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UNIVERSITY
OF OSTRAVA



ENERGY
AND ENVIRONMENTAL
TECHNOLOGY CENTRE

ENERGY
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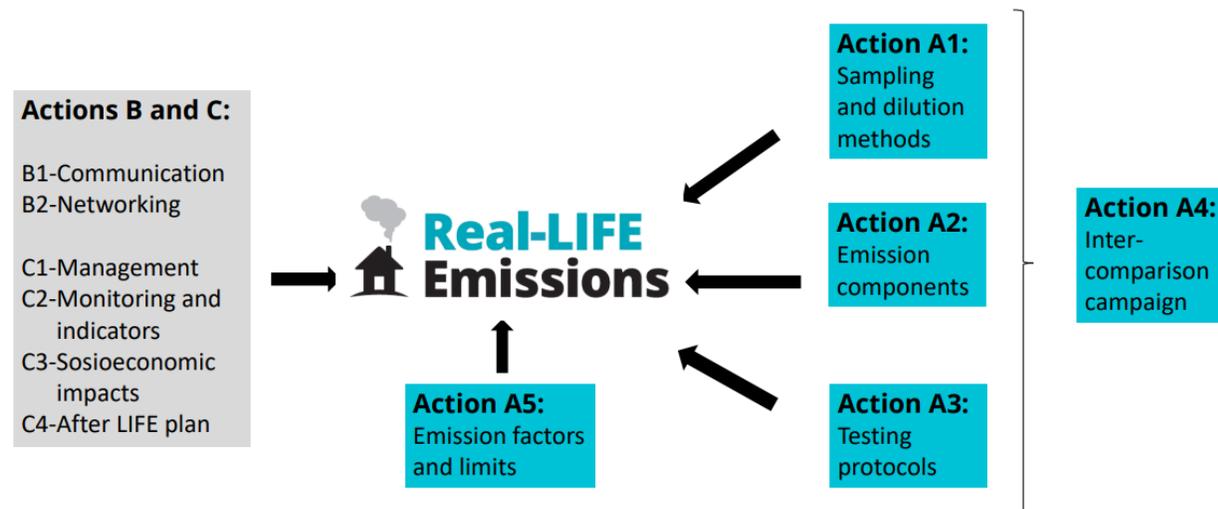
Overview of PM measurement methods for local space heaters burning solid fuels and results from VSB campaign focused on PM sampling methods

9th of November 2022



Real-LIFE emission project – Action A1: Sampling and dilution methods

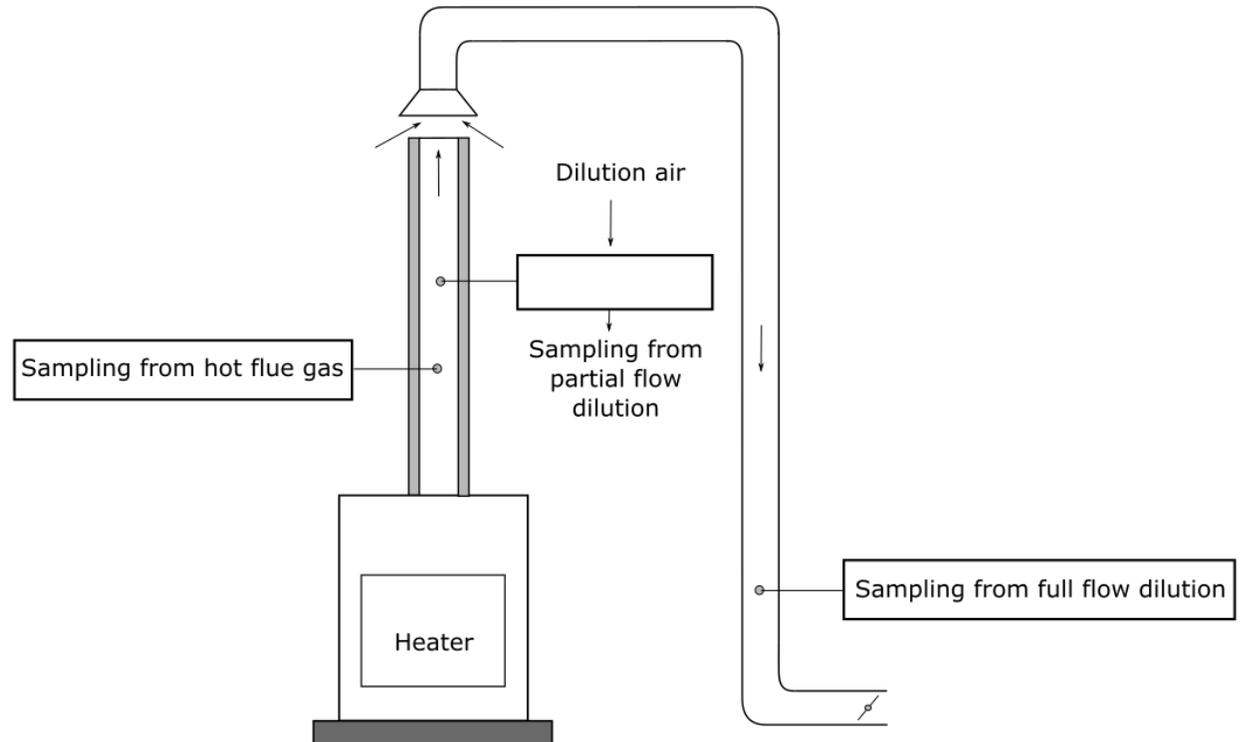
- VSB is partner of Real-LIFE emission project, Beneficiary in charge for Action A1
- Many sampling and dilution methods used in research and type testing of LSHs
- PM emission factors can vary between countries depending on the method used
- **Action A1 of Real-LIFE emission** starts with a review of existing knowledge
- Some methods will be chosen for the second phase – testing phase of Real-LIFE emissions project



Sampling and dilution methods – Introduction

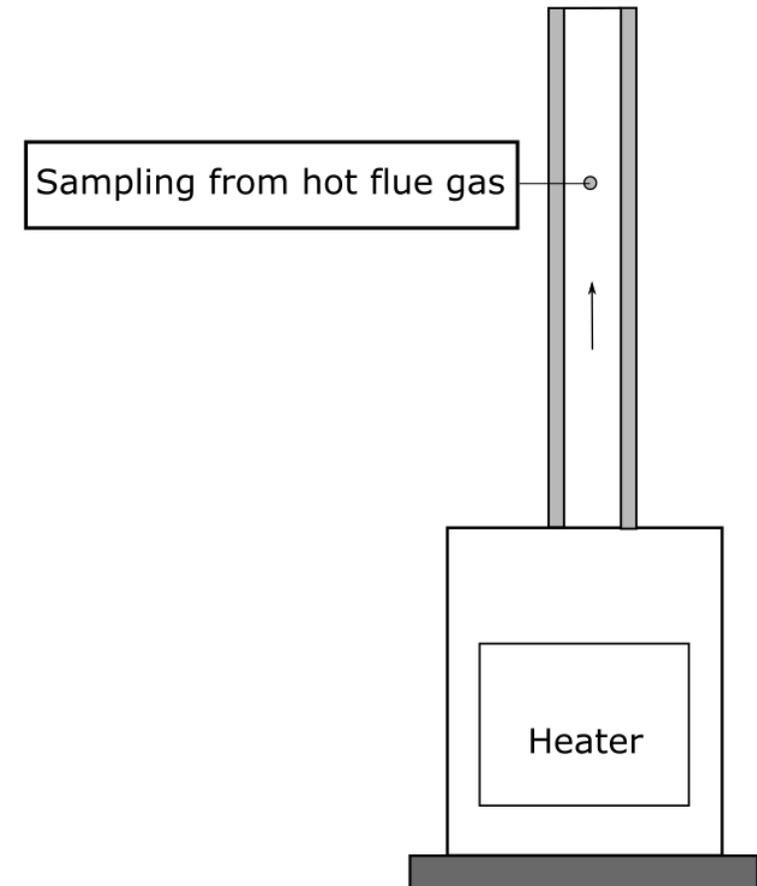
Different methods available for determination of PM
in flue gas from LSHs:

1. Sampling from the **hot flue gas**
2. Sampling from the **diluted flue gas**:
 - a. Sampling with **full flow dilution**
 - b. Sampling with **partial flow dilution**



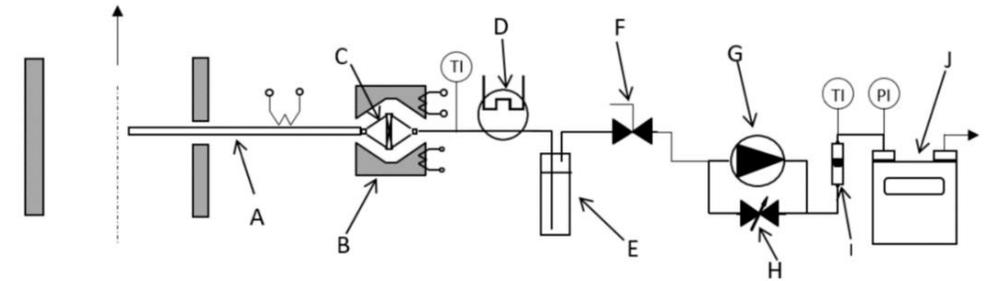
Sampling from hot flue gas

- **Sampling from chimney after the heater without further dilution**
- Sampling from hot flue gas does not collect condensable particles, that condense when flue gas cools down -> this leads to underestimation of PM emission -> not very suitable for determination Real-life emissions
- Most commonly used standardized approach for PM measurement in Europe
- Several sampling methods exist for hot flue gas in EU and other countries:
 1. **New common EN-PME method**
 2. **Heated filter method according EN 16510-1:2018**
 3. **Dust measurement according DIN+**
 4. **Determination of PM according VDI 2066-1 and EN 13284-1**
 5. **US EPA Method 5H** – includes sampling of condensables
 6. **SPC-IPA method (INERIS)** – includes sampling of condensables



Sampling from hot flue gas: EN-PME method

- EN-PME method is only one method listed in the latest revision of EN 16510-1 for LSHs
- 2 m sampling probe and the filter holder are heated to constant temperature in range of $180 \pm 10 \text{ }^\circ\text{C}$
- Flue gas temperature at the PM filter is kept at $180 \pm 10 \text{ }^\circ\text{C}$ for flue gas temperature range from 40 to $400 \text{ }^\circ\text{C}$ in chimney
- The sample probe is rolled in box and heated by electric resistive heating
- Outer diameter of probe is 8 mm and inner diameter 7,5 mm
- The inlet of the probe (nozzle) is positioned at a 90° angle to the flue gas flow direction for preventing of capture randomly distributed coarse particles -> better of repeatability of PM measurement



Description

A - heated sampling probe; B - heated sleeve; C - filter holder; D - gas dryer (gas cooler); E - gas dryer (desiccant); F - shut-off valve; G - gas pump; H - regulating by-pass valve; I - flow indicator; J - dry gas meter



Sampling from hot flue gas: EN-PME method

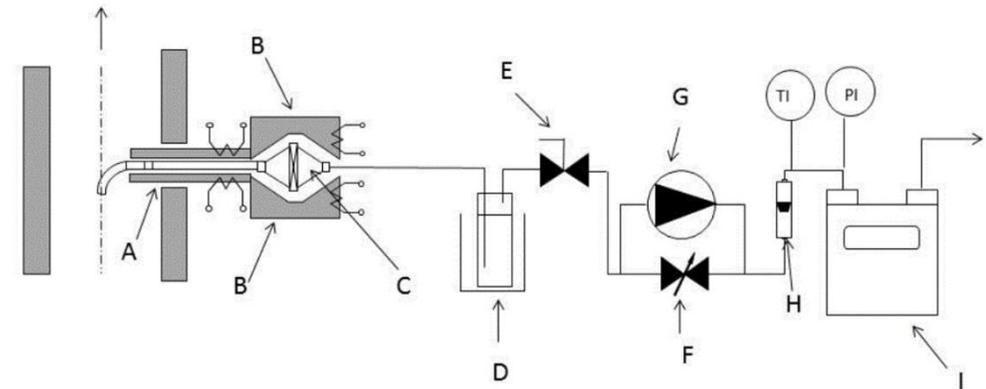
- **For batch fired appliances** the measurement shall start directly after reloading
- **For automatic appliances** starting time of sampling is after reaching stable conditions
- Duration of sampling is **full cycle for most of appliances** with certain exceptions described in method
- **Sampling flow:** constant value of **10 l/min (STP) (0,6 m³/h) ± 10 %**
- For EN-PME method is required weighting of probe deposit by blowing of filtered compressed air into the inlet of the probe and filter holder with new filter for **30 s with minimum flow rate 100 l/min**
- The weight of the probe deposit is divided proportionally to each PM measurement



Photo from: EN-PME validation project, VSB ERC testing laboratory

Sampling from hot flue gas: EN 16510-1:2018 – heated filter method

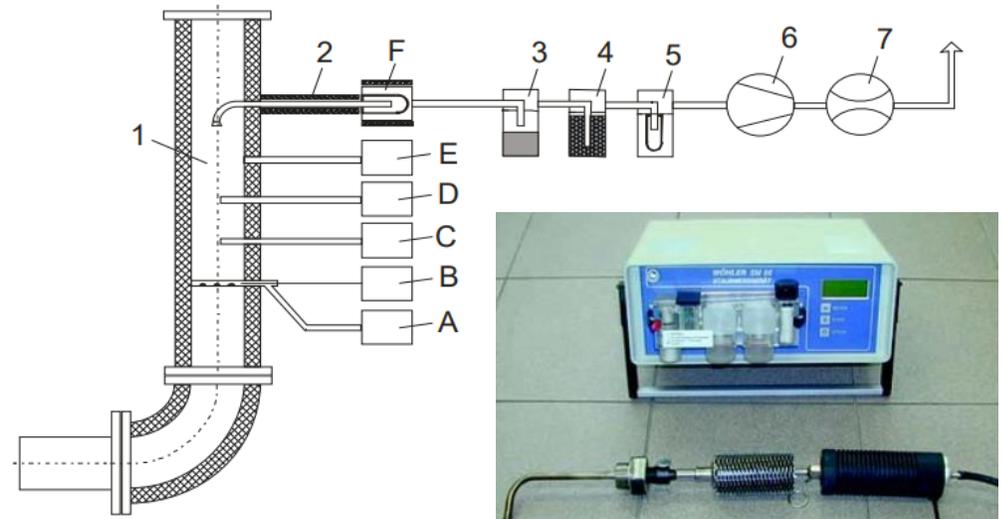
- **Two methods** are given in standard **EN 16510-1:2018** (heated filter and dilution tunnel method)
- The sampling line and filter holder are heated to a temperature of minimum **70 °C** and **maximum 160 °C**
- Lower temperature limit can lead to higher PM
- The sample probe is with an **inner diameter of approximately 8 mm** and a maximum **length of 1000 mm**
- **The sampling start 3 minutes after reloading** and sampling duration is 30 minute
- **Nozzle orientation of 180 °**
- **Sampling flow is set to (0.5-0.6) m³/h**
- **PM deposit in probe is not determined**



A - heated sampling probe; B - heated sleeve; C - filter holder; D - gas dryer; E - shut-off valve; F - regulating by-pass valve; G - gas pump; H - flow indicator; I - dry gas meter

Sampling from hot flue gas: DIN+ method

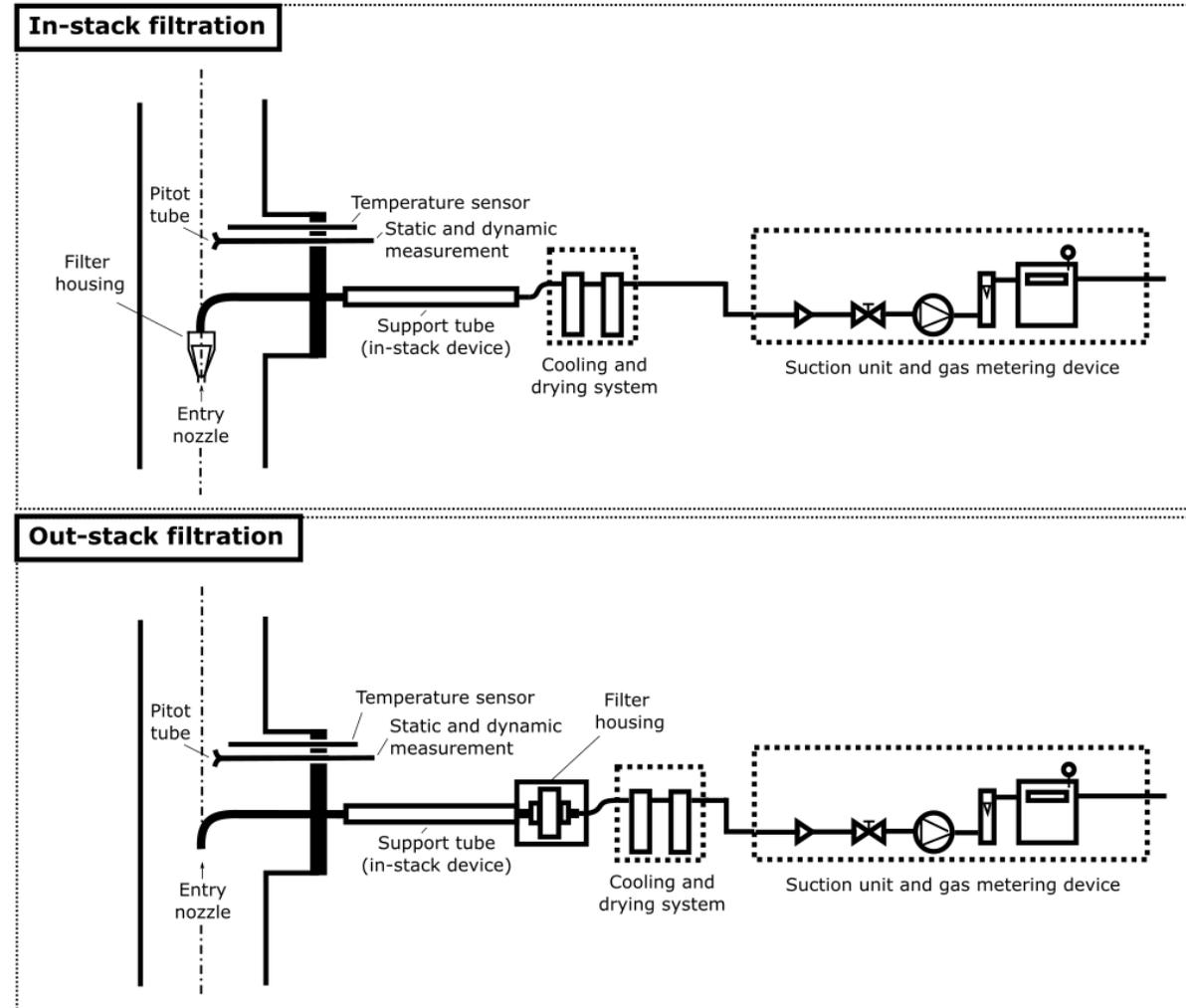
- The dust measurement accord. DIN+ in hot flue gas is carried out parallel to the CO, NO_x, C_nH_m measurement
- PM sampling **starts 3 minutes** after the refuelling of appliance and **sampling time is 30 minutes**
- The temperature of the area of **filter holder** are heated to a **constant temperature of 70 °C**
- **The flue gas volume is 280 ± 28 l** for this sampling time. The sampling probe has an inner diameter of 8 mm and at the end the inlet is increased to a opening size of 9.74 mm
- The probe is positioned against the flue gas flow with a **nozzle orientation of 180 °**
- **PM deposit in probe is not determined**



1 - Measuring section; 2 - Gas sample-taking probe and connection for the dust measurement (thermally insulated); 3 - Water separator; 4 - Silica gel filter; 5 - Ultra fine filter; 6 - Pump; 7 - Gas flow metre;

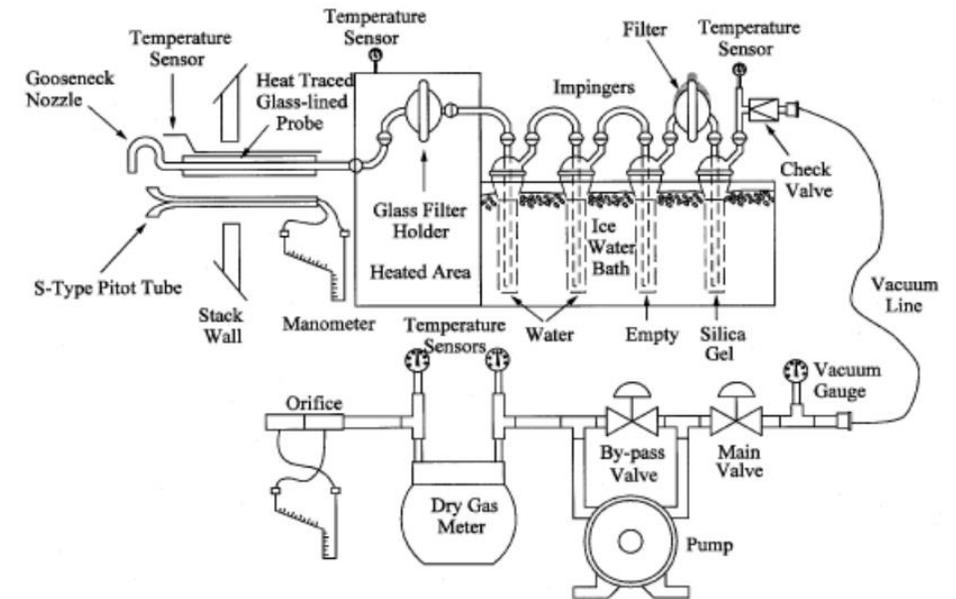
Sampling from hot flue gas: VDI 2066 Blatt 1 and EN 13284-1

- For dust mass concentration up to 50 mg/m^3 , the technical requirements of **VDI 2066-1 standard** are identical to requirement of **EN 13284-1**
- **Nozzle orientation of 180°** and **isokinetic sampling**
- Sampling is carried out at an **filtration temperature at least 160°C**
- For in-stack filtration filter diameter is typically up to 50 mm and for out-stack filtration filter diameter is between 50-150 mm
- Deposition in the probe is added to individual tests in proportion to the mass collected on each filter



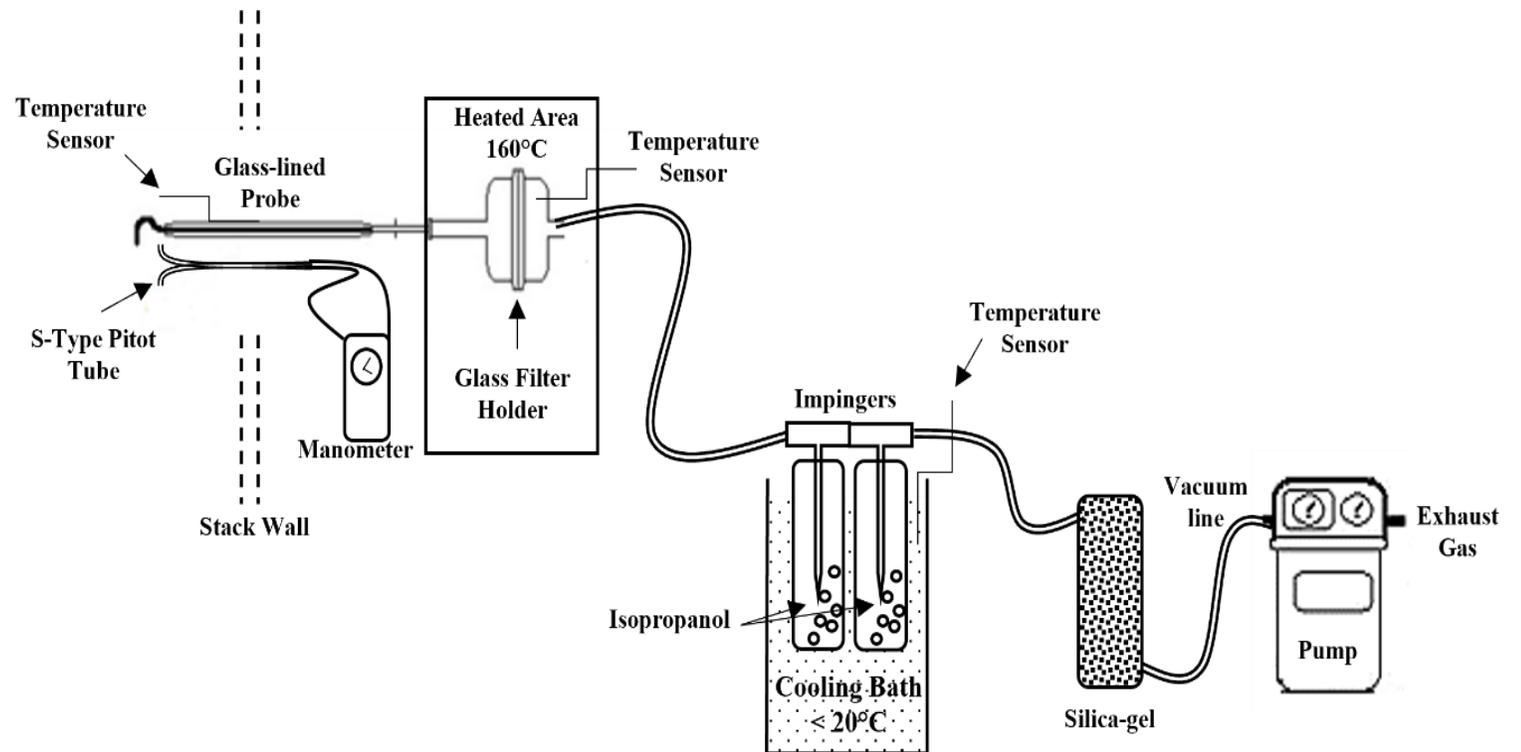
Sampling from hot flue gas: EPA Method 5H

- This EPA method is used for the determination of PM and condensable emissions from wood heaters in US
- **PM is collected on two glass fiber filters.** The first filter is positioned immediately after the probe and before to the first impinger
- First filter is kept at a temperature $< 120\text{ }^{\circ}\text{C}$.
- Second filter is cooled by impingers system and maintained at temperature $< 20\text{ }^{\circ}\text{C}$
- *Sampling starts on the beginning of the test runs as defined in **Method 28** (Certification and auditing of wood heaters). The sampling lasts throughout the whole test run*
- **The probe is positioned against the flue gas flow with a nozzle orientation of 180 °**



Sampling from hot flue gas: SPC-IPA method

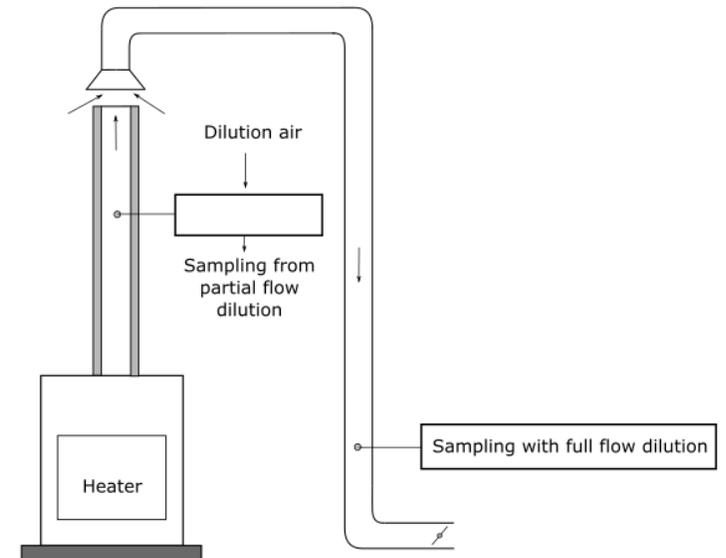
- The SPC-IPA method promoted by Ineris is close to the EPA Method 5H (simplified method)
- Combination of heated filter (160°C) and impingers filled with isopropanol for collection of the condensable fraction of PM
- Impingers are placed in series in a cooling bath to hold a sampling temperature below 20°C



Sampling from diluted flue gas

- The studies show, that dilution methods are an appropriate sampling technique to measure the most PM emissions from the residential combustion
- Flue gas after dilution is in state, which is closer to conditions behind of chimney outlet in real-life operation
- Dilution and cooling of the flue gas cause higher PM emissions compared to hot flue gas sampling, mostly with incomplete combustion

- **Full flow dilution:** All the flue gas from heater is collected in a hood of dilution tunnel and mixed with ambient air
- **Partial flow dilution:** Small portion of flue gas is mixed with dilution air and then sampling is realized

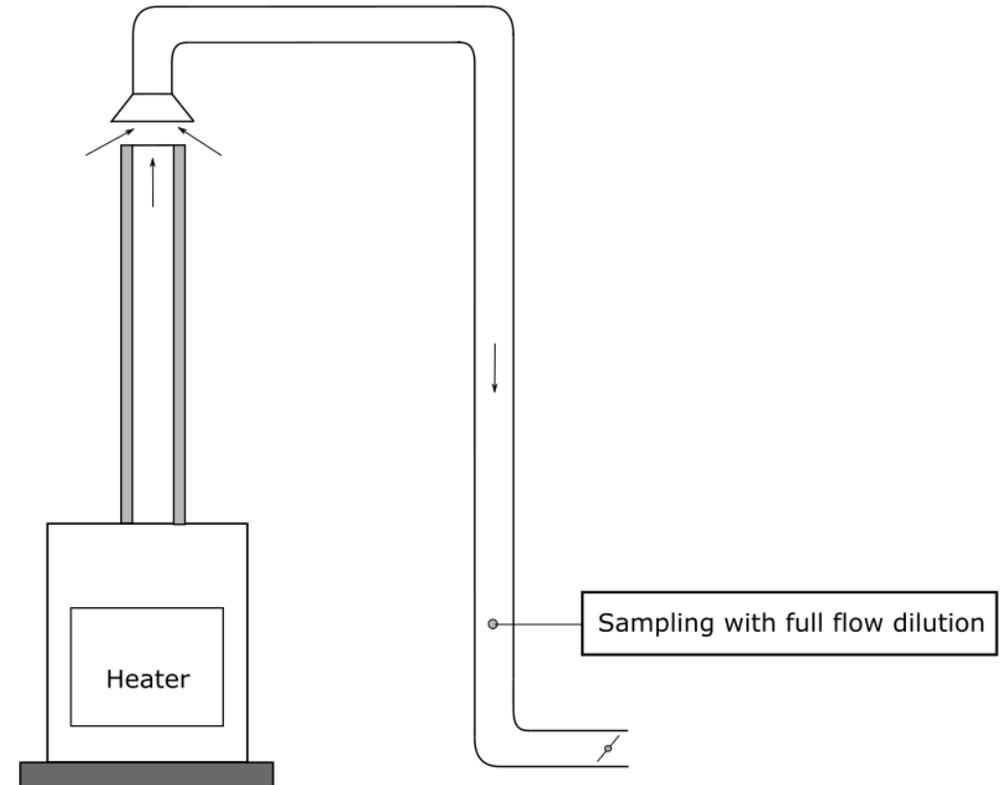


Sampling from diluted flue gas: Full flow dilution

Usually used in a type-testing with standardized test procedures:

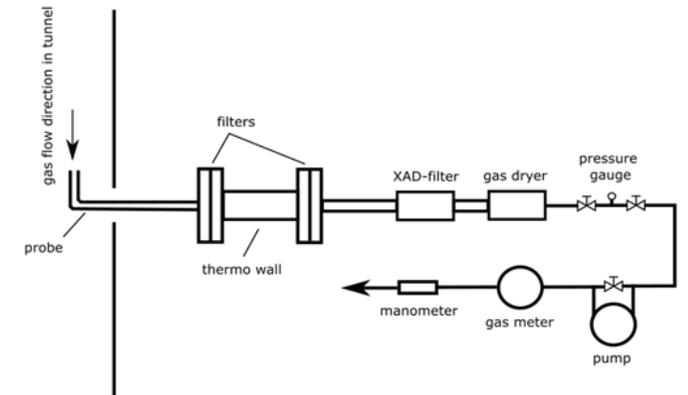
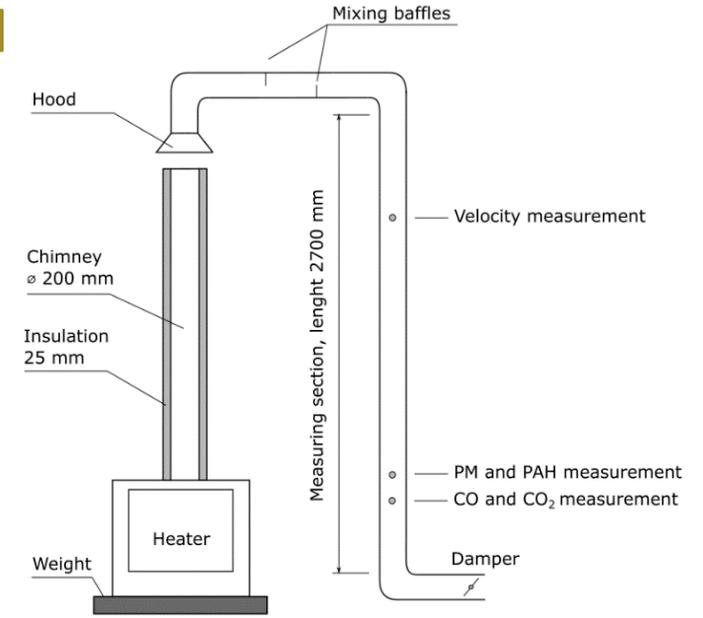
Dilution ratio in the dilution tunnel is lower (10-20) and the dilution tunnel have large dimension with high construction costs -> these methods are inappropriate for a research purposes and field testings

- **NS 3058-2:1994 Norwegian standard method**
- **EN 16510-1:2018: Full flow dilution tunnel**
- **BS 3841-2:1994 Dilution tunnel method**
- **US EPA Method 5G**
- **AS/NZS 4013:2014 Dilution tunnel method**



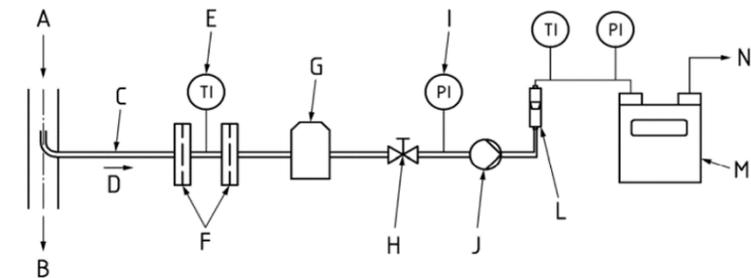
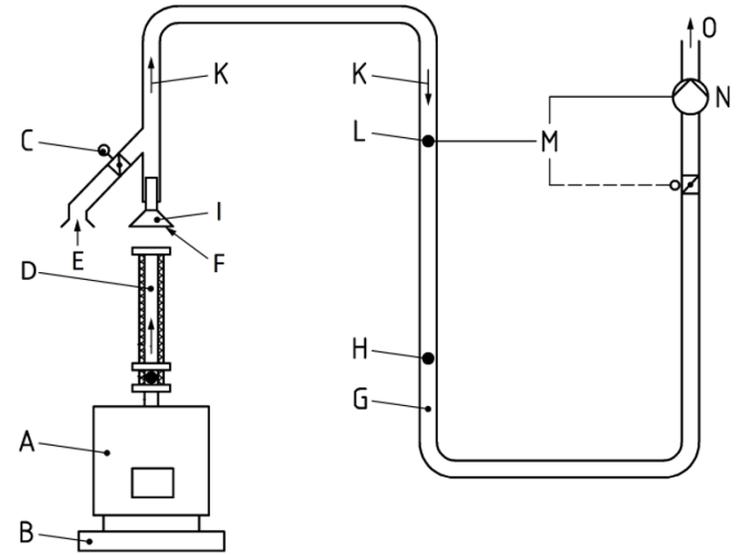
Full flow dilution: NS 3058-2:1994 Norwegian standard method

- NS 3058-2 determines specification of PM measurement with FFDT
- **Sampling probe oriented 180 ° (up-stream)**
- Stainless or glass probe with **inner diameter of 10 mm and length from 0,3 to 0,6 m**
- Used glass fiber filters shall be without organic compounds and **shall have minimum 100 mm in diameter**
- **The filter holder gas temperature shall be no greater than 35 °C during measurement**
- **Sampling flow is approximately 15 l/min**



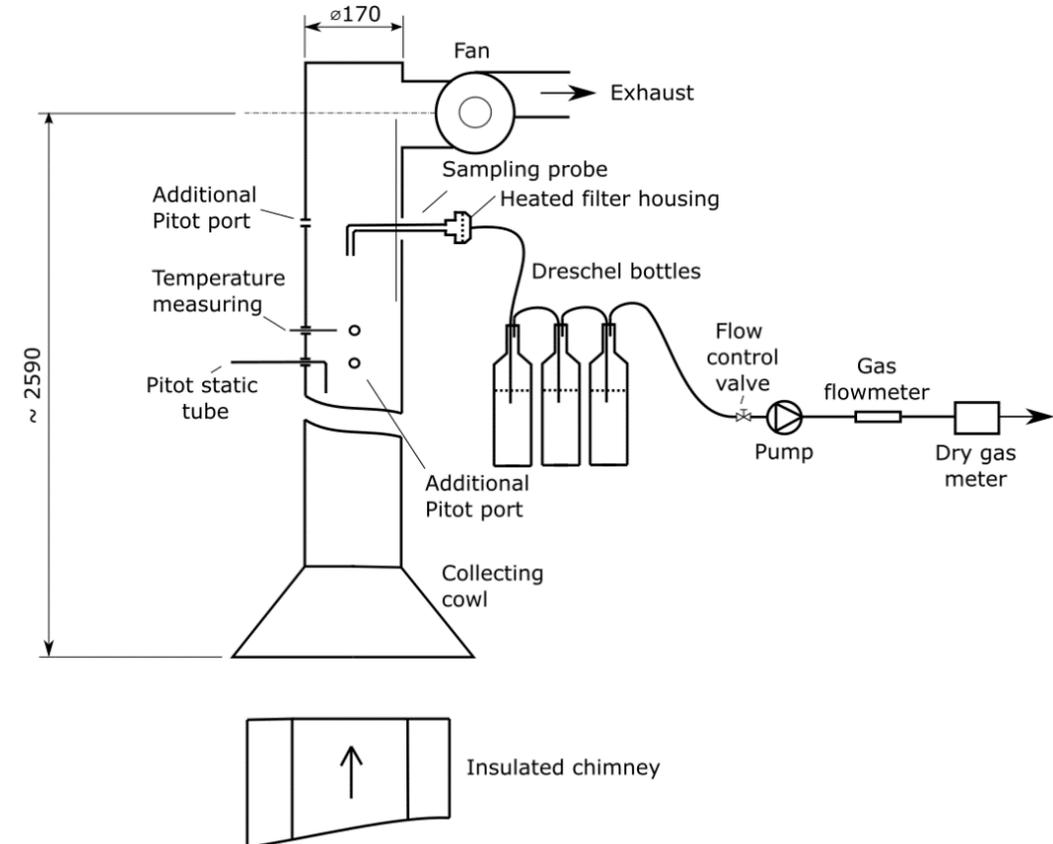
Full flow dilution: Full flow dilution tunnel (EN 16510-1:2018)

- The method given in EN 16510-1:2018 is used to determination of PM and condensables in FFDT
- Bypass with a damper for control required draught and to keep diluted gas at constant flow
- **Sampling probe oriented 180°** (up-stream), during sampling is necessary to keep isokinetic conditions
- **Filter holder shall be kept at ambient temperature but not less than 20°C**
- The sampling probe is made by stainless steel with **int. diameter of minimum 8 mm and a length of 300 to 600 mm** (nozzle with int. diameter 10 mm)
- A starting time of the sampling is directly after reloading the appliance
- A probe deposit is not considered in the calculation of PM



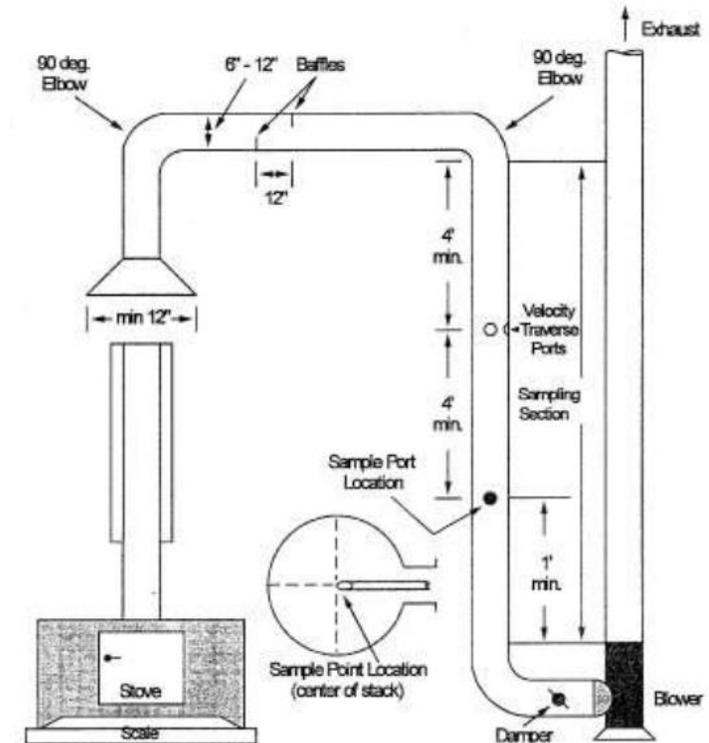
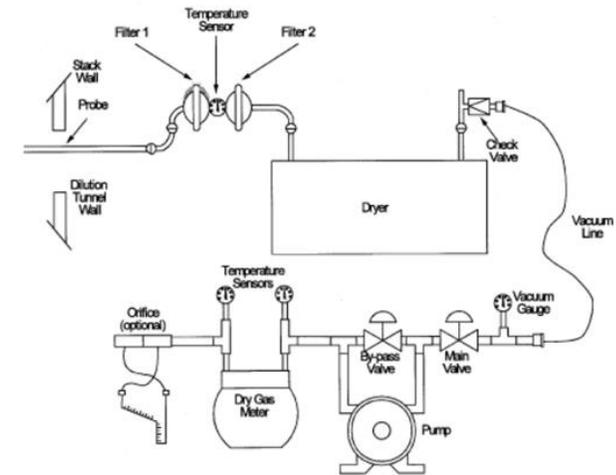
Full flow dilution: BS 3841-2:1994 – Dilution tunnel method

- British sampling method described in BS 3841-2:1994 is the dilution tunnel method with isokinetic sampling
- **Filter holder is maintained at 70 °C**
- **Recommended filter diameter is 47 mm**
- **Sampling probe oriented 180 ° (up-stream)**
- Sampling probe shall be made by stainless steel with length of 200 mm and 9 mm internal diameter with various diameter of nozzle for isokinetic sampling
- A probe deposit is considered in the calculation of PM



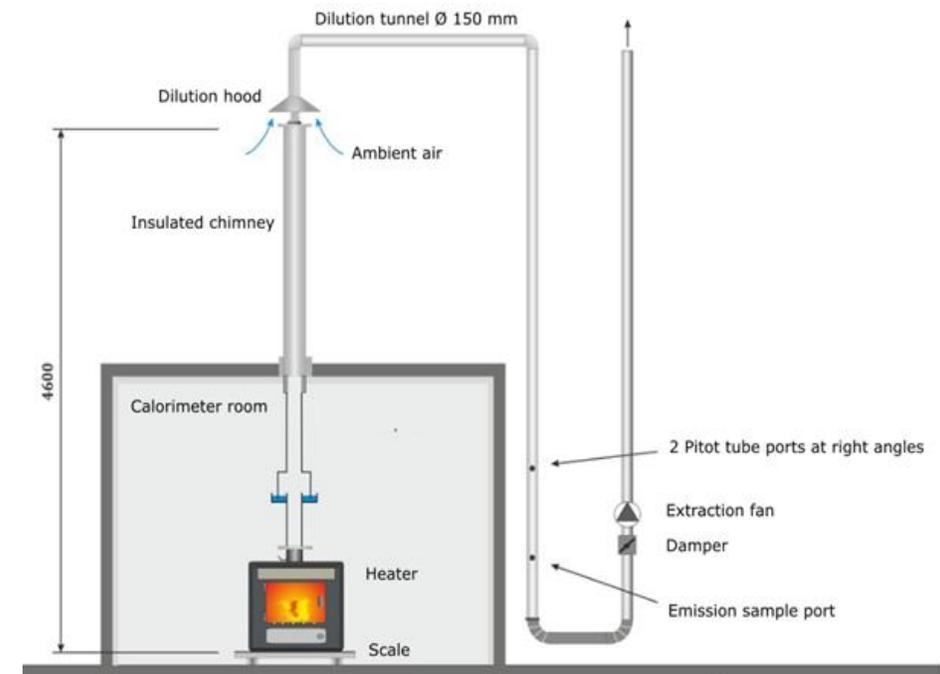
Full flow dilution: US EPA Method 5G

- **Similar requirements as Norwegian NS 3058-2**
- The PM is collected on two glass fiber filters
- **Both filters are maintained at a temperature no greater than 32 °C**
- **Probe: stainless steel or glass with 9,5 mm inner diameter and 0,6 m in length**
- Start of sampling is same as Method 5H and sampling starts on the beginning of test run as defined in Method 28



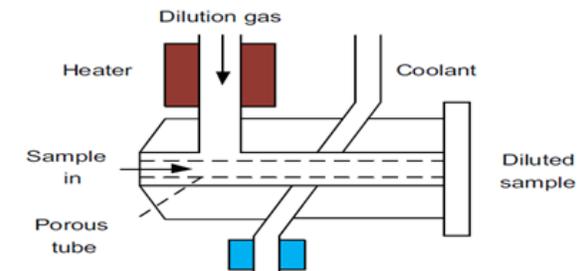
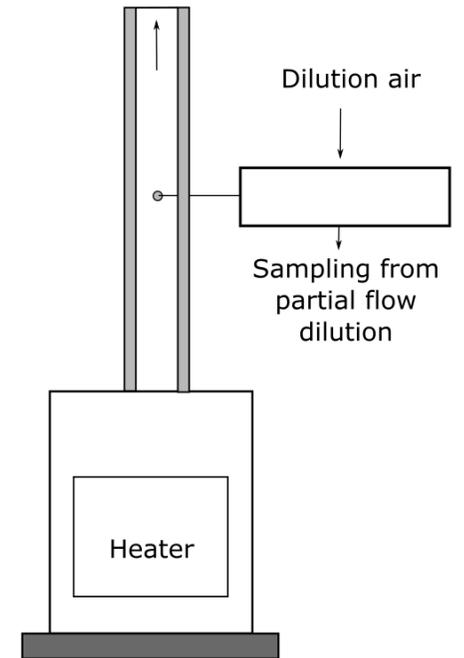
Sampling from diluted flue gas: AS/NZS 4013:2014 Dilution tunnel method

- **Standard AS/NZS 4013** is used in Australia and New Zealand for determination of particulate matter in DT
- The appliance is installed in a calorimeter room and all flue gas is collected and diluted with the ambient air
- The sampling train consists of 450 mm long seamless stainless steel or glass probe with internal diameter of 9.5 mm with one end cut off at 90° to its axis
- **Two filter holders with 50 mm glass fibre filters are used, sampling gas temperature between filters: 15 – 32°C**
- **Dilution tunnel temperature shall be more than 25°C**
- **Flow rate in DT at $6.0 \pm 0.5 \text{ m}^3/\text{min}$ and sampling train shall be operated with flow rate of 4 to 10 l/min (20°C, 101.3 Pa)**
- Deposits on the probe and filter holders are considered as PM



Partial flow dilution system

- **Mainly used for research purposes**
- Partial flow dilution method dilutes only a fraction of the total exhaust flow
- Partial dilution methods are popular in laboratory and field experiments due to their several advantages over FFDT
- **The most partial flow dilution systems are smaller, portable, less expensive and easy to use compared to full flow dilution methods**
- With partial flow dilution system it is easier to set parameters such as temperature, flow rate, dilution ratio and others in comparison of FFDT
- **Partial flow dilution tunnel – Caltech dilution sampler, Partial flow dilution tunnel (ISO 8178-1), Portable partial flow dilution tunnel, Compact dilution sampler (CDS), Porous and perforated tube diluter, Ejector diluter, Rotating disk diluter, Concentric tube diluter, Dilution Chamber method and others ...**



Porous tube diluter (Giechaskiel et al., 2014)

VSB campaign focused on PM sampling methods

VSB campaign – Comparison on EN-PME, Heated filter and FFDT method

VSBs tasks in the framework of Real-LIFE project – Action A1:

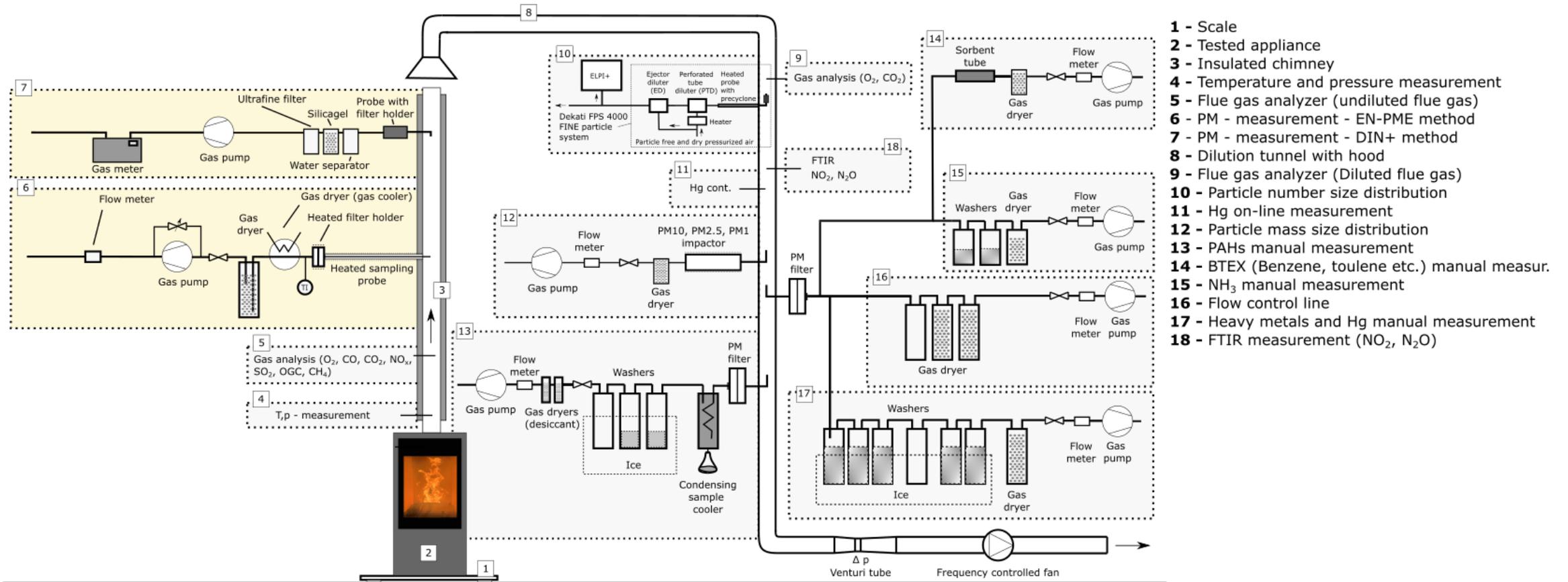
- Laboratory tests and evaluations focused on comparison of EN-PME method and heated filter method or other methods with different kind of local heaters and boilers

Ongoing measurement campaign is mainly focused on:

- Comparison of EN-PME, Heated filter method and FFDT method
- LSHs like stoves, cookers and insets with wood logs and briquettes in first step of campaign, operated mainly at NHO and some at PHO
- In addition of that: Determination of OGC, NO_x, CH₄, CO, PM₁₀, PM_{2.5}, PM₁, Heavy metals and Hg measurement, Particle number mass and size distribution, PAHs, BTEX, NH₃ - in evaluation state



VSB campaign – Comparison on EN-PME, Heated filter and FFDT method



VSB campaign – Comparison on EN-PME, Heated filter and FFDT method

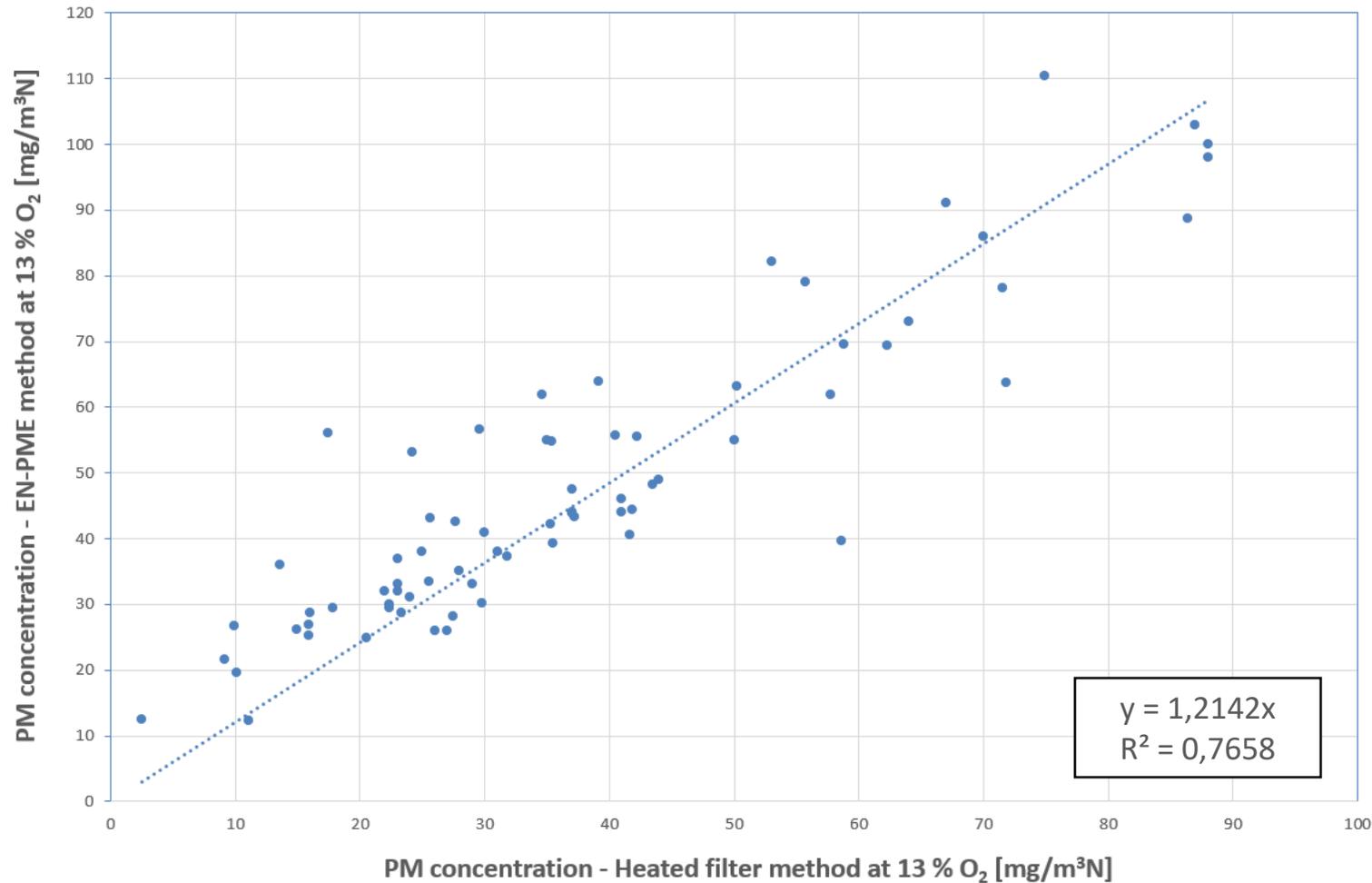
A view of fireplace insert testing as part of the VSB campaign



VSB campaign – Comparison on EN-PME, Heated filter and FFDT method

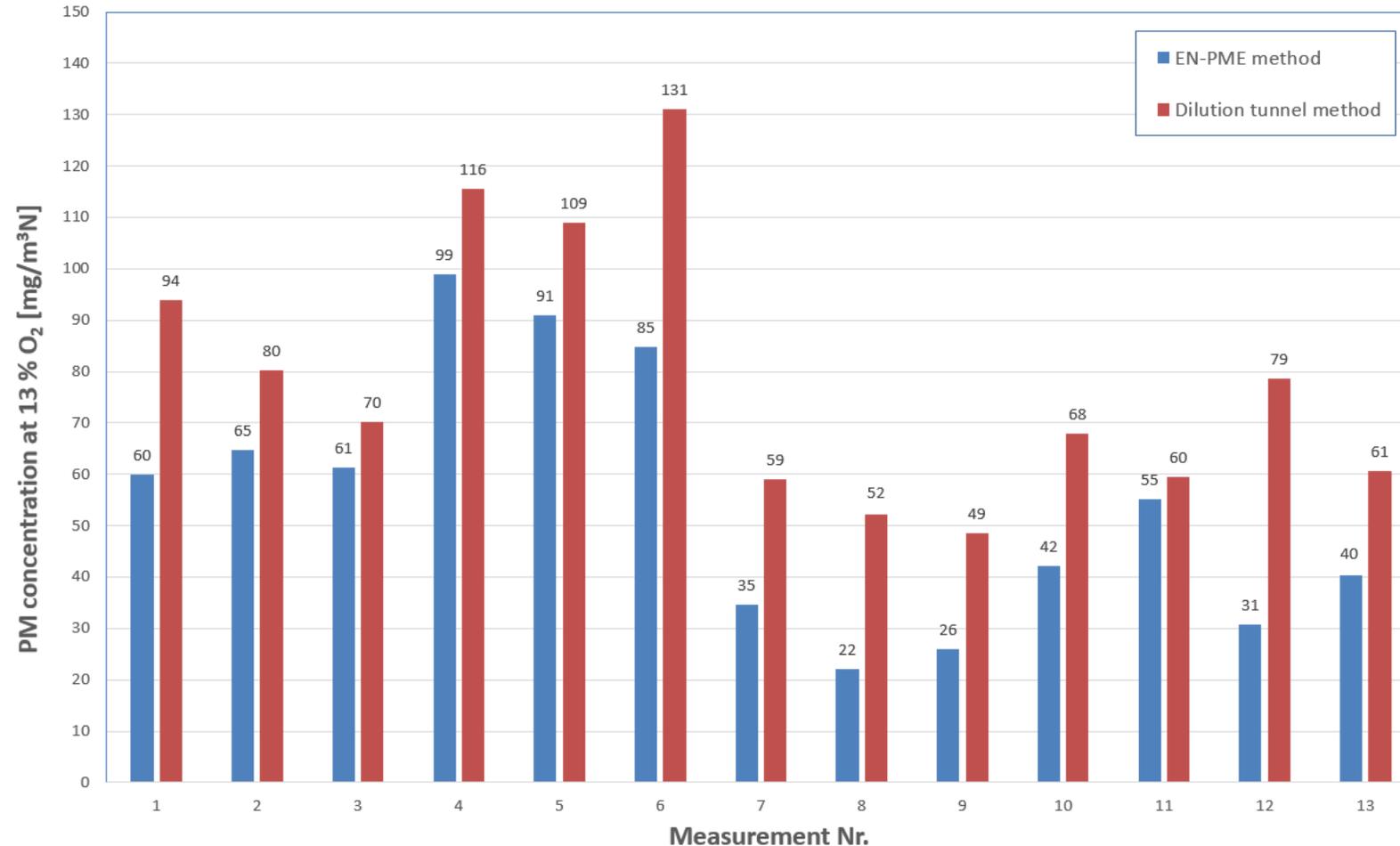
	EN-PME method	Heated filter method	FFDT method
Sampling point	Chimney	Chimney	Dilution tunnel
Start time for sampling	After reloading	3 min after reloading	After reloading
Sampling duration	Whole combustion period	30 min	Whole combustion period
Filter temperature	180 °C	70 °C	30 – 40 °C
Nozzle orientation	90° (perpendicularly)	180° (upstream)	180° (upstream)
Isokinetic sampling	No	No	Yes
Filter treatment after sampling	180 °C for 1 h	105 °C for 1 h	Ambient temperature for 24 h
Probe deposit	Yes	No	Yes

VSb campaign – Comparison on EN-PME and Heated filter method



- **72 measurements with wood logs burning stoves, inserts and cookers**
- 93 % of these measurements, where EN-PME results method were higher than Heated filter method
- Important role plays different starting time and duration of sampling of each method

VSB campaign – Comparison on EN-PME and FFDT method



- **13 measurement days** with wood logs burning stoves and inserts
- **3-5 cycles per day** (warming up phase is not included – 1st and 2nd batch)
- **Same sampling start time and duration of tests for both methods**
- FFDT results are always higher than results from EN-PME (Approx. +40 %)

Thank you for your attention

9th of November 2022

