Incident Summary #II-1806066-2024 (#55151) (FINAL)

SUPPORTING INFORMATION	Incident Date		September 3, 2024
	Location		West Vancouver
	Regulated industry sector		Gas - Natural gas system
	Impact – Injury	Qty injuries	6
		Injury description	Several people residing and working in a residential home experienced illness symptoms related to carbon monoxide exposure.
		Injury rating	Minor
	Impact – Damage	Damage description	Dangerous concentrations of carbon monoxide were being produced by a heating boiler and migrated indoors causing exposure to the occupants.
		Damage rating	Moderate
	Incident rating		Moderate
	Incident overview		A wall hung condensing boiler installed in a large residential home, produced high concentrations of carbon monoxide (CO). The venting system for the boiler allowed the flue gasses to enter the home and expose the occupants to levels of CO that resulted in illness symptoms over a two-year period.
INVESTIGATION CONCLUSIONS	Site, system and components		The 13,359 square foot residential home was built in 2009. The radiant heating and domestic hot water system for the home was designed to use a geothermal heat pump system as the primary source for heat, with a gas fired condensing boiler as a secondary source of heat. The natural gas fired boiler for the system was installed in the mechanical room on the lower level of the three-story home. The boiler used a PVC venting system which drew fresh air for combustion and vented flue gasses at the exterior wall of the home. The boiler has a modulating input to meet variable heating demands with a 10:1 turndown ration. The maximum input of the boiler is 199,000 btu and the minimum input is 19,900 btu. Natural gas requires a minimum amount of oxygen for complete combustion. When the minimum amount of required oxygen is not supplied to a gas burner, the result is incomplete combustion. A by-product of incomplete combustion is CO. CO is a colourless, odourless, tasteless gas that is toxic to humans and animals. Exposure to CO interferes with the body's ability to absorb oxygen, which can result in serious illness or death. For more CO information, visit CO safety tips. ## Code requirements The CSA B149.1 natural gas and propane installation code adopted in BC requires: • Before leaving installations, installers shall ensure that the appliance, accessory, component, equipment, or piping and tubing they installed complies with the code requirements, and the person initially activating the appliance shall ensure that the appliance is in safe working order. • The use of an appliance, accessory, component, equipment, or material shall be prohibited where a hazard is created.

- Vents constructed using plastic piping shall be certified to ULC S636.
- A vent or chimney shall provide effective venting and shall be designed and constructed to remove all flue gases to the outdoors.
- A special venting system or a BH venting system shall be installed in accordance with the terms of its listing and the appliance and vent manufacturer's instructions.

Boiler manufactures instructions

Venting

The boiler manufacture provides specific instruction on how to properly install venting systems for the appliance to provide proper and safe operation. The boiler in the home was installed with a direct vent system terminating out the sidewall of the home. For this application the manufacture provides many requirements including the following:

- Material for the vent shall be S636 certified stainless steel, PVC, CPVC, or Polypropylene.
- The vent size for the model of boiler (199) shall be 3" with max equivalent length of 100 feet (4" is only used for larger models 285 or 399).
- All PVC vent pipes must be glued, properly supported, and the exhaust must be pitched a minimum of a 1/4 inch per foot back to the boiler (to allow drainage of condensate).
- When using a sidewall termination, maintain clearances as shown:

Figure 4-1 *Field Supplied Fittings with Vent Termination Elbow*

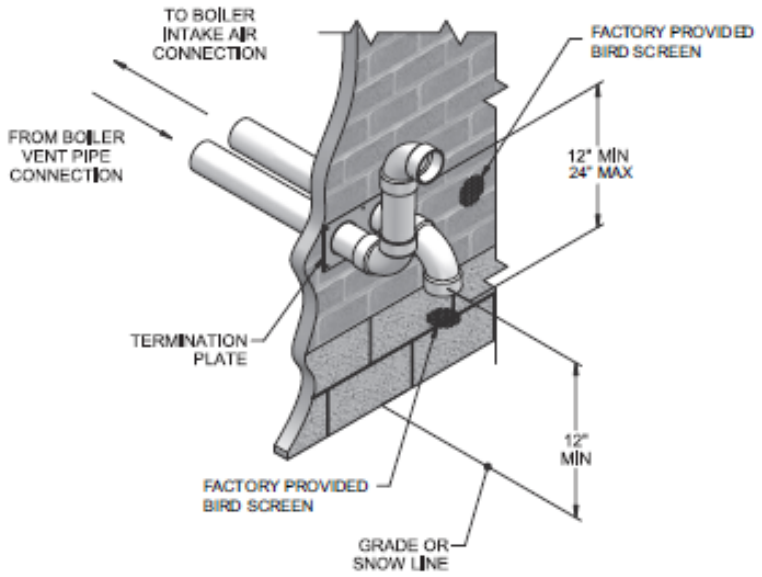
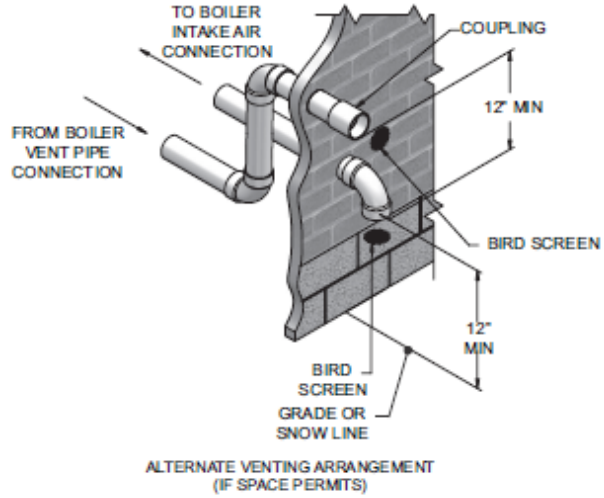


Figure 4-5B Field Supplied Fittings with Vent Termination Coupling



The installation manual also provied the following warning for vent installation:

⚠WARNING A gas vent extending through an exterior wall shall not terminate adjacent to a wall or below building extensions such as eaves, parapets, balconies, or decks. Failure to comply could result in severe personal injury, death, or substantial property damage.

Combustion setup

All the new boilers of this model are test fired from the factory by the manufacturer and the gas valve adjustments are factory set. When the boiler is newly installed, the manufacture installation and operation manual require the combustion to be confirmed by a technician with a combustion analyzer. The instructions state the boiler should be set to service mode and operated at full fire while measuring the flue gasses with a combustion analyzer. If the readings are within the range specified in the manual, then the combustion setup is complete. If the readings are out of range, then the boiler manufactures service manual outlines how to adjust the settings under the troubleshooting section. The service manual identifies how to measure and adjust the combustion using adjustment screws on the gas valve to achieve the flue gas measurements withing the identified ranges at both high fire and low fire.

Plastic venting directive

(Technical Safety BC Directives are regulatory instruments issued by safety managers to clarify or provide new interpretation, application, or operation of a regulation or code. Compliance is mandatory.)

Incident Summary #II-1806066-2024 (#55151) (FINAL)

	Technical Safety BC issued directive: (Plastic Venting Directive) in 2011 confirming the requirements for the S636 certification of plastic venting systems for gas appliances and allowing existing venting to be used with new appliances in specific circumstances. The directive was issued due to the investigated failures in a number of existing plastic gas venting systems throughout Canada. The directive states that there may be situations where the replacement of the entire vent is not possible or is impractical due to specifics of that particular installation. For those situations, the holder of a valid installation permit may use the existing vent provided that all of the following conditions are met: 1. It is not possible to replace the entire vent. 2. The first five feet immediately downstream of the appliance is replaced with vent that is: a. Suitable for the appliance; and, b. Certified to ULC S636. 3. The existing vent is visually inspected and found in good working order (cracked or damaged vent is not allowed to be repaired - the entire vent shall be replaced). 4. The existing vent is pressure tested following the procedure outlined in the directive. 5. If a vent fails the pressure test, the entire venting system shall be replaced with vent suitable for the appliance and certified to ULC-S636.
Failure scenario(s)	When the home was originally built in 2009 it was designed to have a geothermal heat pump as the primary source of heating and a gas fired boiler as a secondary source of heating. The geothermal and boiler systems were installed but the geothermal system was never completed and the gas fired boiler became the primary source of heat and hot water for the home. The home was calculated during initial design as having a heating load of 210,440 btu and a 250,000 btu boiler was originally installed. The boiler was installed with a PVC venting system for the combustion air intake and flue gas venting of the boiler. Some time recently prior to the new owner purchasing the home in 2023, the original boiler was replaced with a new boiler. The new boiler was smaller than the original with a 199,000 btu input and was undersized for the full heating load of the home. The boiler was installed without an appropriate installation permit and as such there was no opportunity for an inspection by a gas safety officer to be conducted. The boiler was installed using the existing PVC venting system from the previous boiler but did not meet the requirements to do so outlined in the Technical Safety BC (Plastic Venting Directive). The original 4” venting system was oversized for the new boiler and the vent terminations were not compliant with applicable codes or the manufacturers installation instructions. The air intake and vent outlet did not have the required separation, and the vent outlet had a 90-degree elbow on the end which directed the flue gassed adjacent to the exterior wall against the manufacturer’s instructions and warning (Image 3). The boiler was not operating within the factory specifications outlined by the manufacturer. When the boiler was operating on high fire, the combustion flue gasses met the manufacturers specified settings. When the boiler was operating on low fire, the boiler fuel adjustment created incomplete combustion and hazardous levels of CO (<4000ppm). The undersized boiler being the primary source of heat for the large residential home, resulted in the boiler running for prolonged periods of time, likely with long stretches of operating at low fire while producing the hazardous levels of CO in the flue gasses. The incorrect venting system directed the flue gasses

Incident Summary #II-1806066-2024 (#55151) (FINAL)

	along side the house under a ventilated soffit. The oversized vent piping reduced the velocity of the flue gasses coming from the boiler, especially during the periods of low fire. The 90-degree elbow on the vent termination combined with the low velocity of the flue gas at low fire, allowed the flue gasses containing high amounts of CO to rise alongside the exterior of the home and infiltrated into the ventilated soffit and migrated into the walls of the home. During multiple service calls by contractors hired by the owner to troubleshoot the plumbing, boiler and heating system, the non-compliant venting system, and improper low fire combustion went unidentified by the contractor's technicians. The home was equipped with a total of 9 operational built-in combination smoke/carbon monoxide detectors. Three were located in the hallways of each floor and an additional plug-in dedicated CO detector in the hallway outside the mechanical room. It is likely that although high concentrations (<400ppm CO) were measured within the walls of the third floor at West side of the home while the boiler was operating on low fire, that concentrations may not have reached the threshold required to cause the CO detectors in the home to alarm.
Facts and evidence	**Interview statements** **House manager:** • The family complained of being sick after they moved into the house including the nanny and the house cleaner. • Their symptoms included headaches, dry cough, itchy red eyes, feeling tired, dizziness and vomiting, chest pain. • On two separate occasions when the family was away from the home of vacations for weeks at a time, they did not complain of illness symptoms until they returned to the house at which point the symptoms returned. **Sibling of owner:** • The geothermal system wasn't working, and the boiler was undersized and would occasionally quit working and some areas of the house would get too hot. • Many contractors have been brought in to try to resolve issues with the heating and plumbing systems. • There had been water or condensation leaking on top of the boiler causing damage to the outer case, internal components, and wiring. • He had spent time in the home but maybe two days max before leaving back to his place, but he never experienced and symptoms while he was there. • There were CO detectors throughout the house, but he is not aware of them ever alarming. • There had been extra plug-in CO detectors in the house as well and all but one of them have since been removed. • The occupants had multiple animals in the home including dogs, rabbits, guinea pigs, a bird and a lizard. None of the animals ever had observed health issues or had unexpectedly died.

Incident Summary #II-1806066-2024 (#55151) (FINAL)

Primary plumbing contractor:

- The boiler in the home had been installed by others when they had been brought to the home to work on the heating system.
- The boiler was undersized for the application without the geothermal being operational.
- Their two technicians are journeyman plumbers with gas certifications.
- They have combustion analyzers and use them to set up gas equipment, they are trained and typically get the analyzers calibrated on a regular basis.
- The boiler in the home had quit working and after they had attended the home and repaired the operation of the boiler, a senior technician used a combustion analyzer on the boiler on Aug 26th.
- The combustion analysis was only prompted by the repair of the boiler and not to investigate the boiler for excessive CO.
- The combustion analysis printouts from that time show CO withing acceptable ranges in relation to the manufacture's specifications.
- They had replaced flame rod, ignitor, wiring harness and control board on boiler in the past.
- The boiler may have operated on low fire for long periods of time if it had a constant heat load.
- The vent piping for the boiler was probably original to the home.
- They did not identify non-compliances or potential hazards with the venting system or suggest to the owner to have it repaired.
- They were not aware of the TSBC plastic venting directive during the time they worked on the boiler system.
- They were never aware of any CO detectors in the home alarming.
- Their technicians never made any adjustments to any of the settings on the gas valve.
- They were aware that when they touch an appliance, they take on the responsibility for its safe operation.

Site observations

Boiler venting and terminations

- The vent was 3" diameter in the mechanical room but increases to 4" behind enclosed walls and terminated outdoors at 4".
- Due to a leak on air intake piping from an unglued joint, a section above the boiler in the mechanical room had been replaced with CPVC piping.
- The sidewall vent termination was non-compliant. It was too close to a separation between the air intake and exhaust piping and the exhaust was directed alongside the home's exterior wall under a ventilated soffit.
- The air intake was at the same height as the vent outlet.

Equipment testing

During the investigation, the boiler was examined and tested by an independent third-party gas contractor who produced a report of their findings.

- When testing the boiler flue gas with a calibrated combustion analyzer, the high fire settings were within the manufacture's specifications. When the boiler was set to low fire, the O2 level dropped to 0% then the CO rose above the 4000ppm CO maximum advertised accurate testing level of the instrument and the max reading on the display of the instrument was recorded at 75,272 ppm CO before the instrument went into sensor protection mode.
- While in low fire, the volume of vent products was very low and while exiting the 4" vent termination, it was observed having a very low velocity.
- The vent had an elbow pointing the vent parallel to the exterior wall and the flue products were witnessed rising up into the soffit located 24" above which had a ventilation strip that allowed the flue products, containing very high concentrations of CO, to enter the soffit and wall spaced at that location of the home.
- A separate third-party contractor later inspected and tested the vent piping for the boiler and identified that the venting was continuous and had not separated behind the enclosed walls.

Contractor report:

- The vent termination was oversized at 4" for the boiler model and, with no bird screens and improper spacing between the air intake and exhaust.
- The termination was observed to be under a soffit near the windows.
- At low fire, the low fan speed, flue gas velocity and incorrect spacing between the air intake and exhaust allowed flue gases to be pulled into the boiler air intake piping.
- The gas inlet pressure was measured and confirmed to be within operational specs of boiler requirements static and at low and high fire.
- Corrosion was observed on top of the boiler from a previous leak on top of the boiler.
- No water leaks were found on the boiler or attached piping systems.
- The fan was tested and confirmed to be working correctly.
- Boiler error code history showed a history of 10 error codes. All error codes were flame ignition failure codes. The first two occurred on one date then the last 8 occurred on another date (The last 8 occurred one hour after each previous error).
- Combustion analysis of the boiler (as found) showed high fire readings to be withing the boiler manufacturer's specification range (Appendix A).
- On low fire the (10% fire) oxygen reading went to 0% and the CO reading rose to a max display reading on the analyzer of 75,000ppm before the analyzer went into protection mode.
- The burner was disassembled the condensate trap was found to be full, the burner looked good with no hot spots, clear of debris, and clean mesh that light shone clearly through.
- The heat exchanger looked good with no signs of cracks, major sooting.

- The boiler refractory, ignitor and flame rod were in good condition.
- Water was flushed through the heat exchanger and no blockages were found and the water drained quickly through the unit and discharged via the condensate trap.
- The boiler was reassembled and adjusted to correct the combustion.
- The gas valve was able to be adjusted to get correct combustion readings at low and high fire that were within range on the manufactures specified targets.
- The manufactures representative stated that all boilers are test fired at the factory before being shipped to customers.
- The technician commented that they had started up a lot of new boiler equipment from the manufacturer including the model being tested and they have never seen combustion readings so far out on new factory equipment, and it is likely that adjustment was likely done by someone after the settings were set at the factory.

CO detector manufacturer literature

The CO detectors in the home have manufactures literature that indicate the CO sensors meet the alarm response time requirements of the applicable product standards for Canada. The CO sensor will not alarm to levels of CO below 30 ppm and will alarm in the following time range when exposed to the corresponding levels of CO:

- At 70ppm CO the alarm must not activate before 60 minutes but must activate before 240 minutes.
- At 150ppm CO, the alarm must not activate before 10 minutes but must activate before 50 minutes.
- At 400ppm CO the alarm must not activate before 4 minutes but must activate before 15 minutes.

CO measurements in home

Measurements were taken with a calibrated combustion analyzer throughout the home while the boiler was held on a low fire over a time of approximately 30 minutes. On all three levels from the East side and center of the home no measurable CO was found indoors. On the West side of the home where the boiler and vent termination are located. Very small amounts (3-5ppm) of CO were measured in the ambient air of the walk-in closet. When the analyzer probe was placed between the built-in cabinetry in the closet the wall the CO measurements rose to a maximum of 439ppm (Image 5) while the immediate area outside of the probed location measured up to 26ppm. In the office on the main floor the probe was placed into a cable access hole inside a built-in cabinet and measured to a max of 72 ppm. In the laundry room on the main floor measurements taken from inside a wall cavity though an already removed access grill for water valves measured a maximum of 38ppm.

Incident Summary #II-1806066-2024 (#55151) (FINAL)

Causes and contributing factors	The operation of the gas boiler created hazardous levels of CO in the flue gas that migrated into the home exposing the occupants to low levels of CO that caused varying illness symptoms. Contributing factors to the incident include: • The original installation and subsequent reuse of the incorrectly orientated venting system with the new boiler allowed possible exhaust gas recirculation into the appliance and for the exiting flue gases to enter the home through the ventilated soffit. • The nonfunctioning geothermal system, improper combustion setup and undersized boiler created a condition of the boiler operating on low fire for long periods of time creating hazardous concentrations of CO in the flue gases that remained at hazardous levels even after the dilution of venting outdoor and migrating back into the home.

Image 1 – The large residential home.

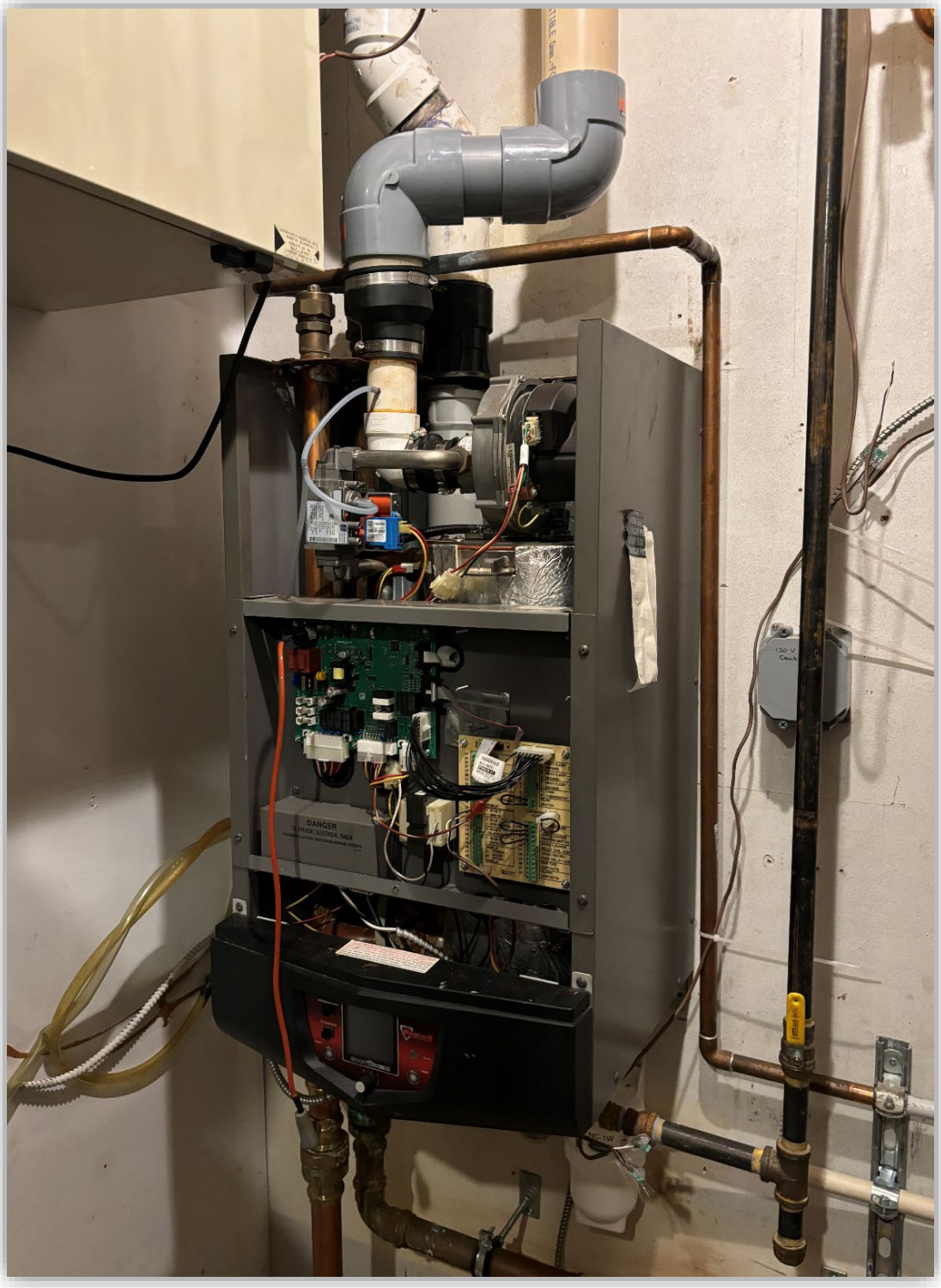


Image 2 – The boiler installed in the mechanical room.

Image 3 - The boiler vent termination on the West side of the home.

Image 4 - The boiler vent termination showing the flue gasses on high fire directed along side the house under the ventilated soffit.

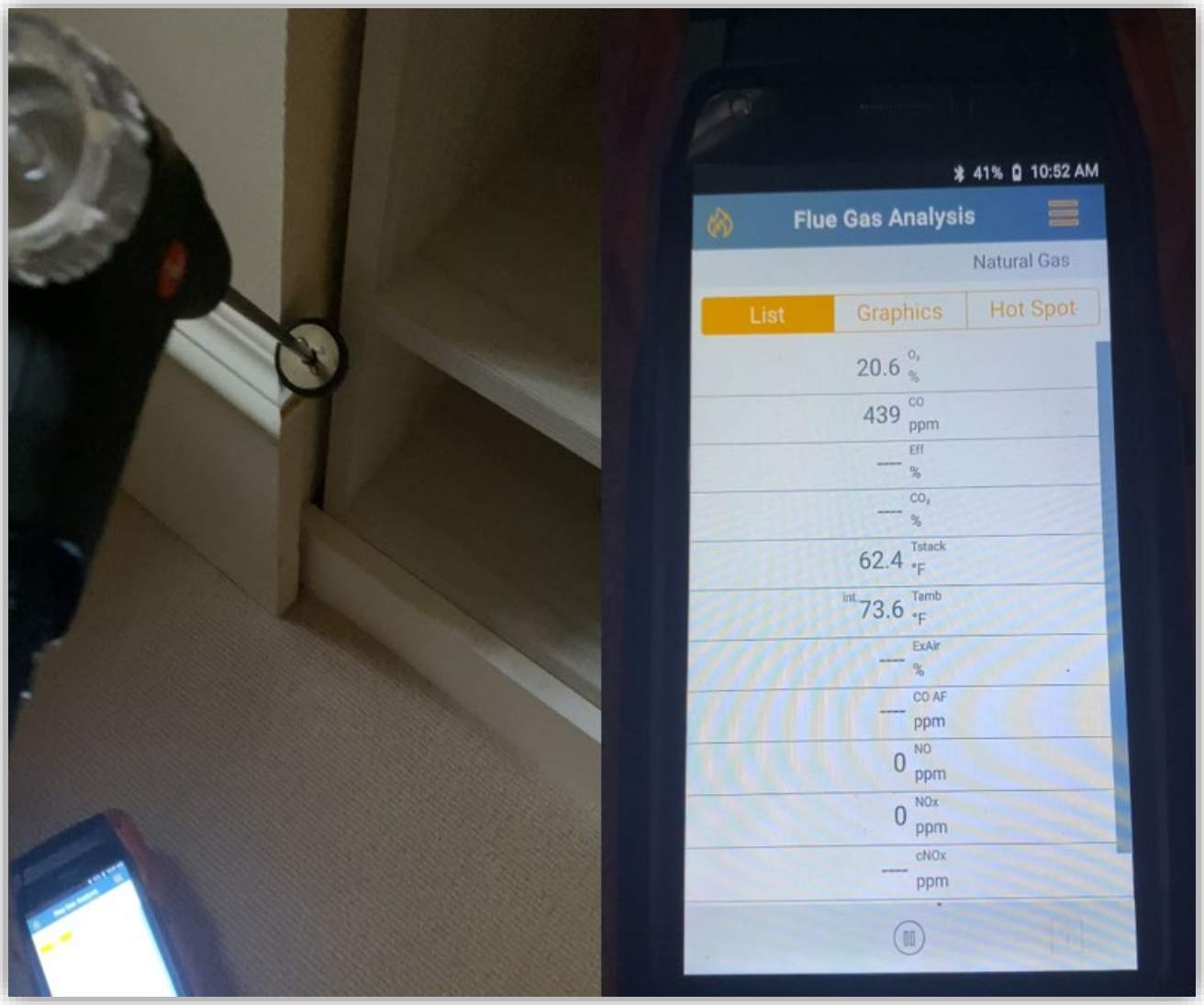


Image 5 - The CO testing location in the master bedroom closet and highest CO reading on the analyzer.

Appendix A - Boiler combustion analysis readings during investigation testing.

Table 3-5 Flue Products Chart

Natural Gas				
Input Rate	Target		Range	
	CO_2	O_2	CO_2	O_2
High Fire	9.2%	4.5%	9.0% - 10.5%	2.1% - 4.8%
Low Fire	9.0%	4.8%	8.8% - 9.5%	3.9% - 5.2%
CO levels should be less than 200 ppm.				

Manufactures flue gas measurement targets and ranges.

Category	Reading 1	Reading 2
Fuel	Nat gas	Nat Gas
O2	4.6%	4.0%
CO	103ppm	137ppm
Co2	9.3%	9.6%
Stack temp	137.2F	126.6F

Flue gas measurements from previous contractor.

Category	Test during examination – High fire	Test during examination - Low fire
Fuel	Nat gas	Nat Gas
O2	4.0%	0.00%
CO2	9.54%	11.8%
CO	87ppm	**75272ppm**
Stack temp	125.8F	106.9F

Flue gas measurements as found during appliance examination and investigation.

Category	Test High fire – After setup	Test Low Fire – After Setup
Fuel	Nat gas	Nat Gas
O2	4.4%	4.9%
CO2	9.32%	9.03%
CO	64ppm	27ppm
Stack temp	136.4F	124.7F

Flue gas measurements after gas valve adjustment during appliance examination and investigation.