In-Cab Air Quality of Trucks Air Conditioned and Kept in Electrified Truck Stop

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At night, long-haul truck drivers rest inside the cabins of their vehicles. Therefore, the in-cab air quality while air conditioning (A/C) is being provided can be a great concern to the drivers' health. The effect of using different A/C methods [truck's A/C, auxiliary power unit (APU), and truck stop electrification (TSE) unit] on in-cab air quality of a heavy-duty diesel vehicle was investigated at an electrified truck stop in the El Paso, Texas, area. The research team measured the in-cabin and the ambient air quality adjacent to the parked diesel truck as well as emissions from the truck and an APU while it was providing A/C. The measured results were compared and analyzed. On the basis of these results, it was concluded that the TSE unit provided better in-cab air quality while supplying A/C. Furthermore, the truck and APU exhaust emissions were measured, and fuel consumption of the truck (while idling) and the APU (during operation) were compared. The results led to the finding that emissions from the APU were less than those from the truck's engine idling, but the APU consumed more fuel than the engine while providing A/C under given conditions.

Currently about 3 million long-haul trucks operate in the United States. Because the U.S. Department of Transportation mandates that truck drivers rest 10 h for every 14 h of driving (*1*), drivers rest and sleep in the cabs of their trucks for extended periods. Consequently, long-haul truck drivers idle their vehicles to operate heating systems and air conditioners (A/C), generate electricity, charge their vehicles' batteries, and warm up the engines.

Although the U.S. Environmental Protection Agency's (EPA's) guidance defines long-duration idling as idling that occurs for a period of 15 min or longer, studies have found that truck drivers idle their engines from six to 10 h per day while on the road (*2*). A typical long-haul truck is on the road for an estimated 250 to 300 days per year, resulting in an average annual idling duration per truck of between 1,500 and 3,000 h (*3–5*). At an idling emissions rate for oxides of nitrogen (NO_x) of approximately 135 grams per h, it is estimated that on a daily basis more than 500 tons of NO_x is emitted. In addition, extended idling can result in a considerable waste of fuel and cause wear on truck engines. More than 2 million gal of diesel is wasted on a daily basis nationwide (*6*). Studies (*5*) have shown that a long-haul truck can idle away more than a gallon of diesel fuel per hour.

Several methods have been developed to reduce extended truck idling. These methods can be divided into stationary and mobile technologies. The former refers to stationary equipment that can connect to the truck to reduce idling. An example of this technology is truck stop electrification (TSE) as produced by companies such as IdleAire Technologies Corporation and Shurepower. Mobile technologies include auxiliary power units (APUs) that are installed onboard the trucks.

In this study, the effect of using different A/C methods on in-cab air quality on a heavy-duty diesel vehicle (HDDV) was investigated at an electrified truck stop in the El Paso, Texas, area. The research team measured the air quality in the cabin and the ambient air quality adjacent to the parked diesel truck while A/C was provided by one of four different modes [A/C-in, A/C recirculation, auxiliary power unit (APU), and TSE] as well as while no A/C was provided (off mode). Furthermore, emissions from the truck and an APU were measured when they provided A/C. The measured data were analyzed and compared.

METHODOLOGY

General

To investigate the in-cab air quality of an HDDV while A/C was being provided by each of four different modes (A/C-in, A/C recirculation, APU, and TSE), the research team conducted the following tasks:

- Measurement of truck idling and APU exhaust emissions and fuel consumption,
- Examination of factors affecting results and analysis, and
- Measurement of in-cab and ambient air quality.

Using two portable emissions measurement system (PEMS) units, researchers measured pollutants from the vehicle and the APU exhausts to examine the effects of their emissions on in-cab and local air quality. Furthermore, vehicle and APU fuel consumption rates were estimated and compared. Researchers measured gaseous and particulate matter (PM) pollutants to examine in-cab and ambient (adjacent to the HDDV) air quality. The measured results of in-cab and ambient air quality were compared and analyzed. In addition, other factors, including number of trucks parked and idled, other nearby emissions sources, and local meteorology, were examined.

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Test Setup

The four different A/C modes to cool the diesel truck cabin were these:

- A/C-in. Outside (ambient) air flows inside the cabin through the system while the vehicle's A/C system, powered from engine idling, supplies A/C.
- A/C recirculation. Same as A/C-in mode, but only in-cab air keeps circulating through the system.
- APU. A/C is provided by the APU-powered A/C system; ambient air flows inside the cabin through the system.
- TSE. A/C is provided by a closed electrified unit.

Researchers also conducted a test in the A/C-off mode, in which no A/C was provided.

Test Vehicle

The test vehicle was a 2006 400-hp International truck (with a 15-L Cummins ISX 400 diesel engine). The vehicle was equipped with an APU to provide A/C inside the cabin, eliminating the need to idle the vehicle. The Cummins APU had an 8.85-hp (at 2,400 rpm) Kubota 479-cc two-cylinder, four-stroke diesel engine. Figure 1 shows the test vehicle, the APU, and the installation of predictive emissions monitoring systems flow meters to the vehicle and the APU.

Test Location

The study was performed at the Petro truck stop, which is located at Exit 37 on the eastbound section of I-10 in Socorro, Texas (about 10 mi southeast of the El Paso city center). The truck was parked in a spot in the electrified parking area in the truck stop and remained there during the entire study period (Figure 2). Most trucks parked in the electrified parking lot were not idling, while trucks in other parking areas idled as necessary. The truck stop had 258 parking spaces. Among them, 87 spaces were equipped with TSE units. Trucks could park in any available space as long as they did not block traffic entering or exiting the truck stop. During the study, researchers observed as many as 330 trucks parked at the truck stop.

FIGURE 1 Test vehicle and installation: (*a*) test vehicle, (*b*) flow meter installation on vehicle, (*c*) APU, and (*d*) flow meter installation on APU.

FIGURE 2 Test site map (from Google Earth).

Test Schedule with Meteorology Data

The test was performed from May 17 to May 20, 2007. On May 17 and 18, three modes were tested: A/C-in, A/C recirculation, and A/C-off. Around 6:00 p.m. on May 17, the test vehicle's engine was running at 600 rpm, and the A/C was set at maximum speed to bring outside air into the cabin (A/C-in mode). At approximately 7:30 p.m., the A/C setting was changed to circulate air only inside the cabin instead of bringing outside air into the cabin (A/C recirculation mode). At about 9:00 p.m., the A/C and the test vehicle engine were turned off (A/C-off mode).

This process continued until about 7:00 p.m. on May 18; the three modes were interchanged while researchers varied the mode durations. Table 1 summarizes the total duration of each mode and shows the ambient temperature and relative humidity ranges reported by the Texas Commission on Environmental Quality's (TCEQ's) continuous ambient monitoring sites (CAMS) 49 and 415. Station 49 is located about 2 mi west of the test site, and Station 415 is about 1.5 mi west northwest of the site.

For meteorology data, a mobile weather station was located at approximately 100 m to the northwest of the parked vehicle. Unfortunately, the weather station was damaged when hit by lightning during the study period. After the damaged weather station was fixed, an additional study was performed at the same location for 17 days (June 4 to 21) to ensure accuracy of the alternative way, which is to use the meteorological data obtained from the two nearby CAMS, Station 49 and Station 415. The additional study showed that the meteorological data measured by the fixed weather station were well correlated to the averages of those at two sites. Therefore, the meteorological data from the average of CAMS 49 and 415 were used as the surrogate data for the truck idling study from May 17 to 20.

On May 18 at approximately 7:00 p.m., researchers activated the APU air conditioner to cool the test vehicle's cabin. The unit was turned off at 10:00 p.m. to gather data for the A/C-off mode. Until

TABLE 1 Test Modes, Duration with Temperatures, and Relative Humidity

Mode	A/C Power Source	Duration (h)	Date	Temperature (°C)	Relative Humidity (%)
A/C (in)	Vehicle	7.75	5/17–5/18	15–28	25–37
A/C (recirculation)	Vehicle	7.75		15–27	26–37
Off	—	9.5		15–28	25–45
APU	APU	15	5/18–5/19	18–28	26–37
Off	—	5		18–28	26–37
TSE	Electrified	17	5/19–5/20	15–28	25–35
Off	—	2		20–22	25–30

3:00 p.m. on May 19, the APU had been turned on and off alternately, with various durations of the modes. Table 1 summarizes the total durations of the APU mode and the A/C-off mode, along with the ambient temperature and relative humidity ranges. At 3:00 p.m. on May 19, researchers activated the TSE unit to cool the cabin, and operated it continuously for 17 h. As Table 1 shows, the ambient temperature and humidity ranges were approximately the same regardless of the test modes so that there were no temperature or relative humidity effects on local air quality.

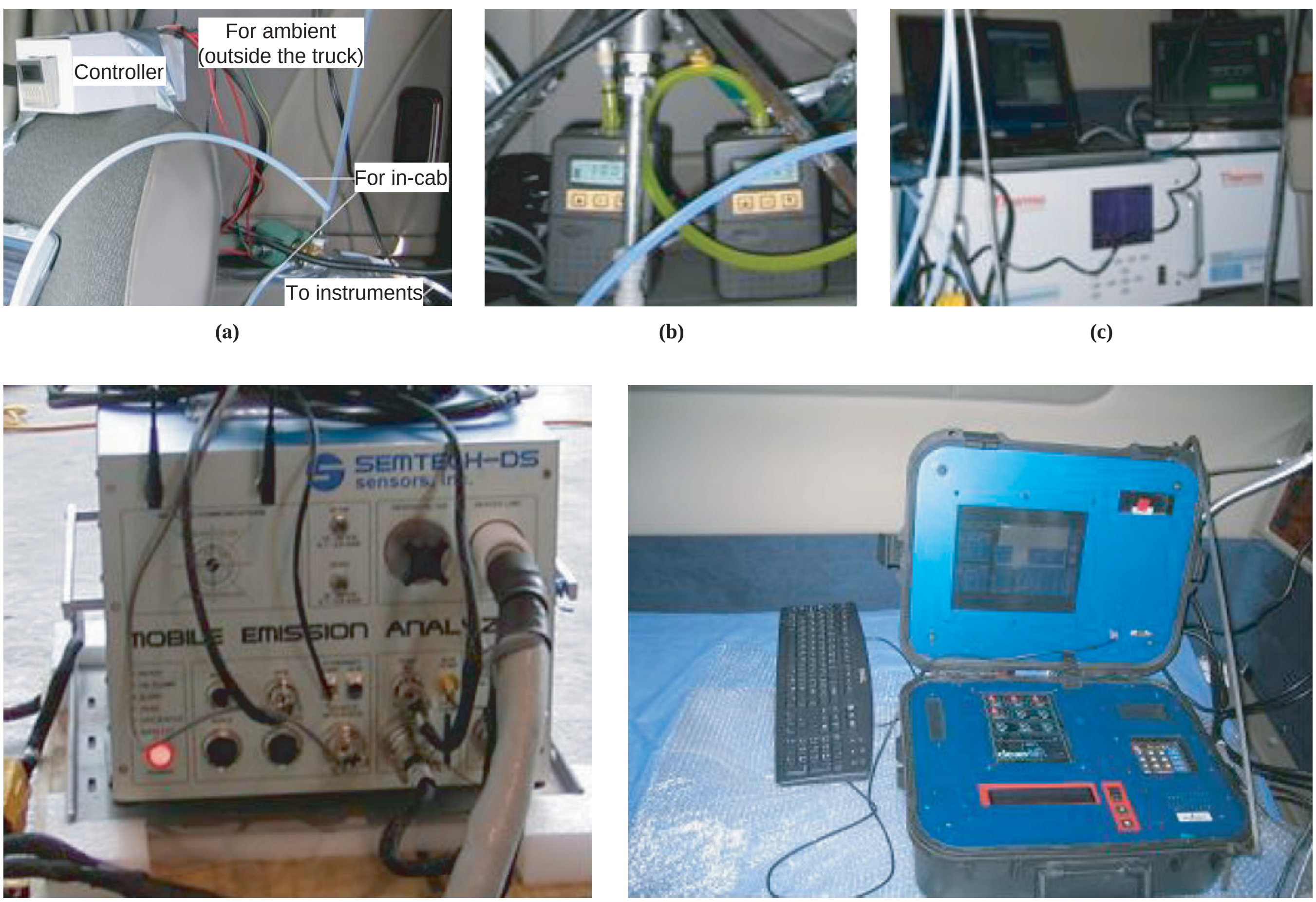
TEST EQUIPMENT

Researchers used two sets of instruments to measure gaseous pollutants and PM: one set for lower concentrations of ambient and in-cab air and the other for higher concentrations from vehicle and APU exhausts.

Gaseous Pollutants (Ambient and In-Cab Air)

NO_x and carbon monoxide (CO) analyzers and aldehyde samplers were placed inside the cabin. By means of a three-way valve, NO_x and CO concentrations of in-cab and ambient air were measured alternately every 10 min. Figure 3*a* shows the sampling lines and the valve; the ambient-air sampling line was located outside the cabin through a window of the truck. Aldehydes (formaldehyde and acetaldehyde) were measured with a set of 2 DNPH (2,4-dinitrophenylhydrazine) cartridge samplers, shown in Figure 3*b*. Two Waters DNPH solid phase extraction (SPE) cartridges were used to collect samples. Samples were taken for about 8 to 14 h depending on the test modes. The cartridges were eluted with acetonitrile, and the effluent was stored in a refrigerator for later analysis by high-performance liquid chromatography.

For NO_x measurements, a Model 42i gas analyzer manufactured by Thermo Scientific Inc. (Thermo) was used to measure NO_x concentrations. By using chemiluminescence technology, the Thermo 42i unit provides outputs for nitric oxide (NO), nitrogen dioxide (NO_2), and NO_x. The concentrations were recorded and reported at intervals of approximately 60 s. The lowest detectable limit at a 60-s reporting rate was 0.40 ppb. For CO, researchers used a Thermo Model 48i gas analyzer, which measures CO by using gas filter correlation technology. The concentrations were recorded and reported at intervals of approximately 60 s. The lowest detectable limit at a 60-s reporting rate was 40 ppb (parts per billion). Figure 3*c* shows the gas analyzers.



(a) (b) (c)

(d) (e)

FIGURE 3 Setups and instruments: (*a*) three-way valve, (*b*) aldehyde samplers (in-cab on left, ambient on right), (*c*) CO (on left) and NO_x (on right) monitors, (*d*) SEMTECH-DS unit, and (*e*) Clean Air Technologies International, Inc. (CATI) unit.

PM (Ambient and In-Cab Air)

For in-cab and ambient PM, two tapered-element oscillating microbalances (TEOMs, Thermo Series 1400 ab) were deployed. To monitor PM-2.5 (PM of aerodynamic diameters equal to or smaller than 2.5 µm) mass concentrations, sampling inlets of both TEOMs were equipped with Thermo PM-2.5 sharp-cut cyclones. Mass concentration data were recorded and reported in micrograms per cubic meter ($\mu g/m^3$) at standard intervals of 10 min. The TEOM resolution is 0.1 $\mu g/m^3$. Both TEOMs were placed inside A/C enclosures to ensure proper working environments.

Gaseous Pollutants (Exhaust Emissions)

The PEMS unit for gaseous emissions was a SEMTECH-DS manufactured by Sensors Inc. This unit included a set of gas analyzers, an engine diagnostic scanner, a Global Positioning System (GPS), an exhaust flow meter (EFM), and embedded software. The gas analyzers measured the concentrations of NO_x, total hydrocarbons (THC), CO, and carbon dioxide (CO_2) from the vehicle or APU exhausts. The unit also obtained the test vehicle's engine speed (rpm) data via a vehicle interface connected to the vehicle engine control module. The SEMTECH-DS used the SEMTECH EFM to measure vehicle exhaust flow. The unit's postprocessor application software used this exhaust mass flow information to calculate exhaust mass emissions for all measured exhaust gases. Figure 3*d* shows the PEMS unit. The effect of temperature and humidity on the emissions of the HDDV exhaust was automatically adjusted by the PEMS software by using the Code of Federal Regulations 40 1065.670 method.

PM (Exhaust Emissions)

The PEMS unit used to measure PM was the OEM-2100 Montana system manufactured by CATI. The unit, shown in Figure 3*e*, consisted of a gas analyzer, a PM measurement system, an engine diagnostic scanner, a GPS unit, and an onboard computer. For this study, only the PM measurement system was used. The PM measurement capability includes a laser light–scattering detector and a sample conditioning system. The PM concentrations were converted to mass PM emissions by using concentration rates produced by the CATI unit and exhaust flow rates produced by the SEMTECH-DS unit.

Engine exhaust typically produces three size ranges of particulates: 3 to 30 nanometers (nm), 30 to 500 nm, and larger than 500 nm (or 0.5 µm). Most particles produced from a diesel engine are 0.5 µm or less (*7*). This size is comparable to the PM-2.5 particle size as regulated by the EPA.

RESULTS

Exhaust Emissions and Fuel Consumption

By means of the two PEMS units, gaseous pollutants and PM were measured from the test vehicle and the APU engine exhausts. Table 2 summarizes the calculated quantities of pollutants emitted from the exhausts (as g/h) along with exhaust flow rates (as standard f^3/min [SCFM]) and fuel consumption rates (as gal/h).

On the basis of the test results in Table 2, CO_2 emissions and fuel consumption rates from the APU were higher (1.15 times as high for CO_2 and 1.2 times for fuel consumption rates) than those from the test vehicle. One possible explanation is that the test vehicle was idled at a low engine speed (600 rpm with almost no load), while the APU was operated at a full-load condition all the time. Further investigations are required to verify the effects of the APU's engine speed and load (if variable) on emissions and fuel consumption.

Other pollutant emission rates as well as exhaust flow rates from the APU were lower than from the test vehicle, as Table 2 shows. CO, NO_x, THC, and exhaust flow rates from the APU were about one-third of those from the vehicle. The APU emitted only about one-eighth of the PM measured from the test vehicle exhaust.

Factors Affecting In-Cab and Ambient Air Quality

Other Emissions Sources from Vicinity

To examine the effects of emissions from the test vehicle and the APU on local air quality, other emissions sources in the area needed to be identified and considered. Researchers examined emissions point source (in both the United States and Mexico) data available from the Commission for Environmental Cooperation (CEC).

Figure 4 shows that wind direction at the test site ranged from 0° to 235° during the test period (May 17 to May 20, 2007). The CEC data indicated only one emission source in the range of the 0° to 235° direction from the test site: Air System Components, LP. However, the quantity of emissions from this source was negligible. Therefore, researchers concluded that the major emissions sources affecting air quality at the test site during the test period were only from the idling trucks at the site, two other nearby truck stops (located on the westbound side of I-10), and the traffic on I-10.

TABLE 2 Gaseous and PM Emissions from, and Fuel Consumptions by, Test Vehicle Engine and APU Exhaust A/C Supplied to Vehicle Cabin

	Mass Emissions Rate (*g*/h)					Q_{ex}^a (SCFM)	Fuel (gal/h)
	CO_2	CO	NOx	THC	PM		
Vehicle							
AVE	6,700	31	109	13	0.48	120	0.64
V	3.5%	6.3%	5.5%	20%	10%	1.6%	6.1%
APU							
AVE	7,700	11	47	4.5	0.058	43	0.76
V	4.0%	14%	2.2%	8.9%	17%	4.3%	5.7%

NOTE: AVE = average; *V* = coefficient of variation.
[a] Q_{ex} = exhaust flow rate.

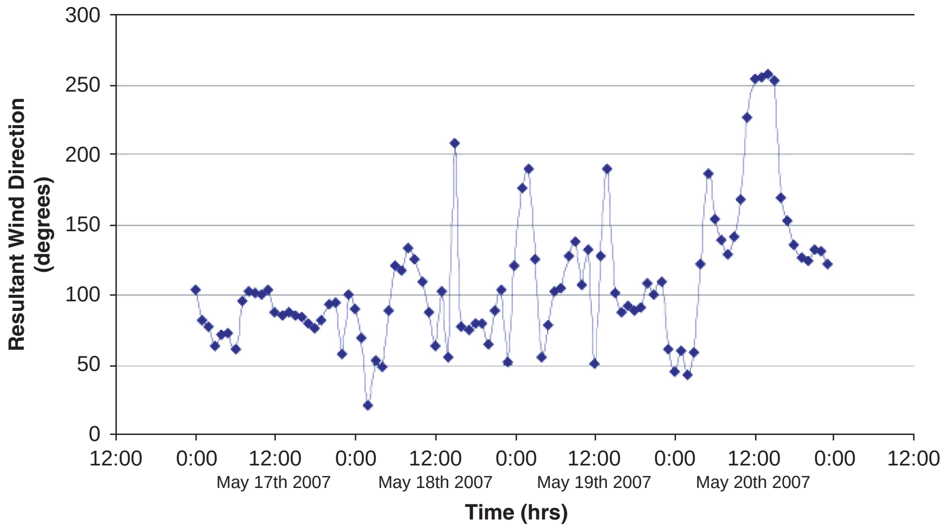


FIGURE 4 Wind direction during study period (May 17 to May 20, 2007).

Truck-Counting Results

During the study period, researchers counted the number of trucks parked and the number of idling trucks every 2 h. The average number of trucks parked at the test site was 249 (± 49). The greatest number of trucks parked at the site, 299, was during the TSE mode test period, May 19 (Saturday) to 20 (Sunday). The next greatest number of trucks parked, 264, was during the A/C-in and A/C recirculation modes test period May 17 (Thursday) to 18 (Friday), and the least number parked, 234, was during the APU mode test May 18 to May 19.

Because trucks that park overnight arrive around 6:00 p.m., remain overnight, and then leave around 7:00 a.m., the number of trucks parked at the truck stop was higher in the evening and at night (283 ± 26 trucks 6:00 p.m. to 6:00 a.m. during the test period) than during the daytime (202 ± 32 trucks 7:00 a.m. to 5:00 p.m. during the test period). Figure 5 shows the truck-counting results.

The number of idling trucks was 60 (± 11) trucks on average throughout the test period. For diurnal variation, the number of idling trucks was almost the same, as shown in Figure 5, except that it was higher between 4:00 and 6:00 p.m., with the highest number, 77, at 6:00 p.m., and lower between 8:00 and 10 a.m., with the lowest count, 47, at 8:00 a.m. For the test modes, the number of idling trucks during the TSE mode test, 68, was higher than those during the other test modes, A/C-in and A/C recirculation mode (58) and APU mode (56).

In-Cab and Ambient Air Quality

Gaseous Pollutants (NO_x and CO)

Table 3 summarizes the measured average concentrations of in-cab and ambient (adjacent to the vehicle) NO_x and CO concentrations for all the test modes. Furthermore, NO_x concentrations at the TCEQ CAMS 49 station are shown as ranges for the associated test modes (CAMS 415 does not provide air quality data). The concentrations at the CAMS 49 station were much lower than those measured at the site. This was expected because the major emissions sources during the test period (as noted earlier) were idling trucks at the test truck stop and at two nearby truck stops and traffic on I-10. The emissions from these sources would definitely be diluted as they traveled to the CAMS 49 station.

The relatively high end of the TCEQ NO_x range during the TSE test period was possibly associated with the higher number of trucks parked during the TSE mode test than during the other modes as noted earlier in the section on truck-counting results. The higher number of parked trucks indicated higher traffic volumes on I-10, which resulted in higher emissions rates. For the A/C-off mode test, it was expected that the concentrations would be in a wider range than those for other modes because segments of the A/C-off mode, conducted between two other modes, were sporadic during the test period. CO concentrations from the CAMS 49 station were either 0 or 100 ppb; just at or below the detection limit, 100 ppb.

Table 3 shows that ambient (adjacent to the test vehicle) NO_x concentrations when the test vehicle or APU was used for supplying A/C to the cabin were higher on average than those when no engine was operating (i.e., TSE or A/C-off mode). During the TSE mode, there was no difference on average between in-cab and ambient concentrations. However, when the test vehicle or APU engine was used to supply A/C, in-cab concentrations were higher than ambient concentrations. The ratio of in-cab-to-ambient concentrations was greatest for the A/C recirculation mode (8:85), followed by the ratio for the APU mode (6:15). The lowest ratio was for the A/C-in mode, 3:88. The higher in-cab concentrations during these three modes indicate that engine emissions penetrated through openings in the cabin.

While the engine was running, the emissions (from the engine crankcase) possibly penetrated through openings in the cabin floor, as discussed in the literature (*8*). In the A/C-in mode, some ambient air entered the cabin and mixed with the in-cab air; thus, it is obvious that the in-cab concentration and the ratio for A/C-in mode were lower than those for the A/C recirculation mode. During the APU mode, emissions from the APU's engine exhaust appeared to enter the cabin through the APU-powered A/C unit (Figure 1*d*), although some of the emissions could penetrate through the cabin floor. In the A/C-off mode, average in-cab concentrations were higher than ambient concentrations because the average concentrations contained some elevated in-cab concentrations from the previous test modes.

Results for CO were similar to those for NO_x. As Table 3 shows, in-cab concentrations for the A/C-in, A/C recirculation, and APU modes were higher than ambient concentrations. The A/C recirculation mode showed the greatest ratio of in-cab-to-ambient CO concentrations (6:27). The ratio for the APU mode (5:80) was next. For the A/C-in mode, the lowest ratio was 1:71, as Table 3 shows. The APU mode

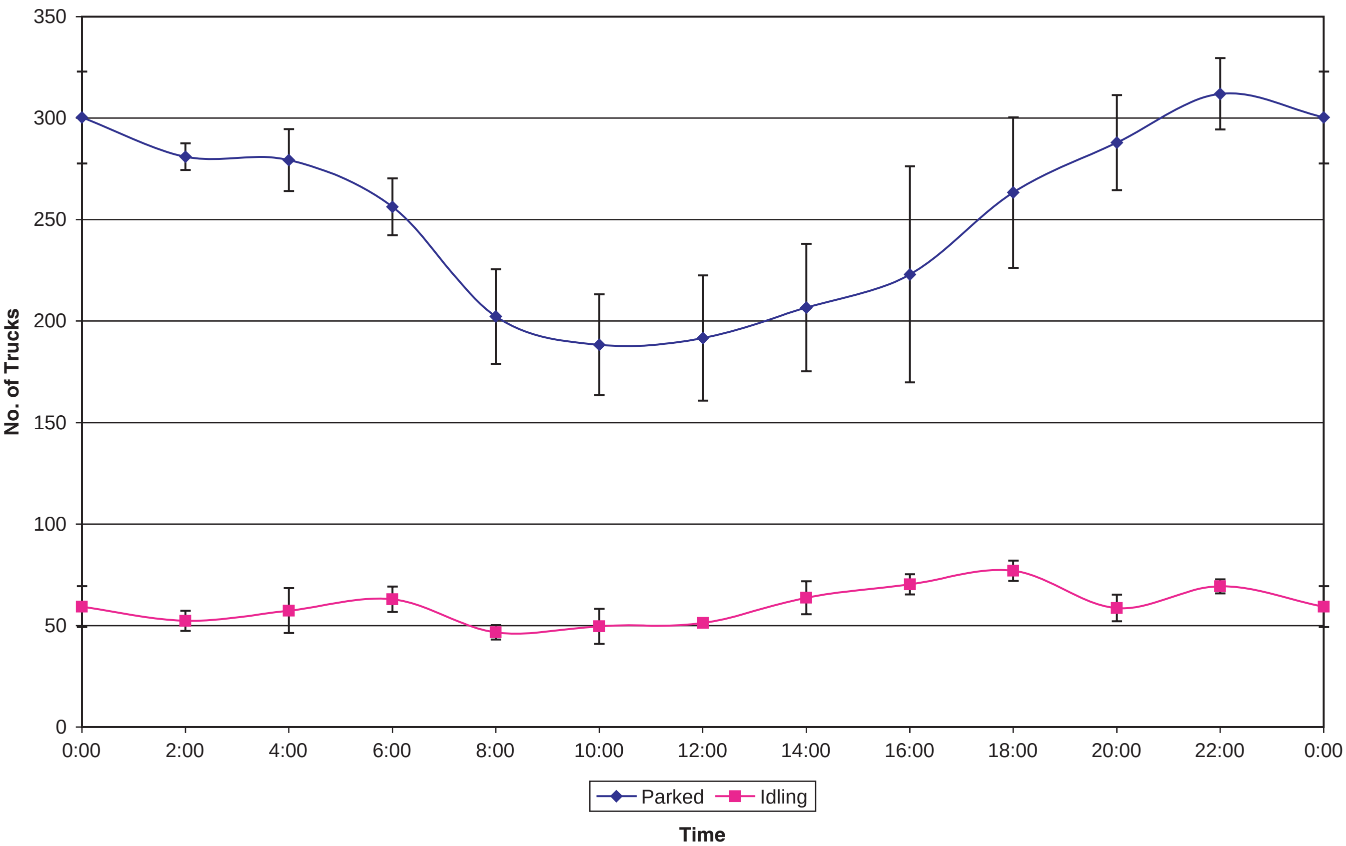


FIGURE 5 Truck counting results: number of trucks parked and idling during study (May 17 to May 20, 2007); points on curve show averages and error bars show associated standard deviations.

TABLE 3 NO_x and CO Average Concentrations with Associated Standard Deviations and Ratios for All Test Modes

	Test Mode				
	A/C (in.)	A/C (recirculation)	APU	TSE	Off
NO_x					
In-cab					
AVE	675	2,373	1,854	127	242
SD	105	568	565	42	142
Ambient					
AVE	174	268	302	125	98
SD	83	264	138	50	87
TCEQ (range)	0–8	0–5	0–7	0–12	0–15
Ratio (in-cab:ambient)	3:88	8:85	6:15	1:02	2:48
CO					
In-cab					
AVE	290	940	1,160	170	160
SD	74	235	396	47	101
Ambient					
AVE	170	150	200	170	130
SD	74	89	90	58	124
Ratio (in-cab:ambient)	1:71	6:27	5:80	1:00	1:23

NOTE: AVE = average, SD = standard deviation.

ratio was similar to the NO_x ratio (5:80 versus 6:15), but the ratios for the A/C recirculation mode, 6:27, and for the A/C-in mode, 1:71, were lower than the NO_x ratios, 8:85 and 3:88, respectively, for unknown reasons. There were no differences between the in-cab and ambient concentration for the TSE mode: they were the same as for NO_x (1.00).

PM-2.5

In-cab and ambient PM-2.5 concentrations were measured with two TEOMs simultaneously. In contrast to the gaseous pollutant results, in-cab concentrations were generally lower than ambient, as shown in Figure 6.

In Figure 6, the TSE mode showed the greatest difference between average in-cab and ambient concentrations. During the TSE mode, the average in-cab concentration was 7.02 $\mu g/m^3$, while the average ambient concentrations were 16.1 $\mu g/m^3$. The ratio of in-cab-to-ambient concentrations was 0:43; that is, the in-cab concentrations were 57% lower than the ambient concentrations. This means that the TSE A/C system, while supplying A/C inside the cabin of the test vehicle, filtered 57% of the ambient PM-2.5 on average. In addition, the data for the APU-powered A/C system and the test vehicle's A/C system for the recirculation mode show in Figure 6 that the systems filtered 40% and 42% of the PM-2.5, respectively (i.e., the ratios of in-cab to ambient PM-2.5 were 0:60 and 0:58, respectively).

However, in Figure 6, the A/C-in mode shows the smallest concentration differences [i.e., the ratio is the highest (0:89)]. During the A/C-in mode, outside (ambient) air, which was not filtered, entered into the cabin and mixed with filtered and conditioned air through the vehicle's A/C system, resulting in the highest ratio. The ratio for the A/C-off mode was lower than that for the A/C-in mode due to the effects of contaminated data from the other test modes (as stated in the discussion of NO_x results).

Figure 6 shows that the average ambient PM concentration during the TSE mode was the highest. As stated earlier, the number of idling trucks was about 20% higher during this mode than during other modes. In addition, the number of trucks parked during the TSE mode test was the highest, which indicates higher emissions rates from the increased truck traffic during the test period. However, further analysis with more data, including detailed meteorological data, is necessary to verify and quantify the effects on ambient air quality from the number of idling trucks.

Gaseous Pollutants (Aldehydes)

Formaldehyde and acetaldehyde were collected as integrated samples with DNPH cartridges. The integrated in-cab and ambient samples required sampling periods of 10 to 12 h to obtain a sufficient sample but were collected simultaneously with two sampling pumps. An equipment malfunction prevented the collection of integrated samples during the TSE portion of the tests. The most striking result was the very high ratios of in-cab to ambient formaldehyde (2:1 with truck idling and 3:2 with APU while ambient concentrations were about 1.6 $\mu g/m^3$), especially when compared with acetaldehyde ratios (five with truck idling and four with APU while ambient concentrations were about 1.0 $\mu g/m^3$). Typical idling levels of formaldehyde can be three to five times as high as acetaldehyde (*9*), so, if significant exhaust penetration into the cab was occurring, then the ratio would also be higher. Another possible source of formaldehyde in the cab is the insulation. This truck was fairly new, and the materials in the cab

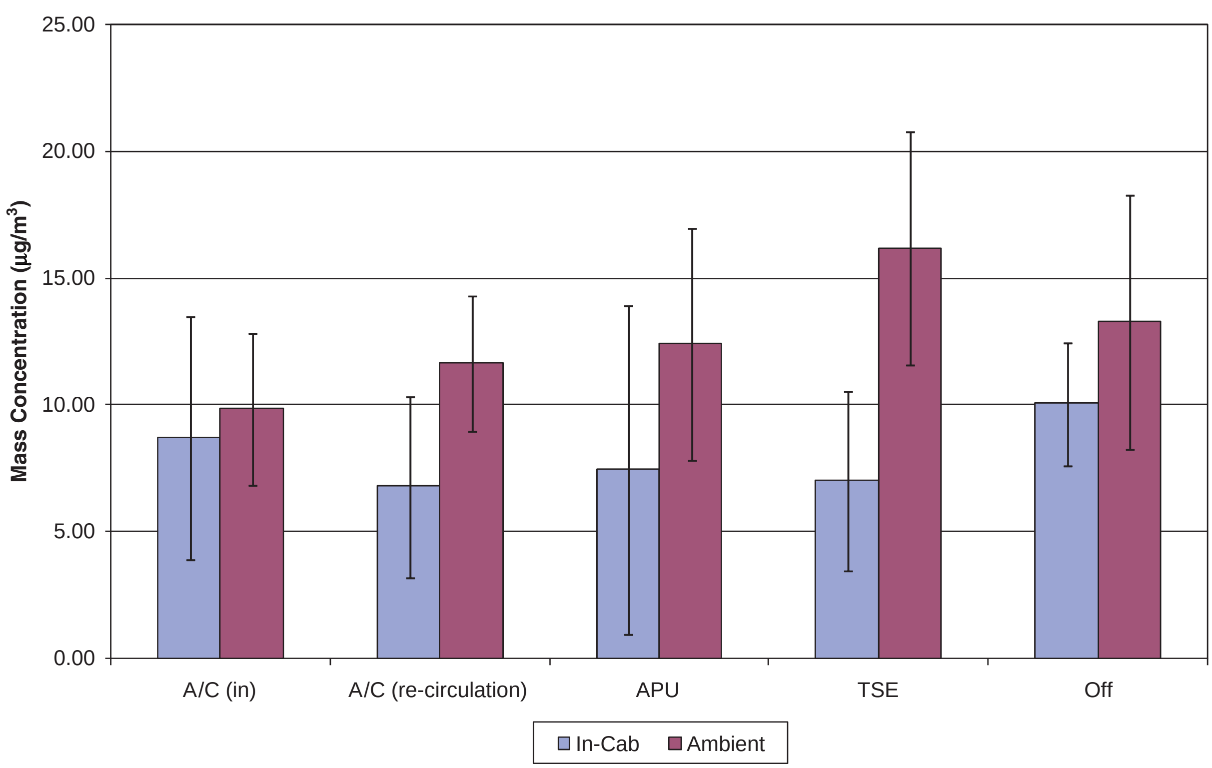


FIGURE 6 Average PM-2.5 concentrations for all test modes.

could have been off-gassing, especially when the in-cab temperatures were higher than 40°C during periods of no A/C.

Another significant difference in formaldehyde concentrations exists between the day and night concentrations in the cab: 29.1 μg/m^3 for day and 43.5 μg/m^3 for night while the truck was idling, and 46.0 μg/m^3 for day and 51.3 μg/m^3 for night while APU was being used. This difference may result from the presence of more stagnant air during the nighttime and therefore the concomitant possibility of more infiltration into the cab.

CONCLUSIONS

With an HDDV parked at an electrified truck stop, the in-cab air quality was investigated under different A/C modes: A/C-in, A/C recirculation, APU, and TSE (a closed electrified unit) as well as A/C-off. In-cab and ambient air pollutant concentrations and exhaust emissions from the test vehicle and the APU were measured, compared, and analyzed. On the basis of the results, the electrified unit (the TSE mode) provided better in-cab air quality during A/C use for NO_x, CO, and PM emissions than the other modes.

For emissions from the vehicle and APU exhausts, fuel consumption and CO_2 rates for the APU were 19% and 15% higher than those for the vehicle, respectively. The authors concluded that the APU's continuous operation at maximum load for providing A/C to the cabin caused the APU to consume more fuel and, consequently, to emit more CO_2 than the test vehicle's engine, which was always in a low idle mode (600 rpm). For gaseous pollutants, NO_2, CO, and THC, the APU emissions were about one-third of those from the vehicle, while PM emissions were just about one-eighth. These low APU emissions resulted from the APU's smaller engine size and therefore lower amount of exhausts. On the basis of the EPA's point source data and TCEQ meteorological data near the test site, researchers concluded that vehicles parked at the test site and at two other nearby truck stops and traffic on I-10 were the only sources affecting the in-cab and ambient air quality during the test period.

For NO_x and CO, the ratios of in-cab-to-ambient concentrations for the A/C recirculation mode test were the greatest. The ratios for NO_x and CO in THE APU mode were the second greatest, and those in the A/C-in mode were next; the least ratios were found in the TSE mode. During the TSE and A/C-off modes, in-cab and ambient concentrations were almost the same.

For PM, in-cab concentrations were lower than ambient ones because PM is filtered when air passes through the A/C systems. The TSE mode showed the greatest PM reduction at 57%. The A/C recirculation mode and the APU mode reductions were 42% and 40%, respectively. The A/C-in mode reduction was the least at 11% because some unfiltered PM in the ambient air was mixed in this mode.

For formaldehyde, in-cab concentrations were much higher than ambient concentrations: 21 times as high while the truck was idling (for both the A/C-in and recirculation modes) and 32 times as high during the APU mode. These striking differences mean that there was significant penetration of formaldehyde into the cab. Another possible source of formaldehyde was off-gassing of the insulation of this fairly new vehicle, especially when the in-cab temperatures were higher than 40°C during periods of no A/C. Unfortunately, there were no results for the TSE mode due to malfunctioning of the samplers.

This study was based on one HDDV test vehicle, one APU, and one TSE in an actual truck stop in limited days of testing (about one day of testing was performed for each mode.) A larger sample size (e.g., more vehicles, more APUs, and more TSEs) would increase the statistical confidence of the results, and more testing days would provide more statistical strength to the analysis. Furthermore, tests conducted in a more controlled environment (e.g., absence of emissions from other vehicles, constant or controlled meteorological conditions, etc.) would assist in developing gas and PM emissions infiltration models that can be useful for predicting in-cab air quality for vehicles parked at truck stops running A/C units.

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