Measuring the performance of community face coverings in Europe and beyond

ASHRAE VIRTUAL ANNUAL CONFERENCE

June 28-30, 2021

Seminar 7: COVID-19 Particle Removal by Air Filter Devices

Measuring the Performance of Community Face Coverings in Europe and Beyond

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Learning Objectives

- Understand the principles of airborne infectious disease transmission
- Learn the basic principles of current technologies for the removal of COVID-19 particles
- **Understand current methods for testing the removal of COVID-19 particles, and the effectiveness of air filter devices, especially masks**
- **Provide information that would help to stop the spread of COVID-19 particles**

Acknowledgements

Experimental data and data processing

- Jesús Marval, Politecnico di Torino
- Luis Medina, Politecnico di Torino
- Emanuele Norata, Politecnico di Torino
- Geraldine Torres, Politecnico di Torino
- Group of volunteers at Politecnico di Torino

Outline/Agenda

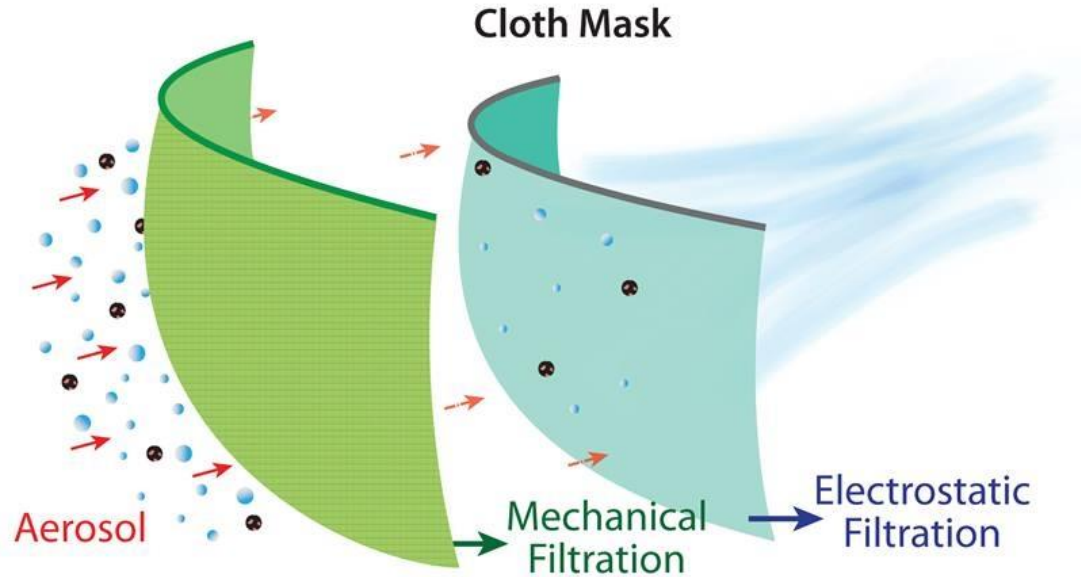
- Types of face masks
- Human expired aerosol size distributions
- Universal test method for facemasks
- Comparison with existing standards for assessing the performance of face masks
- Conclusions

Masks of various types and purposes

Surgical masks	Respiratory protective half masks ("Respirators")	Community face coverings ("Community masks")
EN 14683:2019 ASTM F2101 - 19	EN 149:2001+A1:2009 42 CFR Part 84	UNI/PdR 90:2020 (Italia) CWA 17553:2020 - prCEN/TS 17553:2021 ASTM F3502 – 21
Medical device (MD)	Personal protective equipment (PPE)	Neither MD nor PPE
Protects the others from the wearer	Protects the wearer from the others	Protects the others from the wearer
Could be used by infected individuals	Could be used by infected individuals (only without exhalation valve)	Shall not be used by individuals aware of being ill of infectious

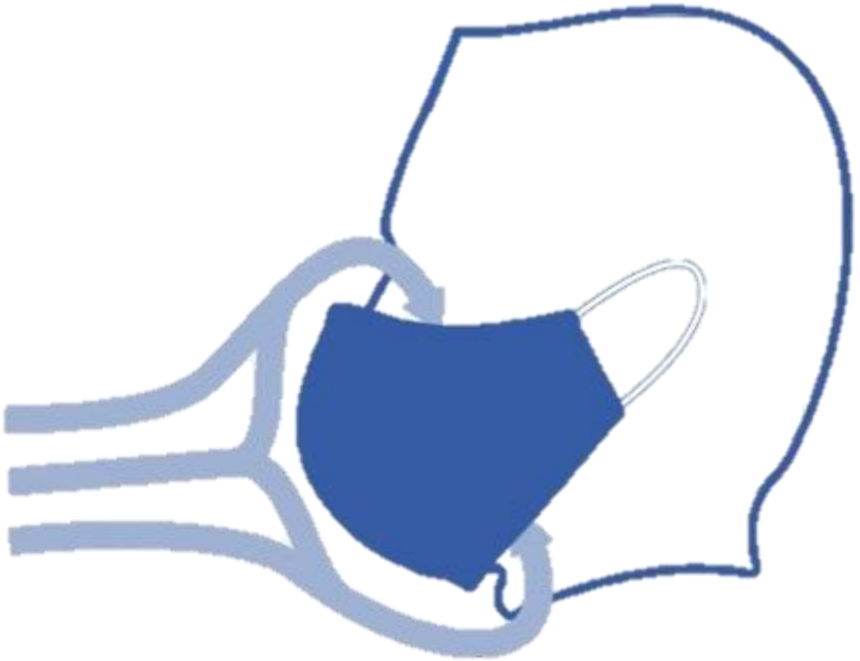
Performance of facemasks

Filtration efficiency

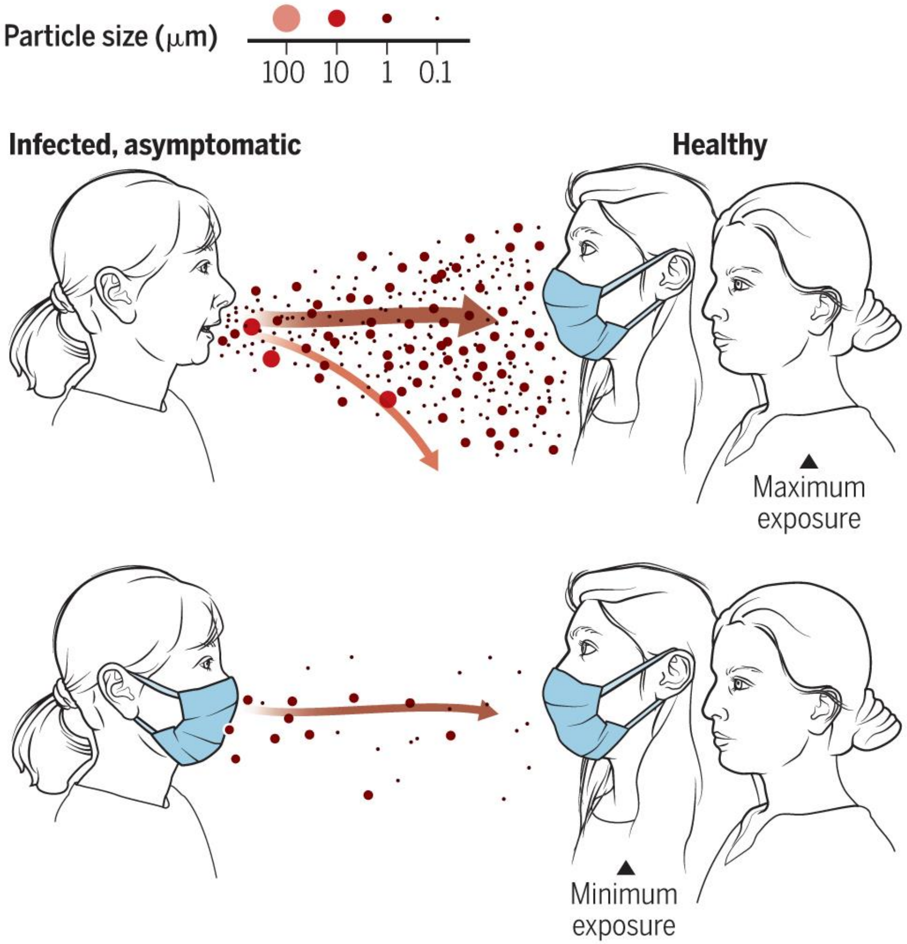


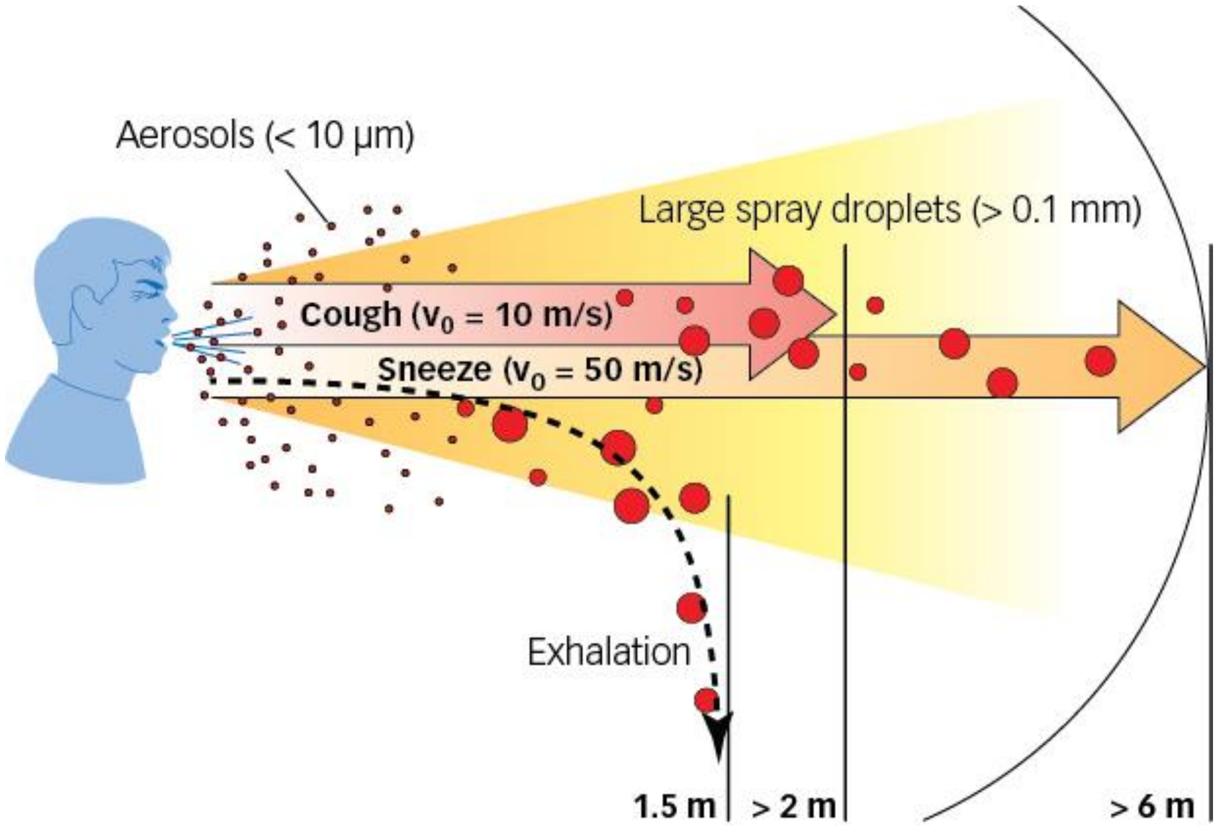
Konda, A., A. Prakash, G. Moss, M. Schmoldt, G. Grant, and S., Guha. 2020. “Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks”. ACS Nano. 14 (5), pp. 6339-6347, DOI: 10.1021/acsnano.0c03252

Resistance to airflow



Airborne transmission of diseases





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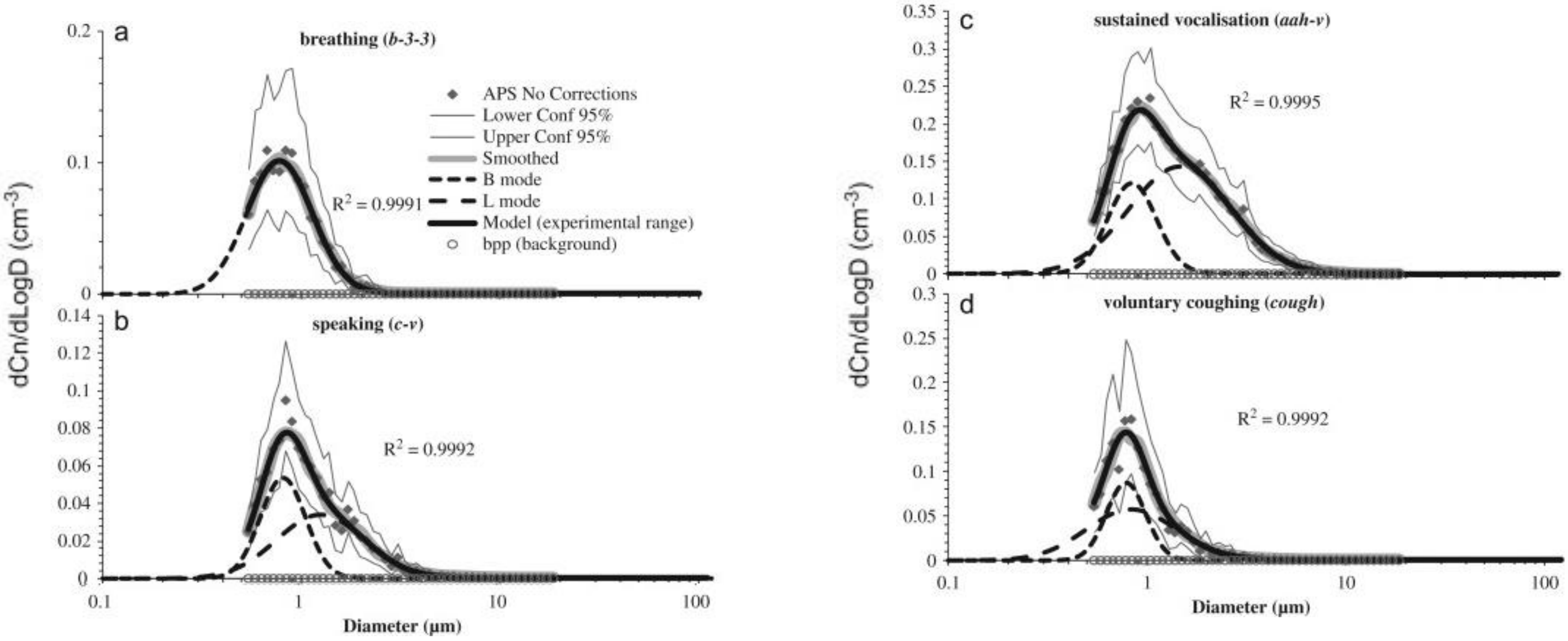
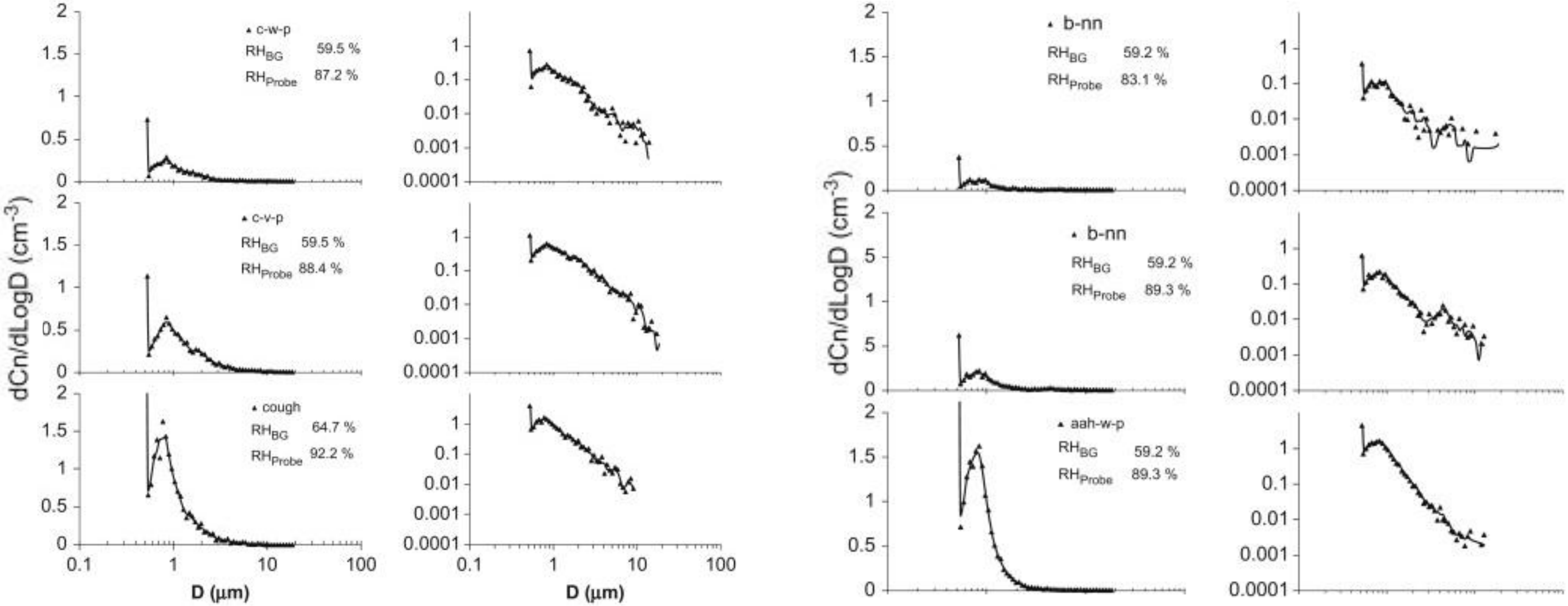
Human expired aerosol size distributions



Johnson, G., et al. 2011. “Modality of human expired aerosol size distributions”. J. Aerosol Science. vol. 42, no. 12, pp. 839–851, DOI: 10.1016/j.jaerosci.2011.07.009

Size distributions of droplets expelled from the human respiratory tract



Morawska, L., et al. 2009. “Size distribution and sites of origin of droplets expelled from the human respiratory tract during expiratory activities”. J. Aerosol Science. vol. 40, no. 3, pp. 256–269, DOI: 10.1016/j.jaerosci.2008.11.002

UNI/PdR 90:2020 – Community face coverings

UNI/PdR 90-1:2020

Specifies performance requirements of CFC

- Maximum resistance to airflow rate
- Minimum initial particle removal efficiency

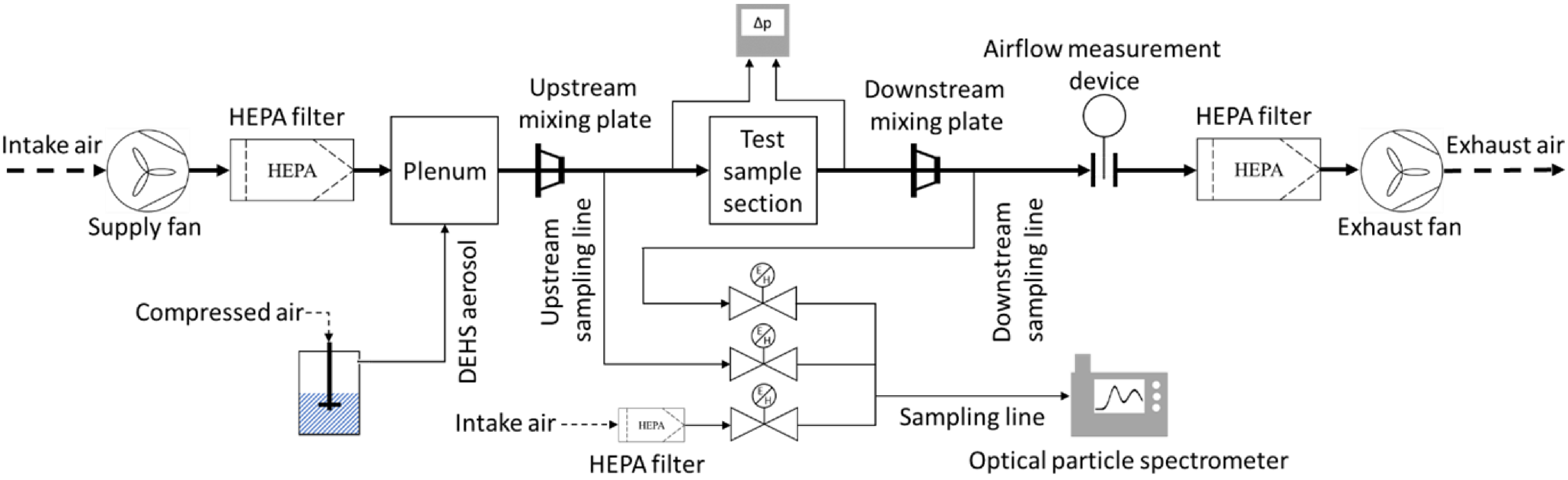
- Combination of fractional efficiency curve and a given upstream particle size distribution (very similar to ISO 16890:2016)
- Considering the size range 1-3 µm to provide single number indicator named *eCFC* (efficiency of community face covering)

UNI/PdR 90-2:2020

Specifies the test method to measure efficiency by particle size and airflow resistance of CFC

- Fully described test rig
- Test aerosol made up of liquid DEHS particles
- Optical particle spectrometers in the size range 0.3-10 µm (option to expand the measuring range)
- Prescribes detailed qualification tests and procedure to verify the reliability of test rig
- Procedure to assess the minimum filtration efficiency by exposing the CFC to IPA vapor

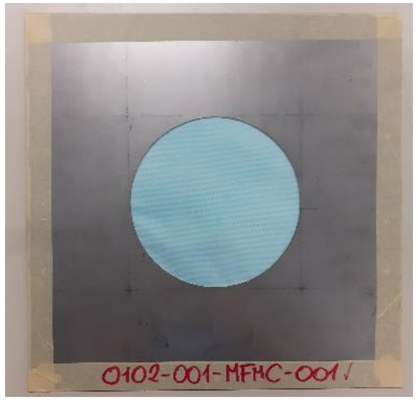
Test rig according to UNI PdR 90-2:2020

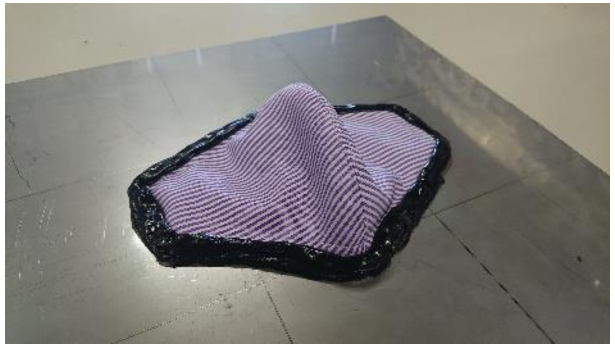


Examples of tested samples

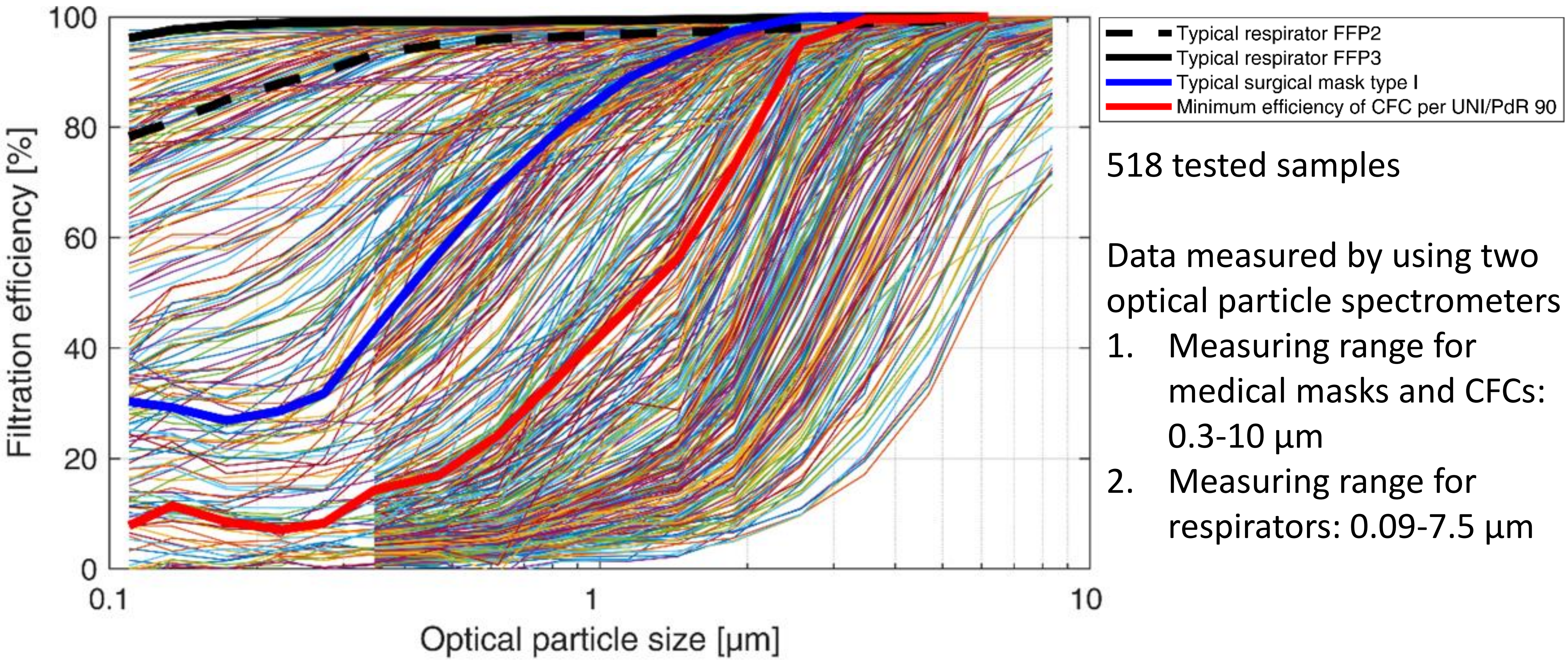
Samples were fixed to adapter plates

- Surgical masks sealed using tape
- Respirators sealed using hot glue or mastic butilic





Data obtained with UNI PdR 90:2020

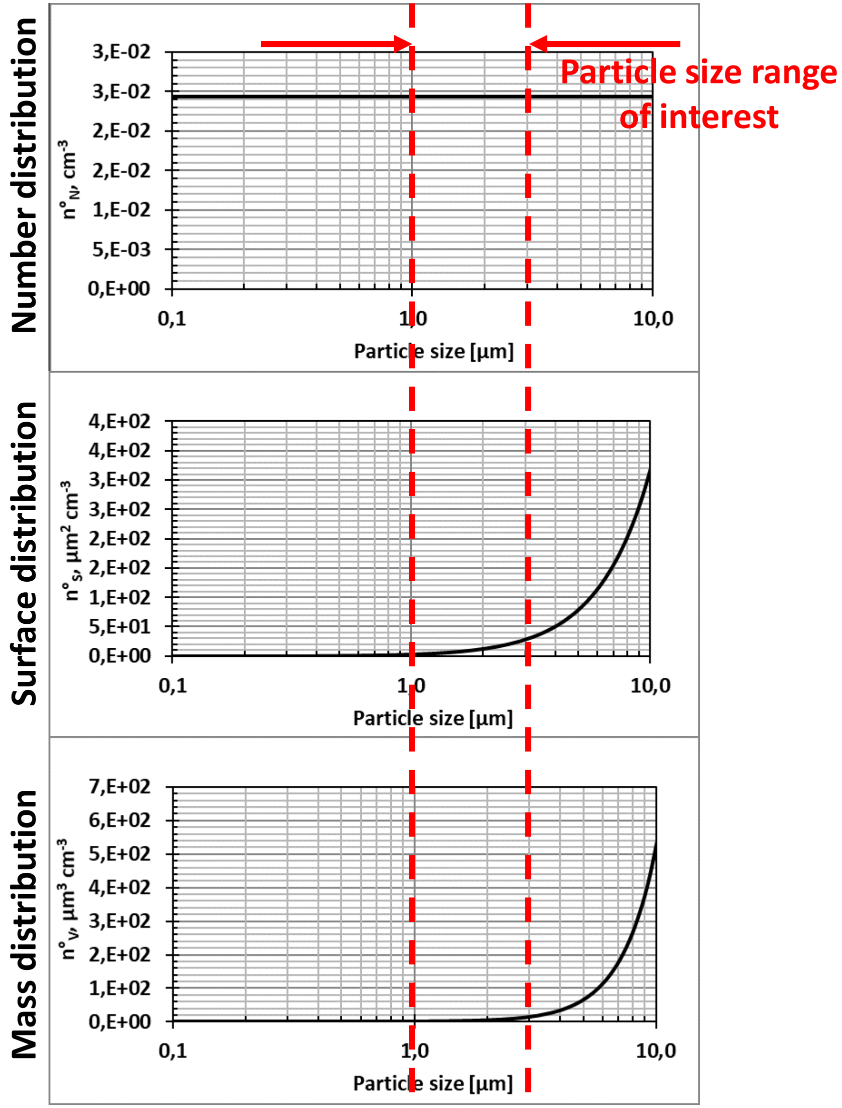


518 tested samples

Data measured by using two optical particle spectrometers

1. Measuring range for medical masks and CFCs: 0.3-10 μm
2. Measuring range for respirators: 0.09-7.5 μm

UNI PdR 90 – Reference challenge aerosol and *eCFC value*



- Uniform particle size distribution in number upstream
- Particle size range of interest: 1-3 µm
- Size range taking into consideration the phonation
- Can be changed to suit any specific challenge aerosol

$$eCFC = \frac{\sum_{i=1}^{n} E_i q_3(\bar{d}_i)\Delta\ln(\bar{d}_i)}{\sum_{i=1}^{n} q_3(\bar{d}_i)\Delta\ln(\bar{d}_i)}$$

$$\Delta\ln(\bar{d}_i) = \ln(d_{i+1}) - \ln(d_i)$$

E_i: Filtration efficiency of particle size range i

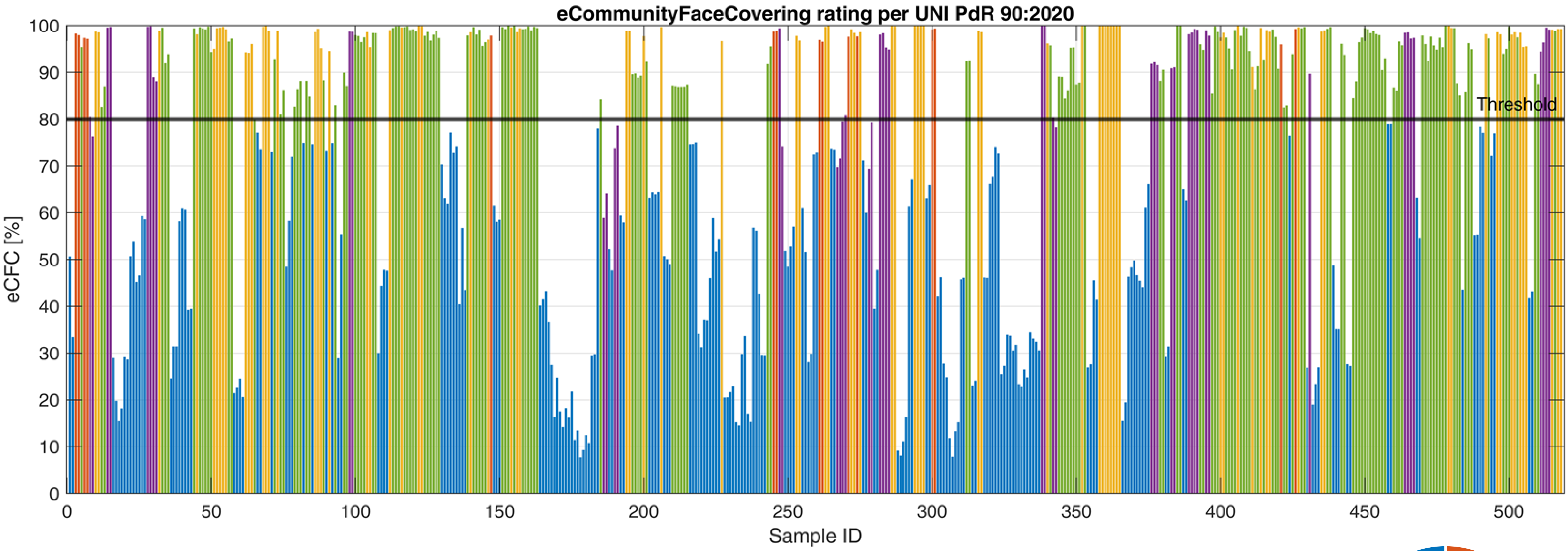
$q_3(\bar{d}_i)$: Volume fraction of particle size range i

UNI PdR 90-1:2020 – Classification of CFC

Designation	Maximum respiratory resistance at 27,2 cm/s [Pa]	Maximum respiratory resistance of rigid masks (cup masks) at 95 l/min - Annex A of UNI/PdR 90-1:2020 [Pa]	Minimum initial $eCFC_{average}$ (without electrostatic removal procedure) [%]
CFC-NR	294	210	80
CFC-R	294	210	80
CFC-BIO	294	210	80

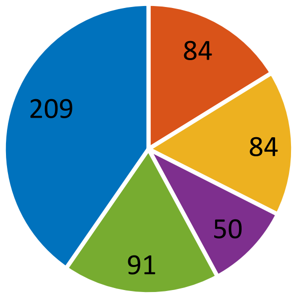
- NR: Non reusable; R: Reusable; BIO: Biodegradable
- Specific rating system for sporting masks (same minimum efficiency and lower airflow resistance)

Universal test method for facemasks



- Medical masks and respirators show higher *eCFC* values than the threshold of UNI/PdR 90
- UNI PdR 90 can distinguish suitable masks

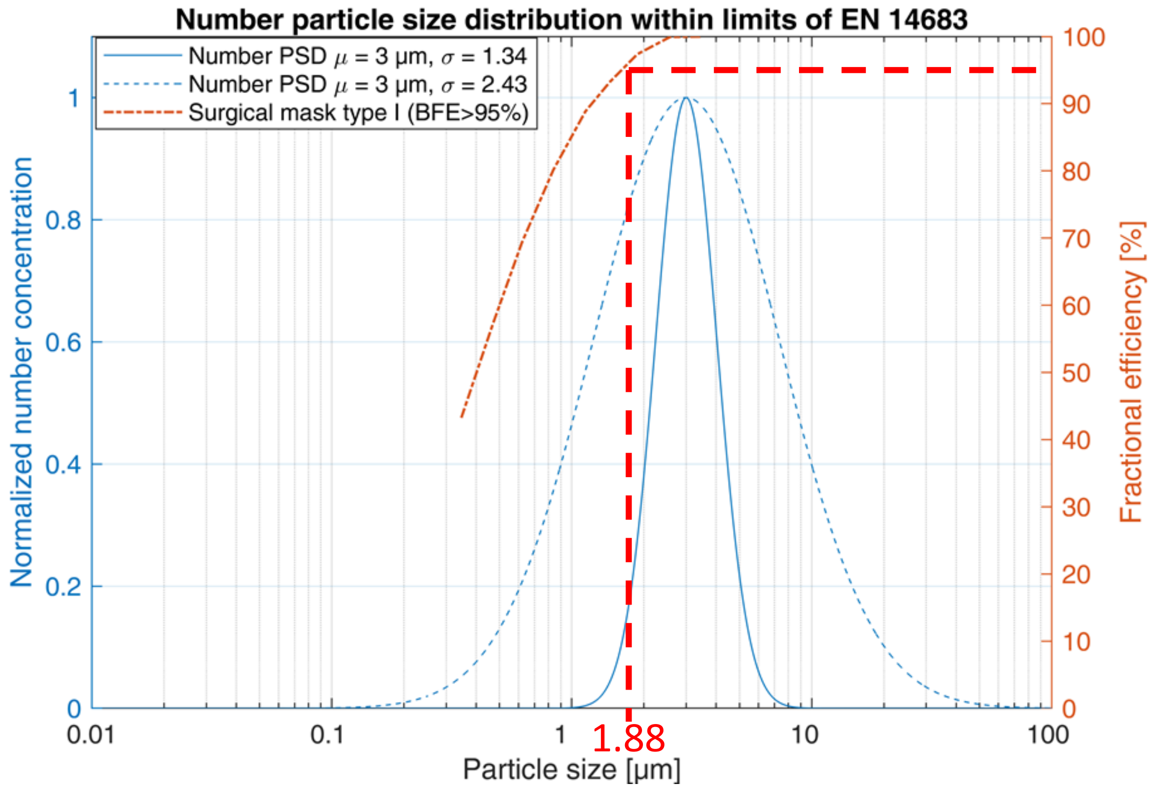
Pass EN14683 test
Pass EN 149 test
Resistance to airflow too high
In accordance to UNI PdR 90:2020
Efficiency too low



EN 14683 – Medical face masks

- Biological aerosol (Staphylococcus aureus)
  - Requires laboratory authorized to deal with pathogens
- Particle size distribution not fully described
  - Prescribes only the mean particle size (3.0 ± 0.3 µm) and not explicitly the geometric standard deviation
  - If CMD = 3.0 µm the geometric standard deviation can be between 1.34 e 2.43 (assuming lognormal distribution)
- At least two days to obtain useful data
- Uncertainty of test method not clearly defined

Example of comparison of fractional efficiency and BFE

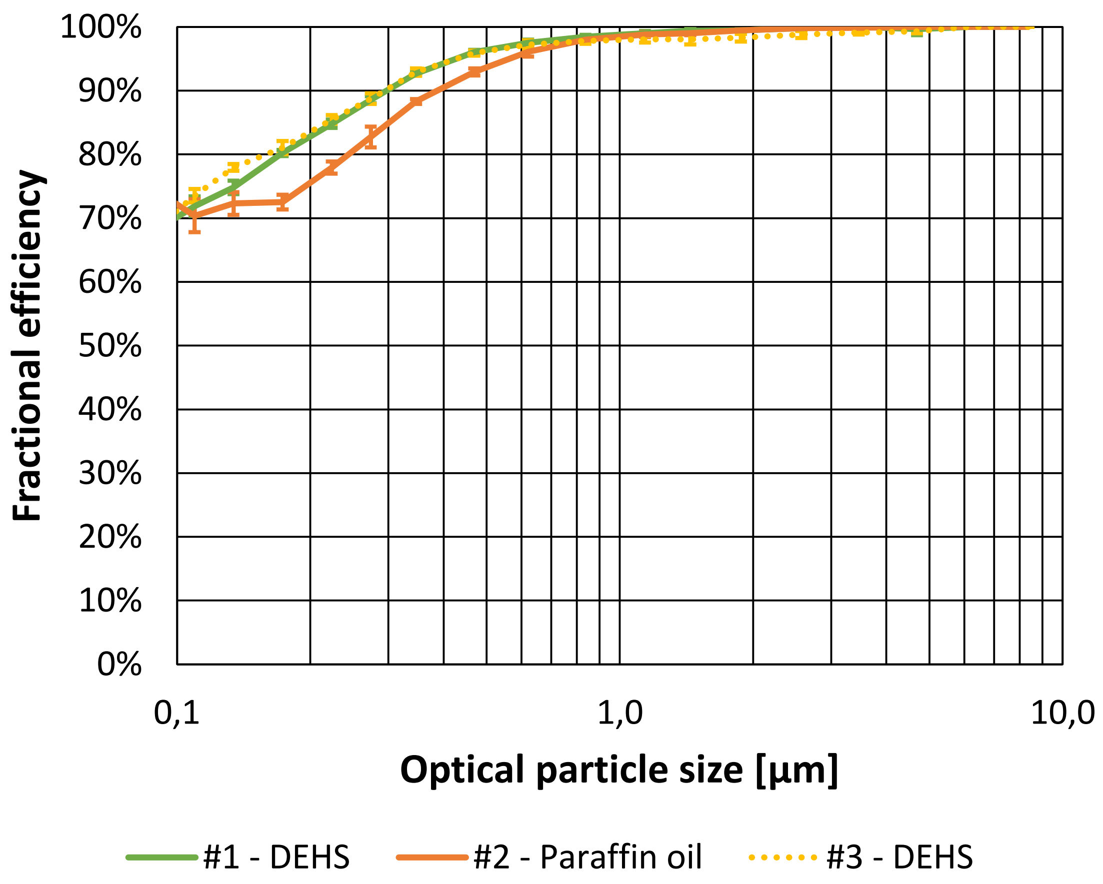


- The BFE results (95%) were provided by University of Bologna → Surgical mask Type I
- Blue curves: CMD = 3.0 µm with two GSD allowed by EN 14683
- Filtration efficiency at 3.0 µm is much higher than 95%, even for a Type I surgical mask (in this example 99.97%)
- Filtration efficiency at 1.88 µm measured with PdR 90 provides values with a good correlation with the obtained from BFE tests

EN 149 and 42 CFR 84 – Respiratory protective devices

- Measuring instrument for efficiency is a photometer (mass concentration)
- Allows a large range for the upstream particle size distribution
- EN 149
  - NaCl: Count median diameter from 0.06 to 0.10 µm and geometric standard deviation from 2.0 to 3.0 (initial penetration)
  - Paraffin oil: Count median diameter from 0.29 to 0.45 µm and geometric standard deviation from 1.6 to 2.2 (exposure test to reveal the minimum efficiency by discharging the filter media)
- 42 CFR 84
  - NaCl: Count median diameter from 0.055 to 0.095 µm and geometric standard deviation not exceeding 1.86 (for N-series of masks)
  - Paraffin oil: Count median diameter from 0.155 to 0.205 µm and geometric standard deviation not exceeding 1.60 (for P-series or R-series of masks)

Fractional efficiency measurement with different test aerosols per UNI/PdR 90



- UNI/PdR 90 prescribes measurements with DEHS aerosol
- Paraffin oil aerosol provides slightly lower filtration efficiency values below 1 µm compared to DEHS aerosol
- Fractional efficiency data obtained with liquid aerosol can estimate the initial mass efficiency obtained with paraffin oil per different respirators standardized test methods
- To predict N95 or KN95 mass efficiency, fractional efficiency data shall be obtained with KCl or NaCl solid aerosol (because of charged particles)

Potential of UNI/PdR 90

- It can be used to assess what would be the expected mass efficiency per different standards with only one measurement of fractional efficiency
- The column “Mass fraction below 0.09 µm” reports the mass fraction that would be “ignored” by performing measurements with optical particle spectrometers
- The column “Mass fraction above 1.0 µm” reports the mass fraction that would be “ignored” by performing measurements with electrical particle spectrometers

	CMD [µm]	GSD	MMD [µm]	Mass fraction below 0.09 µm	Mass fraction above 1.0 µm
NaCl - EN 149	0.080	2.50	0.993	0.4%	49.6%
Paraffin oil - EN 149	0.370	1.90	1.273	0.0%	64.6%
NaCl - 42 CFR 84	0.075	1.86	0.238	5.8%	1.0%
Paraffin oil - 42 CFR 84	0.185	1.60	0.359	0.2%	1.5%

Conclusions

- UNI/PdR 90 provides size-resolved efficiency curve with associated uncertainty in less than 30 min
- UNI/PdR 90 allows assessing the performance of rigid and semirigid CFC
- Non biological test aerosol (biosafety level laboratory not needed)
- Test method validated by during ISO 16890 and ISO 21083 preparation (under Mandate M/461 of the EC)
- Allows distinguishing leaks and holes from low-efficiency materials
- Assessing minimum filtration efficiency by conditioning process
- Possibility to change the reference PSD to suit any specific aerosol challenge (rating can be changed easily)
- Potential for measuring and classifying any kind of facemask, including respirators classified according to any international standard

Bibliography

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Questions?

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