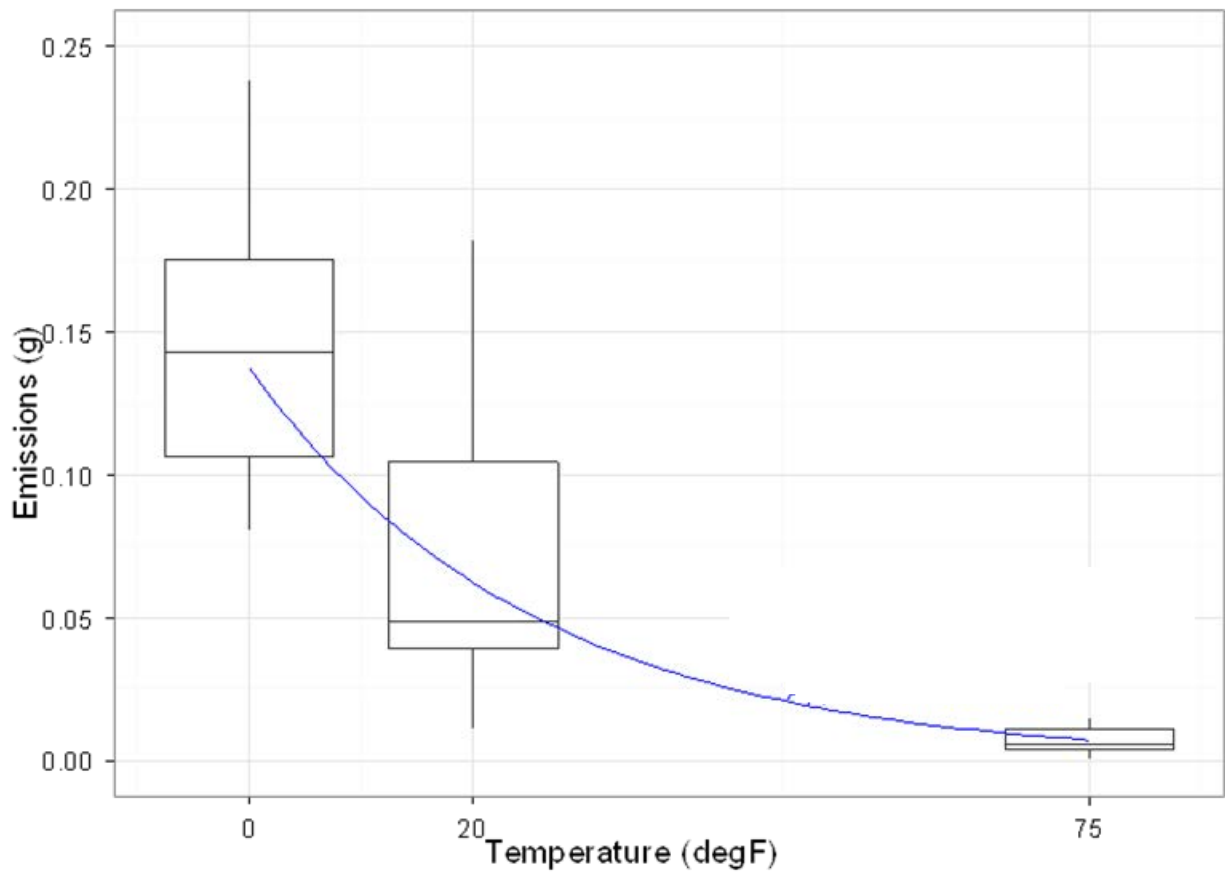
Model Year	LDVs / LLDTs	LHDTs / MDPVs
2008	11.1	11.1
2009	11.1	11.1
2010	10.3	11.1
2011	9.4	11.1
2012	8.6	10.3
2013	7.8	9.4
2014	7.8	8.6
2015+	7.8	7.8

Solving for the corresponding log-linear terms gives us these "A" values:

Table 2-11 Log-linear Temperature Effect for Start PM_{2.5} Emissions (Coefficient A) for Gasoline Vehicles

Model Year	LDVs / LLDTs	LHDTs / MDPVs
2008	0.0463	0.0463
2009	0.0463	0.0463
2010	0.0448	0.0463
2011	0.0432	0.0463
2012	0.0414	0.0448
2013	0.0394	0.0432
2014	0.0394	0.0414
2015+	0.0394	0.0394

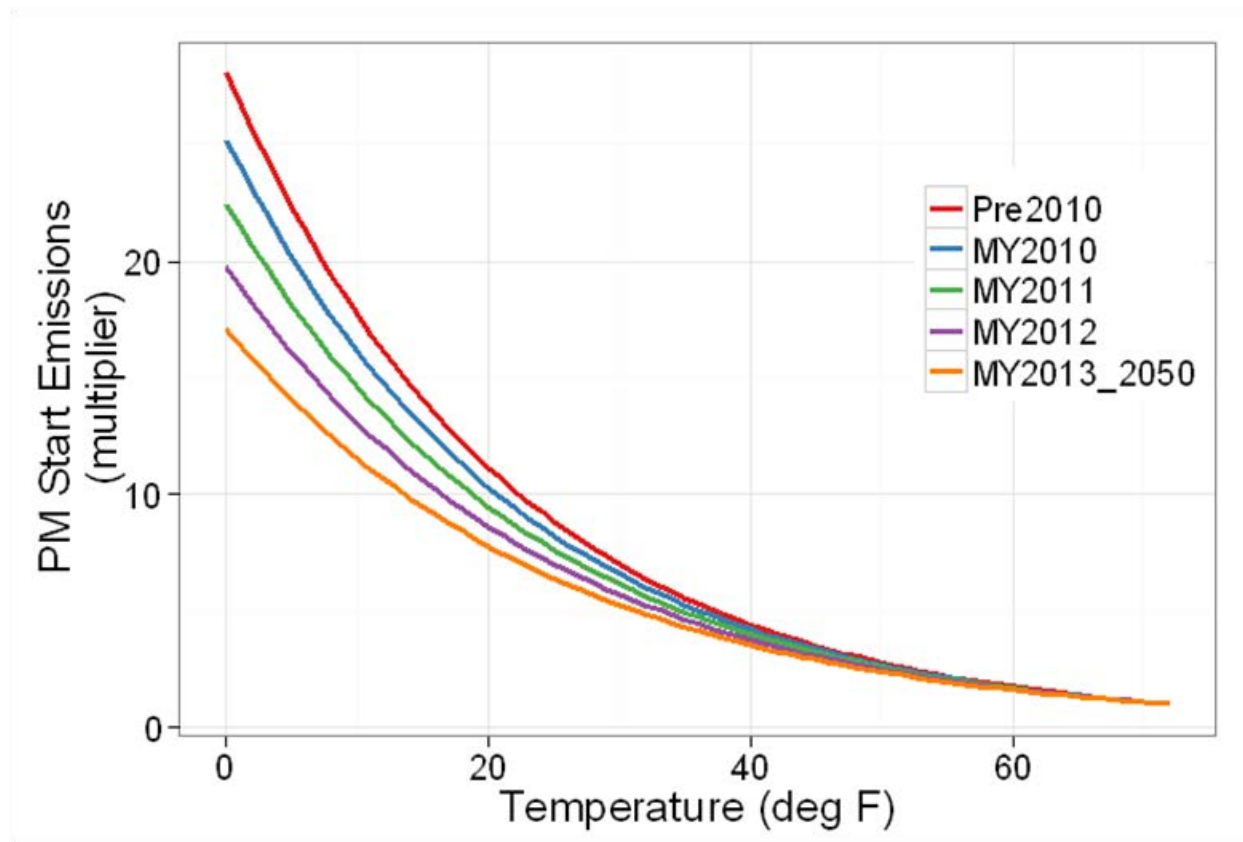
We confirmed this theoretically derived temperature effect for MSAT-2 compliant vehicles by comparing it to data from the OTAQ Cold Temp Study, which including only the MY 2010 PFI vehicles (Appendix B). The temperature effect developed for MOVES fits this data well, as shown in Figure 2-7. Note, as discussed in the light-duty report, we significantly updated the start PM_{2.5} emission rates to account for GDI vehicles in MOVES³¹⁰, but we did not revisit the temperature effects for start emissions.



Note: In MOVES3, "MY13_50" applies to all model years 2013-2060.

Figure 2-7. FTP PM_{2.5} Start Emissions, MSAT-2 Compliant Vehicles (7 PFI Vehicles, 40 Tests with Nonzero PM Measurements on E10 Fuel) from OTAQ Cold Temperature Program

Figure 2-8 presents the light-duty multiplicative temperature effects using the coefficient from Table 2-11, and the model form of Equation 2-12.



Note: In MOVES3, "MY13_50" applies to all model years 2013-2060.

Figure 2-8. PM Start Exhaust Emissions Effect for Gasoline Light-Duty Vehicles in MOVES

Because the PM_{2.5} speciation profile for gasoline vehicles did not change significantly between the winter and summer rounds of the KCVES,²⁰ we apply the same temperature adjustment to each component of the PM emissions, including elemental carbon, organic carbon, sulfate and other species. The PM start temperature adjustment does not vary with soak time since it is multiplicative.

2.3 Temperature Effects on Running Exhaust Emissions from Gasoline Vehicles

While MOVES is designed to model the impact of ambient temperature on running exhaust emissions, current data suggests that there is little effect of temperature on THC, CO, NO_x or PM. The sections below discuss the relevant data and analysis for gaseous pollutants and for particulate matter.

THC, CO and NO_x Running Exhaust Temperature Effects

We examined the same data described above for starts to evaluate potential running temperature effects. These test data suggest that there is very little effect of temperature on running emissions of THC, CO, or NO_x. Regression analyses found that the coefficients (slopes) were not statistically significant (that is, the slopes were not distinguishable from zero). This contrasts with the significant temperature effect in THC, CO, and NO_x Bag 2 of the Kansas City Light-Duty Vehicle Emissions Study (KCVES) with higher emissions at colder temperatures.¹⁸ As discussed for PM emissions in the next subsection, we attribute the temperature effect on THC, CO, and NO_x emissions observed in the KCVES to the short duration and mild acceleration of Bag 1 of the LA-92 driving cycle, such that the vehicles had not fully reached hot-stabilized condition by the beginning of Bag 2.

As an additional test, we examined a set of continuous data collected on the IM240 cycle in the Chicago I/M program. To avoid potential confounding due to variable levels of conditioning vehicles experienced in the queues at the I/M stations, we only used the second IM240s when back-to-back IM240s were performed, and for single IM240s, we examined only the final 120 seconds of full duration IM240s. Based on this analysis, we found no evidence of a temperature effect for THC, CO, and NO_x between 5 and 95°F.

Because most of the data sets evaluated did not find a significant temperature effect, and the temperature effect observed in the KCVES is attributed to the test conditions not achieving hot-stabilized running conditions, we do not model temperature effects for THC, CO, and NO_x in MOVES for running exhaust for all gasoline vehicles. In MOVES, these effects are coded using polynomial functions as multiplicative adjustments. Therefore, in MOVES, we set all of those adjustments equal to 1.0.

PM_{2.5} Running Exhaust Temperature Effects

The initial analysis of the Kansas City Light-Duty Vehicle Emissions Study (KCVES) data^{18,19} indicated that significant ambient temperature effects existed for both start (Bag1-Bag3) and running (Bag 2) PM emissions on the LA-92 cycle^c. Thus, MOVES2010 and MOVES2014 applied a temperature effect for running emissions for all model year vehicles based on the Bag 2 measurements from paired vehicles tests conducted in the winter and summer of the KCVES.

For MOVES2014, we updated the PM temperature effect for running emissions for Tier 2 and later model year vehicles (2004+) based on data from the 2012 Cold Temperature Program (documented in Section 2.1.). Experimental data collected in the 2012 OTAQ program involved measurement of PM emissions on both the FTP (by phase) and the US06 cycles at temperatures of 0, 20 and 75°F of Tier 2 and MSAT-2-compliant vehicles and PFI and GDI (See Appendix B). The results from these programs are plotted against temperature in Figure 2-9. We also fit log-linear models to the data and found the effect of

^c The temperature effects in MOVES2010 and MOVES2014 for pre-2004 vehicles were substantial. Emissions increased by a factor of 10 between ambient temperatures of 72°F and 0°F.

temperature was not statistically significant on either cycle. Based on these results, we removed the temperature effect for Tier 2 vehicles (model year 2004 and later) in MOVES2014.

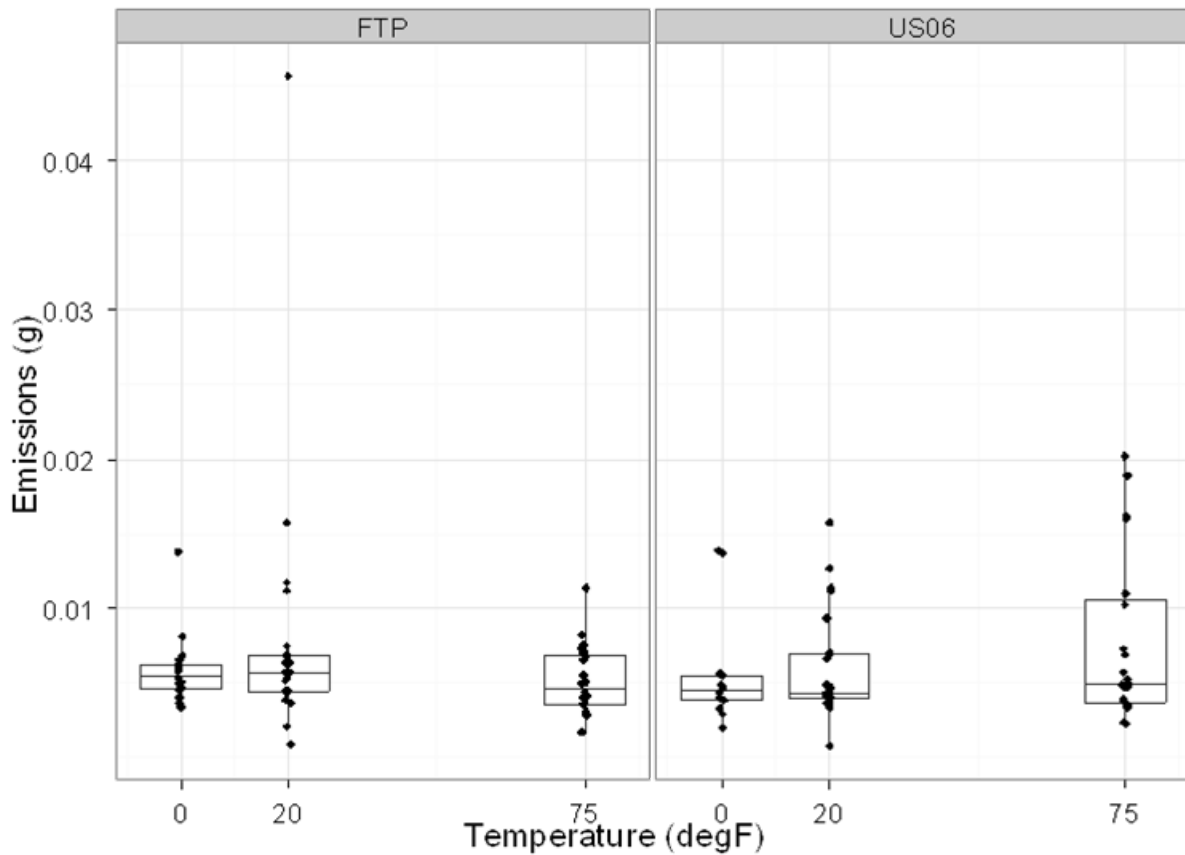


Figure 2-9. Hot-running PM Emissions Measured on Two Cycles (FTP Bag 2, US06) on MSAT-2 Compliant MY 2010 Gasoline Vehicles, Reported as Grams/cycle

These results contrast with the significant PM running temperature effect detected for Bag 2 emissions in the KCVES. Upon further analysis of the PM emissions from the KCVES study, we determined that much^d of the temperature effect observed in the KCVES Bag 2 emissions was due to the short duration and relatively mild accelerations of the cold-start phase of the LA92 cycle, which is only 310 sec (1.18 mi) in length. We note that the PM temperature effect was much larger at the beginning of Bag 2 than at the end. In contrast, the cold-start phase of the FTP, used in the Cold Temperature Program is 505 seconds (3.59 miles) in length.

^d We believe that the small, but statistically significant temperature effect that persists at the end of Bag 2, even after 1,025 seconds (17 minutes) of operation on the LA-92 in KCVES may be an artifact of this particular study, because this persistent temperature effect on hot-stabilized running emissions was not observed in other studies.

For MOVES3, we conducted a literature review from other studies that conducted measurements of particulate matter emissions from gasoline vehicles including model years before 2004 at different ambient temperatures. The results are summarized in Table 2-12.

Table 2-12. Literature Review of Temperature Effects on Running PM_{2.5} emissions from Gasoline Vehicles

Study	Vehicles and Test conditions	Findings on PM _{2.5} emissions
Measurements of Exhaust Particulate Matter Emissions from In-Use Light-Duty Motor Vehicles in the Denver, Colorado Area ^{21,22}	71 light-duty gasoline vehicles from model year 1970 to 1996 tested in the summer of 1996 and winter of 1997 on a chassis dynamometer using bag 2 of the FTP driving schedule.	Linear mixed model was fit and no significant temperature effect was observed.
Comprehensive particle characterization of modern gasoline and diesel passenger cars at low ambient temperature ²³	Two Euro-3 (apply to 2000 -2004 model year vehicles) port-injection gasoline vehicles (Renault Megane and Alfa 406 TS) Tested +23, -7 and -20 °C on a chassis dynamometer on the common Artemis driving cycle (CADC), after warmed up on 50-minute IUF15 driving cycle.	No temperature effect observed on running emissions.
Characterization of Metals Emitted from Motor Vehicles ²⁴	Emission rates derived from PM _{2.5} concentrations measured at the entrance and exit concentration of the Howell tunnel in Milwaukee, WI in the summer of 2000 and the winter of 2000-2001. Light-duty vehicles constituted between 90.6 percent to 93.9 percent of the vehicle fleet, with 6.1 percent to 9.4 percent heavy-duty trucks. Chemical mass balance methods were used to estimate the contribution of tunnel emission rates to gasoline tailpipe, diesel tailpipe, brake wear, resuspended road dust, and tire wear emissions.	Carbonaceous PM _{2.5} (EC+OC) emission rates (mg/km) were significantly lower (49-51 percent) in the winter than the summer. Gasoline tailpipe emissions are estimated to be the largest contributors to EC and OC emissions ^a ; more than diesel tailpipe, brake wear, and resuspended road dust. The winter tests had comparable or larger PM measurements of inorganic ions and metals (including Na and Cl) presumably due to road salt in the winter.

^a Gasoline tailpipe and tire wear are combined together because they have similar source profiles. However, gasoline tailpipe emissions in MOVES contribute a much larger share of PM_{2.5} emission rates (and thus EC and OC) than brake wear emissions.²⁵

The result of the literature review (Table 2-12) suggested no temperature effects on PM exhaust emissions, even for model year vehicles similar to the years measured in the KCVES. Thus, we now believe the significant running PM temperature effect in KCVES was an artifact of the measurement conditions of the study, including the short Bag 1 of the LA-92 cycle. Therefore, in MOVES3, we have

removed the running temperature effect for exhaust particulate matter emissions for all model year light-duty gasoline vehicles.

2.4 Temperature Effects on Diesel Vehicles

The data used to evaluate and estimate temperature effects on diesel vehicles were limited to laboratory tests on pre-2007 model year light-duty diesel vehicles. From this analysis, MOVES models a temperature effect only for THC start emissions. The THC start temperature effect estimated from the light-duty diesel was applied to all model year diesel vehicles in MOVES, including heavy-duty diesel vehicles. None of the other pollutants in MOVES have temperature effects for diesel start emissions, and MOVES has no temperature adjustments for running emissions.

As described below, in developing MOVES3, we reviewed more recent studies conducted on modern diesel and heavy-duty diesel vehicles, but additional analysis of temperature effects data for US light-duty and heavy-duty diesel are needed to fully evaluate the values now in MOVES.

THC, CO and NO_x Temperature Effects for Diesel Vehicles

For the development of the diesel temperature effects in MOVES, we were able to identify only 12 diesel vehicles tested on FTP at multiple temperatures (9 passenger cars and 3 light-duty trucks). However, only two of those 12 vehicles were tested at temperatures within the normal FTP range (68° to 86° F). None of these diesel trucks were equipped with aftertreatment devices.

Diesel Start Effects

The average start (Bag-1 minus Bag-3) emissions for those tests are shown in Table 2-13. We stratified the test results into four temperature bands which yielded the following emission values (grams per start) and average temperature value:

Table 2-13 Average Light-duty Diesel Vehicle Incremental Start Emissions (Bag 1- Bag3) by Temperature (grams per start)

Temperature, F	Count	THC	CO	NO _x
34.6	6	2.55	2.44	2.6
43.4	7	2.68	2.03	0.32
61.5	10	1.69	3	0.67
69.2	2	1.2	1.91	0.36

Figure 2-10 shows the plot of mean THC start emissions versus temperature (where the vertical lines represent 90 percent confidence intervals and the "dashed" line represents a linear regression through the data).

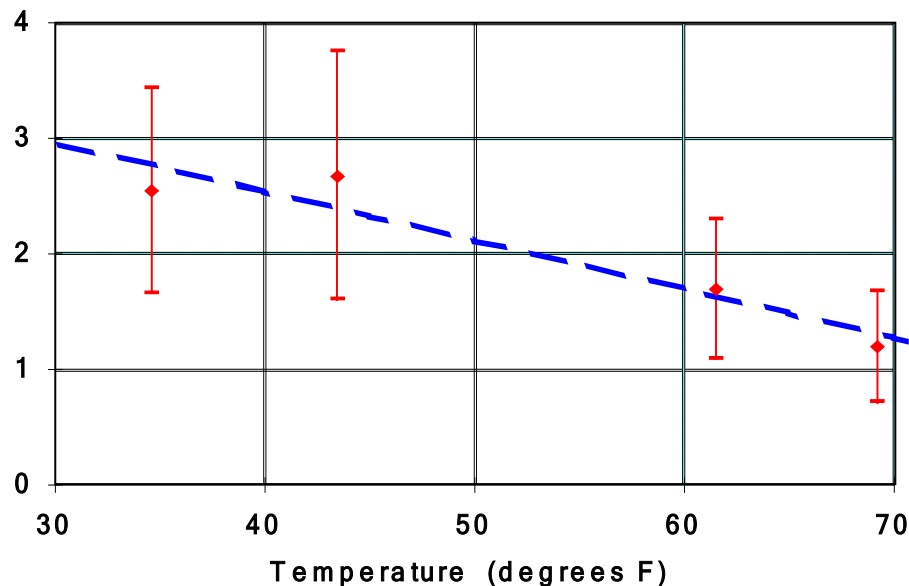


Figure 2-10 Mean Light-duty Diesel Cold-start THC Emissions (in grams, shown on the y-axis) with 90 percent Confidence Intervals vs Temperature

The dashed (blue) line in Figure 2-10 represents a linear regression line:

$$\text{THC} = (-0.04 * \text{Temperature}) + 4.22 \quad R^2 = 0.90 \quad \text{Equation 2-13}$$

Transforming this equation into an equation that predicts the (additive) change/adjustment in the cold-start THC emissions from light-duty diesel vehicles (in the MOVES format), we obtain:

$$\text{THC additive temperature adjustment} = A * (\text{Temp.} - 75) \quad \text{Equation 2-14}$$

where: $A = -0.04$ and Temp. is $<75\text{F}$.

The coefficient associated with this temperature adjustment term is statistically significant although its coefficient of variation is relatively large (23 percent). We apply this adjustment to heavy-duty as well as light-duty vehicles due to limited data on heavy-duty diesel starts.

The modified temperature adjustments for diesel THC emissions for starts with shorter soak times (operating modes 101-107) are described in the MOVES heavy duty exhaust report.¹¹

On the other hand, the cold-start CO and NO_x emissions did not exhibit a clear trend relative to the ambient temperature. Plotting the mean CO and NO_x cold-start emissions versus ambient temperature (with 90 percent confidence intervals) produced the following two graphs:

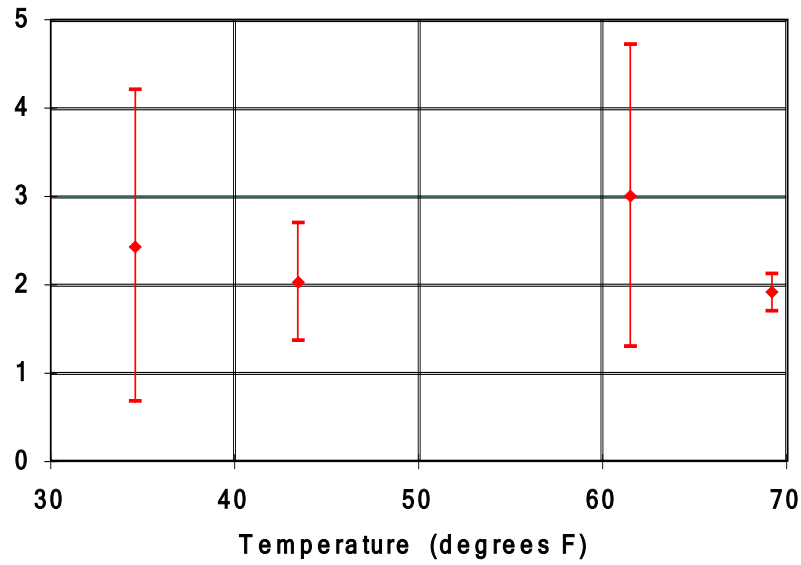


Figure 2-11 Mean Light-duty Diesel Cold-start CO Emissions (in grams) with 90 percent Confidence Intervals vs Temperature

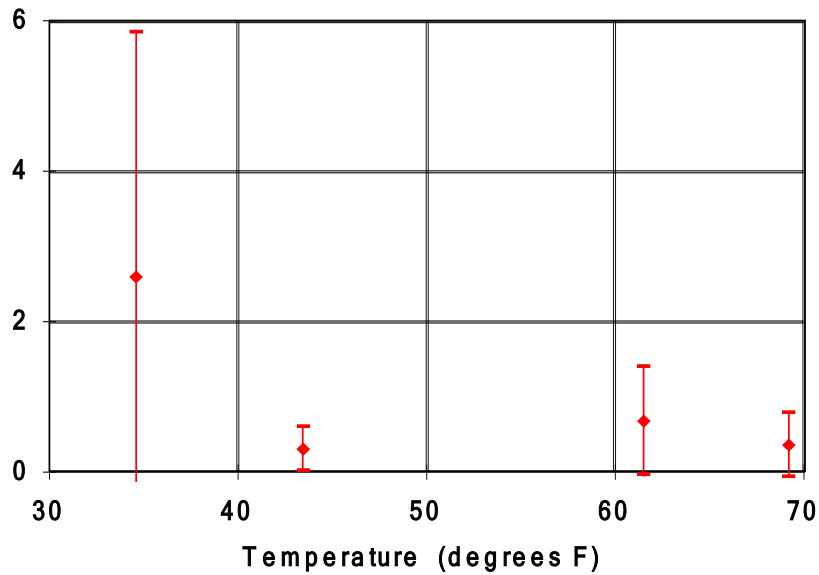


Figure 2-12 Mean Light-duty Diesel Cold-start NO_x Emissions (grams) with 90 percent Confidence Intervals vs Temperature

Statistical analyses of both the diesel cold-start CO and NO_x emissions showed that the coefficients were not significantly different from zero. Therefore, for both cold-start CO and NO_x adjustments for diesel vehicles, we set the temperature adjustment for start emissions to zero.

Diesel Running Effects

Since the diesel start temperature effects were either very small or zero, we did not evaluate the diesel running temperature effect for THC, CO and NO_x for MOVES – we set temperature effects for diesel running exhaust to zero, similar to the gasoline running exhaust adjustments.

More recently some researchers have suggested that diesel NO_x may be underestimated in current US emission inventories during the wintertime.²⁶ In the US, one road-side study²⁷ and one tunnel study²⁸ have suggested that there is an increase in heavy-duty diesel NO_x emissions at cold temperatures. A recent European study using road-side measurements estimated a strong temperature dependence of light-duty diesel NO_x emissions, with higher NO_x emissions observed at low temperatures.²⁹ However, the penetration of light-duty diesel vehicles and diesel emission control technologies employed in Europe and the US differ significantly. These studies suggest that US diesel NO_x emissions may increase in wintertime, but additional analysis of data on US light-duty and heavy-duty diesel are needed to confirm and quantify the increase for incorporation into MOVES.

PM Temperature Effects for Diesel Vehicles

MOVES does not include any temperature effects for particulate matter emissions from diesel vehicles. As presented in the previous section, hydrocarbon emissions from conventional diesel engines have much lower temperature sensitivity than catalyst-controlled light-duty gasoline emissions. Limited data exists on the ambient temperature effects of particulate matter emissions from diesel engines.

The EPA does not have data on PM start emissions on US-certified diesel vehicles tested across different ambient temperatures. From a literature search, we were able to find two European test programs that measured PM diesel start emissions from European light-duty diesel engines and vehicles at cold and warm ambient temperatures.

Mathis et al. (2005)²³ evaluated particle mass and number emissions from a conventional light-duty diesel vehicle and a light-duty diesel equipped with a diesel particulate filter (DPF) at laboratory conditions measured at +32, -7 and -20 °C. Although the researchers observed an increasing trend in particle mass emissions (g/start) from the conventional diesel vehicle at colder temperatures, over the entire drive cycle, the particle number emission rates were not significantly impacted by the cold start contribution. The particle mass emissions from the DPF-equipped vehicle were two orders of magnitude smaller than the conventional diesel engines, but the start contributed the majority of the particle number emissions over the entire test cycle.

Sakunthalai et al. (2014)³⁰ also reported significant increase in PM start emissions from a light-duty diesel engine tested in a laboratory at +20 and -20 °C. However, they only reported the PM mass concentrations of the exhaust and not emission rates. Additionally, the engine was not equipped with an emission control system. Other researchers have reported that PM emissions are larger at cold start than hot start from diesel engines^{31,32}, but have not investigated the relationship of cold starts with ambient temperatures.

The reviewed studies suggest that temperature does influence cold start PM emissions from diesel vehicles. However, at this time, MOVES does not include temperature adjustments to diesel start

emissions due to limited data on diesel engines and because diesel starts are a minor contributor to particulate mass emissions to the mobile-source emission inventory. The diesel particulate matter emission temperature effects in MOVES can be revisited in the future as additional data become available.

2.5 Temperature Effects on Compressed Natural Gas Vehicles

MOVES3 models emissions from heavy-duty vehicles running on compressed natural gas. However, at the time the temperature corrections were developed, no data were available on temperature impacts of compressed natural gas emissions. As discussed in the heavy-duty report¹¹, the start emissions for CNG emissions for THC, CO, NO_x and PM are set equal to diesel start emissions. We also applied the same temperature adjustments to CNG as diesel, that is, only start temperature effects on THC emissions.

2.6 Temperature Effects on Start Energy Consumption

The temperature effects on energy consumption in MOVES have not been updated since MOVES2004. No temperature correction is applied to energy consumption from running activity. As presented in heavy-duty report¹¹, the energy consumption from starts is a small fraction compared to the total energy use of both gasoline and diesel vehicles. As such, we have not prioritized updating the start energy rates or temperature adjustments in subsequent versions of MOVES.

In this section, we provide a summary of the start temperature effects on energy consumption in MOVES. The analysis used to derive the temperature effects on start energy consumption in MOVES is documented in the MOVES2004 energy report.³³ No significant temperature effects for energy consumption were found for warmed-up vehicles in the analysis, thus MOVES does not apply a temperature effect on running energy consumption.

MOVES applies temperature adjustments to the start energy consumption through a multiplicative adjustment. The form of the multiplicative adjustments used in MOVES is shown in Equation 2-15, which is applied to all ambient temperatures. Unlike the temperature adjustments for criteria pollutants, MOVES does not limit the energy consumption adjustments to only cold temperatures, but also adjusts the energy consumption for hot temperatures. This ambient temperature adjustment is separate from the air conditioning adjustment described in Section 4, below.

The multiplicative temperature adjustments are applied to all start operating modes of varying soak lengths. MOVES does have different baseline (75°F) start energy consumption rates for different soak times, which are documented with the baseline energy start rates in the greenhouse gas and energy report⁴ for light-duty vehicles and heavy-duty exhaust report.¹¹

$$\begin{aligned}
 &\textit{Multiplicative temperature adjustment} \\
 &= 1.0 + \textit{tempAdjustTermA} \times (\textit{temperature} - 75) \\
 &\quad + \textit{tempAdjustTermB} \times (\textit{temperature} - 75)^2
 \end{aligned}
 \qquad \textbf{Equation 2-15}$$

Table 2-14 displays the coefficients used to adjust start energy consumption for gasoline, E85, diesel and CNG-fueled vehicles. MOVES has no correction for electric vehicles. The temperature coefficients are stored in the MOVES temperatureAdjustment table by pollutant, emission process, fuel type and model year range. E85-fueled vehicles use the same energy adjustments as gasoline vehicles, because they also

use the same energy rates as comparable gasoline-fueled vehicles.⁴ CNG vehicles use the same adjustments as diesel vehicles, because they use the same energy start rates as comparable diesel vehicles.¹¹

Table 2-14. Multiplicative Temperature Coefficients Used in MOVES

tempAdjustTermA	tempAdjustTermB	Fuel types	Model Years
-0.01971	0.000219	Gasoline, E85	1960-2050
-0.0086724	0.00009636	Diesel, CNG	1960-2050

Figure 2-13 displays the multiplicative temperature adjustments for starts as a function of temperature. At 75°F, the multiplicative adjustment is one. Gasoline vehicles have a larger temperature effect than diesel vehicles, increasing to 4.8 at -20°F, while decreasing to 0.64 at 100°F. Whereas, the adjustment for diesel vehicles only increases to 2.7 at -20°F and decreases to 0.85 at 100°F.

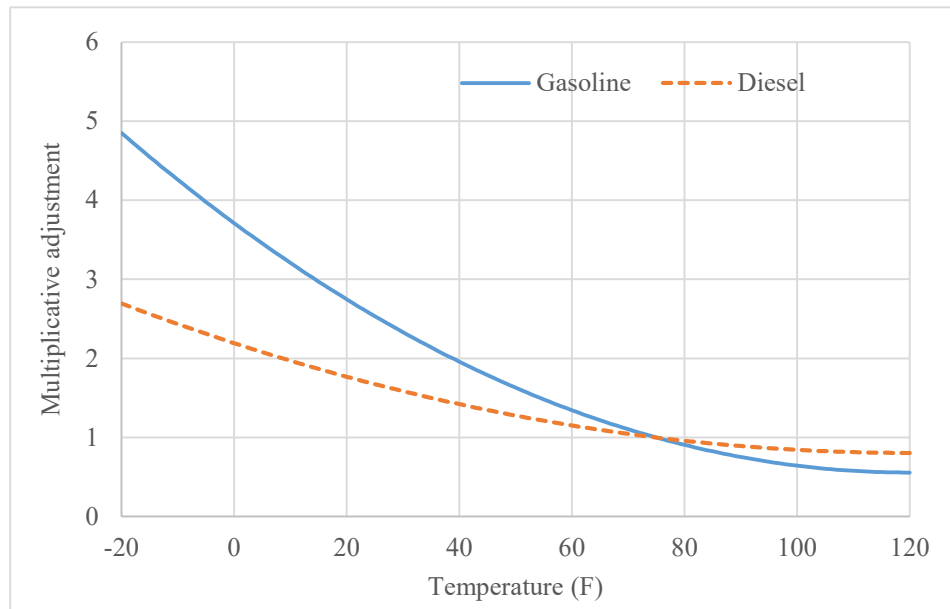


Figure 2-13. Multiplicative Temperature Adjustments for Starts from Energy Consumption as a Function of Ambient Temperature

2.7 Conclusions and Future Research

With improved calibration and temperature management, ambient temperatures have less impact on emissions of newer vehicles than older ones, but MOVES3 continues to estimate temperature effects for start THC, CO, NO_x and PM emissions from gasoline vehicles and THC start temperature effect for diesel and CNG vehicles.

We recognize that additional data and analysis could improve the MOVES temperature effects. Additional studies and analyses could include:

- Evaluating the benefits of applying log-linear or other mathematical models for pre-MSAT2 gasoline vehicle THC & CO temperature effects and considering whether all temperature effects could be multiplicative rather than using additive effects for THC/CO/NO_x start emissions.
- Investigating ambient temperature effects on cold start emissions at temperatures warmer than 75 °F.
- Evaluating the interaction of ambient temperature effects and fuel effects.
- Evaluating the interaction of ambient temperature effects and deterioration.
- Analyzing ambient temperature effects for modern (2007 and later) diesel vehicles from recent studies, especially those equipped with emission control devices, including diesel particulate filters (DPF) and selective reduction catalysts (SCR).
- Conducting studies of temperature effects in vehicles using alternative fuels such as compressed natural gas and ethanol blends
- Incorporating data on the impact of temperature effects on new technology vehicles, including Tier 3 gasoline direct injection and dual port-fuel and direct injection, stop-start technologies, battery electric vehicles and hybrid technologies.
- Analyzing the effect of temperature on other pollutants estimated in MOVES including ammonia (NH₃)

3. Humidity Adjustments

Water in the air cools the peak combustion temperature and lowers engine out NO_x emissions. The NO_x exhaust emissions data used to develop emission rates for MOVES are adjusted from actual measurement conditions to a standard humidity, including the emissions data from the Evaluation Sample for the Denver Metropolitan I/M Program used to develop NO_x emission rates for MY 1990 and later gasoline vehicles¹⁰ and the emissions data from the Heavy-Duty Diesel In-Use Testing Dataset used to develop NO_x emission rates for MY 2010 and later heavy-duty diesel vehicles.¹¹ At run time, these base NO_x exhaust emission rates are adjusted from the standard humidity level to the humidity conditions specified by the run spec as described below.

3.1 Humidity Adjustment Equation

In MOVES, the base exhaust emission rates for NO_x in all modes and all processes are multiplied by a (unitless) humidity factor, K. This factor is calculated using the following formula:

$$K = 1.0 - ((\text{Bounded Specific Humidity} - 75.0) * \text{Humidity Correction Coefficient}) \quad \text{Equation 3-1}$$

The form of Equation 3-1 is based on the humidity adjustment equation given in the Part 86 of the Code of Federal Regulations (CFR) for light-duty vehicle emissions testing.³⁴ Equation 3-1 is the inverse of the Part 86 CFR equation, because the Part 86 CFR equation is used adjust the NO_x emissions data from test conditions to the standard humidity level (75 grains water vapor per pound of dry air); whereas MOVES adjusts the base emission rates from the standard humidity level to the conditions requested in the run spec. The bounded specific humidity is in units of grains of water per pound of dry air. The specific humidity is not allowed to be lower than 21 grains and is not allowed to be higher than 124 grains. If the specific humidity input exceeds these limits, the value of the limit is used to calculate the humidity adjustment. Appendix A.6 shows how the hourly relative humidity values are converted to specific humidity used in this equation using temperature and barometric pressure. Table 3-1 lists the humidity correction coefficients used in MOVES.

Table 3-1. Humidity correction coefficients used by MOVES

Fuel Type	Humidity Correction Coefficient
Gasoline	0.0038
Diesel Fuel	0.0026
CNG	0
E-85	0.038
Electricity	0

The gasoline humidity correction coefficient is carried over from the coefficient used in the MOBILE6 model. The E-85 coefficient is set equal to the coefficient for gasoline. Coefficients for CNG and electricity are set to zero. The humidity correction coefficients are recorded in the MOVES database fuelType table. In our 2017 peer-review of heavy-duty emission rates,³⁵ we proposed updating the humidity corrections to be based on the same equations and coefficients as are used for emission testing

in the Code of Federal Regulations for both light-duty³⁴ and heavy-duty vehicles.³⁶ This change is not incorporated in MOVES3, but we anticipate incorporating these updates in a future version of MOVES.^e

3.2 Future Research

Future work could investigate whether the real-world emissions impact of humidity is similar to the corrections developed from laboratory testing used in the Code of Federal Regulations. Additional work could evaluate the emission impact of humidity on more recent gasoline, diesel and alternative-fueled engines and consider whether modern engine calibration and emission control technologies impact the humidity effect.

^e The update equations required a code change that was not incorporated into MOVES3.

4. Air Conditioning Adjustments

MOVES3 applies air conditioning adjustments to THC, CO, NO_x and energy consumption from passenger cars, passenger trucks and commercial light trucks. The air conditioning (A/C) effects described below and incorporated in MOVES3 were originally derived for MOVES2010.

The air conditioning adjustment factors used in MOVES are based on data collected from light-duty vehicles in a test procedure meant to simulate air conditioning emission response under extreme “real world” ambient conditions. These factors predict emissions which would occur during full loading of the air conditioning system and are then scaled down in MOVES according to the ambient conditions specified in a modeling run. The second-by-second emission data were analyzed using the MOVES methodology of binning the data according to vehicle characteristics (MOVES source bins) and vehicle specific power bins (MOVES operating modes). The results of the analysis showed statistically significant and consistent air conditioning effects for three types of operation (deceleration, idle and cruise/acceleration) and the three primary exhaust pollutants (hydrocarbon, carbon monoxide and nitrous oxides) and energy consumption. This section shows the results of the analysis for the air conditioning adjustments used in MOVES for THC, CO, NO_x and energy consumption. The impact of A/C on particulate matter has not been evaluated for MOVES and therefore, MOVES currently has no air conditioning effect for PM emissions.

The MOVES A/C adjustment varies by operating mode for total energy consumption and exhaust running THC, CO and NO_x emissions and applies only to passenger cars, passenger trucks and commercial light trucks. The HD emission rates do not require explicit A/C adjustments because they are based on real-world driving that includes A/C usage depending on ambient conditions when the test was conducted. For example, the model year 2010 and later HD diesel energy rates are based on manufacturer-run Heavy-Duty In-Use Testing (HDIUT) data.¹¹

4.1 Air Conditioning Effects Data

The data for the MOVES A/C Correction Factor (ACCF) was collected in 1997 and 1998 in specially designed test programs. In the programs, the same set of vehicles were tested at standard FTP test conditions (baseline) and at a nominal temperature of 95°F. Use of the same set of vehicles and test cycles was intended to eliminate most of the vehicle and test procedure variabilities and highlight the difference between a vehicle operating at extreme ambient conditions and at a baseline condition.

The data used to develop the MOVES ACCF consisted of emission results from 54 individual cars and light trucks tested over a variety of test schedules. Overall, the database consisted of a total of 625 test cycles and 1,440,571 seconds of emission, speed and acceleration data. Because of the need to compute vehicle specific power on a modal basis, only test results which consisted of second-by-second data were used in the MOVES analysis. All second-by-second data were time-aligned and checked for errors.

The distribution of test vehicles by model year is shown in Table 4-1. Model years 1990 through 1999 were included. The data set consists of 30 cars and 24 light trucks. No test data were available on other vehicle types (e.g. motorcycles or heavy-duty trucks). The individual test cycles on which the vehicles were run are shown with the test counts in Table 4-2. The data shows a balance between different test cycles and cars and trucks. The individual vehicles are listed in Appendix C.

Only vehicles which were coded as having an emission test with the A/C system on were selected for this analysis. The A/C On tests and the A/C Off (default for most EPA emission tests in general) were matched by VIN, test schedule and EPA work assignment. The matching ensured that the same vehicles and test schedules were contained in both the A/C On sample and the A/C Off sample.

Table 4-1 Distribution of test vehicles by Model Year

Model Year	Count
1990	5
1991	5
1992	6
1993	5
1994	7
1995	5
1996	13
1997	4
1998	3
1999	1
TOTAL	54

Table 4-2 summarizes the distribution of test-cycles analyzed. The test-cycles are defined in a MOBILE6 report.³⁷

Table 4-2 Distribution of tests by test cycle

Schedule Name	Count
ART-AB	36
ART-CD	36
ART-EF	36
F505	21
FTP	21
FWY-AC	57
FWY-D	36
FWY-E	36
FWY-F	36
FWY-G	36
FWY-HI	36
LA4	23
LA92	35
LOCAL	36
NONFRW	36
NYCC	36
RAMP	36
ST01	36
TOTAL	625

4.2 Air Conditioning Effects on Emissions and Energy

The data described above was then used to estimate factors to account for increases in emissions and energy consumption with full loading of the air conditioning system. These factors are recorded for running and extended idle emissions by sourcetype, pollutant and operating mode in the

fullACadjustment table of the MOVES database. Thus, the same effects are applied for all fueltypes and model years.

Full A/C Adjustments for THC, CO and NO_x Emissions

Average emissions for each pollutant (HC, CO and NO_x) with and without A/C operation were computed for each of the MOVES light-duty running operating modes as defined using vehicle specific power (VSP).¹⁰ This resulted in 69 (23 VSP bins x 3 pollutants) pairs of emission averages. However, the trends were erratic and the results were generally not statistically significant. In addition, most of the high-speed bins had little data. An analysis of cars versus light-duty trucks showed no statistical difference between the two. To produce more consistent results, the individual VSP bins were consolidated to three principal bins: Braking / Deceleration, Idle, and Cruise / Acceleration as defined in Table 4-3. These consolidated operating mode bins are quite different in terms of engine operation and emissions performance.

Full A/C adjustments were then generated by dividing the mean “With A/C” emission factor by the mean “Without A/C” emission factor for each combination of consolidated operating mode and pollutant. Full A/C adjustments are shown in Table 4-3. Measures of statistical uncertainty (coefficient of variation of the mean) were also computed using the standard error of the mean. They are shown in Table 4-3 as “Mean CV of CF.”

A/C adjustments of less than or equal to one were found for the Braking / Deceleration mode for all three pollutants. These were set to one for use in the MOVES model.

Table 4-3 Full air conditioning adjustments for THC, CO and NO_x

Pollutant	Consolidated Operating Mode	opModeIDs	Full A/C CF	Mean CV of CF
THC	Braking / Decel	0	1.0000	0.48582
THC	Idle	1	1.0796	0.74105
THC	Cruise / Accel	11 - 40	1.2316	0.33376
CO	Braking / Decel	0	1.0000	0.31198
CO	Idle	1	1.1337	0.77090
CO	Cruise / Accel	11 - 40	2.1123	0.18849
NO _x	Braking / Decel	0	1.0000	0.19366
NO _x	Idle	1	6.2601	0.09108
NO _x	Cruise / Accel	11 - 40	1.3808	0.10065

These adjustments are applied to passenger cars, passenger trucks and light commercial trucks only.

Note the higher air conditioning effect for NO_x at idle. These results are consistent with those obtained from Nam et al. (2000)³⁸ who showed that at low load conditions, A/C greatly increased NO_x emissions due to reduced residual gas fractions in-cylinder.

Full A/C Adjustments for Energy Consumption

The use of a vehicle’s A/C system will often have a sizeable impact on the vehicle’s energy consumption. This was found statistically by analyzing the available second-by-second data on CO₂ and other gaseous emissions and converting them to an energy basis using standard EPA vehicle fuel economy certification equations. The vehicle emission data were binned by running operating mode and mean values were

computed. A separate analysis was done as a function of sourceBinID (combination of vehicle type, fuel type and model year), however, the results were not statistically different across sourceBinID given the relatively small sample sizes. As a result, the A/C adjustments for energy are a function only of running operating mode.. The resulting A/C adjustments are shown in Table 4-4.

Table 4-4 Full air conditioning adjustments for energy

opModelID	A/C Factor	opModelID	A/C Factor	opModelID	A/C Factor
0	1.342	21	1.294	30	1.294
1	1.365	22	1.223	33	1.205
11	1.314	23	1.187	35	1.156
12	1.254	24	1.167	37	1.137
13	1.187	25	1.157	38	1.137
14	1.166	26	1.127	39	1.137
15	1.154	27	1.127	40	1.137
16	1.128	28	1.127		
		29	1.127		

These adjustments are applied to passenger cars, passenger trucks and light commercial trucks only

Only very small amounts of data were available for operating modes 26 through 29 and 37 through 40. As a result, the data from these bins was averaged together and binned into two groups. The resulting group averages were used to fill the individual VSP bins. This averaging process has the effect of leveling off the effect of A/C at higher power levels for an engine. This is an environmentally conservative assumption since it is likely that the engine power devoted to an A/C compressor probably continues to decline, sometimes to zero, as the overall power demand of the engine is increased.

Fuel economy and GHG regulations are expected to reduce energy consumption with air conditioning. However, because, the MOVES A/C factors are multiplicative adjustments to the running energy rates, a reduction in running energy rates also reduces energy consumption from air conditioning. In MOVES, we project the light-duty A/C improvements of regulatory rules using the running energy rates as documented in the MOVES3 Greenhouse Gas and Energy Consumption Rates Report.⁴

4.3 Adjustments to Air Conditioning Effects

In MOVES, the adjustments for each operating mode are weighted together by the operating mode distribution calculated from the driving schedules used to represent the driving behavior of vehicles. Average speed, road type and vehicle type will affect the operating mode distribution.

$$\text{meanBaseRateACAdj} = \text{SUM}(\text{meanBaseRate} * (\text{fullACAdjustment} - 1.0) * \text{opModeFraction})$$

Since not all vehicles are equipped with air conditioning and air conditioning is normally not on all the time, the full air conditioning effect on emissions is adjusted before it is applied to the emission rate. The adjustment account for (a) the fraction of vehicles in each model year that are equipped with air conditioning, (b) the fraction of vehicles equipped with air conditioning of each age that have an operational air conditioning system and (c) the fraction of those vehicle owners who have air conditioning available to them that will turn on the air conditioning based on the ambient temperature and humidity (heat index³⁹) of the air outside their vehicles. These MOVES defaults are documented in the Population and Activity report.⁴⁰ The fraction of vehicles equipped with air conditioning, the fraction of operational

air conditioning and the fraction of air conditioning use are used to adjust the amount of "full" air conditioning that occurs in each hour of the day.

$$\text{EmissionRate} = (\text{meanBaseRateACAdj} * \text{ACPenetration} * \text{functioningACFraction} * \text{ACOnFraction}) + \text{meanBaseRate}$$

The air conditioning adjustment is a multiplicative adjustment applied to the emission rate after it has been adjusted for fuel effects.

Air conditioners are also employed for defogging at all temperatures, particularly, at lower temperatures. This secondary use of the A/C along with associated emission effects is not addressed in MOVES.

4.4 Conclusions and Future Research

MOVES applies air conditioning effects to emissions from passenger cars, passenger trucks and commercial light trucks. The impact depends on pollutant, operating mode, ambient temperature and humidity and the anticipated availability of air conditioning in the vehicle type, model year and age being modeled.

There are a number of areas where our understanding of air conditioning impacts could be improved. These include:

- Evaluation of the impact of air conditioning use on particulate matter emissions.
- Studies of air conditioning effects in a broader range of model years, particularly those with the most recent emission control technologies.
- Evaluation of air conditioning effects in the highest VSP/STP bins.
- Updates to information on the fraction of vehicles equipped with air conditioning and their malfunction rates.

5. Inspection and Maintenance Programs

Inspection and Maintenance (I/M) programs are generically any state or locally mandated inspection of highway motor vehicles intended to identify those vehicles most in need of emissions-related repair and require repairs of those vehicles. There is great variation in how vehicles are selected for inclusion in the programs, how and when vehicles are tested, and what happens when vehicles fail. MOVES is designed to take these variations into the account when estimating the emission benefits of these programs.

5.1 Inspection & Maintenance in MOBILE6

Because MOVES draws heavily on the approaches developed for MOBILE6.2 to represent the design features of specific I/M programs, it is useful to briefly review these methods. Readers interested in a more thorough treatment of the topic are encouraged to review the relevant MOBILE6 documentation.⁴¹

The MOBILE6.2 model used a methodology that categorized vehicles according to emitter status (High emitters and Normal emitters) and applied a linear growth model to project the fraction of the fleet that progresses from the Normal emitter to the High emitter status as a function of age. Average emission rates of High and Normal emitters were weighted using the High emitter fraction to produce an overall average emission rate as a function of age, model year group and vehicle type. The emissions generated represented the emissions of the fleet in the absence of I/M (the No I/M emission rate).

A similar approach was used to generate I/M emission rates. In this case, the initial starting point for the function (where age=0) was the same as the No I/M case. However, the effects of I/M programs and associated repairs were represented by reductions in the fraction of high emitters, which consequently affected the average emission level of the fleet. Balancing these emissions reductions due to I/M repairs were the re-introduction of high emitters in the fleet due to deterioration of vehicle emission control systems after repairs. The underlying I/M and non-I/M deterioration rates were assumed to be the same.

MOBILE6 modeled the non-I/M and I/M emission cases diverging from each other over time, with the I/M rates being lower. The percentage difference between these two rates is often referred to as the overall I/M reduction or I/M benefit.

5.2 Inspection & Maintenance in MOVES

The MOVES emission rates contain estimates of emission levels as a function of age, model year group and vehicle type for areas where no I/M program exists (the mean base rate, or the non-I/M reference rates) and for an area representing the “reference I/M program” (the I/M reference rates). As detailed in the MOVES light-duty emission rate report, the mean base rates for light-duty gasoline vehicles (the principal target of I/M programs), initially developed for MOVES2010 and MOVES2014, were based on data from the enhanced I/M program in Phoenix, Arizona (as operated from calendar year 1995 through 2005) and represent the design features of that program. The ratio differences between the non-I/M and I/M reference rates, which differ by age, were also primarily derived from analyses of data from within the Phoenix program, and are assumed to represent the I/M benefit of the Phoenix program design assuming perfect compliance. However, we did compare these differences to analogous differences in two other geographic areas, Northern Virginia and Atlanta, and found them in broad agreement with the Phoenix results. Equation 5-1 shows this relationship in a mathematical form.

$$\text{Standard IM Difference} = E_{\text{nonIM}} - E_{\text{IM}} \quad \text{Equation 5-1}$$

where $E_{\text{non-IM}}$ and E_{IM} are the non-I/M and I/M reference rates in a given age group, respectively.

The Phoenix program design was selected as the reference program because at the time, most of the underlying data for MOVES light-duty emission rates came from this source. The selection does not imply any judgment on the strengths or weaknesses of this specific program.

The object of this process is to generate a general model which can be used to represent all I/M programs in the United States. The MOVES approach is to compare individual program designs against the reference program for purposes of developing adjustment to the “standard I/M difference” representing design features differing from those in the reference program. This concept is shown mathematically in Equation 5-2,

$$E_p = RE_{\text{IM}} + (1 - R)E_{\text{nonIM}} \quad \text{Equation 5-2}$$

where E_p is the adjusted emission rate for a “target” I/M program, E_{IM} is the reference rate, E_{nonIM} is the non-I/M reference rate and R is an aggregate adjustment representing the difference in average emission rates between the target program and the reference program.

Depending on the value of R , E_p may be greater than E_{nonIM} , fall between E_{nonIM} and E_{IM} , or be less than E_{IM} . Thus, this framework can represent target programs as more effective or less effective than the reference program. In MOVES, R is referred to as the “IMFactor.”

Re-arranging Equation 5-2 and solving for R gives leads to Equation 5-3. This equation shows the I/M adjustment as the ratio of the emission difference between a proposed I/M program design and the Standard I/M Difference

$$R = \frac{E_p - E_{\text{nonIM}}}{E_{\text{IM}} - E_{\text{nonIM}}} \quad \text{Equation 5-3}$$

5.3 Development of MOVES I/M Factors

Early in the MOVES development process, it was decided that developing the I/M adjustment factors based on a completely new analysis was infeasible. A major obstacle was a lack of suitable emissions and I/M program data representing the full range of program designs. Data sets for certain I/M programs (i.e., transient test-based programs) were generally quite complete and robust. However, mass emission results and random vehicles samples were quite scarce for other test types such as the Acceleration Simulation Mode (ASM), steady-state, idle tests and OBD-II scans. This situation was particularly true for data on old model years at young ages (i.e., a 1985 model year at age five).

As a result, EPA developed I/M adjustment factors based on the information incorporated in MOBILE6.2. Mechanically, this step was achieved by running the MOBILE6.2 model about 10,000 times over a complete range of pollutant–process combinations, inspection frequencies, calendar years, vehicle types, test types, test standards and model year group / age combinations. The mean emission results for each combination were extracted from the output and used to compute estimated values for IMFactor. The IMFactor table includes the following fields:

- Pollutant / Process
- Test Frequency
- Test Standard (see Table 5-1 below)
- Source Type
- Fuel Type (Only gasoline/ethanol fuels have IMFactors)
- Model Year Group
- Age Group
- IMFactor

Table 5-1 MOVES I/M Test Standards

testStandardsID	testStandardsDesc	shortName
11	Unloaded Idle Test	Unloaded Idle
12	Two-mode, 2500 RPM/Idle Test	2500 RPM/Idle
13	Loaded / Idle Test	Loaded/Idle
21	ASM 2525 Phase-in Cutpoints	A2525 Phase
22	ASM 5015 Phase-in Cutpoints	A5015 Phase
23	ASM 2525/5015 Phase-in Cutpoints	A2525/5015 Phase
24	ASM 2525 Final Cutpoints	A2525 Final
25	ASM 5015 Final Cutpoints	A5015 Final
26	ASM 2525/5015 Final Cutpoints	A2525/5015 Final
31	IM240 Phase-in Cutpoints	IM240 Phase
33	IM240 Final Cutpoints	IM240 Final
41	Evaporative Gas Cap Check	Evp Cap
42	Evaporative System Pressure Check	Evp Pressure
43	Evaporative System OBD Check	Evp OBD
44	Evaporative Gas Cap and Pressure Check	Evp Cap, Prs
45	Evaporative Gas Cap and OBD Check	Evp Cap, OBD
46	Evaporative Pressure and OBD Check	Evp Prs, OBD
47	Evaporative Gas Cap, Pressure and OBD Check	Evp Cap,OBD,Prs
51	Exhaust OBD Check	Exhaust OBD
61	HDDV Engine Reflash Program	HDDV Reflash

The IMFactor value was computed for all reasonable combinations of the parameters listed in the IMFactor table. A separate MOBILE6.2 run was done for each parameter combination (Target design, E_p) and a second set of runs were done for the reference program (Reference design, E_{IM}). The IMFactor (R) was then calculated from the mean emission results from these two runs and the non-I/M case using Equation 5-3. The reference program has inputs matching the Phoenix, Arizona I/M program during the time in which the data used in the MOVES emission rate development were collected (CY 1995-2005). The reference design represents a biennial frequency with an exemption period for the four most recent

model years. It uses three different I/M test types (basic idle test for MY 1960-1980, transient tailpipe tests for MY 1981-1995 (IM240, IM147) and OBD-II scans for MY 1996 and later). Each of these test types became the reference for the respective model year groups.

The specific combinations of MOBILE6.2 runs performed are shown in Table 5-2 below. Each of these runs represents a particular test type and test standard design which was expressed as a ratio to the standard reference tests. A set of these runs were done for each calendar year 1990 through 2030, for cars, light trucks and heavy-duty gasoline vehicles and for pollutants THC, CO and NO_x.

The first four runs represent the Non-I/M reference and the three Arizona I/M references.

Table 5-2 MOBILE6.2 runs used to populate the MOVES I/M adjustment factor

RUN #	Description	Type
1	Non I/M Base	Non I/M Reference
2	IM240 Base (Biennial IM240/147)	I/M Reference
3	OBD Base (Biennial OBD Test)	I/M Reference
4	Basic Base (Loaded – Idle Test)	I/M Reference
5	Biennial - IM240 - Phase-in Cutpoints	Target I/M Design
6	Annual - IM240 - Phase-in Cutpoints	Target I/M Design
7	Biennial - IM240 - Final Cutpoints	Target I/M Design
8	Annual - IM240 - Final Cutpoints	Target I/M Design
9	Biennial - ASM 2525/5015 - Phase-in Cutpoints	Target I/M Design
10	Annual - ASM 2525/5015 - Phase-in Cutpoints	Target I/M Design
11	Biennial - ASM 2525/5015 - Final Cutpoints	Target I/M Design
12	Annual - ASM 2525/5015 - Final Cutpoints	Target I/M Design
13	Biennial - ASM 2525 - Phase-in Cutpoints	Target I/M Design
14	Annual - ASM 2525 - Phase-in Cutpoints	Target I/M Design
15	Biennial - ASM 2525 - Final Cutpoints	Target I/M Design
16	Annual - ASM 2525 - Final Cutpoints	Target I/M Design
17	Biennial - ASM 5015 - Phase-in Cutpoints	Target I/M Design
18	Annual - ASM 5015 - Phase-in Cutpoints	Target I/M Design
19	Biennial - ASM 5015 - Final Cutpoints	Target I/M Design
20	Annual - ASM 5015 - Final Cutpoints	Target I/M Design
21	Annual - OBD -	Target I/M Design
22	Annual - LOADED/IDLE	Target I/M Design
23	Biennial - IDLE	Target I/M Design
24	Annual - IDLE	Target I/M Design
25	Biennial - 2500/IDLE	Target I/M Design
26	Annual - 2500/IDLE	Target I/M Design

The MOBILE6.2 database output option was chosen for all runs. This step produced large sets of results which were further stratified by facility-cycle / start process and age. This output format necessitated additional processing of the facility rates into composite running and start factors (in MOVES, the IMFactor is a function of running and start processes).

Note that MOVES2014 had an error in the calculation of the IMFactor values which affected the 1981 through 1995 model years for vehicles 10 years and older. This problem was noted by the Coordinating Research Council in their E-101 report⁴² on the MOVES2014 version of the model. This problem was

rectified in MOVES3 by recalculating the IMFactor values for all source types in this model year and age range. The new IMFactor values increase THC, CO and NO_x emissions compared to MOVES2014 in I/M areas with programs that cover these model years by less than 1 percent in calendar year 1999 increasing to nearly 3 percent in calendar year 2010. The impact of this problem diminishes after calendar year 2010 as these model years are retired from the fleet. The impact of this change for specific areas will vary depending on the age distribution and other factors.

5.4 I/M Compliance Factors

In addition to the IMFactor, MOVES adjusts rates for particular programs by applying an additional multiplicative "Compliance Factor." While the IMFactor (*R*, see Equation 5-3) represents the theoretical effectiveness of a specific I/M program design relative to the reference design, as described above, the values of the I/M compliance factor (*C*) are specific to individual programs and represent their overall operational effectiveness and efficiency. Program characteristics which impact the I/M compliance factor include waiver rates, compliance rates and overall operational efficiency. The compliance factor may vary from 0 to 100 where zero would represent a totally failed program and 100 a perfectly successful program. Factors which tend to reduce the compliance factor include the systematic waiver of failed vehicles from program requirements, large numbers of motorists who completely evade the program, technical losses from improperly functioning equipment or inadequately trained technicians.

The MOBILE6 compliance rate, waiver rate and effectiveness rate were used to determine the MOVES I/M Compliance Factor. The MOVES Compliance Factor is a broader concept that incorporates three separate MOBILE6.2 inputs. Equation 5-4 shows the relationship.

$$C = M6ComplianceRate * M6EffectivenessRate * (1 - M6WaiverRate) \quad \text{Equation 5-4}$$

MOVES does not have separate inputs for the effect of waivers on I/M benefits. The Inspection Maintenance section of the technical guidance document for MOVES3⁴³ describes how to calculate the MOVES compliance rate to include the effect of waivers.

In MOVES, it is assumed that any repairs attempted on vehicles receiving waivers are not effective and do not result in any reduced emissions.

5.5 Calculation of I/M Emission Rates

Calculation of the emission rate for vehicles subject to an I/M program begins with the calculation of the IMAdjustFract. The IMAdjustFract combines the IM Factor for the program design and the Compliance Factor for the program characteristics to create a single factor. The Compliance Factor is in units of percent and is converted to a fraction.

$$IMAdjustFract = (IMFactor * ComplianceFactor * 0.01) \quad \text{Equation 5-5}$$

The next step is to estimate a program-specific "with I/M" emission rate by weighing together the emission rate for the I/M reference program and the non-I/M emission rate, using the IMAdjustFract.

$$\text{TargetRate} = \text{IMRate} * \text{IMAdjustFract} \\ + \text{NonIMRate} * (1.0 - \text{IMAdjustFract})$$

Equation 5-6

5.6 Default I/M Program Descriptions (IMCoverage)

Information about which pollutant-processes are covered by I/M programs in various counties and calendar years is listed in the MOVES database table IMCoverage. This coverage information may vary by pollutant, process, county, year, sourcetype and fuel type. The table also lists the I/M compliance factors described above.

The IMCoverage table includes the use of I/M program identifiers called IMProgramIDs. A particular county will likely have several IMProgramIDs that reflect different test types, test standards or inspection frequencies being applied to different sourcetypes, model year groups or pollutant-process combinations. For example, a county in calendar year 2007 may have an IMProgramID=1 that annually inspects pre-1981 model year cars using an Idle test and an IMProgramID=2 that biennially inspects 1996 and later model year light-trucks using an OBD-II test.

The IMCoverage table also shows other important I/M parameters for each IMProgramID. These include the relevant model year range (beginning and ending model year), the frequency of inspection (annual, biennial, continuous/monthly), test type (Idle, IM240, ASM, OBD-II) and the test standard.

The structure of the IMCoverage table in the MOVES database is:

- Pollutant / Process
- State / County
- Calendar Year
- Source Use Type
- Fuel Type (only gasoline and ethanol fuels)
- IMProgramID
- Beginning Model Year of Coverage
- Ending Model Year of Coverage
- InspectFreq
- I/M Test Standards (see Table 5-1)
- UseIMyn
- Compliance Factor

The UseIMyn toggle is a user feature that allows the user to completely disable the modeling of I/M for one or more of the parameter combinations.

When modeling for regulatory purposes, it is expected that a state will enter their own set of program descriptive parameters and compliance factors which reflect current and expected future program operation. However, MOVES contains a set of I/M program descriptions for all calendar years intended to reflect our best assessment of the programs in each state.

The data used to construct the default inputs for I/M programs before calendar year 2011 were taken from MOBILE6.2 input files used in the NMIM model to compute the National Emission Inventory of 2011.

The MOBILE6 data fields listed in Table 5-3 were extracted and processed into the various fields in the MOVES IMCoverage table for each state and county.

As seen in Table 5-3, MOBILE6.2 and MOVES do not have exactly compatible parameter definitions. The MOBILE6.2 I/M Cutpoints data were used only to determine level of stringency of a state's IM240 program (if any). The MOBILE6.2 Test Type inputs provided a description of the specific I/M tests performed by the state and test standards for the ASM and Basic I/M tests. The MOBILE6.2 inputs of Grace Period and Model Year Range were used to determine the MOVES Beginning and Ending model year data values for each I/M program. The MOBILE6.2 vehicle type input was mapped to the MOVES sourcetype.

Table 5-3 I/M Coverage table data sources

MOBILE6 Data	MOVES I/M Coverage Parameter
Compliance Rate	Used in the MOVES Compliance Rate Calculation
I/M Cutpoints	Used to determine MOVES I/M Test Standards
Effectiveness Rate	Used in the MOVES Compliance Rate Calculation
Grace Period	Used in MOVES to Determine Beginning Model Year of Coverage
Model Year Range	Used in MOVES to Determine Ending Model Year of Coverage
Test Type	Used to determine MOVES I/M Test Type
Vehicle Type	Used to determine MOVES Sourcetype
Waiver Rate	Used in the MOVES Compliance Rate Calculation

For calendar year 2011 through 2013, the IMCoverage table default parameters were derived using the IMCoverage tables from the county databases (CDBs) provided to EPA for the 2011 National Emission Inventory (NEI) project⁴⁴ (Version1). These tables were available for review by states and updated as needed. The I/M program descriptions from these CDBs were extracted from the CDBs and compiled in the default IMCoverage table for calendar year 2011. The I/M descriptions for 2012 and 2013 calendar years were derived from the 2011 I/M descriptions, assuming no changes in the basic I/M program design, but updating the model year coverage values to properly account for the existing grace periods in the future calendar years.

The calendar year 2014 and later values were initially derived from the 2014 NEI (Version 1)⁴⁵ CDBs following review by the states with the 2015 and later calendar year assuming no changes in the basic 2014 I/M program design, but updating the model year coverage values to properly account for the existing grace periods in the future calendar years. All of the I/M program descriptions were checked using a script to look for cases where a model year coverage either conflicted with other rows in the I/M description or where gaps without coverage were left between model years. This check also looked for cases where the coverage beginning model year occurred later than the ending model year coverage. Each problem identified was compared to the I/M program descriptions found in the 2013 EPA I/M Program Data, Cost and Design Information report⁴⁶ to resolve conflicts. The county coverage values in some states were also updated for some calendar years. In addition to the updates in the I/M program descriptions, the table was updated to make sure each I/M program covered E85-fueled vehicles in the same way as for gasoline in all calendar years. Any program elements claiming benefits for inspections to reduce liquid fuel leaks (pollutant process ID 113) were dropped from the default I/M program descriptions. MOVES does not offer any benefits from inspection programs to detect liquid fuel leaks.

For MOVES3, the table was further updated based on state supplied data through the OBD Clearinghouse website⁴⁷ and 2017 National Emissions Inventory (NEI).⁴⁸ The updates include adding I/M program for Ascension Parish, Iberville Parish, and Livingston Parish in Louisiana; adding I/M program for Hamilton County, Tennessee, and for Cache County, Utah. We also updated the program stop years for terminated I/M programs. These terminated programs include ones in Anchorage Borough, Alaska; Grundy County, Illinois; Clark County and Floyd County, Indiana; Shelby County, Tennessee; and seven counties in Minnesota, 26 counties in North Carolina, and six counties in Ohio.

We also deleted the I/M program for Harrison County, Indiana (for all the CY years), since it was confirmed that Harrison County, IN has never been in nonattainment for any National Ambient Air Quality Standards (NAAQS) and does not have a I/M program. We also updated the beginning model year for North Carolina I/M counties to reflect changes to their program for 2020 and later.⁴⁹ In addition, to reflect the termination of I/M program in Washington state, I/M programs have been removed from IMCoverage table for all counties in Washington state after CY2019.

California currently has three different I/M programs: an enhanced program, basic program, and ownership change program. These may vary by zipcode region.. We mapped California counties with I/M program types by checking all the zipcodes in each county. We use the basic program to represent a county if it has mixed programs. This methodology is consistent with previous work. We updated I/M program details for ten counties in California based on our research.

Table 5-4 shows the states with I/M program descriptions in the updated I/M coverage table and shows the number of counties covered by the programs by calendar year. For example, Idaho has two counties that have I/M programs; one county's program covers from CY 1990 to CY 2060, while the other county's program covers from CY 2011 to CY 2060.

Table 5-4 States With I/M Programs as Listed in MOVES3

State	StateID	Calendar Years		Counties
		Minimum	Maximum	
Alaska	2	1990	2009	1
		1990	2012	1
Arizona	4	1990	2060	2
California	6	1990	2060	8
		1999	2060	32
Colorado	8	1990	2060	9
Connecticut	9	1999	2060	8
Delaware	10	1990	2060	3
District of Columbia	11	1990	2060	1
Georgia	13	1999	2060	13
Idaho	16	1990	2060	1
		2011	2060	1
Illinois	17	1990	2060	10
		1990	2005	1
Indiana	18	1990	2007	2
		1990	2060	2
Kentucky	21	1990	2005	4
Louisiana	22	2000	2060	5
Maine	23	1990	2060	1
Maryland	24	1990	2060	14
Massachusetts	25	1990	2060	14
Minnesota	27	1990	1999	7
Missouri	29	1990	2060	5
Nevada	32	1990	2060	2
New Hampshire	33	2002	2060	3
		2011	2060	7
New Jersey	34	1990	2060	21
New Mexico	35	1990	2060	1
New York	36	1990	2060	9
		2001	2060	53
North Carolina	37	2003	2060	12
		2006	2060	37
Ohio	39	1990	2008	6
		1990	2060	8
Oregon	41	1990	2060	4
		2001	2060	2
Pennsylvania	42	1990	2060	11
		2001	2060	14
Rhode Island	44	2000	2060	5
Tennessee	47	2000	2060	1
		2011	2060	6
Texas	48	1990	2060	4
		2000	2060	6
		2011	2060	7
Utah	49	1990	2060	4
		2017	2017	1
Vermont	50	1990	2060	14
Virginia	51	1990	2060	10
Washington	53	1990	2019	5
Wisconsin	55	1999	2060	7

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Appendix A Derivation of Default Temperature and Humidity Values and Other Meteorology Calculations

The MOVES default database includes default ambient temperature and humidity values for every county, month, and hour. If modelers do not enter local data, MOVES will use these values to calculate the temperature and humidity adjustments described in the main body of this report. These values were derived from 10-year average temperature and relative humidity values from calendar years 2001 through 2011 by month and by hour (standard time) for each county in the United States for all calendar years.

Due to the limited number of hourly observation stations (about 200 sites), interpolation of the available data was required. This interpolation will not always produce accurate results, particularly in areas where climate can vary significantly over distance, such as in mountainous terrain and near coastlines or deserts. Moreover, it is important that the diurnal range of the average hourly temperatures match those of the average monthly minimum and maximum values. This aspect arises due to the averaging process and to the fact that daily maximum and minimum temperatures do not always occur at the same hourly observation time.

To correct the diurnal range problem, EPA has developed a method to adjust the average hourly temperatures so that the corresponding hourly-based maximum and minimum temperatures match those of the true monthly maximum and minimum values. To correct the spatial problem, all of the daily and monthly maximum and minimum temperature observations made by the National Weather Service (NWS) and its Cooperative Observation branch (over 6000 sites) and the Federal Aviation Administration (FAA) are used.

Note, temperature and humidity data are one of the many inputs that are averaged for simplified national and state level onroad MOVES runs. The algorithms for this averaging (“aggregation”) are described in the MOVES code documentation at https://github.com/USEPA/EPA_MOVES_Model.

A.1 Data Sets and Quality Control

The National Climatic Data Center (NCDC) is the national and international depository for weather observations. As part of its many duties, the NCDC publishes and maintains many climatic data sets. “Quality Controlled Local Climatological Data” (QCLCD) files were obtained for all locations across the United States, Puerto Rico and the Virgin Islands from the NCDC for this analysis.

There can be significant problems with this information. Primary among these problems is that many stations with daily data do not have corresponding monthly averages, and vice-versa. Further, some stations may have the same identification numbers while others may have missing or incorrect latitude and longitude coordinates. During the processing of the 2009 data, nearly 10 percent of the 1654 stations were found to have identification and/or location problems.

Missing monthly temperatures can be calculated from the daily maximum and minimum observations for these stations for the years of interest. To resolve the mislabeled station IDs and location data, it was necessary to contact NCDC to obtain updated tables with corrected IDs before processing the data.

In addition to the hourly temperature and dew point data, the identification number and geographic location (latitude and longitude) for all available weather stations across the United States, Puerto Rico, and the Virgin Islands were obtained from the NCDC files. Using Geographical Information System (GIS) software, the locations of the hourly weather observation stations were validated. To resolve duplicate IDs and latitude/longitude issues, careful analysis of the station history files and conversations with state climatologists and National Weather Service offices were made. Our contractor, Air Improvement Resource Inc. (AIR), hand-edited the IDs and latitude/longitude data and supplied updates to our data and to the NCDC.

For temperature disputes, such as maximum temperature less than minimum temperature (caused by mistyped data), hourly and/or daily data from nearby sites were consulted and the data corrected accordingly.

For each station, an inventory was made as to the number of hours with joint temperature and dew point data. In order to be included in the analysis, each station had to have at least 50 percent data recovery for each hour of each month.

The daily absolute maximum and minimum temperature data for all available stations were processed into monthly averages. These stations covered all classifications, including First-Order (National Weather Service), Second-Order (both Automated Surface Observing System (ASOS) and Automated Weather Observing System (AWOS)) and cooperative (local). Following NCDC guidelines, a month's averages were considered valid when no more than 5 days had missing data during that month. For each station, the hourly temperature and dew point data was scanned for missing values. For missing data periods lasting only 1 hour, the missing values was replaced with an interpolated value from the two adjacent valid readings

After these filters were applied, the average monthly maximum and minimum temperature data were adjusted to the common midnight-to-midnight observational period. This adjustment is necessary since many of the cooperative stations take their observations either early in the morning or late in the afternoon rather than at midnight. These observation times induce a bias into the monthly temperature averages. Correction values were obtained from the NCDC and applied to the monthly averages.

A.2 County Temperature Assignment

An octal search with inverse distance weighting was used to assign the monthly maximum and minimum temperatures to each U.S. county. Population centroids (latitude and longitude) for each county were obtained from the 2010 United States Census. Population, rather than geographic, centroids were used to provide a reasonable estimate of where the county's vehicle miles traveled and nonroad activity would be concentrated. From each county's centroid, the distance and direction to each weather station was calculated. The shortest distance was computed using the standard great circle navigation method and the constant course direction was computed using the standard rhumb line method. A rhumb line is a line on a sphere that cuts all meridians at the same angle; for example, the path taken by a ship or plane that

maintains a constant compass direction. Based on the computed directions, the stations were assigned to an octant, as follows:

- Octant 1: $0^\circ < \text{Dir} \leq 45^\circ$
- Octant 2: $45^\circ < \text{Dir} \leq 90^\circ$
- Octant 3: $90^\circ < \text{Dir} \leq 135^\circ$
- Octant 4: $135^\circ < \text{Dir} \leq 180^\circ$
- Octant 5: $180^\circ < \text{Dir} \leq 225^\circ$
- Octant 6: $225^\circ < \text{Dir} \leq 270^\circ$
- Octant 7: $270^\circ < \text{Dir} \leq 315^\circ$
- Octant 8: $315^\circ < \text{Dir} \leq 360^\circ$

For each octant, the stations were sorted by distance. The station closest to the centroid for each octant was chosen for further processing. If the closest station was more than 200 miles away, that octant was ignored. Such situations occurred near the oceans and the along the Canadian and Mexican borders. The temperatures from these 8 (or fewer) stations were then weighted together using inverse-distance weighting

Sometimes the county centroid and the octant weather stations are in different time zones. To remove the effects of differing time zones between county centroids and the weather stations, the temperature and dew point data from each octant weather station was synchronized to the same local hour (that is, the standard time at the county centroid was used).

A.3 Temperature Recalculation

Each county has daily maximum and minimum temperatures based on the spatial averaging describe above. The daily maximum and minimum temperature were averaged over all the days in each month to generate the monthly average maximum (AMax) and monthly average minimum (AMin) temperature.

The temperatures in each of the 24 hours are separately averaged over all the days in each month. This produces a set of 24 temperatures for each month for each county. This set is a time profile for the average daily temperatures in the month.

This temperature profile is stretched so that the maximum and minimum values match the average maximum and minimum temperatures for the month. The equation used for each hour is given below:

$$\text{AdjTemp}_h = \text{AMin} + (\text{Temp}_h - \text{PMin}) * ((\text{AMax} - \text{AMin}) / (\text{PMax} - \text{PMin}))$$

Where:

h is hour of the day,

AdjTemp_h is the adjusted hourly temperature,

Temp_h is the hourly temperature in the profile,

AMin is the average monthly minimum temperature,

AMax is the average monthly maximum temperature,

PMin is the minimum temperature based on the averaged 24 hourly temperatures in the profile,

PMax is the maximum temperature based on the averaged 24 hourly temperatures in the profile.

After this adjustment is applied, the maximum and minimum of the adjusted hourly temperatures will exactly match the average monthly maximum and minimum temperatures.

A.4 Relative Humidity Recalculation

Relative humidity depends on both temperature and dew point. Unfortunately, unlike daily maximum and minimum temperatures, supplemental dew point data is not available. Consequently, an investigation and literature search was made to determine a suitable estimation method. Surprisingly, few were found. The scheme outlined below was suggested by the NCDC and was used in this analysis:

At any given time, the difference between the temperature and dew point is known as the dew point depression (DPD). Since the dew point can never exceed the temperature, the minimum DPD is zero (100 percent relative humidity) while the maximum can be several tens of degrees, depending on how dry the air is. From the original data, the DPD was computed at each hour.

After the hourly temperatures were adjusted to be consistent with the county minimum and maximum temperatures as described above, the DPDs were subtracted from the hourly temperatures to estimate the corresponding dew point. The corresponding relative humidity was then computed from these two values. In keeping with standard meteorological practices, the relative humidity is always computed with respect to water, even if the temperature is below freezing. Comparative tests showed that the new calculated relative humidity results were very close to the original values, which is the desired outcome.

A.5 Calculation of 10 Year Averages

The monthly average hourly temperatures for each county from each calendar year from 2001 through 2011 were averaged to determine the default 10-year average temperatures stored in the MOVES ZoneMonthHour table for each county. The relative humidity values were converted to specific humidity (humidity ratio) for each hour before averaging and then converted back to relative humidity.

A.6 Calculation of Specific Humidity

While the MOVES default humidity is stored as relative humidity, the humidity adjustment uses specific humidity. Equations to convert relative humidity in percent to specific humidity (or humidity ratio) in units of grains of water per pound of dry air (ref. CFR section 86.344-79, humidity calculations).

Inputs:

T_F is the temperature in degrees F.

P_b is the barometric pressure.

H_{rel} is the relative humidity

$$T_K = \left(\frac{5}{9} \right) [T_F - 32] + 273$$

$$T_0 = 647.27 - T_K$$

$$H_{ratio \text{ or } specific \text{ humidity}} = 4347.8 * P_V / (P_b - P_V)$$

$$P_V = \left(\frac{H_{rel}}{100} \right) P_{db}$$

$$\begin{aligned} P_{db} &= 29.92 * 218.167 * 10^{(-T_0/T_K) \left[\frac{(3.2437 + 0.00588T_0 + 0.0000000117T_0^3)}{1 + 0.00219T_0} \right]} \\ &= 6527.557 * 10^{(-T_0/T_K) \left[\frac{(3.2437 + 0.00588T_0 + 0.0000000117T_0^3)}{1 + 0.00219T_0} \right]} \end{aligned}$$

A.7 Calculation of Heat Index

MOVES air conditioning demand is calculated as a function of the heat index as described in the MOVES Population and Activity report.⁴⁰ In MOVES, the heat index is a function of temperature and relative humidity.

$$\begin{aligned} \text{Heat Index} = \min (& (-42.379 + 2.04901523T + 10.14333127H \\ & + 0.22475541TH + -0.00683783T^2 \\ & + 0.05481717H^2 + 0.00122874T^2H \\ & + 0.00085282TH^2 + 0.00000199T^2H^2), 120) \end{aligned}$$

Where:

T= temperature

H = relative humidity

T >=78 ° F

Appendix B OTAQ Light-duty gasoline 2012 Cold Temperature Program

EPA's Office of Transportation and Air Quality (OTAQ) contracted the testing of nine Tier 2 vehicles (2006 and 2010 model year car and light-duty trucks). Eight of the nine vehicles were Mobile Source Air Toxics (MSAT-2) rule compliant. Vehicles were tested on the FTP and US06 under controlled conditions 75, 20, and 0°F. Note: we excluded the two GDI vehicles (Cadillac STS and the VW Passat) from the estimation of the THC and CO cold starts^b as mentioned in Section 2.2.

Information on the tested vehicles is summarized in Table B-1.

Table B-1 Vehicles Tested in 2012 Cold Temperature Study

Vehicle Name	Model Year	Injection	Emissions Std	MSAT?	Odometer	Displ (L)	Cyl.
Buick Lucerne*	2010	PFI	Tier 2/Bin 4	MSAT-2	22000	3.9	V-6
Honda Accord*	2010	PFI	Tier 2/Bin 5	MSAT-2	24000	2.4	I-4
Hyundai Sante Fe	2010	PFI	Tier 2/Bin 5	MSAT-2	18000	2.4	I-4
Jeep Patriot*	2010	PFI	Tier 2/Bin 5	MSAT-2	22000	2	I-4
Kia Forte EX*	2010	PFI	Tier 2/Bin 5	MSAT-2	25000	2	I-4
Mazda 6*	2010	PFI	Tier 2/Bin 5	MSAT-2	24000	2.5	I-4
Mitsubishi Gallant*	2010	PFI	Tier 2/Bin 5	MSAT-2	38000	2.4	I-4
Cadillac STS	2010	GDI	Tier 2/Bin 5	MSAT-2	21000	3.6	V-6
VW Passat	2006	GDI	Tier 2/Bin 5	pre-MSAT	103000	2	I-4

***Tested at 0°F**

Appendix C Air Conditioning Analysis Vehicle Sample

The data for the MOVES A/C Correction Factor (ACCF) was collected in 1997 and 1998 in specially designed test programs. In the programs, the same set of vehicles were tested at standard FTP test conditions (baseline) and at a nominal temperature of 95 F.

Table C-1 lists the vehicles in the test program.

Table C-1 Vehicle Sample for the Air Conditioning Analysis

Model Year	Make	Model	Vehicle Class	Weight
1990	DODGE	DYNA	CAR	3625
1990	NISSAN	MAXI 0	CAR	3375
1991	CHEVROLET	CAVA 0	CAR	2750
1991	FORD	ESCO GT	CAR	2625
1992	CHEVROLET	CAVA	CAR	3000
1992	CHEVROLET	LUMI	CAR	3375
1992	MAZDA	PROT	CAR	2750
1992	SATURN	SL	CAR	2625
1992	TOYOTA	CORO	CAR	2500
1993	CHEVROLET	CORS	CAR	3000
1993	EAGLE	SUMM 0	CAR	2500
1993	HONDA	ACCO 0	CAR	3250
1993	TOYOTA	CAMR 0	CAR	3250
1994	CHRYSLER	LHS	CAR	3750
1994	FORD	ESCO	CAR	2875
1994	HYUNDAI	ELAN	CAR	3000
1994	SATURN	SL	CAR	2750
1995	BUICK	CENT	CAR	3995
1995	BUICK	REGA LIMI	CAR	3658
1995	FORD	ESCO	CAR	2849
1995	SATURN	SL	CAR	2610
1995	SATURN	SL	CAR	2581
1996	CHEVROLET	LUMI 0	CAR	3625
1996	HONDA	ACCO	CAR	3500
1996	HONDA	CIVI	CAR	2750
1996	PONTIAC	GRAN PRIX	CAR	3625
1996	TOYOTA	CAMR	CAR	3625
1997	FORD	TAUR	CAR	3650
1998	MERCURY	GRAN MARQ	CAR	4250
1998	TOYOTA	CAMR LE	CAR	3628
1990	JEEP	CHER	LDT1	3750
1990	PLYMOUTH	VOYA	LDT1	3375
1991	CHEVROLET	ASTR 0	LDT1	4250
1991	PLYMOUTH	VOYA	LDT1	3750

Model Year	Make	Model	Vehicle Class	Weight
1992	CHEVROLET	LUMI	LDT1	3875
1993	CHEVROLET	S10	LDT1	2875
1994	CHEVROLET	ASTR	LDT1	4750
1994	PONTIAC	TRAN	LDT1	4250
1996	FORD	EXPL	LDT1	4500
1996	FORD	RANG	LDT1	3750
1990	CHEVROLET	SURB	LDT2	5250
1991	FORD	E150 0	LDT2	4000
1994	FORD	F150	LDT2	4500
1996	FORD	F150	LDT2	4500
1996	DODGE	DAKO PICK	TRUCK	4339
1996	DODGE	D250 RAM	TRUCK	4715
1996	DODGE	GRAN CARA	TRUCK	4199
1996	DODGE	CARA	TRUCK	4102
1996	FORD	F150 PICK	TRUCK	4473
1997	DODGE	GRAN CARA	TRUCK	4318
1997	DODGE	DAKOT	TRUCK	4382
1997	PONTIAC	TRANSSPOR	TRUCK	4175
1998	DODGE	CARA GRAN	TRUCK	4303
1999	FORD	WIND	TRUCK	4500