Technical Report

# Effects of Low Ambient Temperature on the Exhaust Emissions and Fuel Economy of 84 Automobiles in Chicago

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by

Wayne Heinmiller

Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air, Noise and Radiation

Abstract

This report describes the results of a project in which pairs of tests were conducted on 84 in-use passenger cars, once under low temperature conditions (16°F to 57°F), and again under standard laboratory conditions. Each sequence included the 1975 Federal Test Procedure (exhaust emissions only), the Highway Fuel Economy Test and three short cycle tests. The vehicles were obtained randomly from private owners in the Chicago area and represented the 1972-1977 model years. They were tested in an "as-received" condition. The work was performed during the period from January through March, 1978 using a test cell exposed to prevailing outdoor ambient conditions.

Results show that HC and CO are most sensitive to cold temperature, while NOx is affected only slightly. At an average of 23°F, vehicles in the fleet produced approximately 50% more HC, 75% more CO, and 5% less NOx when compared to results under normal conditions. Fuel economy suffered by an average of 7%. The initial (cold transient) phase of the FTP is the most negatively affected by colder temperatures. The final (hot transient) phase is least sensitive to low temperature operation. Vehicle fleets from manufacturers which use different control technologies were found to behave considerably differently at low temperatures.

## Introduction

Serious attempts have been made to reduce air pollution created by motor vehicles in the past several years. Emission standards for new vehicles have been set by the federal government to try to control this problem. Tests are performed to determine if new vehicles meet these standards. However, these tests are performed under a narrow range of environmental conditions, while vehicles in actual use operate under more varied conditions. To more fully evaluate success in controlling total emissions, the contribution of motor vehicles must also be evaluated under environmental conditions that differ from the narrow range used for certification.

One of the larger variations that a vehicle must undergo in-use is temperature. To determine if pollution control efforts now in use are reducing emissions across the entire spectrum of temperatures normally encountered, testing at various temperatures is necessary. Certification tests are run between 68° F and 86° F, towards the higher end of the temperature range in which most vehicles usually operate. Of interest then, is vehicle emission performance at lower temperatures.

## Objective

The objective of this program was to gather information on how exhaust emissions from typical passenger cars are affected by low ambient temperatures.

## Program Design

General Test Design - The goal of the project was to provide two sets of emissions results on each vehicle, one set under conditions of low ambient temperature and the other under standard test conditions. Each vehicle underwent a test sequence at a low temperature followed by a test sequence under normal laboratory temperatures. Tests performed included the 1975 Federal Test Procedure, Highway Fuel Economy Test, Federal Short Cycle Test, Two-Speed Idle Test, and the Federal 3-Mode Test.

Selection of Test Vehicles Vehicles for low-temperature testing were selected from the 433 vehicles used in the FY77 Emission Factors program in Chicago. These vehicles were of the 1972-1977 model years and were obtained from randomly-selected local residents. A vehicle's participation in the low-temperature portion of the program was determined by the testing schedule and the forecast of the outside temperature at the time it was scheduled for its first test.

In all, 84 vehicles were selected for low temperature tests. Originally, 150 vehicles were scheduled, but the rapid onset of warm weather prevented testing all of them. The original 150 vehicles were chosen to be representative of the national fleet in age, make and type. Since

TABLE 1: Fleet Breakdown by Make and Model Year

| | Model Year | | | | | | |
|---|---|---|---|---|---|---|---|
| | 77 | 76 | 75 | 74 | 73 | 72 | Total |
| American Motors | 1 | 1 | - | - | - | - | 2 |
| Buick | 2 | 2 | 2 | 1 | 1 | 1 | 9 |
| Cadillac | 2 | 1 | 1 | - | - | - | 4 |
| Chevrolet | 6 | 6 | 3 | - | 2 | 2 | 19 |
| Chrysler | - | - | 1 | - | - | - | 1 |
| Dodge | 2 | 1 | 1 | 1 | 1 | 1 | 6 |
| Ford | 9 | 4 | 3 | 1 | 2 | 1 | 20 |
| Lincoln | - | - | 1 | - | - | - | 1 |
| Mercury | 1 | - | - | - | - | 1 | 2 |
| Oldsmobile | 4 | 3 | 2 | 1 | 1 | - | 11 |
| Plymouth | 1 | - | - | 1 | 1 | - | 3 |
| Pontiac | 2 | 1 | - | - | - | 1 | 4 |
| Volkswagen | 1 | - | - | - | - | - | 1 |
| Totals | 31 | 19 | 14 | 5 | 8 | 7 | 84 |

TABLE 2: Fleet Breakdown by Number of Engine Cylinders

| | | Model Year | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 77 | 76 | 75 | 74 | 73 | 72 | Totals |
| Number | 8 | 24 | 16 | 12 | 3 | 7 | 6 | 68 |
| of | 6 | 4 | 2 | 1 | 2 | 1 | 1 | 11 |
| Cylinders | 4 | 3 | 1 | 1 | 0 | 0 | 0 | 5 |

not all of the 150 vehicles were tested, the actual sample is not as representative as originally planned. A breakdown of the test fleet by year, make and number of cylinders is given in Tables 1 and 2.

Test Facilities Testing was performed during January, February and March of 1978 at the facilities of Automotive Testing Laboratories in Bensenville, Illinois, a suburb of Chicago. This facility consisted of three separate areas (See Figure 1). One area was used for both the cold soak and low-temperature dynamometer tests. The large garage doors in this area were left open in an attempt to maintain temperatures in the dynamometer and test area equal to those outside. The second area contained another dynamometer for normal laboratory testing, as well as all analyzer equipment for both the cold and warm testing areas. The third section was used for soaking the vehicle which would be tested inside the laboratory. Vehicles undergoing the cold weather test were soaked outside.

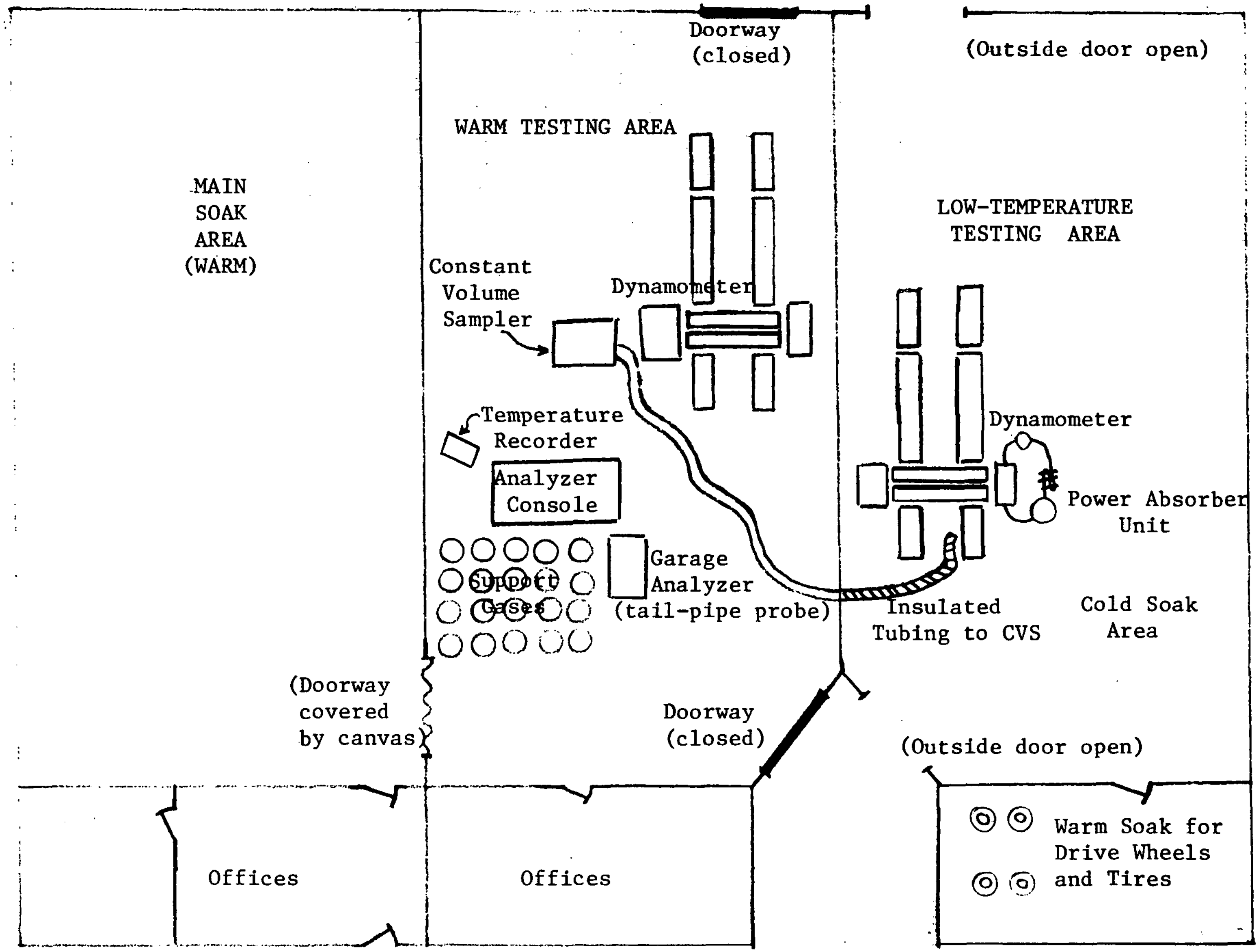
There were several differences between the equipment set-up in the cold test area and the normal set-up for performing basic emission testing. To allow the dynamometer power absorber unit (PAU) to operate in below-freezing temperatures, anti-freeze had to be added to the water in the system. The system was set up to recycle the fluid rather than to operate on a once-through basis. After passing through the PAU, the fluid was run through a heat-exchanger and then into a 55 gallon drum used as a reservoir. From the drum, it returned to the PAU. The flywheels on the dynamometer were completely enclosed and the bearings were heated by radiation from incandescent lights. The exhaust tubing was wrapped in insulation and passed through the wall to the constant volume sampling unit and analyzer in the warm test area.

Test Procedures Vehicles were allowed to soak under outdoor conditions between 12 and 24 hours before testing.

Cold tires inflated to the pressure necessary for dynamometer operation were expected to produce problems with tire breakage, so the drive tires and wheels were removed from the vehicle and stored in a warm area while the vehicle was soaking outside. The vehicles were tested in an "as-received" condition. No maintenance work or adjustments were performed before testing.

For the cold testing, the vehicle was tested with its own tank fuel. For the warm tests, the tank was drained and refilled with appropriate Indolene fuel. No heat builds were performed on the fuel tank and no evaporative emission tests were performed.

FIGURE 1: Layout of Test Facilities



## General Results

Different methods of quantifying the data to allow analysis and comparison were investigated. Ratios of cold emissions to warm emissions, differences between warm and cold emissions and absolute levels of emissions were all examined. Statistical analysis showed that all figures generated for comparison are strongly correlated to a vehicle's performance on the standard FTP, which depends on the condition of the engine and the degree to which it is tuned to specifications. Because these variables are not quantifiable, it is not possible to directly compare results from different vehicles. However, it is possible to note general trends in the vehicle population tested.

For each of the six model years of vehicles tested, the mean composite hydrocarbon (HC) and carbon monoxide (CO) levels are significantly higher in the low-temperature FTP than in the normal FTP(See figures 2 and 3, and table 3). These means are likely to be exaggerated by outliers. For the model years 1975-1977, the majority of the vehicles tested lie below the mean (see table 4). Overall, 86% of the vehicles produced higher HC levels in the low-temperature FTP, while 87% produced more CO. The significance of the differences in oxides of nitrogen (NOx) caused by temperature varies with model year. With model years 1972-74 grouped together, and using a signficance level of .80, it may be concluded that the cold and warm NOx emissions do not differ. To make the same conclusion with 1977 vehicles, a much tighter significance level of .02 must be used.

As the test sequence progressed and the vehicle warmed up, the HC and CO emissions from the vehicles in low-temperatures generally improved in relation to the normal-temperature test emissions. In many cases, the final sample bags from low-temperature tests showed fewer emissions than the same sample bags in the warm tests.

## Results of FTP measurements

Three kinds of comparisons were made. First, a qualitative comparison between the level of emissions on the warm and cold tests can be made. Secondly, a quantitative comparison of these figures can be made by calculating the ratio of cold emissions to warm emissions. This is the technique which has been used frequently by other researchers investigating low-temperature emissions. Finally, it is possible to compare the number of vehicles which produced lower emissions in the warm tests (compared to their cold test results) to the number of vehicles which produced lower emissions in the low-temperature tests.

Mean Composite Emission Levels -- Low-Temperature and Normal FTP

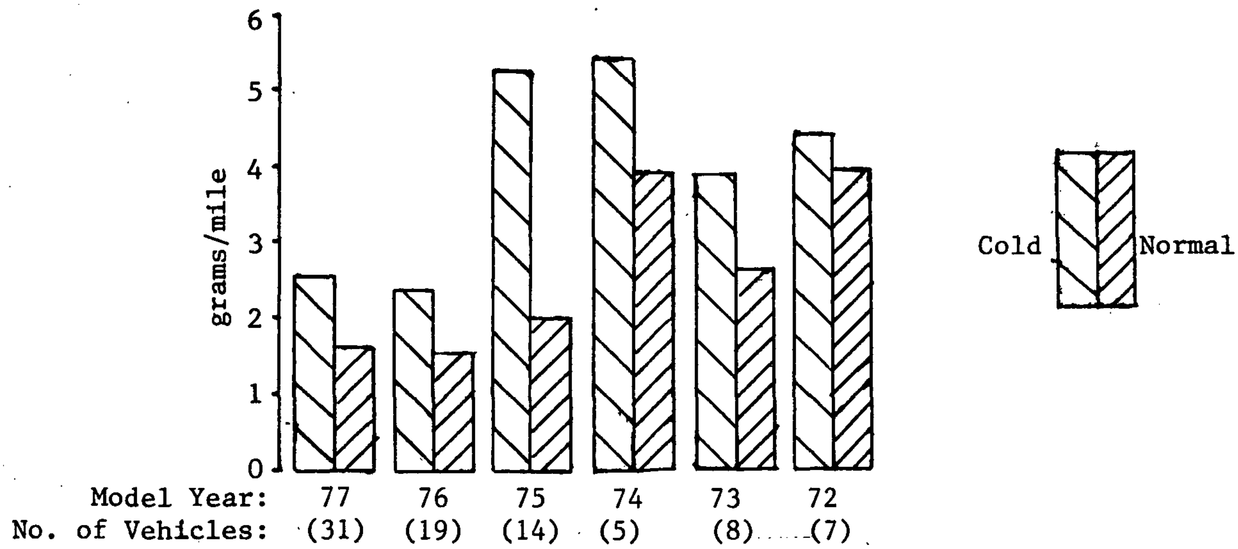



FIGURE 2: Hydrocarbon (HC) Emissions

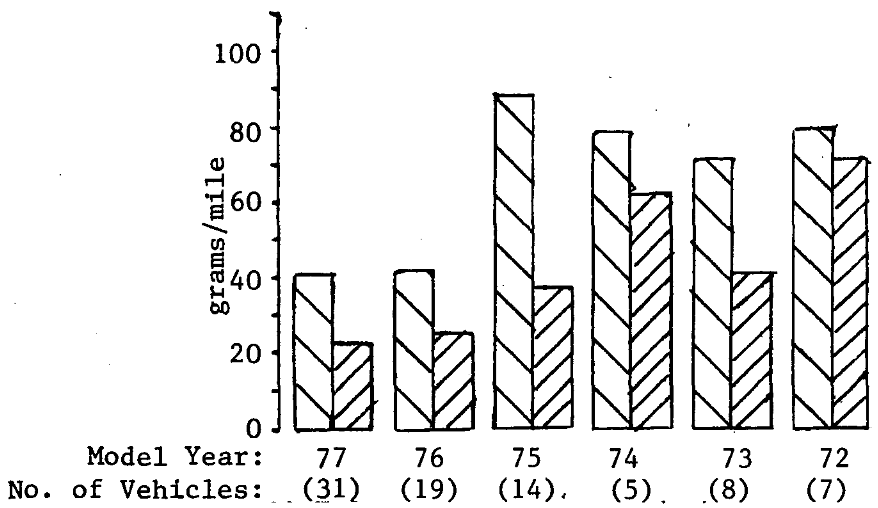



FIGURE 3: Carbon Monoxide (CO) Emissions

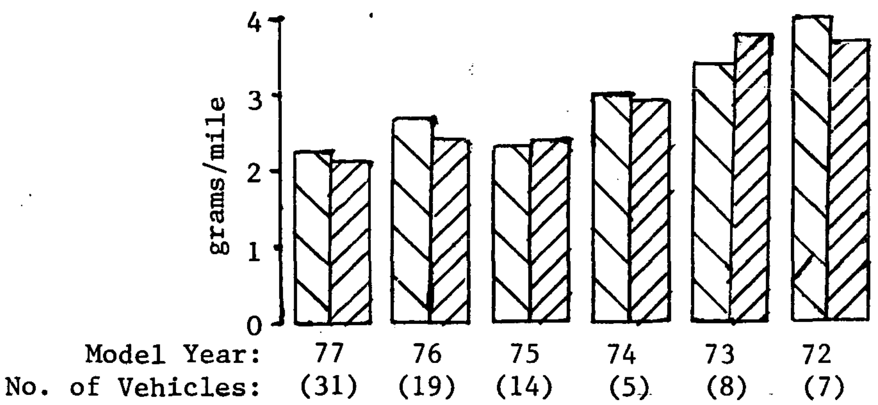



FIGURE 4: Oxides of Nitrogen (NOx) Emissions

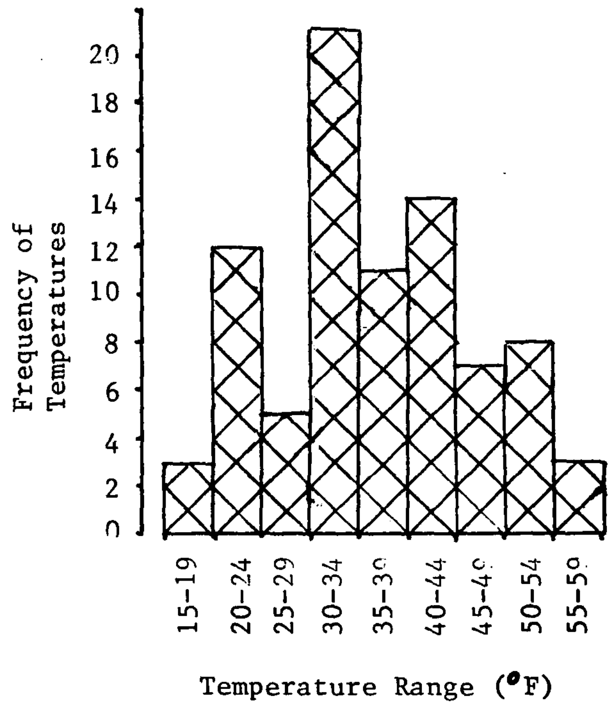
TABLE 3
Mean Composite Emission Levels
Cold and Normal FTP
(in grams per mile)

| | | HC | CO | NOx |
|---|---|---|---|---|
| 1977 (32) | COLD | 2.7 | 39.8 | 2.3 |
| | NORMAL | 1.7 | 22.5 | 2.1 |
| 1976 (19) | COLD | 2.4 | 42.6 | 2.7 |
| | NORMAL | 1.7 | 25.0 | 2.4 |
| 1975 (14) | COLD | 5.3 | 88.8 | 2.3 |
| | NORMAL | 2.0 | 37.2 | 2.4 |
| 1974 (5) | COLD | 5.4 | 78.0 | 3.1 |
| | NORMAL | 3.9 | 60.8 | 2.9 |
| 1973 (8) | COLD | 3.9 | 71.3 | 3.5 |
| | NORMAL | 2.7 | 40.8 | 3.8 |
| 1972 (7) | COLD | 4.4 | 79.0 | 4.0 |
| | NORMAL | 4.0 | 70.4 | 3.7 |
| All Years | COLD | 3.3 | 57.1 | 2.7 |
| | NORMAL | 2.2 | 33.1 | 2.6 |

TABLE 4
Number of Vehicles Below or Equal to Mean FTP Emissions

| | HC | | CO | | NOx | |
|---|---|---|---|---|---|---|
| | Cold | Normal | Cold | Normal | Cold | Normal |
| 1977 (32) | 20 | 18 | 19 | 18 | 17 | 21 |
| 1976 (19) | 12 | 13 | 13 | 13 | 13 | 11 |
| 1975 (14) | 9 | 8 | 8 | 9 | 8 | 8 |
| 1974 (5) | 2 | 3 | 3 | 2 | 2 | 3 |
| 1973 (8) | 4 | 3 | 4 | 4 | 4 | 5 |
| 1972 (7) | 2 | 3 | 4 | 3 | 3 | 4 |

FIGURE 5
Distribution of Temperatures for Low-Temperature Tests



Overall Fleet Emissions and Fuel Economy

The average composite FTP emissions of the entire fleet when tested at low temperatures were higher than when tested under normal conditions (see table 3). However, 11 cars produced less HC in the low temperature test than they did in the warm test, 12 cars produced less CO in the cold test, and 34 produced less NOx in the cold test. Hydrocarbon emissions in low temperatures ranged from one half to twenty times the emission levels under normal temperatures. Carbon monoxide ratios ran from one half to eighty times normal levels, and oxides of nitrogen went from a quarter to twice normal levels.

The entire fleet obtained 7% fewer miles per gallon on the FTP in cold temperatures than in warm. Still, 14 cars or 16% got better fuel economy in the low temperature FTP. The largest increase in fuel economy in low temperatures was 9%, while the greatest loss was 36%.

Temperature and Composite Emissions

To examine the effect of different temperatures on emissions, groups of vehicles in 3 temperature ranges were examined. The first group consisted of 14 vehicles tested at temperatures from 16° to 25° F (average 23°), the second group of 26 vehicles were tested from 26° to 35° F (average 32°) and the third group of 13 vehicles were tested from 46° to 55° (average 50°). Each group had vehicles from different manufacturers and model years.

Hydrocarbon emissions showed an increase as temperature decreased. The fleet of cars around 23° showed a 75% increase in hydrocarbons, the fleet at 32° showed a 54% increase, and the fleet at 50° showed a 12% increase (see figure 6).

Carbon monoxide emissions showed a greater sensitivity to temperature decreases. The 23° group of vehicles showed a 82% increase in CO, the 32° group increased CO emissions by 74%, and the group at 50° produced 21% more emissions (see figure 7).

Oxides of nitrogen were not very sensitive to temperature differences. The 23° and 32° group showed 7% and 6% increases, respectively (see figure 8). The group at 50° showed no signficant increases in NOx after an analysis of differences between paired tests.

The test groups at 25° and 32° each showed a 9% loss of fuel economy (see figure 9). The group at 50° showed only a 1% loss in fuel economy.

Mean Emissions at Various Temperatures Normalized to Standard Conditions
(Composites)

FIGURE 6
Hydrocarbons (HC)

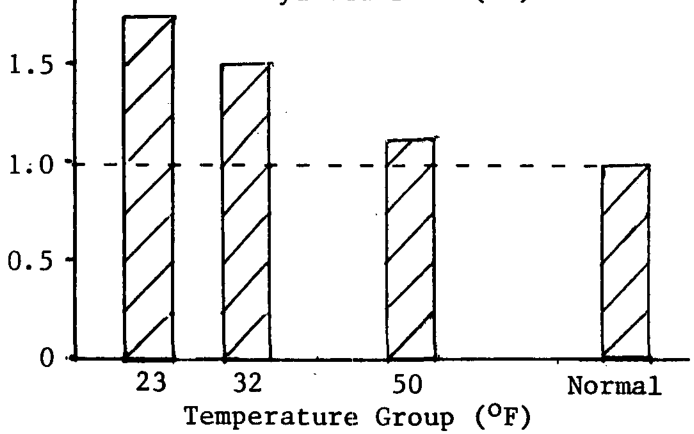



FIGURE 7
Carbon Monoxide (CO)

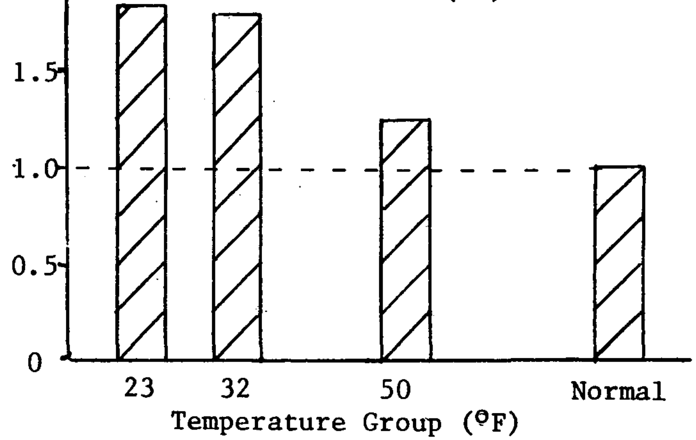



FIGURE 8
Oxides of Nitrogen (NOx)

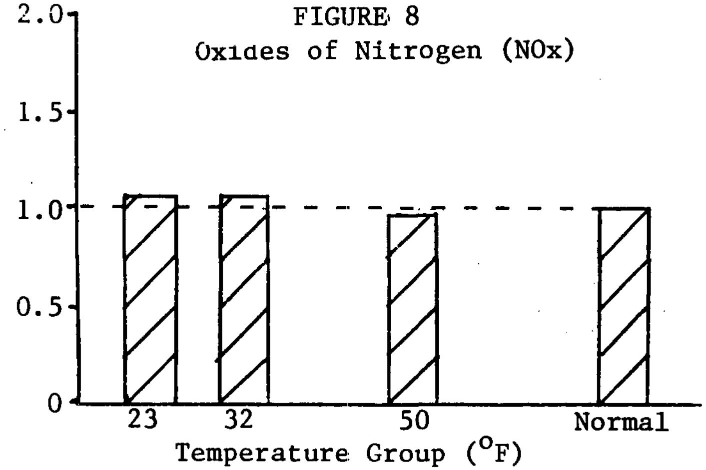
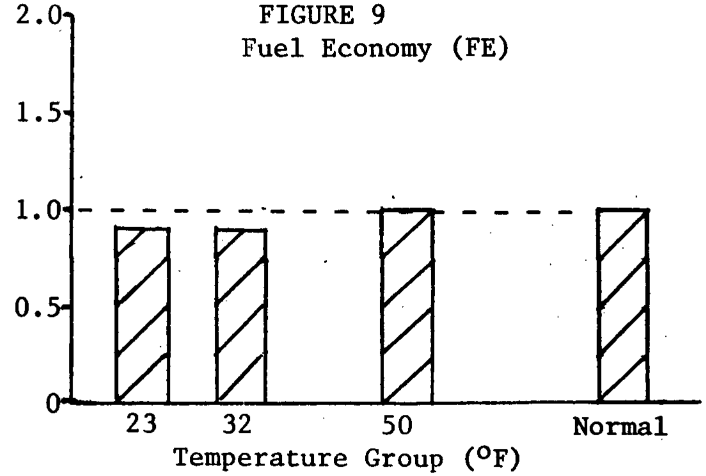



FIGURE 9
Fuel Economy (FE)



FTP: Bag by Bag

The greatest increase in the HC and CO emissions in the low-temperature tests occurred in the cold transient phase. For the entire fleet, HC and CO emissions during this phase of the low-temperature FTP were approximately 3 times the level of the emissions under standard conditions. Over the entire fleet, HC and CO emissions were 27% higher in the stabilized phase, and about the same (within 5%) in the hot transient phase (see table 5). Low-temperature NOx emissions were about the same percent greater than normal test emissions (3 to 6%) in all three phases.

The greatest loss in fuel economy occured during the cold transient phase when the fleet fuel economy dropped 16% compared with the normal FTP results. Fuel economy was reduced by 7% in the cold stabilized phase of the low-temperature tests, and remained the same (within 2%) in the hot transient phase.

While overall NOx emissions during the cold transient phase were greater in cold temperatures, the majority of vehicles tested (approximately 60%) actually produced lower NOx emissions during this phase in low temperatures. Very few vehicles (4-5%) produced fewer HC or CO emissions during the cold transient phase in low temperatures, and all vehicles had lowered fuel economy (see figure 10).

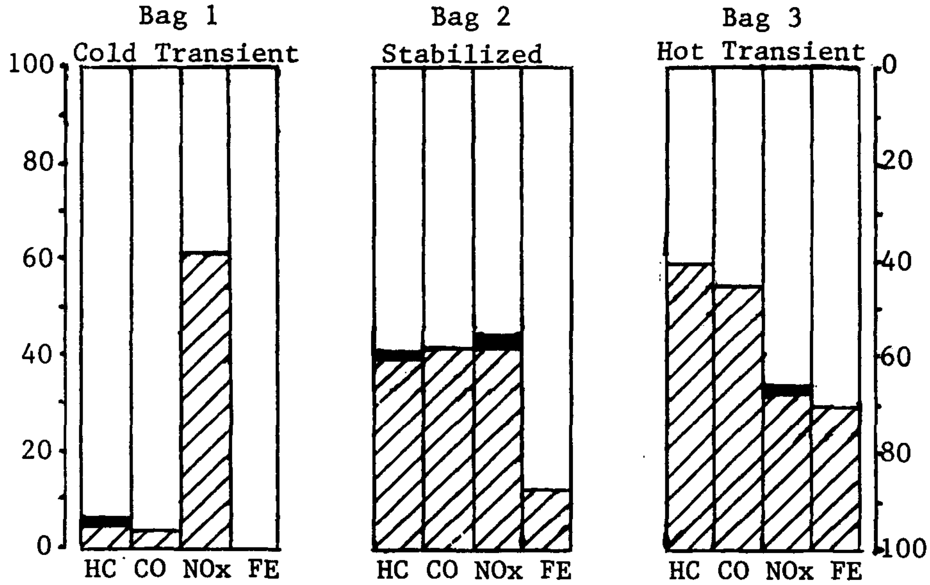
During the stabilized phase of the low-temperature FTP, a significant number of vehicles (about 40%) had lower emissions on each HC, CO, and NOx compared to their results at normal temperature.

A majority of vehicles produced fewer emissions on each HC and CO (60% and 55% respectively) during the hot transient phase of the low-temperature FTP when compared to the same phase on the normal FTP. The percent of vehicles producing fewer NOx emissions during this phase dropped to 31%. Some vehicles (30%) achieved better fuel economy during this phase in cold weather than they did in tests at normal temperature.

Temperature and Bag-by-Bag Emissions

The results from the groups tested around 23°F and 32°F are very similar. On the cold transient phase, HC and CO emissions for both fleets were about three times higher in cold weather than under normal test conditions (see figures 11 and 12). Both groups suffered a 20% loss in fuel economy during this phase (see tables 6 and 7). Each of the two groups had large percentages of vehicles (66-72%) that produced less NOx in cold weather on this phase (see figures 17 and 18).

**Figure 10**
**Bag by Bag Profile of 84 Vehicles Given Low-Temperature FTPs**




Hatched Area -- represents those vehicles with fewer emissions or better fuel economy on the low-temperature test

Solid (or Cross-Hatched) Area -- represents those vehicles with the same performance on both the low-temperature and warm tests

Blank Area -- represents those vehicles with fewer emissions or better fuel economy on the warm test

**Table 5**
**Bag by Bag Mean Emissions for 84 Vehicles**
**Low-Temperature and Normal FTPs**
**(emissions in grams per mile)**

| | BAG 1 | | | | BAG 2 | | | | BAG 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HC | CO | NOx | FE | HC | CO | NOx | FE | HC | CO | NOx | FE |
| COLD | 8.5 | 142.3 | 3.5 | 10.6 | 2.3 | 41.0 | 2.0 | 12.8 | 1.8 | 23.8 | 3.2 | 14.9 |
| NORMAL | 3.2 | 46.9 | 3.3 | 12.6 | 1.8 | 32.3 | 2.0 | 13.7 | 1.9 | 22.8 | 3.1 | 15.3 |
| Ratio | 2.68 | 3.03 | 1.06 | 0.84 | 1.27 | 1.27 | 1.03 | 0.93 | 0.96 | 1.04 | 1.04 | 0.98 |

**Mean Bag by Bag Emissions by Temperature**
**Values Normalized to Standard Conditions**

FIGURE 11
Bag 1; Hydrocarbons (HC)

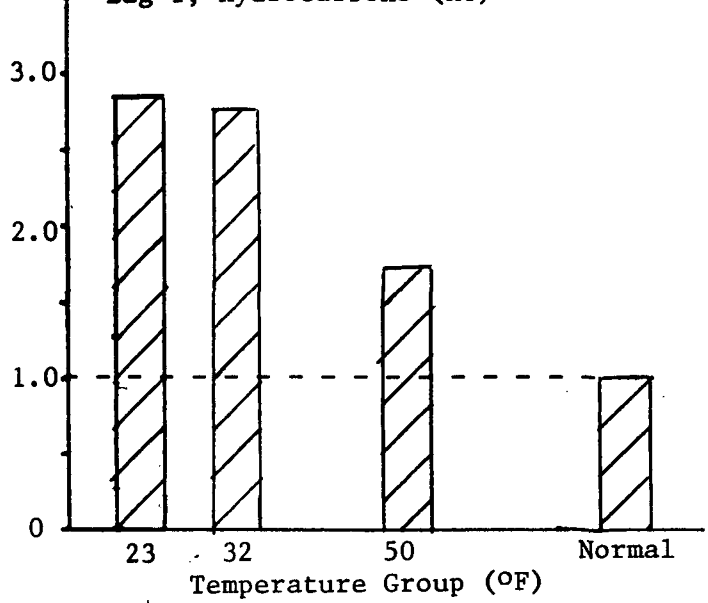



**FIGURE 12**
**Bag 1; Carbon** Monoxide (CO)

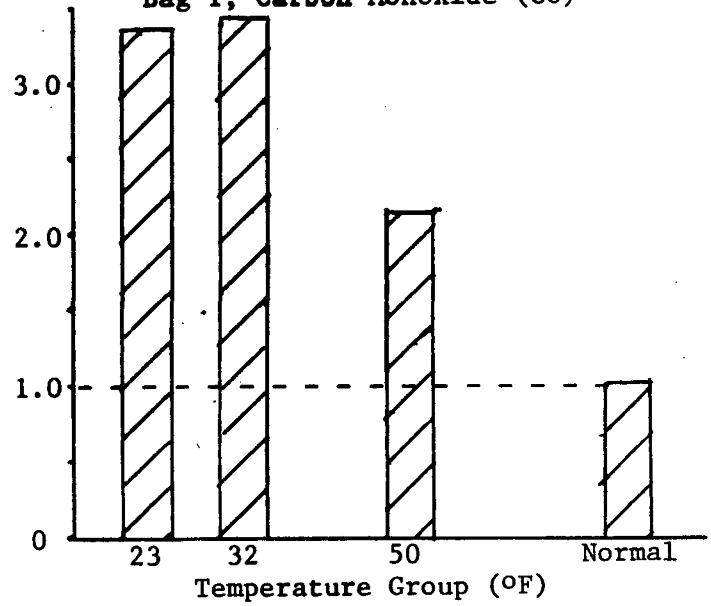



FIGURE 13
Bag 2; Hydrocarbons (HC)

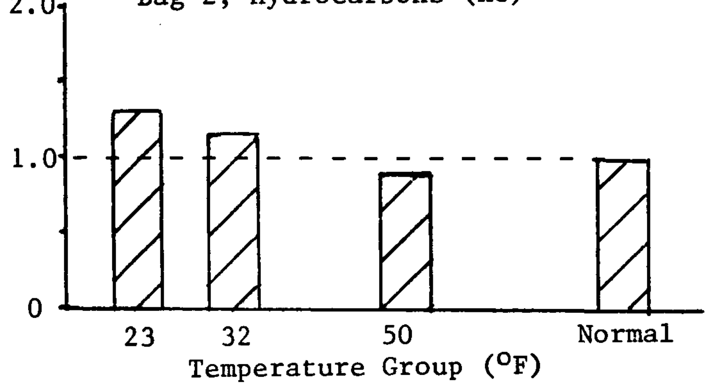



FIGURE 14
Bag 2; Carbon Monoxide (CO)

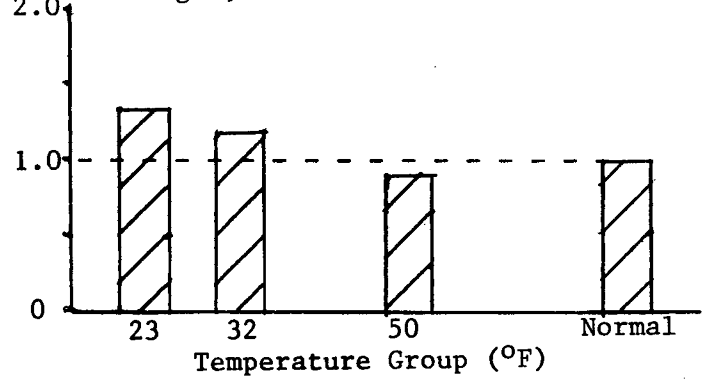



FIGURE 15
Bag 3; Hydrocarbons (HC)

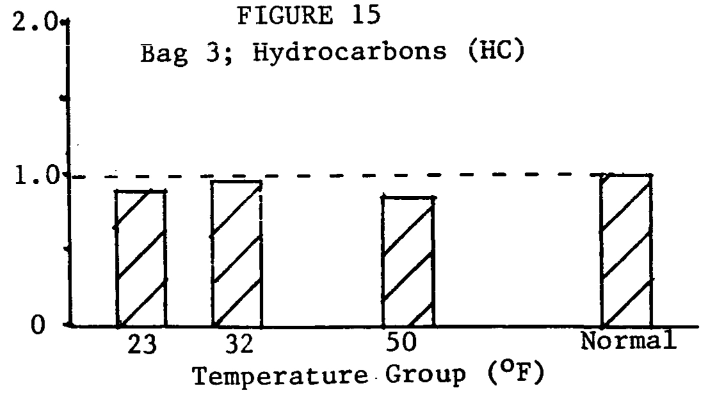
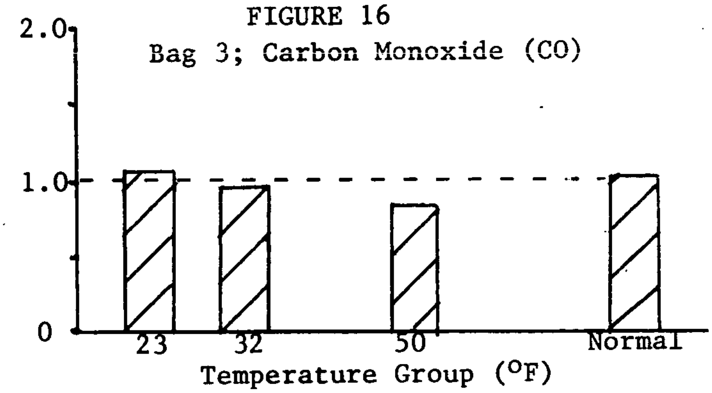



FIGURE 16
Bag 3; Carbon Monoxide (CO)



On the stabilized phase, in the 23° and 32° groups, between 22% and 36% of the vehicles in each group achieved lower emissions in each HC, CO, and NOx. Total HC and CO emissions were higher: 29% and 35% in the 23° group, and 14% and 20% in the 32° group, respectively (see figures 13 and 14). NOx emissions in both groups were also greater, but by only 7-10%. Both groups suffered a 6% loss of fuel economy at these temperatures.

For the hot transient sample, the 23° group produced 9% less HC, and 6% more CO. 70% of the vehicles in the group produced less HC in cold temperatures and 57% produced less CO. The 32° group produced 5% to 6% less of both HC and CO, but fewer vehicles produced less HC and CO (55% and 48% respectively) at cold temperatures than in the 23° group. Both groups had a 7-10% increase in NOx, with only about 30% of the vehicles doing better or as well on the cold tests as they did in the warm.

The 50° group had results different than either the 23° or 32° groups. For the cold transient phase, only a doubling of HC and CO was produced in the cooler temperatures, (see figures 11 and 12) and only half (54%) of the vehicles produced less NOx (see figure 19).

In the stabilized and hot transient phases, total HC and CO emissions for the entire 50° group were reduced between 9% and 16% from the normal levels. Total NOx emissions were also slightly reduced for both these phases. Of the thirteen cars in this group, in both the stabilized and hot transient phases, 7 produced less HC, the same number produced less CO and 8 produced less NOx in the colder temperatures. No major change in the fuel economy for the entire group occured in either phase.

<u>FTP Results - Comparison of Two Manufacturers</u>

The differences in low-temperature emissions that exist between vehicles of different manufacturers is of interest. It is desirable to know if wide variations in low-temperature emissions exist between manufacturers or if fleets from different manufacturers would behave similarly. For this analysis, 16 Ford cars from the 1975-77 model years were chosen for comparison with 15 Chevrolets from the same years. Average temperature for the low-temperature tests on the Fords was 42°F and 32°F for the Chevrolets.

Since the Chevrolets were tested at a lower average temperature, it was expected that the ratio between composite HC and CO low-temperature and normal emissions would be higher than for Ford. This was not the case. HC and CO composite emissions for the Chevrolet cars were only about one and one half times as high at low temperatures as compared to normal temperatures, while the Fords produced 2 times their normal HC and nearly 3 times as much CO as at normal temperatures. The Chevrolets

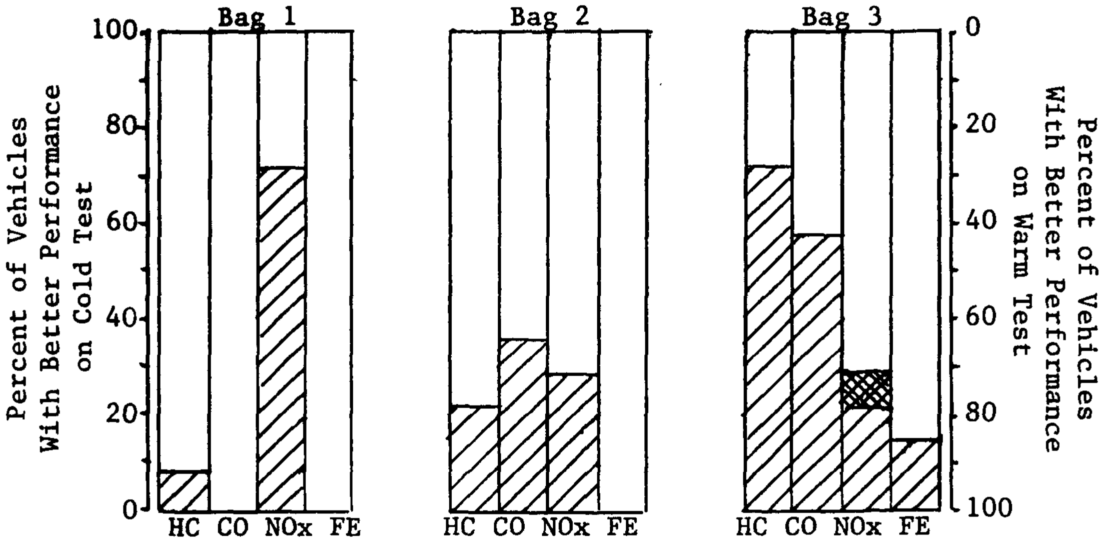



FIGURE 17
Bag by Bag Profile
14 Vehicles
(Cold Tests between 16° and 25°F, average 23°F)

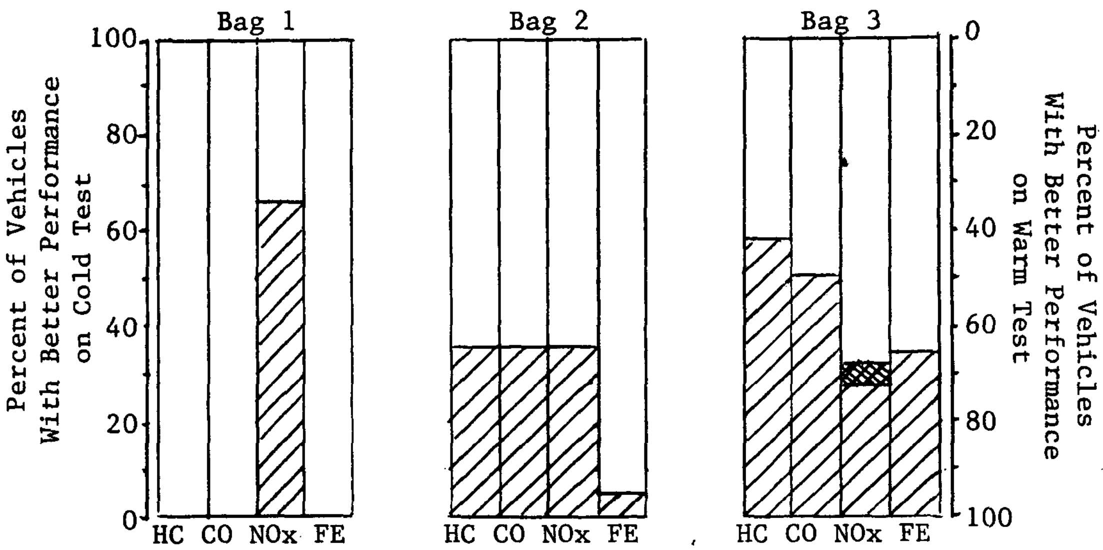



FIGURE 18
Bag by Bag Profile
26 Vehicles
(Cold Tests between 26° and 35°F, average 32°F)

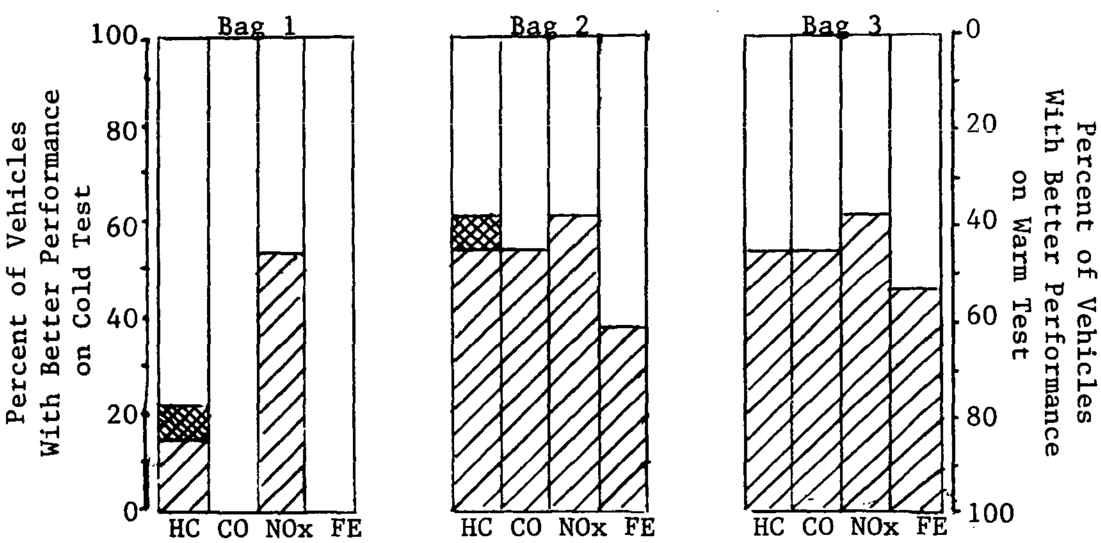



FIGURE 19
Bag by Bag Profile
13 Vehicles
(Cold Tests between 46° and 55°F, average 50°F)

TABLE 6

Composite and Bag by Bag Emissions for 14 Vehicles, Low-Temperature and Normal FTP
(Low-Temperature Tests from $16^{o}$ to $25^{o}$F, average $23^{o}$F)
(All figures are mean emissions in grams per mile)

| | BAG 1 | | | | BAG 2 | | | | BAG 3 | | | | COMPOSITE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HC | CO | NOx | FE | HC | CO | NOx | FE | HC | CO | NOx | FE | HC | CO | NOx | FE |
| COLD | 10.2 | 154.5 | 4.0 | 10.0 | 2.4 | 55.5 | 2.0 | 12.7 | 1.5 | 23.1 | 3.6 | 14.9 | 3.7 | 67.0 | 2.8 | 12.5 |
| NORMAL | 3.6 | 45.9 | 3.8 | 12.5 | 1.8 | 41.0 | 1.8 | 13.5 | 1.7 | 21.8 | 3.4 | 15.3 | 2.1 | 36.8 | 2.7 | 13.7 |
| | | | | | | | | | | | | | | | | |
| Ratio | 2.84 | 3.37 | 1.07 | 0.80 | 1.29 | 1.35 | 1.07 | 0.94 | 0.91 | 1.06 | 1.07 | 0.97 | 1.75 | 1.82 | 1.07 | 0.91 |

TABLE 7

Composite and Bag by Bag Emissions for 26 Vehicles, Low-Temperature and Warm FTPs
(Low-Temperature Test from $26^{o}$ to $35^{o}$F, average $32^{o}$F)

| | BAG 1 | | | | BAG 2 | | | | BAG 3 | | | | COMPOSITE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HC | CO | NOx | FE | HC | CO | NOx | FE | HC | CO | NOx | FE | HC | CO | NOx | FE |
| COLD | 8.7 | 158.4 | 3.7 | 10.2 | 2.3 | 37.1 | 2.4 | 13.0 | 2.1 | 21.1 | 3.7 | 15.0 | 3.5 | 56.9 | 3.0 | 12.7 |
| NORMAL | 3.2 | 46.2 | 3.8 | 12.7 | 2.0 | 30.9 | 2.1 | 13.9 | 2.2 | 22.5 | 3.4 | 15.2 | 2.3 | 32.7 | 2.8 | 13.9 |
| | | | | | | | | | | | | | | | | |
| Ratio | 2.73 | 3.43 | 0.96 | 0.80 | 1.14 | 1.20 | 1.10 | 0.94 | 0.95 | 0.94 | 1.10 | 0.98 | 1.54 | 1.74 | 1.06 | 0.91 |

TABLE 8

Composite and Bag by Bag Emissions for 13 Vehicles, Low-Temperature and Warm FTPs
(Low-Temperature Tests from $46^{o}$ to $55^{o}$F, average $50^{o}$F)

| | BAG 1 | | | | BAG 2 | | | | BAG 3 | | | | COMPOSITE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HC | CO | NOx | FE | HC | CO | NOx | FE | HC | CO | NOx | FE | HC | CO | NOx | FE |
| COLD | 4.8 | 93.4 | 3.6 | 11.5 | 1.8 | 33.7 | 2.0 | 13.6 | 1.6 | 21.8 | 3.0 | 15.3 | 2.4 | 42.8 | 2.6 | 13.5 |
| NORMAL | 2.8 | 43.3 | 3.4 | 12.5 | 2.0 | 37.0 | 2.2 | 13.6 | 1.8 | 26.0 | 3.1 | 15.0 | 2.1 | 35.3 | 2.7 | 13.7 |
| | | | | | | | | | | | | | | | | |
| Ratio | 1.71 | 2.15 | 1.06 | 0.91 | 0.90 | 0.91 | 0.91 | 1.00 | 0.87 | 0.84 | 0.97 | 1.01 | 1.12 | 1.21 | 0.97 | 0.99 |

produced 11% more NOx, while the Fords produced 5% less. Both fleets suffered about the same reduction in fuel economy (7-8%) (see table 11).

In a bag-by-bag analysis, the fleet of Fords produced higher ratios of cold to warm HC and CO emissions in all bags compared to the Chevrolet fleet. However, the Ford fleet produced lower ratios of NOx in all bags compared to the Chevrolets. Bag by bag losses in fuel economy were about the same (by percent) for the two fleets (see tables 9 and 10).

In the cold transient phase (bag 1) 80% of the Fords produced less NOx in cold weather, while only 53% of the Chevrolets produced less NOx (see figures 20 and 21).

The Ford fleet continued into the stabilized phase (bag 2) with a high percentage (80%) of its vehicles producing less NOx, while the same figure for the Chevrolets had dropped to 20%. However, in bag 2, 46% of the Chevrolets produced lower HC levels in cold weather, while 66% produced less CO, compared with 20% and 12% for the Fords.

In the hot transient phase, all but one Chevrolet produced less HC in cold weather (93% of the fleet) and 10 of the 15 produced less CO. In the Ford fleet, 31% of the vehicles produced less HC and 38% produced less CO. Half the Fords produced the same or lower NOx levels, compared with only 20% for the Chevrolets.

There could be any number of reasons for these differences but the major cause could be the difference in control technologies. Ford vehicles generally use air pumps and monolithic catalysts while General Motors cars do not usually employ air pumps and have pelleted catalysts. Thermostats in vehicles by different manufacturers are set to operate at different engine temperatures to meet emissions at standard temperatures. These different settings between manufacturers probably affect emissions performance at low temperatures. Carburetion and ignition timing are also set differently between manufacturers to maximize the effects of their emissions control systems.

FIGURE 20
Bag-by-Bag Performance of 16 Ford Cars On FTP

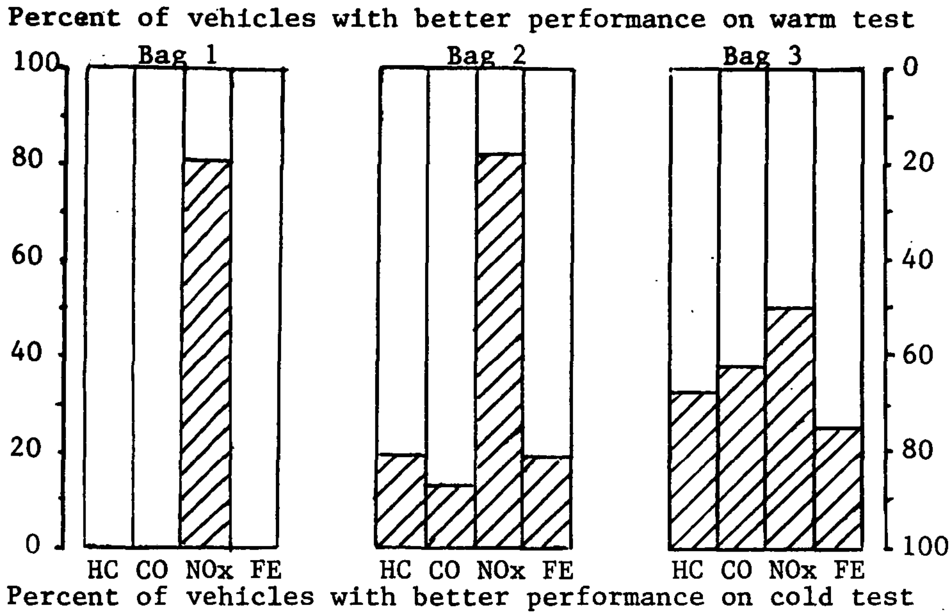
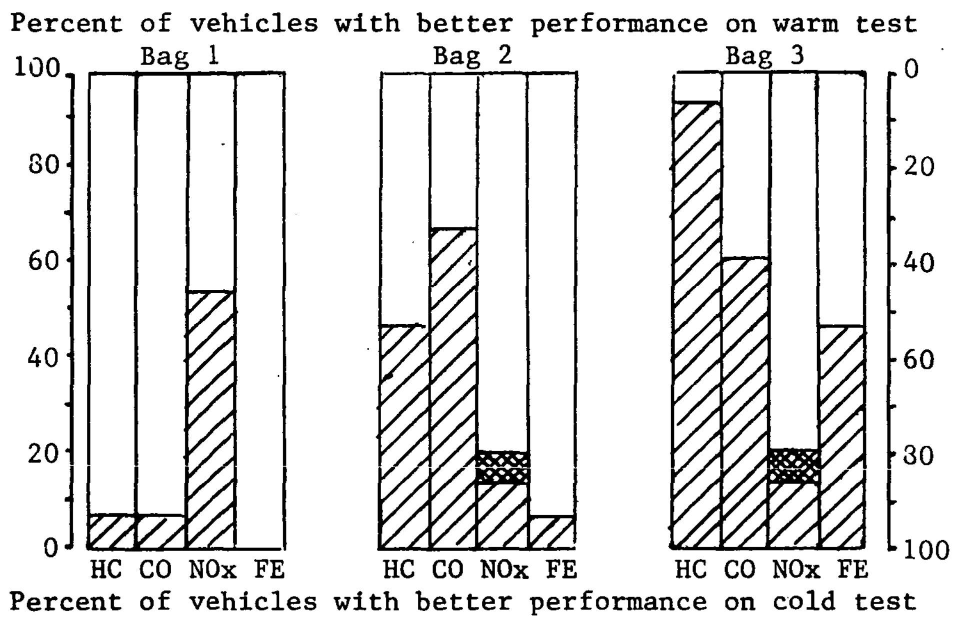



FIGURE 21
Bag-by-Bag Performance of 15 Chevrolet Cars on FTP




NOTES: (1) "Better performance" means fewer emissions or better fuel economy (FE).
(2) Cross-hatched areas indicate percent of vehicles with same performance on warm and cold test.

TABLE 9

Bag by Bag Emissions for 16 Catalyst-Equipped Ford Vehicles
Low-Temperature and Normal FTPs
(average temperature of cold tests is 43°F)
(all figures are mean emissions in grams per mile)

| | BAG 1 | | | | BAG 2 | | | | BAG 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HC | CO | NOx | FE | HC | CO | NOx | FE | HC | CO | NOx | FE |
| COLD | 10.5 | 153.9 | 2.9 | 10.5 | 1.7 | 20.3 | 1.9 | 13.2 | 1.6 | 12.6 | 2.8 | 15.0 |
| NORMAL | 2.3 | 26.1 | 3.0 | 12.6 | 1.4 | 15.5 | 2.0 | 13.7 | 1.5 | 12.6 | 2.9 | 15.1 |
| | | | | | | | | | | | | |
| Ratio | 4.53 | 5.88 | 0.94 | 0.83 | 1.25 | 1.30 | 0.91 | 0.96 | 1.06 | 0.99 | 0.98 | 0.99 |

TABLE 10

Bag by Bag Emissions for 15 Catalyst-Equipped Chevrolet Vehicles
Low-Temperature and Normal FTPs
(average temperature of cold tests is 32°F)

| | BAG 1 | | | | BAG 2 | | | | BAG 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HC | CO | NOx | FE | HC | CO | NOx | FE | HC | CO | NOx | FE |
| COLD | 8.3 | 118.9 | 3.4 | 10.7 | 1.8 | 40.2 | 1.7 | 13.7 | 1.2 | 20.3 | 3.0 | 15.6 |
| NORMAL | 2.7 | 45.5 | 3.2 | 13.0 | 1.9 | 41.6 | 1.5 | 14.3 | 1.6 | 21.4 | 2.7 | 15.8 |
| | | | | | | | | | | | | |
| Ratio | 3.07 | 2.61 | 1.06 | 0.82 | 0.96 | 0.96 | 1.14 | 0.95 | 0.73 | 0.94 | 1.12 | 0.98 |

TABLE 11

Composite Emissions for Low-Temperature and Normal FTPs

| | | HC | CO | NOx | FE |
|---|---|---|---|---|---|
| 16 Ford Vehicles | COLD | 3.5 | 45.7 | 2.3 | 12.8 |
| (average temperature | NORMAL | 1.5 | 15.2 | 2.4 | 13.9 |
| of cold tests was 43°F) | Ratio | 2.34 | 3.02 | 0.95 | 0.92 |
| | | | | | |
| 15 Chevrolet Vehicles | COLD | 3.0 | 50.8 | 2.4 | 13.4 |
| (average temperature | NORMAL | 2.0 | 36.9 | 2.2 | 14.4 |
| of cold tests was 32°F) | Ratio | 1.50 | 1.38 | 1.11 | 0.93 |
| | | | | | |

## Conclusions

1. In general, a vehicle with a cold engine will produce significantly higher emissions of HC and CO in a low-temperature cold-start test than in a similar cold-start test under standard conditions.

2. The major contribution to higher low-temperature emissions on the FTP occurs during the cold transient phase (bag 1). Bag 1 HC and CO emissions increase more greatly with a decrease in temperature than do HC and CO emissions in other phases.

3. Changes in temperature only have minor effects on NOx.

4. Differences in emissions produced from a warm engine do not differ greatly with ambient temperature changes.

5. In the test sequence as run, a vehicle gets worse fuel economy in low temperatures than in warm. The greatest loss of fuel economy occurs during the first bag (cold transient) of the FTP. By the final bag of the FTP (hot transient), there is little difference in fuel economy compared to standard temperatures.

6. There appears to be a range of temperatures (around 46° - 55°) when vehicles produce fewer emissions on the stabilized and hot transient phases without loss in fuel economy.

7. Vehicle fleets from different manufacturers can vary widely in their low-temperature performance.

## Comparisons with Other Works

Two other major studies have been performed to investigate the effect of low temperatures on emissions. One was performed by the U.S. Bureau of Mines[1], the other by Fisheries and Environment Canada[2].

The Canadian study concluded, as does this one, that HC and CO increase sharply at low temperatures, and that low temperatures have their greatest effect on the cold transient phase. It concluded that NOx increases only slightly with a drop in temperature, and that NOx is affected by about the same amount in each phase. This report supports this conclusion, but goes on to add the number of vehicles producing more NOx may change significantly from one phase to the next. The Canadian study also concluded that converters warm up faster at lower temperatures, and that engines warm up slower the colder it is. This study supports the conclusion that the colder it is, the longer it takes the engine to warm up (compare Figs. 9.1, 9.2, 9.3). For converters, however, this report may only conclude that it is likely that converters from different manufacturers warm up differently. This study agrees fairly well with the Canadian study in regards to the magnitude of HC, CO, and NOx increases caused by temperature.

The Bureau of Mines study also concluded that HC and CO are most sensitive to temperature, and that the cold transient phase is the most sensitive part of the FTP. As has been already pointed out, this study supports these conclusions.

## Recommendations

Low-temperature testing can be valuable in providing information about motor vehicle emissions in colder weather. This information may be useful in determining how vehicles contribute to air pollution at different times of the year. It could help to determine which emission controls are best at reducing emissions across the entire temperature spectrum in which a vehicle may be expected to operate.

In order to provide this information, further tests must be designed to provide data from which specific conclusions can be made. Ideally, a test cell should be used in which humidity and atmospheric pressure can be kept in a fairly narrow range while temperature can be made to vary. For the best data base, vehicles tested should be tuned to manufacturer's specifications, and tested several times at both normal and low temperatures. This procedure would eliminate the variables of pressure and humidity. With all vehicles set to manufacturers specification, the variation due to engine adjustment may be discounted.

Multiple tests on a vehicle provide more accurate data than a single test. However, testing in this manner is time consuming. This can be a difficulty when the vehicles used belong to the general public. Also, the facilities best suited to this type of testing are expensive and take time to construct.

A more realistic arrangement would use the same testing facilities and test procedure as described in this report. Selection of vehicles would be different. Combinations of engine configurations, emissions control systems, and vehicle inertia weights of interest would be identified, and vehicles having these characteristics would be noted. When obtaining vehicles for testing, the goal should be to obtain several vehicles of each configuration. Both a low-temperature and a normal test sequence should be run after the vehicle has been tuned to manufacturer's specifications. By obtaining more than one pair of tests for a particular configuration, enough data may be obtained to compare performances between configuration groups. The goal would be to gather enough information on any configuration to be able to predict their performance at different temperatures. A second phase would be to determine how these same configurations perform in the general vehicle population with vehicles in different states of tune. Much of the data from the tests performed for this report could be used for this analysis. The information gathered could be used for two purposes. First, those configurations that are most effective at reducing emissions across a broad spectrum of temperatures could be identified. Second, by noting the distribution of the various configurations in different vehicle populations (city, state, national), it may be possible to better estimate total emissions from a given population at a given temperature.

References

1) Eccleston, B.H. and Hurn, R.W.;"Ambient Temperature and Vehicle Emissions", U.S. Bureau of Mines, EPA-460/3-74-028

2) Ostrouchov, Nicolaus;"Effect of Cold Weather on Motor Vehicle Emissions and Fuel Economy", Fisheries and Environment Canada, SAE-780084