Draft MOVES2009 Highway Vehicle Temperature, Humidity, Air Conditioning, and Inspection and Maintenance Adjustments

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

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This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments.

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1. Introduction

The emission rates in the MOVES model database represent a single (base) scenario of conditions of 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 a methodology for adjusting the base emission rates to reflect the effects of local-run 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 being addressed in a separate report. The crankcase emission processes are chained to running exhaust, engine start and extended idling emissions and are thus similarly affected by the temperature adjustments describe in this report.

2. Temperature Adjustments

In EPA's previous emissions model (MOBILE6), passenger car and light-duty truck tailpipe emissions were adjusted relative to its base emission rates at 75 degrees Fahrenheit based on:

1. ambient temperature **[1]**, and

2. for start emissions, an adjustment factor based on the length of the soak time. **[2]**

MOVES will take a similar approach, but we will substantially alter the nature of the temperature adjustment factors.

2.1 Data Sources for Temperature Effects

For this analysis, we used almost entirely “Bagged” tests. Those data set consisted of Federal Test Procedure (FTP) and LA-92 tests for start emissions. For the temperature effects on running emissions we used the Bag-2 emissions of those FTPs as well as US06 tests (without engine starts). Some second-by-second test data were used (but only) to validate the effects of temperature on running emissions (HC, CO, and NOx). The data used in these analyses come from the following four sources:

1. EPA’s Mobile Source Observation Database (MSOD) as of April 27, 2005. Over the past decades, EPA has performed emission tests (usually the FTP) on tens of thousands of vehicles under various conditions. EPA has stored those test results in its Mobile Source Observational Database (MSOD). (EPA has supplemented those tests with the results from many non-EPA testing programs.)

   For the MSOD data, we limited our analysis to only tests from the vehicles that were tested at two or more temperatures. In this analyses, those paired (MSOD) tests covered the temperature range from 15 to 110 degrees Fahrenheit. Many (most) of those bagged tests (FTPs) were also used in our earlier MOBILE6 analyses.

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

http://www.epa.gov/otaq/models.htm

2. A testing program in Kansas City also yielded pairs of test (using LA92s tests rather than FTPs) from the vehicles that were tested at two or more temperatures.

3. 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 at temperatures of: 75, 40, 20, 0 and –20 ºF. These five vehicles supplemented the vehicles from the MSOD and Kansas City . **[3]**

4. 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 at temperatures of: 75, 20, and 0 ºF. These four vehicles also supplemented the vehicles from the MSOD and Kansas City.

2.2 Temperature Adjustment Methodology

For our analyses, we stratified the paired-test data by the same parameters that MOVES uses to define the Source Bins, namely: fuel type, regulatory class, and model year groups (listed on the next slide).

For this analysis, we started with the model year groups used in MOVES for start emission rates. By combining several model years into single groups, we consolidated those (MOVES) model year groups into these six model year groups:

-- 1960 to 1980
-- 1981 to 1982
-- 1983 to 1985
-- 1986 to 1989
-- 1990 to 2004
-- 2005 and later

A preliminary analysis of the test data indicated that the Tier-0, Tier-1, and LEVs all exhibited similar increases in emissions by the time the ambient temperature drops from 75º F to 20º F. A single additive adjustment factor (for each of HC, CO, NOx) can represent this.

Both the Federal FTP and California's Unified Cycle are 3-mode (or 3-bag) tests in which the first and third modes are identical driving cycles, but the first mode begins with a cold-start and the third mode begins with a hot-start start. We used the adjusted difference of Bag-1 minus Bag-3 emissions to estimate the cold-start emissions (in grams) for each test.

Similarly, we used the emissions from the FTP Bag-2, IM240, and US06 tests to estimate the ratios (i.e., multiplicative changes) in the hot-running emission rates.

We combined the test data from the passenger cars and the light-duty trucks. Therefore, the only stratifying parameter in this analysis (of gasoline-fueled vehicles) was the model year grouping. (Analyses on the heavy-duty vehicles and diesel-fueled vehicles will be presented at a later meeting.)

Then, within each model year group, we used regression analysis (of cold-start and hot-running emissions versus temperature) to find a polynomial fit to describe the change in emissions as a function to temperature.

We limited those polynomials to a multiple of “temperature minus 75º F” to either the first, second, or third degree. This produced (additive) adjustment factors that exhibit zero change at 75 degrees Fahrenheit.

2.3 Effects of Temperature on Gasoline Fueled Vehicles

Based on earlier analyses, EPA decided to model, in MOVES, the effects of ambient temperature on HC, CO, and NOx emissions:

1. Using additive (rather than multiplicative) adjustment factors.

2. Using multiples of one of the following:
   - -- the temperature minus 75° F, or
   - -- the square of the difference of the temperature minus 75° F, or
   - -- the cube of the difference of the temperature minus 75° F.

   This approach guarantees a value of zero (change) for the additive adjustment factor at 75° F (i.e., the nominal temperature of EPA’s FTP test). Those multipliers/coefficients are stored in the MOVES database table named StartTempAdjustment.

   Since the logarithms of the emissions (rather than to the emissions themselves) tend to be normally distributed (i.e., a log-normal distribution), it is often useful to apply regression analysis to the logarithms of the emissions. However, restricting the adjustment factors to one of these three forms made it impractical to use regressions of the logarithms of the emissions.

3. Setting the value of the adjustment factors equal to zero for temperatures higher than 75° Fahrenheit.

2.3.1 Temperature Effects on Gasoline Start Emissions

2.3.1.1 HC and CO Start Emissions for Gasoline-Fueled Vehicles:

As described in an earlier analysis, we used the difference in the Bag-1 emissions minus the corresponding Bag-3 emissions to estimate the cold-start emissions (in grams per start) for each test. For the gasoline-fueled vehicles, those cold-start emissions were then stratified by model year group. The mean emissions at 75 °F were subtracted from each of the means to determine the change in emissions as functions of ambient temperature. (See Appendix A for the resulting average changes.)

As noted at the beginning of this section, EPA had decided to model the changes in cold-start emissions as a polynomial (linear, or a quadratic, or a cubic) of the temperature minus 75° F. Thus, the shape of each adjustment curve at temperature below 75° F would determine the shape of that curve at temperatures above 75° F. However, the predetermined shape of the curve at temperatures above 75° F was not always in agreement (directionally) with the test data above 75° F. Therefore, EPA decided to set the value of those additive adjustment factors equal to zero for temperatures higher than 75° F. We did not use the changes in emissions from temperature above the FTP temperature range (68º to 86º F); however, those values are included (if available) in Appendix A.

We performed a linear, quadratic, and cubic regressions on the data in Appendix A and then selected the best fit from among those three. The following equations were, thus, chosen as the "best fit" predictors of the change in cold-start emissions (in grams) as functions of the ambient temperature:

For the Pre-1981s:

HC temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -0.630705748 R-sqr = 0.99271

CO temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -4.677330289 R-sqr = 0.98973

Each of those linear coefficients is stored in table StartTempAdjustment. (for the cold-start, i.e., opModeID of 108)

For the 1981-1982s:

HC temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -0.413584322 R-sqr = 0.98368

CO temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -4.630546442 R-sqr = 0.97761

For the 1983-1985s:

HC temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -0.360706640 R-sqr = 0.88660

CO temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -4.244442967 R-sqr = 0.96367

For the 1986-1989s:

HC* temperatureAdjustment = tempAdjustTermB * Sqr_of (Temp. – 75)
where: tempAdjustTermB = 0.002413998 R-sqr = 0.98895

CO temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -1.089740827 R-sqr = 0.99401

* HC test data for this model year range were available down to an ambient temperature of -20° F. However, the "best fit" HC regression curves (linear, quadratic, and cubic) all exhibited less than ideal fits to those data at temperatures from zero through 20° F. Deleting the test data at -20° F and rerunning the regressions produced an improved estimate of the cold-start HC emissions in that critical temperature range. Therefore, this proposed quadratic regression is based on the changes in cold-start emissions at only temperatures from zero through 75° F.

For the 1990-2005s:

HC* temperatureAdjustment = tempAdjustTermB * Sqr_of (Temp. – 75)
where: tempAdjustTermB = 0.002924240 R-sqr = 0.99409

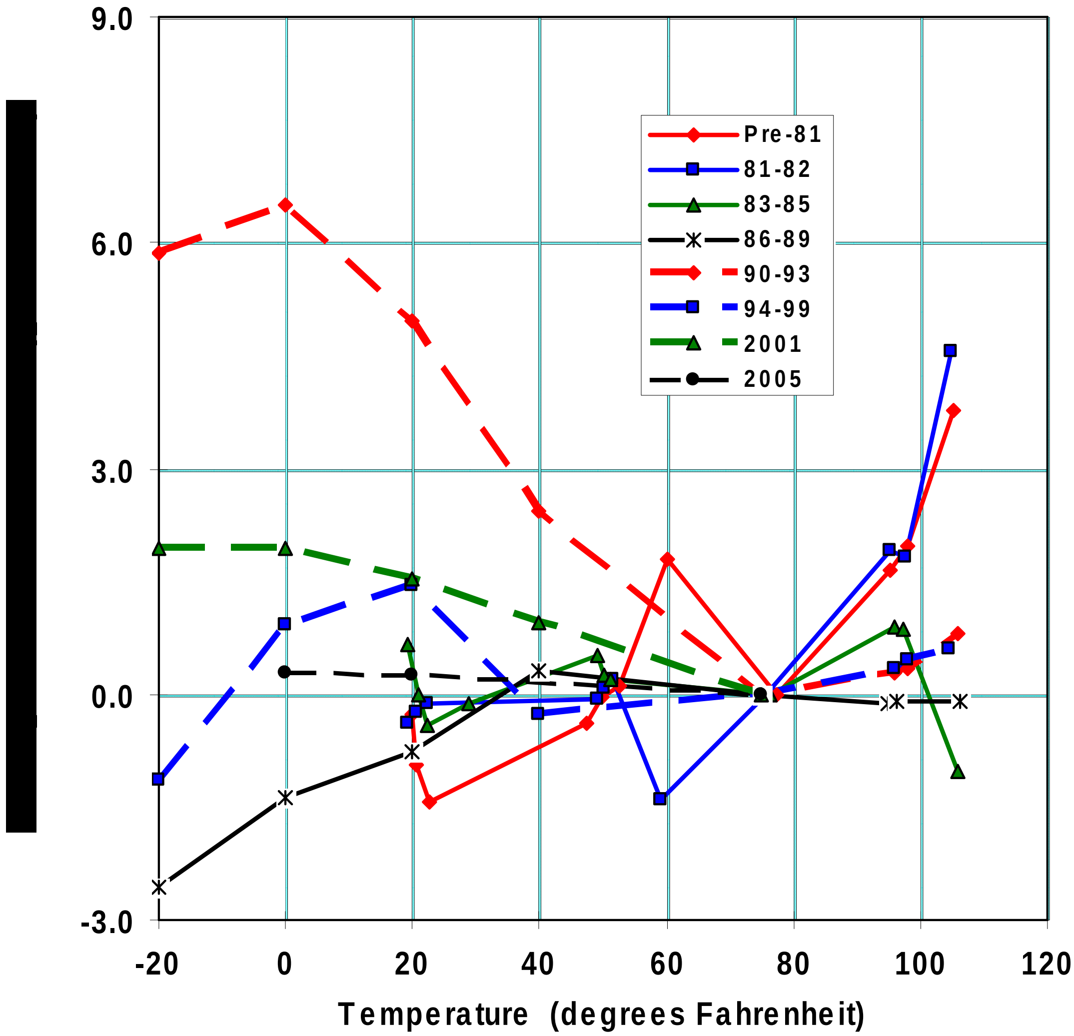
CO* temperatureAdjustment = tempAdjustTermA * (Temp. – 75) (Eqn x.x)
where: tempAdjustTermA = -1.141434345 R-sqr = 0.99017

* As with the regressions performed on the test data from the 1986 through 1989 model years, both the HC and CO regressions produced superior estimators of both HC and CO cold-start emissions (at temperatures above zero degrees F) when the test data at -20° F was omitted. Therefore, both of these regressions were based on the changes in cold-start emissions only at temperatures from zero through 75° F.

2.3.1.2 Temperature Effects on Gasoline NOx Emissions

For the effects on cold-start NOx emissions associated changes in ambient temperature, we attempted the same model year stratification that we used for the HC and CO emissions. However, as is illustrated in the following graph (Figure 1), the "by model year" temperature effects on cold-start NOx emissions did not lend themselves to linear, quadratic, or cubic regressions (possibly due to insufficient sample size). Also, not unexpectedly, most of the coefficients produced by those regression analyses were not statistically significant.

Figure 2-1 **Effects of Ambient Temperature on Changes in Cold-Start NOx**



A visual inspection of Figure 1 suggests that only three model year groups (1990-1993, 2001, and 2005) exhibited patterns that would result in meaningful regression analyses. We attempted to group the data into various other model year groups. The only grouping that produced useful regression analyses was the one in which we average together all of the NOx results (from Appendix A) to obtain the following table:

Temp	Delta NOx (grams)	Temp	Delta NOx (grams)	Temp	Delta NOx (grams)
-20.0	1.201	31.0	-0.007	54.2	0.438
0.0	1.227	40.0	0.876	76.3	0.000
19.4	0.202	48.8	0.127	95.3	0.225
20.7	0.089	49.8	0.333	97.1	0.370
22.4	-0.155	51.0	0.325	105.8	0.543

Performing regression analyses on these data (again, using only the changes in the NOx cold-start emissions for temperatures below 86º F as explained in Section 3.2), we found the "best fit" equation to be:

NOx temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -0.009431682 R-sqr = 0.611349

Although the value of R-squared is not as high as for the HC and CO regression equations, the coefficient is statistically significant. If we were to evaluate that equation for temperatures higher than 75° F, it would predict a negative change (i.e., a decrease) in the cold-start NOx emissions (i.e., a decrease in cold-start NOx emissions), but the actual data indicate that the cold-start NOx emissions increase as the ambient temperature rises above 90° F. Therefore (as with the previous adjustment factors), this additive adjustment factor is set to zero for temperatures higher than 75° F.

2.3.1.3 Temperature Effects on Gasoline PM Emissions

The effects on both cold-start and running emissions of particulate matter (PM) associated changes in ambient temperature will be modeled (in MOVES) using a multiplicative (not additive) exponential (not polynomial) adjustment factor. The analysis for that factor is included as Chapters 7 and 8 of a separate report ("Analysis of Particulate Matter Emissions from Light-Duty Gasoline Vehicles in Kansas City"). **[4]**

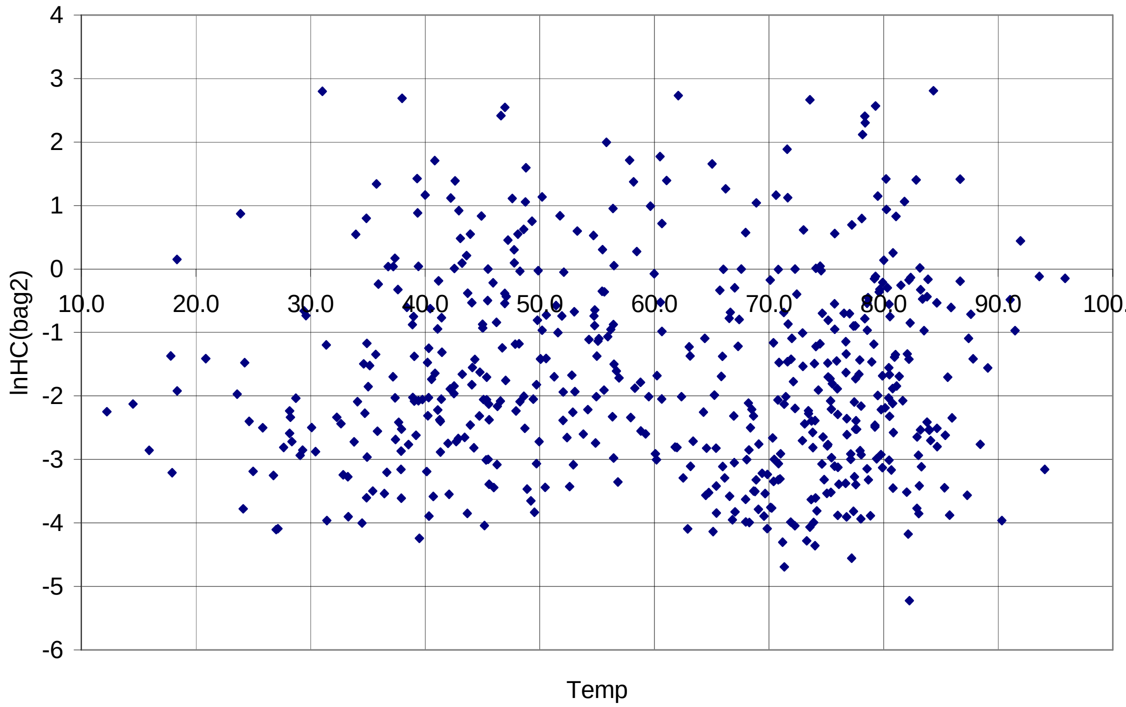
2.3.2 Temperature Effects on Gasoline Running Emissions

The test data analyzed to determine the effects of different ambient temperatures on running emissions consisted of:

1. Bag-2 of the FTP for vehicles tested at multiple temperatures,
2. US06 for vehicles tested at multiple temperatures, and
3. Remote sensing data (RSD) on a random sample of vehicles tested at Kansas City over a wide range of temperatures.
4. FTP and IM240 tests on a random sample of vehicles tested at Kansas City

Those test data suggest that there is very little variation in those running emissions of HC, CO, or NOx. Regression analyses found that the coefficients (slopes) were not statistically significant (that is, the slopes were not distinguishable from zero). This is consistent with what we found in our analysis of the Kansas City data. This lack of correlation between running emissions and ambient temperature is illustrated (as an example) by the following graph of the HC data:

Figure 2-2 Logarithm of Bag-2 HC Versus Temperature



In this plot, each point represents a single FTP Bag-2 test result from the Kansas City program. A visual inspection of this plot of the natural log of the FTP Bag-2 HC emissions suggests no strong relationship between the hot-running HC emissions and the ambient temperature.

The CO and NOx plots are similar in that they also do not indicate a significant trend.

We looked at the second-by-second test data from IM240s run in Chicago (as part of Chicago's I/M program) to validate this conclusion. To avoid the issue of preconditioning, we used only second IM240s when back-to-back IM240s were performed, and for the other IM240s we examined the last 120 seconds of full duration IM240s. We found no evidence of a trend / effect between 5 and 95 degrees F.

The effect of temperature on hot running HC, CO, and NOx emissions will be modeled in MOVES using polynomial functions as multiplicative adjustment factors. In this version of MOVES, we propose to set all of those adjustment factors equal to 1.0, that is, no change in those running emissions with temperature.

This was not the case for PM emissions which are discussed in Section 4.1.3.

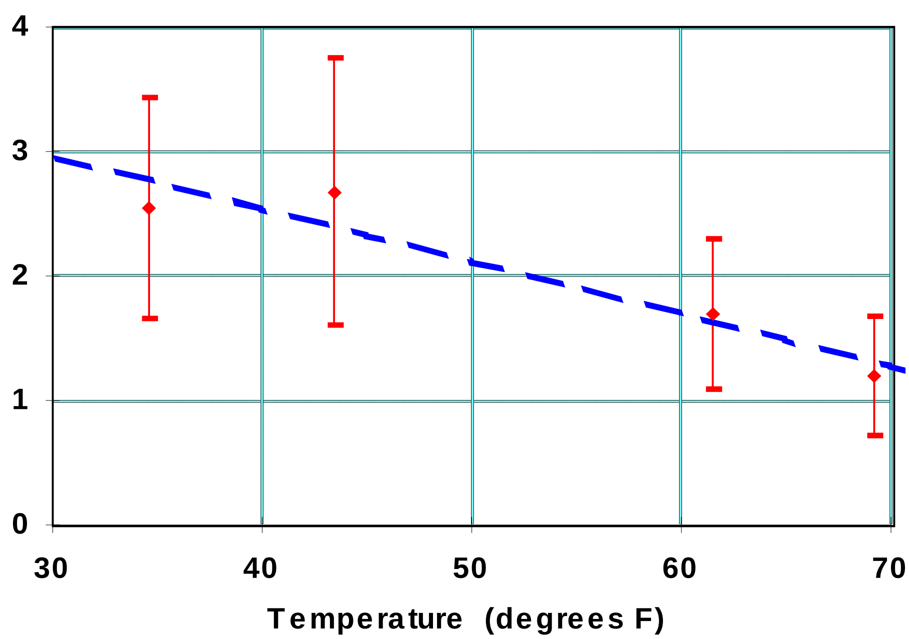
2.4 Effects of Temperature on Diesel Fueled Vehicles

We were able to identify only 12 diesel-fueled vehicles with FTPs at multiple temperatures (nine passenger cars and 3 light-duty trucks). However, only two of those 12 vehicles were tested at temperatures within the normal FTP range (68º to 86º F). The Bag-1 minus Bag-3 emissions for those tests are given below. We stratified the test results into four temperature bands which yielded the following values (grams per start):

Temp	Count	HC	CO	NOx
34.6	6	2.55	2.44	2.60
43.4	7	2.68	2.03	0.32
61.5	10	1.69	3.00	0.67
69.2	2	1.20	1.91	0.36

When we plotted the mean HC start emissions (above) versus temperature, we obtained the following graph with 90 percent confidence intervals (and a "dashed" linear regression line).

Figure 2-3 **Cold-Start HC Emissions (in grams) with Confidence Interval**



The dashed (blue) line in the figure is a linear regression line having as its equation:

HC = (-0.0420985982 * Temperature) + 4.22477812 R-sqr = 0.9040467

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

HC temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -0.0420985982

The coefficient associated with this temperature adjustment term is statistically significant although its coefficient of variation is relatively large (23.04 percent).

Again, this HC adjusstment factor represent the difference of Bag-1 minus Bag-3 and must be adjusted to estimate the cold-start HC emissions.

It proved more difficult to repeat this approach for the cold-start CO and NOx emissions from those same diesel-fueled light-duty cars and trucks because the cold-start CO and NOx emissions did not exhibit a clear trend relative to the ambient temperature. Plotting the mean CO and NOx cold-start emissions versus ambient temperature (with 90 percent confidence intervals) produced the following two graphs:

Figure 2-4 **Bag-1 minus Bag-3 CO Emissions (in grams) with Confidence Interval**

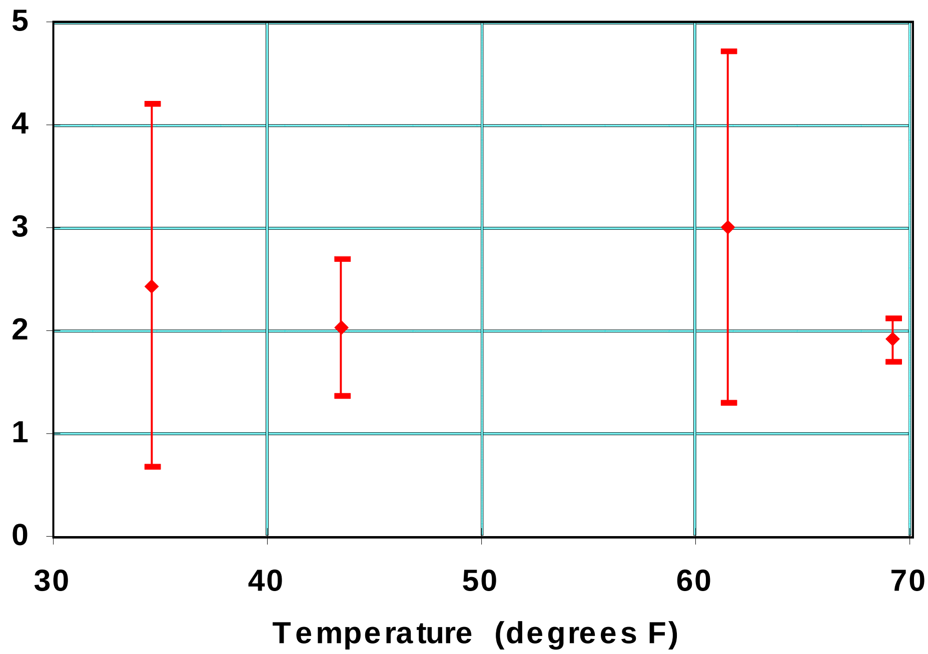
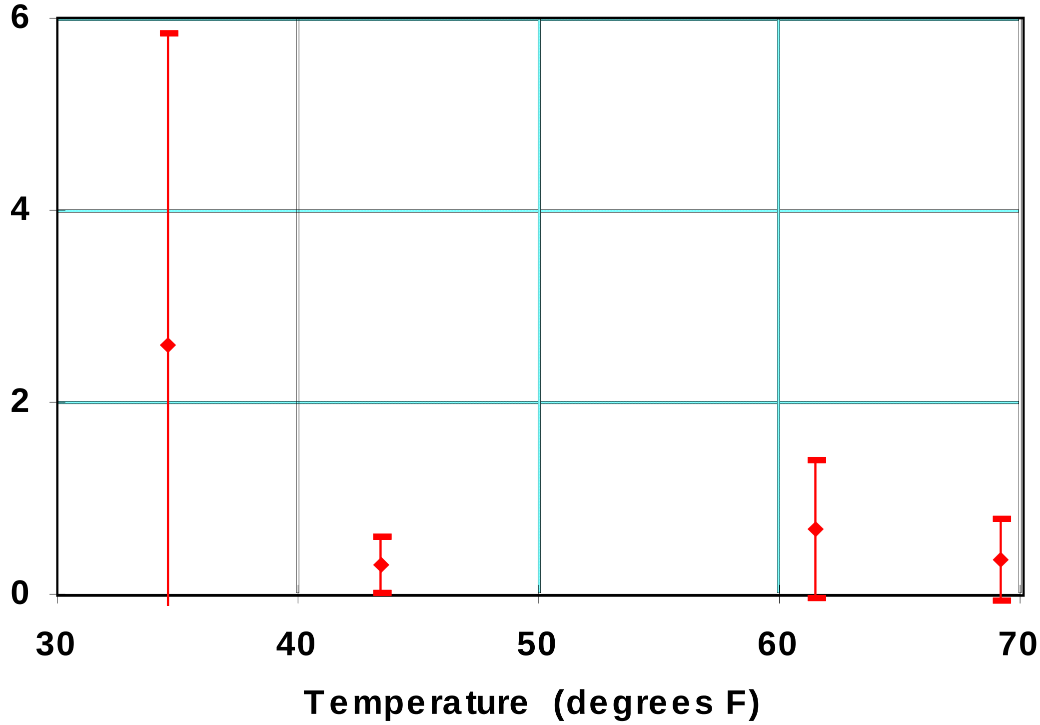


Figure 2-5 **Bag-1 minus Bag-3 NOx Emissions (grams) with Confidence Intervals**



Statistical analyses of both the diesel cold-start CO and NOx emissions failed to produce coefficients that were significantly different from zero. Therefore, for both cold-start CO and NOx adjustments from light-duty diesel-fueled vehicles, we propose to use:

CO temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = 0.0

NOx temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = 0.0

That is, neither the CO nor the NOx start emissions for diesel-fueled vehicles will vary with changes in the ambient temperature. This includes all emissions from the extended idling emission process for heavy duty long haul diesel trucks.

2.5 Cold Weather Effects

There are two sets of regulations that can affect our estimates of emissions at low temperature (i.e., at 20 degrees Fahrenheit), namely the cold weather CO requirement and the cold weather HC requirement.

2.5.1 Cold Weather CO Requirement

The cold weather CO requirement for the 1994 and newer model year LDVs and LDTs limits the composite FTP CO emissions to 10.0 grams per mile at a temperature of 20 degrees Fahrenheit. However, the FTP test results used for our analysis (for those model years) were from vehicles that were certified as meeting that cold weather composite CO requirement. Thus, the temperature adjustments (based on regressions of those FTP results) already incorporated that cold weather CO requirement into MOVES.

2.5.2 Cold Weather HC Requirement

The recently signed Mobile Source Air Toxic (MSAT-2) rule included a limit on low temperature (i.e., at 20 degrees Fahrenheit) non-methane hydrocarbon (NMHC) emissions for light-duty and some medium-duty gasoline-fueled vehicles. 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 FTP NMHC emissions should not exceed 0.3 grams per mile.
- For heavy light-duty trucks (HLDTs) (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 to be phased-in beginning with the 2010 model year, specifically:

Phase-In of Vehicles Meeting Cold Weather HC Standard

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

To incorporate this set of HC requirements into MOVES, we must first determine its impact on the start emissions (both cold-start and hot-start) as well as on the running emissions for each class of vehicles.

We already observed that changes in the ambient temperature do not have a significant effect on the running THC emissions. Therefore, we will assume that the full impact of this requirement will be on the start emissions.

Our earlier analysis of temperature effects on the emissions of Tier-2 vehicles was based on a single gasoline-fueled passenger car and three light-duty trucks that were each FTP tested at zero, 20, and 75 degrees Fahrenheit. The average nonmethane HC (NMHC) composite FTP emissions at 75º F were:

- 0.02 (0.0180) g/mile for the passenger car and
- 0.04 (0.0353) g/mile for the heavy light-duty trucks (over 6,000 GVWR).

Considering the MSAT-2 standards (0.30 and 0.50, respectively), this would mean the NMHC composite FTP emissions increasing by no more than 0.28 grams per mile (i.e., 0.30 minus 0.02) for LDVs/LLDTs and by no more than 0.46 grams per mile for HLDTs/MDPVs as the ambient temperature drops from 75º F down to 20º F.

Applying those increases in NMHC emission rates to the composite FTP (which simulates a trip of 7.45 miles in length), those rates convert to total NMHC increases of 2.086 grams (for LDVs/LLDTs) and 3.427 grams (for HLDTs/MDPVs). Since a composite FTP is composed of a 7.45 mile driving cycle plus a generic engine start (57 percent hot-start and 43 percent cold-start), those increases must represent the increases in the generic start emissions. Using the ratio of hot-start to cold-start from our earlier analysis, this results in increases in NMHC cold-start emissions (as the ambient temperature drops from 75º F down to 20º F) of:

- 0.5611592 grams for the LDVs/LLDTs and
- 0.9219045 grams for the HLDTs/MDPVs.

Since the analysis for the MSAT-2 rule assumed that increase in NMHC is linear with temperature (decreasing 55 degrees from 75 down to 20), then those rates convert to decreases in total NMHC per cold-start of:

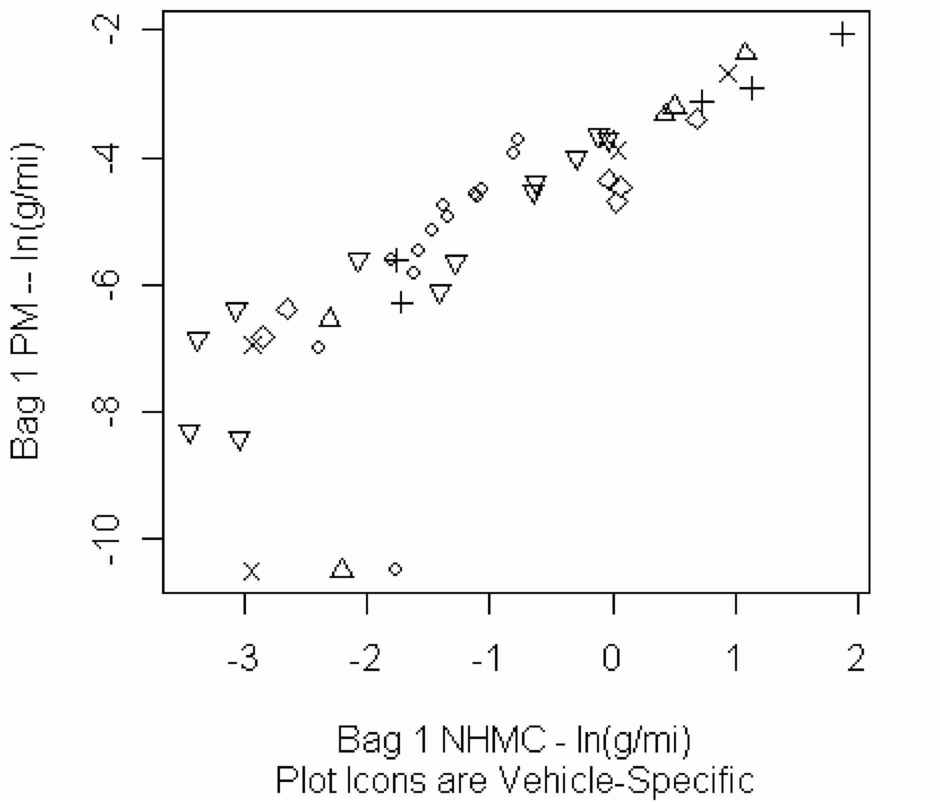
- -0.0102029 grams per degree F for the LDVs/LLDTs and
- -0.0167619 grams per degree F for the HLDTs/MDPVs.

These are the rates (slopes) that we propose to use in MOVES for cold-starts (i.e., starts that follow a 12 hour engine soak). For the seven shorter soak periods (that MOVES uses as opModes), we will continue to use the ARB soak adjustments for HC emissions for catalyst equipped vehicles to estimate those HC emissions (following the seven shorter soak periods).

2.5.3 Cold Weather PM Effects

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) document **[5]** that accompanied that rule noted there is a strong linear correlation between NMHC and PM2.5 emissions. That correlation is illustrated in the following graph (reproduced from that RIA) of the logarithm of the Bag-1 PM2.5 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 HC (or NMHC) emissions is expected to result in an ancillary reduction in cold weather PM2.5 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 20º F). Also, in the RIA, the ratio of PM to NMHC equaling 0.022 was used to estimate that PM2.5 reduction. (The 95 percent confidence interval for that ratio was 0.020 to 0.024.) 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 20º F (for Tier-2 cars and trucks).

EPA's earlier analysis (for MOVES) **[4]** indicated that ambient temperature does affect the rate of running PM emissions as well as start PM emissions, and that effect (for Tier-2 vehicles) is best modeled by (exponential) multiplicative adjustment factors of the form:

Multiplicative factor = $e^{\mathbf{A}*(72-t)}$, where "t" is the ambient temperature

and where **A** = 0.0463 for cold-starts and
0.0318 for hot running
(See Table 12 in Reference **[4]**, page 46.)

Therefore, for Tier-2 vehicles not affected by the MSAT-2 requirements, EPA expects (as the temperature decreases from 72º down to 20º F) the PM emissions to increase by factors of:

- 11.10727 for cold-starts and
- 5.22576 for hot running.

Thus, applying that 30 percent reduction for vehicles that are affected by the MSAT-2 requirements produces estimates (as the temperature decreases from 72º down to 20º F) of PM emissions increasing by factors of:

- 7.77509 for cold-starts and
- 3.65803 for hot running.

Since the vehicles affected by the MSAT-2 requirements begin to be phased-in starting with the 2010 model year, EPA expects the following (multiplicative) increases (as the temperature decreases from 72º down to 20º F):

Multiplicative Increases of PM at 20° Fahrenheit

	LDVs / LLDTs		HLDTs / MDPVs	
Model Year	**Start**	**Running**	**Start**	**Running**
2008	11.10727	5.22576	11.10727	5.22576
2009	11.10727	5.22576	11.10727	5.22576
2010	10.27423	4.83383	11.10727	5.22576
2011	9.44118	4.44189	11.10727	5.22576
2012	8.60814	4.04996	10.27423	4.83383
2013	7.77509	3.65803	9.44118	4.44189
2014	7.77509	3.65803	8.60814	4.04996
2015	7.77509	3.65803	7.77509	3.65803

Solving for the corresponding constant terms so that the preceding exponential equation will yield these increases, gives us these "A" values:

Constant Terms

	LDVs / LLDTs		HLDTs / MDPVs	
Model Year	**Cold-Start**	**Running**	**Cold-Start**	**Running**
2008	0.046300	0.031800	0.046300	0.031800
2009	0.046300	0.031800	0.046300	0.031800
2010	0.044801	0.030301	0.046300	0.031800
2011	0.043175	0.028675	0.046300	0.031800
2012	0.041398	0.026898	0.044801	0.030301
2013	0.039441	0.024941	0.043175	0.028675
2014	0.039441	0.024941	0.041398	0.026898
2015	0.039441	0.024941	0.039441	0.024941

We assume that these same magnitude increases in the PM2.5 emissions also apply to the EC and OC emissions.

Although the ARB factors that adjust the start emissions based on soak time were not developed for PM emissions from gasoline-fuel vehicles, the fact that the ratio of PM emissions to the HC emissions are almost constant suggests that we can apply the HC soak adjustment factors to the start PM emissions.

3. Humidity Adjustments

In EPA's previous emissions model (MOBILE6), only gasoline vehicle exhaust NOx emissions were adjusted for humidity. MOVES adjusts both gasoline and diesel vehicle exhaust NOx emissions. The base exhaust emission rates for NOx in all modes and all processes are multiplied by a humidity correction factor. This factor is calculated using the following formula:

K = 1.0 – ((Bounded Specific Humidity – 75.0) * Humidity Correction Coefficient)

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 larger than 124 grains. If the specific humidity input exceeds these limits, the value of the limit is used to calculate the humidity correction factor. Appendix B shows how the hourly relative humidity values are converted to specific humidity used in this equation using temperature and barometric pressure.

Humidity Correction Coefficients Used by MOVES

Fuel Type	Humidity Correction Coefficient
Gasoline	0.0038
Diesel Fuel	0.0026

The diesel humidity correction coefficient is taken directly from the Combined Federal Register **[6]**. The gasoline humidity correction coefficient is carried over from the coefficient used in the MOBILE6 model.

4. Air Conditioning Adjustments

Revised air conditioning exhaust emission correction factors are included in the MOVES model. The proposed factors are based on testing of 54 vehicles and 625 driving cycle tests in calendar years 1997 and 1998. All "A/C On" testing was done at a nominal temperature of 95 F, using a test procedure meant to simulate air conditioning emission response under extreme "real world" ambient conditions. These factors are meant to predict emissions which would occur during full loading of the air conditioning system, and will be scaled down in MOVES according to ambient conditions in a modeling run. The second-by-second emission data from each individual vehicle-cycle combination were analyzed using the MOVES methodology of binning the data according to vehicle characteristics (source bins in MOVES) and vehicle specific power bins (operating modes in MOVES). The results of the analysis showed statistically significant and consistent results for three bin combinations (deceleration, idle and cruise/acceleration) and the three primary exhaust pollutants (hydrocarbon, carbon monoxide and nitrous oxides). This report shows the results of the analysis for the air conditioning adjustments used in MOVES for HC, CO, NOx and energy consumption.

Past studies conducted in 1997 and 1998 as part of the Supplemental Federal Test Procedure (SFTP) rulemaking development process indicated that vehicle fuel consumption and exhaust emissions increase substantially when the air conditioner is in operation. During these studies vehicles were tested for exhaust emissions under full usage temperature, humidity and solar loading conditions, and at baseline conditions. These studies provided data that was subsequently used to develop multiplicative correction factors that represent full or maximum A/C system usage. In the MOBILE6.2 model these maximum A/C correction factors were scaled down so as to model more normal levels of A/C demand **[7]**.

The past analysis work was fairly complex and the reports present considerable detail in regards to the vehicle testing protocols, the work to correlate data between the two tests sites and expected real-world results, the data analysis and development of correction factors that can be used to model a range of ambient conditions. For a detailed discussion of the test data and the subsequent data analysis the reader is referred to the MOBILE6 correction factor report **[8]**. The MOVES analysis also differs considerably from the MOBILE6 model analysis. The previous analysis focused on the development of detailed mathematical algorithms which were inserted into the MOBILE6.2 model and the adjustments were only applied to exhaust emissions of oxides of nitrogen (NOx). The MOVES model is a data driven and empirical model which contains simple data relationships of highly detailed modal data.

MOVES will make adjustments to total energy consumption and exhaust running HC, CO and NOx emissions separately for each operating mode. The criteria pollutants (HC, CO and NOx) are only affected for passenger car, passenger truck and commercial light truck source types. Energy consumption is affected for all source types. The same adjustment values are used for all source use types affected within a pollutant type.

4.1 Air Conditioning Effects Data

As mentioned in the previous section, the data for the MOVES A/C Correction Factors (ACCF) was collected in calendar year 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 should eliminate most of the vehicle and test procedure variability 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 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 test and speed / 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 analysis. All second by second data were time aligned and quality controlled checked.

The model year breakdown of the data is shown in Table 4-1. It shows that all of the vehicles were 1990 through 1999 model years. It consists of 30 cars and 24 light trucks. No test data were available on other vehicle types (i.e., MC, heavy trucks, etc). The individual test cycles which the vehicles were run on are shown with the test counts in Table 4-2. The data shows a nice balance between different test cycles, and cars and trucks. Unfortunately, the study does not contain any pre-1990 model years. A complete list of the individual vehicles and a basic description is shown in Appendix A.

Only vehicles which were coded as having an emission test with the A/C system on were selected. 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 Distribution of Tests by Schedule Type

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 Method for Calculating Air Conditioning Effects

The overall dataset consisted of a sample of vehicle tests with the A/C system on and a sample of vehicle tests with the A/C system off. Both samples consisted on the same vehicles and all tests were modal with a data sampling of 1 hertz (second-by-second data collection). Prior to analysis the data for each vehicle / test cycle combination was time aligned to insure that the instantaneous vehicle operating mode was in-sync with the emission collection system. Following time alignment, the vehicle specific power (VSP) was calculated for each vehicle test / second combination. This was done using Equation 1.

$$\begin{aligned} VSP = \; & 985.5357 * Speed * Acoeff / Weight \; + \\ & 440.5729 * Speed^2 * Bcoeff / Weight \; + \\ & 196.9533 * Speed^3 * Ccoeff / Weight \; + \\ & 0.19984476 * Speed * Accel \; + GradeTerm \end{aligned} \qquad \text{Eq 1}$$

Where

VSP is the vehicle specific power for a given second of operation in units of KW / tonne.
Speed is the instantaneous vehicle speed for a given second in units miles / hour.
Accel is the instantaneous vehicle acceleration for a given second in unit of miles/hr-sec
Weight is the test vehicle weight in pounds.

Acoeff = 0.7457*(0.35/(50*0.447)) * ROAD_HP
Bcoeff = 0.7457*(0.10/(50*50*0.447*0.447)) * ROAD_HP
Ccoeff = 0.7457*(0.55/(50*50*50*0.447*0.447*0.447)) * ROAD_HP

Where

ROAD_HP = 4.360117215 + 0.002775927 * WEIGHT (for cars)
ROAD_HP = 5.978016174 + 0.003165941 * WEIGHT (for light trucks)

GradeTerm (KW/tonne) = 4.3809811 * Speed * Sin(Radians(GradeDeg))

Where

GradeDeg is the road grade in units of degrees. This term is zero for dynamometer tests.

4.3809811 (m^2 * hr / (s^3 * miles) =
9.80665(m/s^2) * 1609.34(m/mile) / 3600(secs/hr)

KW / tonne = m^2 / s^3

9.80665(m/s^2) is the gravitation constant.

After computation of VSP for each vehicle test / second combination, the individual VSPs' were grouped into the VSP bins. These VSP bins are defined in Table 3. VSP bins 26 and 36 were not defined because bins 27-30 and bins 37-40 overlap them.

VSP Bin Definitions

VSP Label	Definition
0	Braking
1	Idling
11	Low Speed Coasting; VSP< 0; 1<=Speed<25
12	Cruise/Acceleration; 0<=VSP< 3; 1<= Speed<25
13	Cruise/Acceleration; 3<=VSP< 6; 1<=Speed<25
14	Cruise/Acceleration; 6<=VSP< 9; 1<=Speed<25
15	Cruise/Acceleration; 9<=VSP<12; 1<=Speed<25
16	Cruise/Acceleration; 12<=VSP; 1<=Speed<25
21	Moderate Speed Coasting; VSP< 0; 25<=Speed<50
22	Cruise/Acceleration; 0<=VSP< 3; 25<=Speed<50
23	Cruise/Acceleration; 3<=VSP< 6; 25<=Speed<50
24	Cruise/Acceleration; 6<=VSP< 9; 25<=Speed<50
25	Cruise/Acceleration; 9<=VSP<12; 25<=Speed<50
26	Cruise/Acceleration; 12<=VSP; 25<=Speed<50
27	Cruise/Acceleration; 12<=VSP<18; 25<=Speed<50
28	Cruise/Acceleration; 18<=VSP<24; 25<=Speed<50
29	Cruise/Acceleration; 24<=VSP<30; 25<=Speed<50
30	Cruise/Acceleration; 30<=VSP; 25<=Speed<50
33	Cruise/Acceleration; VSP< 6; 50<=Speed
35	Cruise/Acceleration; 6<=VSP<12; 50<=Speed
36	Cruise/Acceleration; 12 <= VSP; 50<=Speed
37	Cruise/Acceleration; 12<=VSP<18; 50<=Speed
38	Cruise/Acceleration; 18<=VSP<24; 50<=Speed
39	Cruise/Acceleration; 24<=VSP<30; 50<=Speed
40	Cruise/Acceleration; 30<=VSP; 50<=Speed

4.3 Air Conditioning Effects on Emissions

4.3.1 A/C Correction Factors for HC, CO and NOx Emissions

An average emission result for each pollutant (HC, CO and NOx) with and without A/C operation was computed for each VSP Bin. This resulted in 69 (23 VSP bins x 3 pollutants) pairs of emission averages. However, preliminary analysis of the data grouped into the 23 bins (defined in Table 3) showed unsatisfactory statistical results. In the general, no trends were evident across VSP bins or within similar subsets of VSP bins. The trends were highly erratic and the results were generally not statistically significant. In addition, most of the bins labeled 30 or higher had very few data members. An analysis of cars versus trucks was also performed, and showed no statistical difference between the two.

To produce more consistent results, the individual VSP bins were collapsed down to three principal bins. These are the Braking / Deceleration bin, the Idle bin and the Cruise / Acceleration bin. All three of these large bins are really quite different in terms of engine operation and emissions performance. The Braking bin consisted of VSP Bin 0 in Table 3, the Idle bin was VSP Bin 1 and the Cruise / Acceleration bin contained the remaining 21 bins. Full A/C correction factors were generated for each of the nine VSP Bin and pollutant combinations. This was done by dividing the mean With A/C emission factor by the mean Without A/C emission factor for each of the VSP Bin / pollutant combinations. The Full A/C correction factors are shown in Table 4. Measures of statistical uncertainty (coefficient of variation of the mean) were also computed using the standard error of the mean. They are also shown in Table 4 in the column labeled Mean CV of CF.

Full Air Conditioning Correction Factors for HC, CO and NOx

Pollutant	Operating Mode	Full A/C CF	Mean CV of CF
HC	Braking / Decel	1.0000	0.48582
HC	Idle	1.0796	0.74105
HC	Cruise / Accel	1.2316	0.33376
CO	Braking / Decel	1.0000	0.31198
CO	Idle	1.1337	0.77090
CO	Cruise / Accel	2.1123	0.18849
NOx	Braking / Decel	1.0000	0.19366
NOx	Idle	6.2601	0.09108
NOx	Cruise / Accel	1.3808	0.10065

4.3.2 Full A/C Correction Factors for Energy Emissions

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 VSPBin (see above for explanation of VSPBin). A mean value was computed for each combination of VSPBin. Separate analysis was done as a function of sourcebinid (combination of vehicle type, fuel type and model year), and the results were not statistically different versus sourcebinid given the relatively small sample sizes. As a result, the A/C correction factors for energy are a function of only VSPBin. The resulting A/C correction factors are shown in Table 5.

Full Air Conditioning Correction Factors for Energy

VSPBin	A/C Factor	VSPBin	A/C Factor	VSPBin	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		

Only very small amounts of data were available for VSPBins 26 through 29 and VSPBins 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 VSPBins. 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 engine power devoted to an A/C compressor probably continues to decline as the overall power demand of the engine is increased. In fact, in some newer vehicle designs the A/C unit will be shut off by an engine controller, if the driver demands a very high level of power from the vehicle. If an when new or additional data become available on this issue, EPA will re-evaluate the assumption of a constant A/C factor for the high VSPBins.

4.3.3 Uncertainty Analysis

Measures of statistical uncertainty -coefficient of variation of the mean (mean CV) were calculated using the following formula. The exact set of equations were used for each of the three pollutants (although the equation are shown only once). The values of X and Y represent second by second emissions from HC, CO and NOx. The variable "X" represents emissions with the A/C On and "Y" represents emission with the A/C Off.

Given:

$$Z = X / Y$$

$$\text{Mean CV} = SE_z / Z$$

Where Z is the ratio of A/C On emissions (X) to A/C Off emissions (Y)
SE_z is the standard error of Z
Mean CV is the coefficient of variation of the mean

$$Vz^2 = (\delta Z/\delta X)^2 * V_x^2 + (\delta Z/\delta Y)^2 * V_y^2$$

Where V_z is the variance of Z, V_x is the variance of X and V_y is the variance of Y
$\delta Z/\delta X$ is the partial derivative of Z with respect to X
$\delta Z/\delta Y$ is the partial derivative of Z with respect to Y

$$(V_z / Z)^2 = ((1/Y^2)*V_x^2) / (X^2/Y^2) + ((X^2/Y^4) * V_y^2) / (X^2/Y^2)$$

This equation reduces down to:

$$(V_z / Z)^2 = (V_x / X)^2 + (V_y / Y)^2$$

And ultimately to:

$$SE_z / Z = \text{SQRT} [(SE_z / X)^2 + (SE_z / Y)^2]$$

The variance term is defined as:

$$V_z = (1/Y)^2 * Sy2x + (-X/Y^2) * (-X/Y^2) * Sy2y;$$

Where

$$X = \text{A/C On emissions}$$
$$Y = \text{A/C Off emissions}$$

The term V_z represents a contribution from both the X and Y emissions terms (A/C On and A/C Off). The terms Sy2x and Sy2y also include variance contributions of the "across sample variance" and the "within a given vehicle test" variance. The "across sample variance" is the standard variance of the sample and is computed within a given sourcetype (vehicle type such as car, light truck, heavy truck, etc) and operating mode bin (one of the 23 VSP bin types – See Table 3). The "within a given vehicle test" variance is the additional variance due to the fact that each vehicle test contributes hundreds or even thousands of test data elements. Because two data elements may come from the same vehicle, they are not strictly independent of each other.

$$Sy2x = SA2x / nVeh + SB2x / nCell$$
$$Sy2y = SA2y / nVeh + SB2y / nCell$$

$SA2x = (1 / (nVeh-1)) * Sum1x$
$SB2x = (1 / (nCell – nVeh)) * Sum2x$

$SA2y = (1 / (nVeh-1)) * Sum1y$
$SB2y = (1 / (nCell – nVeh)) * Sum2y$

And

$Sum1x = \Sigma (YbarVeh_x – YbarCell_x)^2$
$Sum2x = \Sigma (varVeh_x – (nMeas – 1))^2$

$Sum1y = \Sigma (YbarVeh_y – YbarCell_y)^2$
$Sum2y = \Sigma (varVeh_y – (nMeas – 1))^2$

Where

The sums (Σ) are across sourcetype and operating mode.

nMeas Count of data elements within a given sourcetype, operating mode and vehicle test.

nVeh Count of data elements within a given vehicle test

nCell Count of data elements within a given sourcetype and operating mode

varVeh Variance for each vehicle test. Separate values for both X and Y are calculated.

YbarVeh Mean emission rate for each vehicle test. Separate values for both X and Y are calculated.

YbarCell Mean emission rate for each sourcetype and operating mode. Separate values for both X and Y are calculated.

Except for broad groupings, VSP was not found to be an important variable in regards to A/C correction factor and A/C usage. However, Full A/C correction factors greater than unity were found for all pollutants for both Idle and Cruise / Acceleration modes. For NOx Idle mode, a fairly large multiplicative correction factor of 6.2601 was obtained. This large factor reflects the relatively low levels of NOx emissions during idle operation. A moderately high multiplicative A/C correction factor of (2.1123) for CO cruise / Accel was also obtained. This correction factor will double CO emissions under extreme conditions of A/C usage. A/C correction factors of less than unity or unity where found for the Braking / Deceleration mode for all three pollutants. These were set to unity for use in the MOVES model.

4.4 Adjustments to Air Conditioning Effects

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.

weightedFullACAdjustment = SUM(fullACAdjustment*opModeFraction)

Since not all vehicles are equipped with air conditioning and air conditioning is normally not on all of the time, the full air conditioning effect on emissions is adjusted before it is applied to the emission rate. The SourceTypeModelYear table of the MOVES database contains the fraction of vehicles in each model year that are equipped with air conditioning **[7]**.

Fraction of Vehicles Equipped with Air Conditioning (ACPenetration)

Model Year	Passenger Cars	All Trucks and Buses
1971*	0.592	0.287
1972	0.592	0.287
1973	0.726	0.287
1974	0.616	0.287
1975	0.631	0.287
1976	0.671	0.311
1977	0.720	0.351
1978	0.719	0.385
1979	0.694	0.366
1980	0.624	0.348
1981	0.667	0.390
1982	0.699	0.449
1983	0.737	0.464
1984	0.776	0.521
1985	0.796	0.532
1986	0.800	0.544
1987	0.755	0.588
1988	0.793	0.640
1989	0.762	0.719
1990	0.862	0.764
1991	0.869	0.771
1992	0.882	0.811
1993	0.897	0.837
1994	0.922	0.848
1995	0.934	0.882
1996	0.9484	0.9056
1997	0.9628	0.9292
1998	0.9772	0.950
1999	0.980	0.950
2000**	0.980	0.950

* 1971 model year fractions are applied to all previous model years.

Fraction of Vehicles Equipped with Air Conditioning (ACPenetration)		
Model Year	Passenger Cars	All Trucks and Buses
** 2000 model year fractions are applied to all later model years. Motorcycles are not adjusted for air conditioning.		

The fraction of vehicles whose air conditioning is operational varies by age of the vehicle and is stored in the SourceTypeAge table of the MOVES database.

Fraction of Air Conditioning Units Still Functioning By Age					
Age	Functioning	Age	Functioning	Age	Functioning
1	1.00	11	0.98	21	0.95
2	1.00	12	0.98	22	0.95
3	1.00	13	0.96	23	0.95
4	0.99	14	0.96	24	0.95
5	0.99	15	0.96	25	0.95
6	0.99	16	0.96	26	0.95
7	0.99	17	0.96	27	0.95
8	0.98	18	0.95	28	0.95
9	0.98	19	0.95	29	0.95
10	0.98	20	0.95	30	0.95

An equation is used to predict 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 index **[7]**) of the air outside their vehicles. The heat index values are stored in the ZoneMonthHour table of the MOVES database.

ACOnFraction = ACActivityTermA
+ heatIndex*(ACActivityTermB + ACActivityTermC*heatIndex)

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.

ACAdjustment = 1+ ((weightedFullACAdjustment-1)
* ACPenetration*functioningACFraction*ACOnFraction)

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

5. Inspection and Maintenance Programs

Inspection and Maintenance (I/M) programs are generically any state-run or locally mandated inspection of highway motor vehicles intended to identify those vehicles most in need of repair and requires repairs on those vehicles. Since these programs are locally run, there is great variability in how these programs are designed and the benefits that they generate in terms of emission reductions from highway motor vehicles.

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. The reader who is interested in a more thorough treatment of the topic is encouraged to review the relevant MOBILE documentation **[9]**.

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 affects 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.

With the passage of time, the non-I/M and I/M emission cases diverged from each other with the I/M function being lower. The percentage difference between these two functions 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). The I/M reference rates were derived using data from the enhanced program in Phoenix, Arizona, and represent the design features of that program. The difference between the non-I/M and I/M reference rates are assumed to represent the I/M benefit of Phoenix program design assuming perfect compliance. Equation 1 shows this relationship in a mathematical form.

Standard I/M difference = $E_{noim} - E_{im}$ Eq 1

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

The Phoenix program design was selected as the reference program because virtually all of the underlying data came from this source, and not due to the strengths or weaknesses of this specific program. In MOVES, it is this general I/M design which is the model, not the actual Arizona I/M program as it is operated.

The object of this modeling process is to generate a general model which can be used to represent all I/M programs in the United States. This goal was achieved by comparing 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 2,

$$E_{\mathrm{p}} = RE_{\mathrm{IM}} + (1-R)E_{\mathrm{nonIM}} \qquad \text{Eq 2}$$

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 factor 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 less than E_{IM}. In general, this framework can, in concept, 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 2 and solving for R gives leads to Equation 3a and 3b. These equations show the I/M adjustment factor to the ratio of the emission difference between a proposed I/M program design and the Standard I/M Difference

$$R = \frac{E_{\mathrm{p}} - E_{\mathrm{nonIM}}}{E_{\mathrm{IM}} - E_{\mathrm{nonIM}}} \qquad \text{Eq 3}$$

5.3 Development of MOVES IMFactors

Early in the MOVES development process it was decided that developing the IMFactors based on the basis of completely new analysis would prove 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 combinations of old model years at young ages (i.e., a 1985 model year at age five). As a result, EPA decided to develop IMFactors based on the representation of relevant design features 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 utilized. The IMFactor table includes the following fields:

- Pollutant / Process
- Test Frequency
- Test Type
- Test Standard
- Regulatory Class
- Fuel Type (Only gasoline/ethanol fuels have IMFactors)
- Model Year Group
- Age Group
- IMFactor

The IMFactor was computed for each combination 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 describing the reference program (Reference design, E_R). The IMFactor is the ratio of the mean emission results from these two runs. Equation 4 illustrates the simple formula.

$$R_{\mathrm{p}} = \frac{E_{\mathrm{p}}}{E_R} \qquad \text{Eq 4}$$

The Reference program has inputs matching the Phoenix 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 OBC-II scans for MY 1996 and late). 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 5-1 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. The first four runs represent the Non I/M reference and the three Phoenix I/M references. 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 HC, CO and NOx.

Table 5-1. MOBILE6.2 Runs Used to Populate the MOVES IMFactor Table

RUN #	Description	Type
1	Non IM 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 IM Design
6	Annual - IM240 - Phase-in Cutpoints	Target IM Design
7	Biennial - IM240 - Final Cutpoints	Target IM Design
8	Annual - IM240 - Final Cutpoints	Target IM Design
9	Biennial - ASM 2525/5015 - Phase-in Cutpoints	Target IM Design
10	Annual - ASM 2525/5015 - Phase-in Cutpoints	Target IM Design
11	Biennial - ASM 2525/5015 - Final Cutpoints	Target IM Design
12	Annual - ASM 2525/5015 - Final Cutpoints	Target IM Design
13	Biennial - ASM 2525 - Phase-in Cutpoints	Target IM Design
14	Annual - ASM 2525 - Phase-in Cutpoints	Target IM Design
15	Biennial - ASM 2525 - Final Cutpoints	Target IM Design
16	Annual - ASM 2525 - Final Cutpoints	Target IM Design
17	Biennial - ASM 5015 - Phase-in Cutpoints	Target IM Design
18	Annual - ASM 5015 - Phase-in Cutpoints	Target IM Design
19	Biennial - ASM 5015 - Final Cutpoints	Target IM Design
20	Annual - ASM 5015 - Final Cutpoints	Target IM Design
21	Annual - OBD -	Target IM Design
22	Annual - LOADED/IDLE	Target IM Design
23	Biennial - IDLE	Target IM Design
24	Annual - IDLE	Target IM Design
25	Biennial - 2500/IDLE	Target IM Design
26	Annual - 2500/IDLE	Target IM 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).

In addition to the IMFactor, MOVES adjusts rates for particular programs by applying an additional multiplicative "Compliance Factor" (IMCompliance). The IMFactor (R) represents the theoretical effectiveness of a specific I/M program design, relative to the reference design, as described above.

Values of the IMComplianceFactor (C) are specific to individual programs and represent its overall operational effectiveness and efficiency, aside from the effectiveness inherent in its design. Variables which impact the IMCompliance factor include waiver rates, compliance rates and overall operational efficiency. Default IMComplianceFactors are provided in the MOVES database, but alternate values may be entered by the user for specific analyses. The default factors were taken from the 2005 EPA National Emission Inventory (NEI) **[10]**, and are based on data submitted by individual states in their State Implementation Plan (SIP) processes. The vast majority of the default IMCompliance factors are greater than 90 percent.

5.4 Development of MOVES IM Compliance Inputs

The default I/M Compliance inputs are contained in the IMCoverage table in the MOVES database. The structure of the table is:

- Pollutant / Process
- State / County
- Year
- Regulatory Class
- Fuel Type (only gasoline fuels)
- Beginning Model Year of Coverage
- Ending Model Year of Coverage
- InspectFreq
- IMProgramID
- I/M Test Type
- I/M Test Standards
- Ignore I/M toggle (user control variable)
- Compliance Factor

The IMCoverage table structure shows that the IM Compliance Factor is a function of numerous variables that include geography, time, vehicle type / fuel / coverage factors, program test frequency and specific I/M test / I/M test standards types. The Ignore I/M toggle is a user feature that allows the user to completely disable the effects of I/M for one or more of the parameter combinations.

For state SIPs, it is expected that the state will enter their own set of Compliance Factors which reflect current and expected future program operation. The data in the default MOVES table is likely out of date (i.e., 2005 NEI), and has not been cross referenced or updated with recent state I/M program designs / changes.

The underlying data used to construct the default Compliance Factors were taken from MOBILE6.2 input files used in the NMIM model to compute the National Emission Inventory of 2005. The following data files were extracted and processed into the various fields in IMCoverage table.

Table 5-2. I/M Coverage Table Data Sources

NMIM Data Source	MOVES I/M Coverage Parameter
MOBILE6 Compliance Rate	Used in the MOVES Compliance Rate Calculation
I/M Cutpoints	Used to determine MOVES I/M Test Standards
MOBILE6 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 Regulatory Class input
MOBILE6 Waiver Rate	Used in the MOVES Compliance Rate Calculation

As seen in Table 5-2, MOBILE6.2 and MOVES do not have exactly compatible parameter definitions. Extraction and processing of the MOBILE6.2 inputs for all of the individual states was required. The MOBILE6 compliance rate, waiver rate and Effectiveness rate were used to determine the MOVES Compliance Rate. The new MOVES Compliance Rate is a broader concept that incorporates three separate MOBILE6.2 inputs. Equation 6 shows the relationship.

$$C = \text{M6 Compliance Rate} \times \text{M6 Effectiveness Rate} \times (1 - \text{M6 Waiver Rate}) \quad 6$$

The MOBILE6.2 IM 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 regulatory class.

6. References

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Appendix A: Mean Start Emission by Temperature

Change in Mean Start Emissions at Various Temperatures

By Model Year Group

Relative to 75° F

Model Yr Group	Temp	HC (grams)	CO (grams)	NOx (grams)
Pre-81	19.75	36.090	226.941	-0.274
Pre-81	20.67	33.018	254.386	-0.925
Pre-81	22.63	30.560	276.341	-1.445
Pre-81	47.55	18.569	129.472	-0.380
Pre-81	49.78	15.252	120.931	-0.034
Pre-81	52.52	18.099	115.776	0.101
Pre-81	60.14	11.120	53.617	1.790
Pre-81	77.31	0	0	0
Pre-81	95.36	-2.122	-58.656	1.640
Pre-81	98.06	-1.755	-67.555	1.975
Pre-81	105.06	-4.935	-86.689	3.769

Model Yr Group	Temp	HC (grams)	CO (grams)	NOx (grams)
81-82	19.36	21.120	231.180	-0.374
81-82	20.69	23.363	242.806	-0.252
81-82	22.33	25.496	253.865	-0.135
81-82	49.20	7.782	109.851	-0.066
81-82	50.31	8.202	120.239	0.065
81-82	51.43	9.209	132.360	0.194
81-82	59.15	6.432	135.063	-1.416
81-82	75.73	0	0	0
81-82	95.22	-4.659	-144.116	1.915
81-82	97.75	-5.450	-174.532	1.814
81-82	105.00	-9.958	-343.847	4.568

APPENDIX A Continued

Change in Mean Start Emissions at Various Temperatures

By Model Year Group

Relative to 75° F

Model Yr Group	Temp	HC (grams)	CO (grams)	NOx (grams)
83-85	19.32	23.299	218.857	0.665
83-85	21.00	17.755	218.151	-0.017
83-85	22.48	14.599	216.439	-0.414
83-85	28.80	20.594	186.549	-0.126
83-85	48.99	5.213	94.414	0.513
83-85	50.33	5.946	93.032	0.250
83-85	51.30	6.490	95.495	0.183
83-85	76.20	0	0	0
83-85	95.81	-1.044	-29.275	0.903
83-85	97.19	-1.209	-35.995	0.868
83-85	105.79	-1.124	-25.407	-1.010

Model Yr Group	Temp	HC (grams)	CO (grams)	NOx (grams)
86-89	-20	27.252	178.536	-2.558
86-89	0	25.087	147.714	-1.360
86-89	20	14.011	104.604	-0.749
86-89	40	8.316	78.525	0.312
86-89	75	0	0	0
86-89	95.03	-0.127	-4.257	-0.137
86-89	96.43	-0.139	-5.354	-0.091
86-89	106.29	-0.729	-1.017	-0.084

Model Yr Group	Temp	HC (grams)	CO (grams)	NOx (grams)
1990-2005	-20	38.164	143.260	1.201
1990-2005	0	16.540	92.926	1.227
1990-2005	20	8.154	56.641	1.082
1990-2005	40	4.872	33.913	0.876
1990-2005	75	0	0	0

Appendix B – Calculation of Specific Humidity

Equations to convert from 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

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

$$T_0 = 647.27 - T_K$$

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

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

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

$$= 6527.557 * 10^{\left(-T_0/T_K\right)\left[\frac{\left(3.2437 + 0.00588 T_0 + 0.0000000117 T_0^3\right)}{1 + 0.00219 T_0}\right]}$$