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# Emissions from a fuel-fired heater on a battery electric coach: Tests in China

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## BACKGROUND

Around the world, electric buses are becoming common in bus fleets due to their efficiency and environmental benefits. In cold regions, electric bus operations are more demanding. Low temperatures reduce battery performance because both battery heating and cabin heating consume a large amount of electricity; this affects driving range and operational efficiency. According to prior analysis by the ICCT, cabin heating at temperatures as low as -20 °C can consume up to 50% of a vehicle's total energy (Mao et al., 2023b).

In northern regions of China, where winter temperatures can reach -20 °C, electric bus operators and fleet managers typically install auxiliary heating devices known as fuel-fired heaters (FFHs) to maximize the driving range of buses and coaches. As independent heating systems, FFHs provide heat to the passenger cabin without drawing on battery power (Figure 1). By burning diesel or gasoline to generate heat, FFHs optimize the efficiency of winter operations and improve the overall durability of the vehicle. At the same time, FFHs are a source of emissions, and many FFHs lack aftertreatment systems such as diesel particulate filters.

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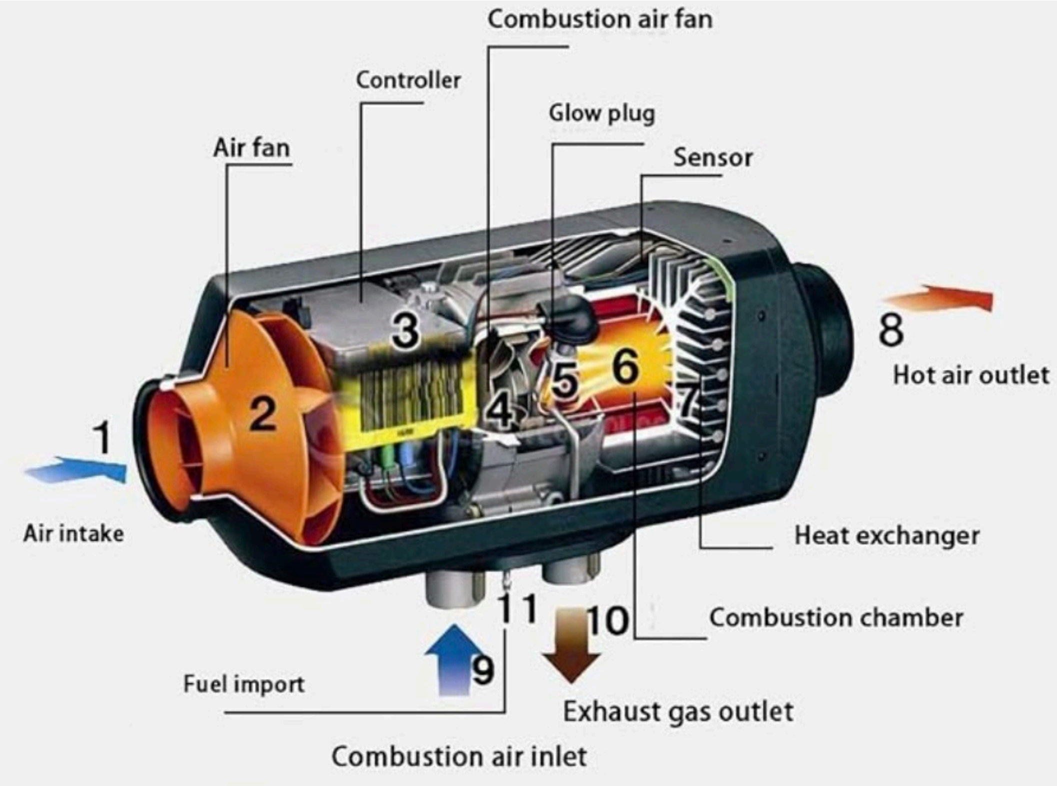
**Figure 1**
**Inner structure of fuel-fired heater**




*Source:* Chong (2019). Reprinted with permission.

China, the European Union, and the U.S. State of California have each established standards for pollutant emissions from FFHs (Table 1). China and the European Union set a parts-per-million (ppm) limit for each pollutant during the testing procedure, while California's regulation assesses the average emissions per mile. These standards cover nitrogen oxides ($NO_x$), carbon monoxide (CO), total hydrocarbon (THC), and non-methane organic gases (NMOG), and other pollutants. The limits are somewhat lenient and there is no requirement for aftertreatment of the exhaust gases. Additionally, none of the standards cover solid particulate matter (SPN/PM) or the greenhouse gases emitted by the heaters such as carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). In China, the standards are industry recommendations and not mandatory national regulations.

**Table 1**
**Regulatory scope and limits in three regional standards for fuel-fired heaters**

| | China JB/T 8127-2021 | California LEV II ULEV | EU R122 |
|---|---|---|---|
| **$NO_x$** | < 100 ppm | < 0.05 g/mi | < 200 ppm |
| **CO** | < 300 ppm | < 1.7 g/mi | < 1,000 ppm |
| **HC** | < 5 ppm | < 0.008 g/mi | < 100 ppm |
| **NMOG** | | < 0.04 g/mi | |
| **PM** | | | < 4 smoke number (Bacharach conversion method) |

Emissions from FFHs are an emerging topic of research. In Sutton et al. (2021), CALSTART collected emissions data from FFHs installed in electric buses from three manufacturers and found that the average CO and $NO_x$ emissions were lower than the limits in the California LEV II ULEV standards. However, the California standards apply to FFHs installed on diesel vehicles, and there are no regulations for heaters on electric buses. The report recommended standardized testing and reporting of FFH emissions to guide future policymaking and support the development of electric buses.

Tests conducted in Canada in 2023 indicated that the CO and NMOG emissions from FFHs largely met California's emission standards, but $NO_x$ emissions exceeded the limit (Humphries et al., 2024). When the same study compared data collected by on-road tests with the EU standards, it found the CO and hydrocarbon emissions were significantly higher than the prescribed levels, particularly during cold starts; the duration of elevated emissions was brief, however.

Although the electric bus and coach market in China has experienced rapid growth in recent years, no publicly available studies have tested and analyzed FFHs installed on electric buses or coaches in the country. This paper aims to help fill this research gap, particularly concerning emissions performance under cold temperatures. We also focus on a broad set of pollutants, including greenhouse gases and PM, which are not currently regulated by any national or regional regulations. The goal is to provide quantitative data to support future policy approaches.

## METHODOLOGY

This paper analyzes the functionality and emissions of FFHs across a range of temperatures that are relevant to both typical and extreme operational scenarios that may be encountered during real-world use. The Xiamen Environment Protection Vehicle Emission Control Technology Center performed the tests.

### TEST SCHEDULE

The tests were conducted at three temperatures: 20 °C, -7 °C, and -20 °C. Although FFHs do not typically operate at 20 °C, the temperature was included in the testing because the emissions calibration of the FFH was completed at 20 °C, according to the manufacturer. The temperature of -7 °C was chosen because it is a typical temperature in winter for most regions in northern China; -20 °C was selected to explore the operational conditions of the FFHs under extreme circumstances.

Table 2 provides information about the testing setups. During the tests, the vehicle was operated in idle and running states. However, according to the calibration trial before the tests, the operational state of the vehicle did not impact the FFH's performance in terms of emissions, fuel consumption, or heating power. It is therefore reasonable to conduct the tests during the idle phase at -7 °C and -20 °C. In the running state, the vehicle followed the CHTC-B driving cycle, which is a standardized test cycle applied to city buses under the China Heavy-duty Commercial Vehicle Test Cycle. The pollutants measured were CO, $CO_2$, $NO_X$, THC, $CH_4$, $N_2O$, and SPN. Estimates of NMOG were obtained by deducting the concentration of $CH_4$ from THC.

**Table 2**
**Testing setups**

<table>
<tr><th>Temperature</th><th>Vehicle state</th><th>Mode of heater</th><th>Test cycle</th><th>Number of tests</th><th>Tested pollutants</th></tr>
<tr><td rowspan="3">**20 °C**</td><td>Idle</td><td>Defrost and defog activated, maximum airflow</td><td>Stationary test (until the heater shuts off automatically when the coolant reaches 85 °C)</td><td>2</td><td rowspan="5">Pollutants: $NO_X$, CO, THC, $SPN_{10}$/$SPN_{23}$<br><br>Greenhouse gases: $CO_2$, $CH_4$, $N_2O$,</td></tr>
<tr><td rowspan="2">Running</td><td>Defrost and defog activated, maximum airflow</td><td>Driving test (cycle: CHTC-B)</td><td>3</td></tr>
<tr><td>Defrost and defog activated, minimum airflow</td><td>Driving test (cycle: CHTC-B)</td><td>1</td></tr>
<tr><td>**-7 °C**</td><td>Idle</td><td>Defrost and defog activated, maximum airflow</td><td>Stationary test (until the heater shuts off automatically when the coolant reaches 85 °C)</td><td>3</td></tr>
<tr><td>**-20 °C**</td><td>Idle</td><td>Defrost and defog activated, maximum airflow</td><td>Stationary test (heater works for at least 1 hour if coolant fails to reach 85 °C)</td><td>3</td></tr>
</table>

## TESTED VEHICLE AND HEATER

The vehicle tested was a coach model typical in the Chinese market. It is manufactured by King Long (Figure 2) and is equipped with an FFH provided by Hebei Hongye Yongsheng Automobile Heater Co. Ltd. (Figure 3). The diesel heater was manufactured within 6 months of the test and has a heating capacity of 35 kW. Detailed specifications of the vehicle and the heater used are in Table 3.

**Figure 2**
**Vehicle tested in this study**

Photo by Shiyue Mao

**Figure 3**
**Fuel-fired heater used in the vehicle in this study**

Photo by Shiyue Mao

**Table 3**
**Specifications of the tested coach and fuel-fired heater**

| | | |
|---|---|---|
| **Vehicle** | **Brand** | King Long |
| | **Model** | XMQ6112AYBEVL05 |
| | **Gross vehicle weight** | 18,000 kg |
| | **Passenger capacity** | 52 |
| | **Max output** | 360 kW |
| | **Battery capacity** | 560 Ah |
| **Heater** | **Manufacturer** | Hebei Hongye Yongsheng Automotive Heater Co. Ltd. |
| | **Age** | Within 6 months of manufacture |
| | **Heating method** | Liquid |
| | **Fuel type** | Diesel |
| | **Output power** | 165 W |
| | **Heating power** | 35 kW |
| | **Input type** | Battery |
| | **Rated voltage** | 24 V |
| | **Temperature control method** | Heater shuts downs when water is heated to 85 °C; the heater reignites to reheat when temperature drops to 65 °C |
| | **Heating areas** | Heating by compartment and front windshield defrosting |
| | **Fuel consumption** | 3.6 kg/h or 4.24 L/h |
| | **Flow rate of pump** | 5,000 L/h |
| | **Weight** | 28 kg |
| | **Installation** | At factory |

## TESTING DEVICE SETUP

Three HORIBA OBS-ONE portable emissions measurement system (PEMS) devices were set up to measure different pollutant emissions from the FFH while in operation. During the testing, one was used to measure THC, $NO_x$, CO, $CO_2$, and $SPN_{23}$; another was used to measure $SPN_{10}$; and the third was used to measure $CH_4$ and $N_2O$. To improve the accuracy of the test, the positioning of the test equipment and sampling points was arranged as shown in Figure 4; the first PEMS device probed $SPN_{23}$ to avoid further condensation through the tube. The testing equipment was provided by the Xiamen Environment Protection Vehicle Emission Control Technology Center and its specifications are listed in Table 4.

**Figure 4**
**Testing devices and sampling points**

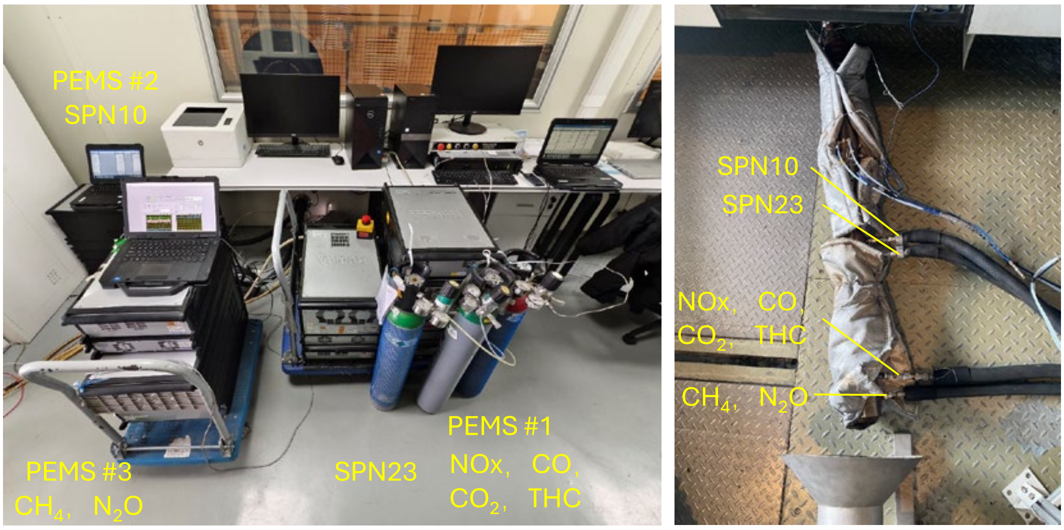



**Table 4**
**Specifications of the HORIBA OBS-ONE portable emissions measurement system devices**

| Pollutant/ Metric | Method | Range | Accuracy |
|---|---|---|---|
| CO | Heat non-dispersive infrared | 0–10 vol% | ±0.3%FS (full scale) or ±2.0%RS (reading span) |
| $CO_2$ | Heat non-dispersive infrared | 0–20 vol% | ±0.3%FS or ±2.0%RS |
| $NO_x$ | Heat chemiluminescence detector | 0–3,000 ppm | ±0.3%FS or ±2.0%RS |
| THC | Flame ionization detector | 0–10,000 ppm | ±0.3%FS or ±2.0%RS |
| $CH_4$ | Quantum cascade laser | 0–2,000 ppm and 0–10,000 ppm | ±0.3%FS or ±2.0%RS |
| $N_2O$ | Quantum cascade laser | 0–1,000 ppm | ±0.3%FS or ±2.0%RS |
| $SPN_{23}$ | Condensation particle counter | 23 nn–1 um, 0–5×$10^7$ #/$cm^3$ | ±10%RS |
| $SPN_{10}$ | Condensation particle counter | 10 nn–1 um, 0-5×$10^7$ #/$cm^3$ | ±10%RS |
| Flow rate | Pitot tube differential pressure measurement | 0–15 $m^3$/min | ±0.3%FS or ±2.0%RS |

# KEY FINDINGS AND DISCUSSION

Table 5 summarizes the results from the emissions testing. The CO concentration increased as the temperature decreased because the diesel fuel in the heater cannot fully combust as the temperature drops. This leads to lower combustion efficiency. For the same reason, the $NO_x$ concentration continuously increased with decreasing temperature.

On the other hand, the emissions of greenhouse gases ($CO_2$, $CH_4$, and $N_2O$) were not greatly affected by temperature during the tests. Inferior combustion efficiency creates higher emissions of greenhouse gases and other pollutants such as $SPN_{23}$ due to lower oxygen concentration in the burning chamber. The group of organic compounds emitted into the atmosphere known as NMOG can be estimated based on the amounts of THC and $CH_4$ ($NMOG \approx THC - CH_4$). However, due to the essentially unavoidable limitations of using the equipment at extreme low temperatures, organic compounds condensed in the sampling system before they reached the gas analyzer. Therefore, we report only the measurements collected at 20 °C.

**Table 5**

**Test results of fuel-fired heaters at different temperatures, average in steady state/ highest value during the test**

| | 20 °C | -7 °C | -20 °C |
|---|---|---|---|
| **$NO_x$/ppm** | 80.6/86.2 | 94.1/102.5 | 96.2/134.5 |
| **CO/ppm** | 53.4/1,076 | 59.7/1,292.7 | 132.6/36,858.5 |
| **$CO_2$/vol%** | 9.3/10.6 | 9.4/10.7 | 9.6/14.1 |
| **$CH_4$/ppm** | 1.9/6.4 | 1.2/11.2 | 1.5/594.3 |
| **$N_2O$/ppm** | 0.2/0.6 | 0.1/0.9 | 0.3/1.3 |
| **$SPN_{23}$/(#/cm³)** | $4.8\times10^5/8.7\times10^6$ | $3\times10^6/2.8\times10^7$ | $6.3\times10^5/5.8\times10^6$ |
| **NMOG/ppm[a]** | 37.1/92.0 | | |

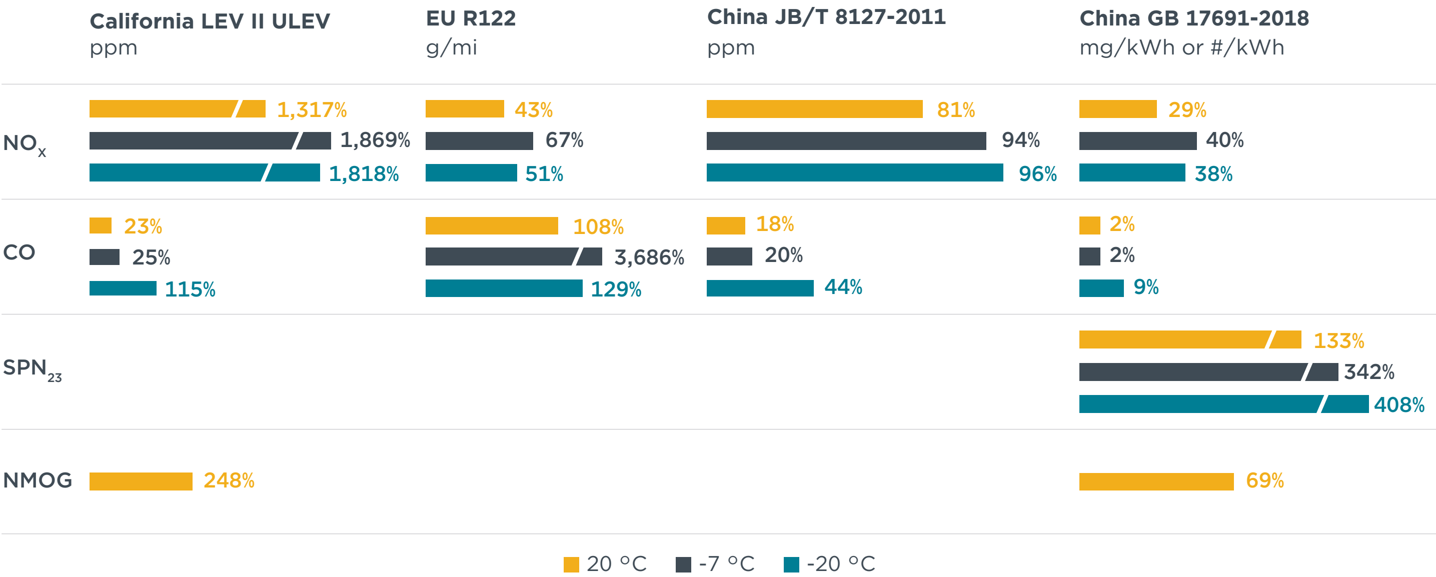
[a] Due to limitations of the equipment setup, organic compounds likely condensed in the sampling system before reaching the gas analyzer at low temperatures. The measured data is thus not reported.

The regulatory approaches in China, the European Union, and California differ slightly, with variations in the types of pollutants regulated and the units used for setting the limits (ppm, g/mi or mg/kWh); thus, the FFH emissions are not directly comparable across regions. Nonetheless, in Figure 5 we illustrate the findings for the pollutant emission limits of the three previously mentioned regulations and the China VI standard (GB 17691-2018), even though the China VI standard regulates emissions from the tailpipes of heavy-duty vehicles, as opposed to FFHs. The EU R122 and China VI standard regulate the peak value throughout the test procedure, while the other regulations are applied to the average. Compared with California's LEV II ULEV standards, our measurements of $NO_x$ and CO mostly exceeded the limit under cold conditions; CO exceeded the limit by more than 30 times under the extreme cold condition of -20°C compared with the EU regulation, as well.

Compared with the China VI standard, our count of SPN exceeded the limit by 200% to 300%, depending on temperature, and that implies that the heater in the electric coach emits more than an internal combustion engine vehicle with similar power configuration. The FFH also emitted about 40% and 69% of the regulatory limits of China VI in terms of $NO_x$ and NMOG, respectively. These results suggest that additional regulations may be needed to control pollutant emissions from FFHs.

**Figure 5**

**Emissions test results at 20 °C, -7 °C, and -20 °C and percentage to regulatory limit in various regional standards**




*Note*: The EU R122 and China VI standard (GB 17691-2018) regulate by the peak value of the test, and the other regulations are applied to the average value.

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To estimate the total $CO_2$ emissions for the electricity consumed by the coach while in operation and from the heater, we applied the assumptions listed in Table 6. For the vehicle, we assumed the coach traveled 12 h and 180 km per day, which is an average distance for city buses and coaches in Chinese cities (Mao & Rodriguez, 2024). We also applied average energy consumption data for the coach at different temperatures from Mao et al. (2023a). The emission factor of the power grid was obtained from the latest announcement by China's Ministry of Ecology and Environment (2025). For the FFH, the emission factors are determined by the tests.

**Table 6**

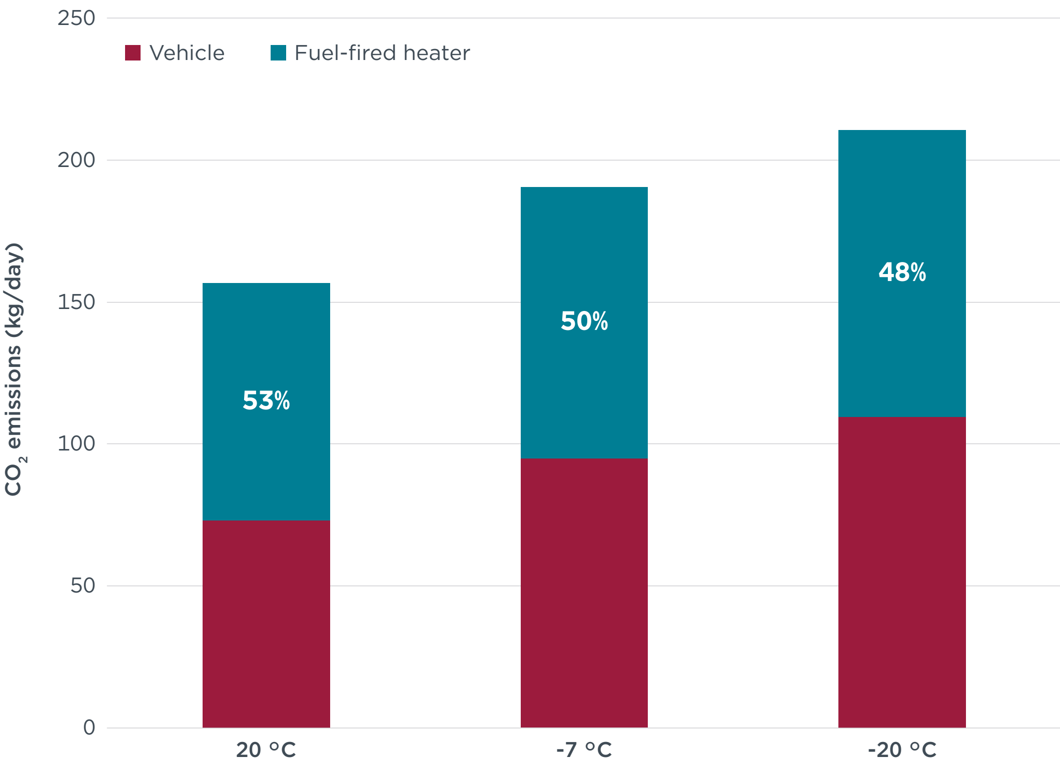
**Assumptions for $CO_2$ emissions estimation**

| | | | | |
|---|---|---|---|---|
| Coach | **Temperature (°C)** | 20 | -7 | -20 |
| | **Traveled distance (km/day)** | 180 | 180 | 180 |
| | **Energy consumption (kWh/100 km)** | 65.4 | 85.02 | 98.1 |
| | **Operating duration (h)** | 12 | 12 | 12 |
| | **Power grid emission factor (kg/kWh)** | 0.6205 | 0.6205 | 0.6205 |
| | **$CO_2$ emissions (kg/day)** | 69.9 | 90.9 | 104.9 |
| Fuel-fired heater | **Emission factor (kg/100 km)** | 46.4 | 53.1 | 56.0 |
| | **$CO_2$ emissions (kg/day)** | 83.5 | 95.6 | 100.8 |
| **Share of fuel-fired heater** | | 53% | 50% | 48% |
| **Total $CO_2$ emissions** | | **156.6 kg/day** | **190.6 kg/day** | **210.5 kg/day** |

Figure 6 shows the $CO_2$ emissions from the coach's energy consumption and from the FFH. As shown, total $CO_2$ emissions rise from 153.5 kg/day at 20 °C to 205.8 kg/day at -20 °C. The proportional decrease in the FFH's share of emissions (54% at 20 °C, to 49% at -20 °C) reflects growing $CO_2$ emissions by energy consumption of the vehicle electric motor in extreme cold weather, due to greater mechanical strain and idling; the heater still produced higher $CO_2$ emissions, from 83.6 (20 °C) to 100.9 kg/day (-20 °C), but account for slightly less of the total at lower temperatures. However, the substantial emissions from the heater across all temperatures highlights the inefficiency of combustion-based heating, suggesting that even in mild conditions, new technologies such as heat pumps could deliver significant reductions (Mao et al., 2023b). While heaters are rarely used at room temperatures such as 20 °C, our test results show that FFHs can be a significant source of $CO_2$ emissions and exhaust pollutants.

**Figure 6**

**Total $CO_2$ emissions from the coach and fuel-fired heater at 20 °C, -7 °C and -20 °C**

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## COMPARISON WITH LITERATURE

Table 7 summarizes the test results from this study and others found in the literature. In this study, a heater with fuel consumption of 4.24 L/h was applied for testing, and it generates more $CO_2$ emissions than the FFHs tested in other studies. The range of fuel efficiency values also suggests that some heater manufacturers could improve the fuel efficiency and $CO_2$ emissions performance of the FFHs they produce. Additionally, note the wide range of exhaust emissions among the studies, including pertaining to $NO_x$ and CO.

**Table 7**

**Summary of results from peer literatures**

| Title | Year | Temp | $NO_x$ | | CO | | Fuel consumption | | $CO_2$ | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | °C | g/mi | g/h | g/mi | g/h | L/100 km | L/h | g/mi | g/h | |
| **Diesel fuel-fired heater emissions from a battery electric transit bus in real-world conditions** | 2024 | 3.4 | 0.34 | 3.85 | 0.05 | 0.99 | 9.00 | 1.78 | 377.00 | 4,689.00 | Humphries et al. (2024) |
| | | -1.5 | 0.34 | 4.21 | 0.08 | 1.90 | 9.10 | 2.00 | 382.00 | 5,233.00 | |
| **Fuel-fired heaters: Emissions, fuel utilization, and regulations in battery electric transit buses** | 2021 | | 0.03 | | 0.11 | | | | | | Sutton et al. (2021) |
| **Testing method for electric bus auxiliary heater emissions** | 2023 | -20 | | 4.20 | | 7.50 | | 1.90 | | 5,900.00 | Pettinen et al. (2023) |
| **Measurement of emissions from diesel fired heaters for buses** | 2018 | | | 9.70 | | 4.40 | | | | | Bræstrup (2018) |
| **This study** | 2024 | -7 | 0.93 | 8.36 | 0.42 | 3.73 | | 4.24 | 854.90 | 8,111.70 | |
| | | -20 | 0.91 | 9.81 | 1.95 | 17.12 | | 4.24 | 902.45 | 8,562.87 | |

# CONCLUSIONS

This paper analyzed the exhaust emissions and greenhouse gases from an FFH installed in a mainstream coach model in China. Around the world, current regulations for FFHs largely adopt the framework for regulating internal combustion engines; certain emissions are unregulated, and standards in some regions do not cover particulate matter and greenhouse gases such as $CO_2$ and $CH_4$.

The testing found that low temperatures exacerbate emissions due to incomplete combustion, and this leads to higher emissions of particulates and hydrocarbons. Additionally, this study found high particulate matter emissions from FFHs, with emissions exceeding the China VI standard for diesel vehicles by over three times.

Current emission controls for FFHs primarily address $NO_X$ and CO. **Our tests found substantial emissions of particulate matter ($SPN_{23}$ and $SPN_{10}$) and NMOG, and many of the pollutants exceeded the regulatory limits of tailpipe regulations for diesel vehicles.** As this undermines the environmental benefits of electric buses and coaches, current emission standards for FFHs could be expanded to include limits on more pollutants.

**The tested FFH accounted for about 50% of total $CO_2$ emissions associated with the electric coach while in use, and the share would be even higher with a cleaner power grid.** Because the emissions from FFHs are not negligible, regulators could consider incorporating them in future emissions modeling and vehicle test certification procedures.

To reduce the emissions from FFHs, further compliance can be enforced by rigorous testing and monitoring. This approach would help maintain the environmental integrity of electric buses and coaches, reduce real-world emissions, and support the overall transition to sustainable transportation. Regular updates to the standards would ensure they remain effective as technology evolves.

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