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Influence of the operating time on the behavior of smoke alarms in typical office environments

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University of Duisburg-Essen, Germany

One of the youngest universities in Germany

- Among the top 10 of the biggest universities in Germany
- Located in the heart of the Ruhr metropolis
- Number of students ≈ 41.000
- Percentage of international students ≈ 13 %
- Number of employees ≈ 4700

- Number of faculties 11
  - Humanities, Social Sciences, Educational Sciences, Mathematics, Engineering, Physics, Chemistry, Biology, Medicine, Economics and Business Administration, Mercator School of Management
- Faculty of Engineering (74 departments) ≈ 11.000 students
  - Department of Communication Systems, NTS
  - Organizer of the “International Conference on Automatic Fire Detection”
    - **AUBE '14**

Heinz Luck Fire Lab, University of Duisburg-Essen, Germany

Fire Lab

- Surface area 34.5 ft * 29.5 ft
- Flexible room height 9.4 ft … 21.5 ft

Test scenarios

- Fire tests in the initial stage of a fire (EN 54)
- Experiments concerning the distribution of smoke and fire gases under variable conditions
- Non-standard test scenarios (e.g. Airbus A400M-reproduction)

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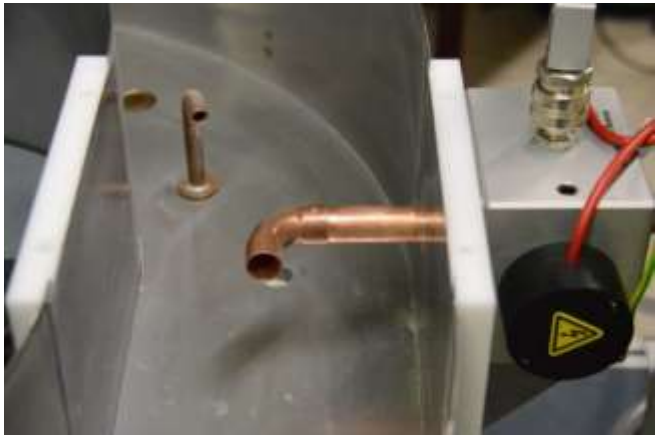


Test scenarios

- Fire tests in the initial stage of a fire (EN 54)
- Experiments concerning the distribution of smoke and fire gases under variable conditions
- Non-standard test scenarios (e.g. Airbus A400M-reproduction)
- Dust, spray and water fog tests
- Nuisance tests of smoke detectors in high humidity environments

Influence of the operating time on the behavior of smoke alarms in typical office environments

The German standard DIN 14675
”Fire-alarm systems - installation and operation”

- Describes the proper setup, operation and maintenance
  of an automatic fire alarm system
  having a direct connection to the fire brigade

- In the framework of maintenance
  the response behavior of smoke alarms has to be tested
  or the detectors have to be replaced after 5 resp. 8 years
  (depending on the detector technology)

➥ Reason for the fixed cycles of substitution of smoke alarms are
expected long-term changes of the response behavior
due to pollution and the aging of components

The German standard DIN 14675
”Fire-alarm systems - installation and operation”

No answer how the value of 8 years has been calculated

- In heavily polluted environments 8 years may be too high
  - An earlier exchange can reduce the number of false alarms

- In clean environments 8 years may be too short (e.g. office buildings)
  - An exchange of smoke alarms in clean environments at a later date can reduce costs and save resources

The standard does not distinguish between different installation conditions

Aim of the study

Determination of long-term changes of the response behavior due to pollution and the aging of components

Measurements possibly are able to give essential hints

- ➥ Response threshold value (RTV) — EN54 part 7, chap. 5.1.5
- ➥ Repeatability — EN54 part 7, chap. 4.3.1
- ➥ Directional dependence — EN54 part 7, chap. 4.3.2
- ➥ Reproducibility — EN54 part 7, chap. 4.3.3

(in our case “as many detectors as possible”)

Aim of the study

- Analysis and documentation
  of the influence of the environment
  and the operating life on the response behavior

- A particular focus of this series of tests was
  to investigate the behavior of new optical smoke detectors
  by comparison with optical smoke detectors of different age groups

- The old detectors were collected from office buildings

- 4 age groups of old detectors
  - ➥ 2 - 5 years of operating life
  - ➥ 6 - 8 years of operating life
  - ➥ 9 - 12 years of operating life
  - ➥ more than 12 years of operating life

Quantity structure of the collected and tested detectors

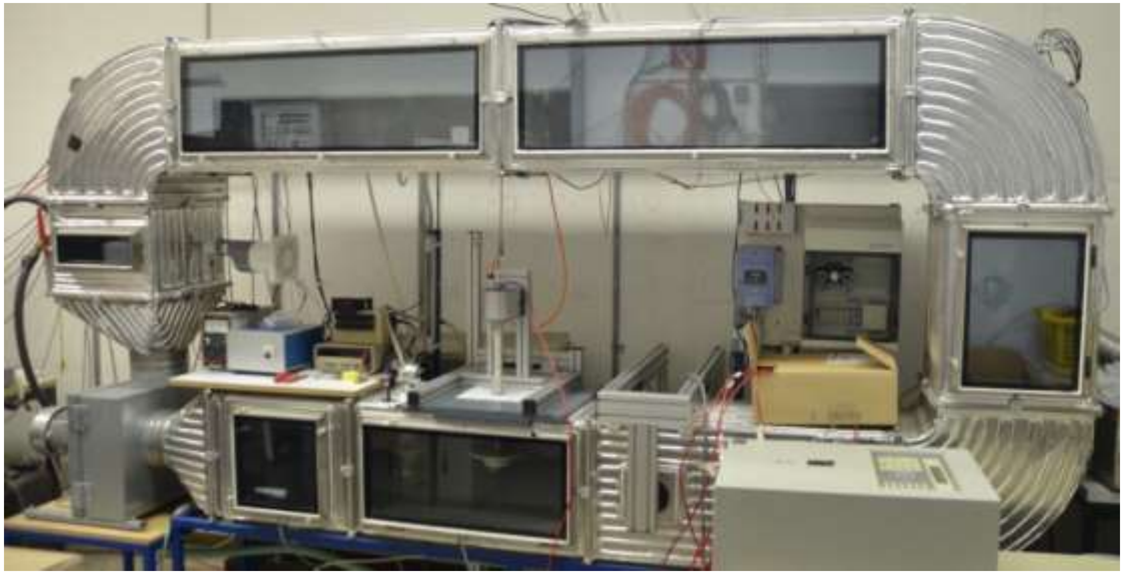
	New detectors	Detectors with 2 - 5 years of operating life	Detectors with 6 - 8 years of operating life	Detectors with 9 - 12 years of operating life	Detectors with more than > 12 years of operating life
Detector type 1	10	0	0	22	12
Detector type 2	11	5	13	10	0
Detector type 3	10	4	16	24	10
Detector type 4	10	5	8	11	0
Detector type 5	4	1	2	0	0
	45	15	39	67	22

No detectors of this type with an operating life of 2 .. 8 years

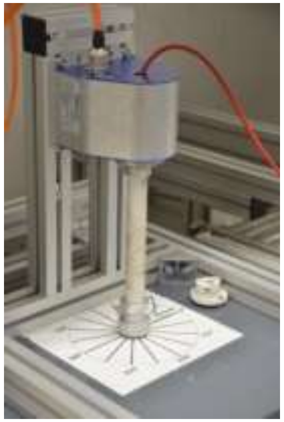
45 new optical smoke detectors
143 old optical smoke detectors

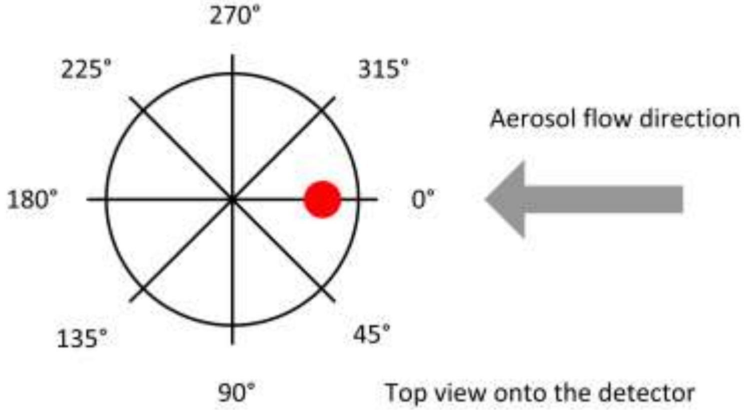
No detectors of this type with an operating life of more than 12 years

Lorenz AGW test aerosol generator & EN54 smoke tunnel

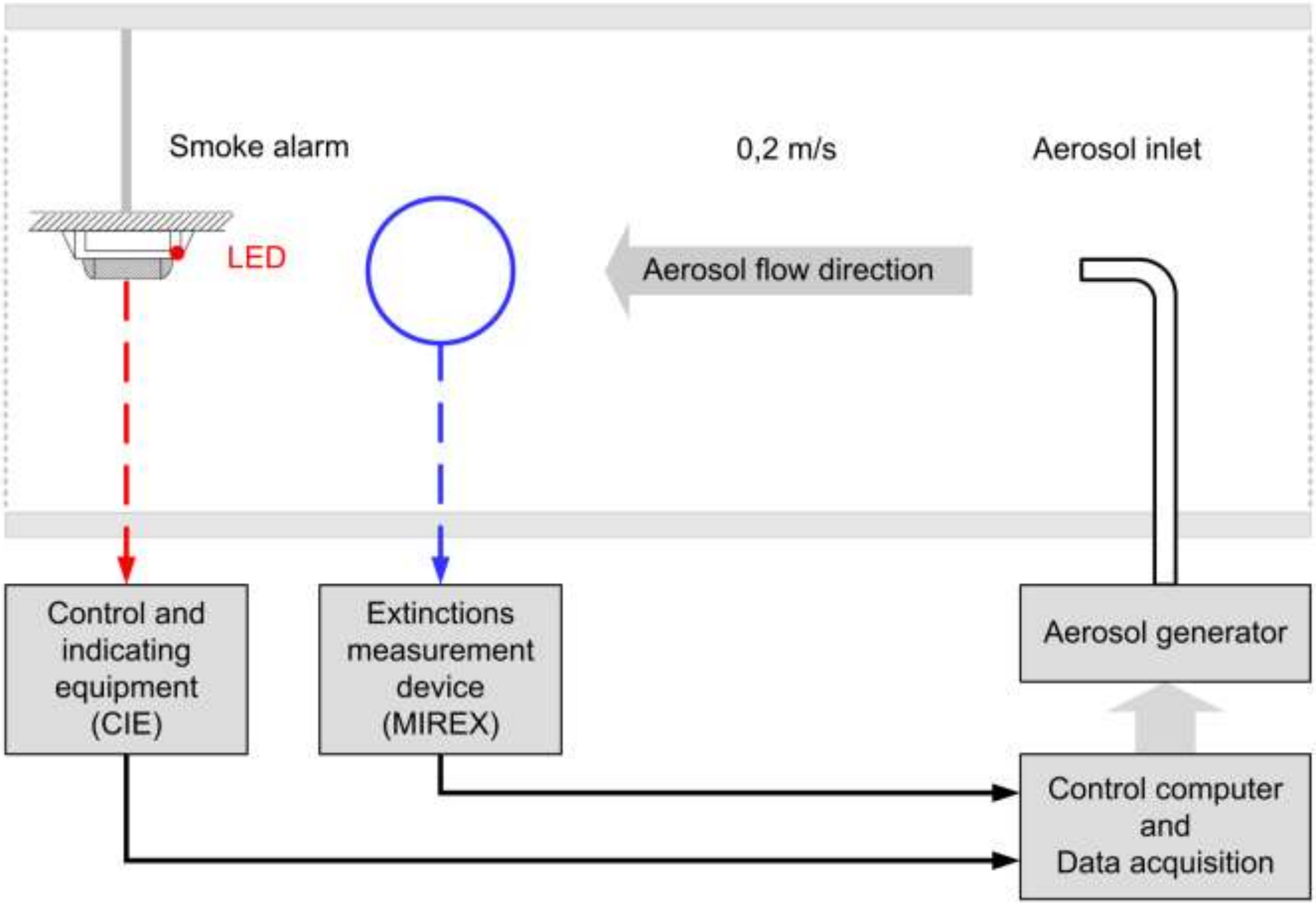


Response Threshold Value was measured by the MIREX extinction measuring device



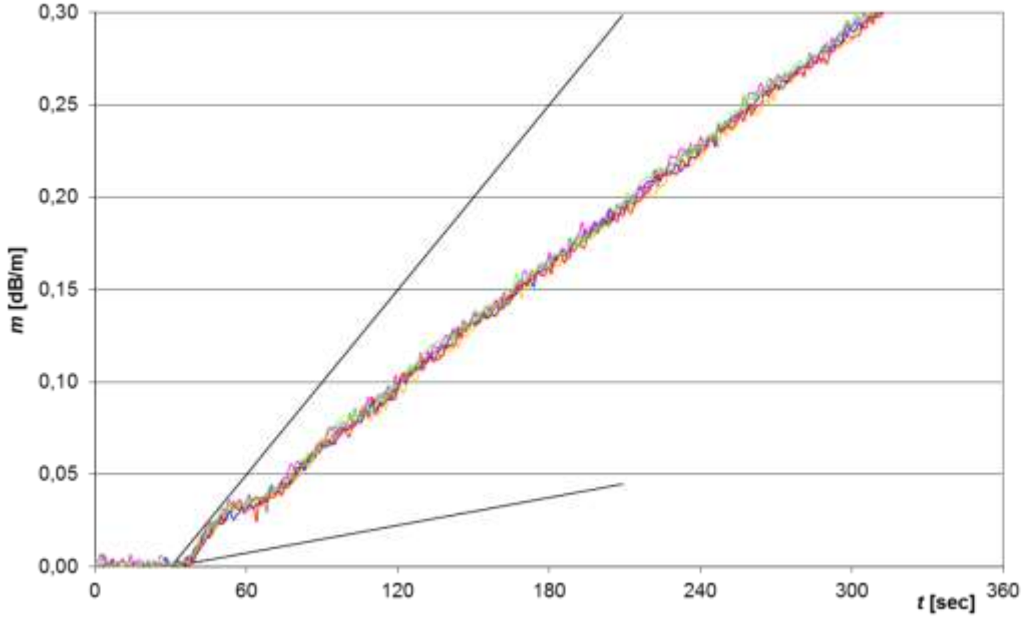


Principle of the measurement system



Requirement for the increase of the aerosol concentration for EN54 tests in the test tunnel

(e.g. measurement of the response behaviour and directionality)



$$0.015\ \mathrm{dB\ m^{-1}\ min^{-1}} \leq \Delta m / \Delta t \leq 0.1\ \mathrm{dB\ m^{-1}\ min^{-1}}$$

Typical slew rate of smoke concentration for EN54 tests ≈ 0,06 dB m^{-1} min^{-1}

Tests with new detectors

Directional Dependence

1 new detector of each detector type

➥ 8 measurements of the **R**esponse **T**hreshold **V**alue (RTV)

after each measurement the detector was turned by 45°

➥ Direction with the highest RTV, m_{max}

➥ direction with the lowest sensitivity

➥ Direction with the lowest RTV, m_{min}

➥ direction with the highest sensitivity

Repeatability

➥ 3 additional measurements at the angle with the highest RTV, m_{max}

Reproducibility

➥ 9 new detectors of each type at the angle with the highest RTV, m_{max}

Measuring results for a new detector, type 1

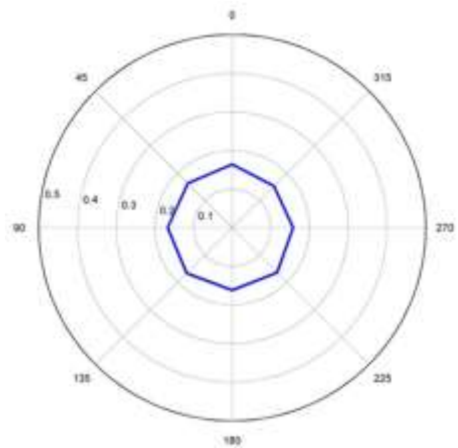
Angle [deg.]	*m* [dB/m]	*m* [dB/m]	*m* [dB/m]	*m* [dB/m]		m_{max} / m_{min} < 1.6
Detector 1 - 6N075						
0	0,155					
						eatability
						endence
Detector 1						
Detector 1						
Detector 1						
Detector 1						m_{mean}
Detector 1						m_{max}
Detector 1						m_{min}
Detector 1 - 6N081	0,199				1,081	m_{max} / m_{mean} ≤ 1.33
Detector 1 - 6N082	0,198				1,133	m_{mean} / m_{min} ≤ 1.5
Detector 1 - 6N083	0,185					Reproducibility

Requirements to pass the EN54 paraffin oil tests

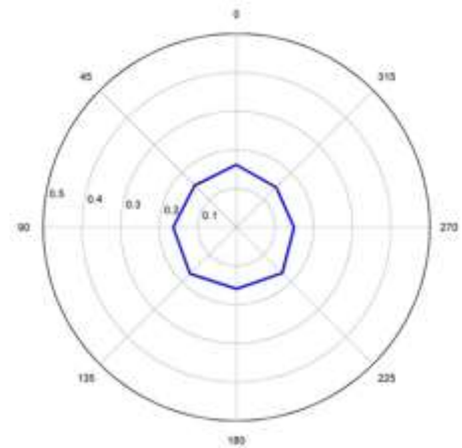
Repeatability	$m_{max} / m_{min} < 1.6$
Directional dependence	$m_{max} / m_{min} < 1.6$
Reproducibility	$m_{max} / m_{mean} \leq 1.33$
	$m_{mean} / m_{min} \leq 1.5$

Directional Dependence of new detectors

Detector type 1

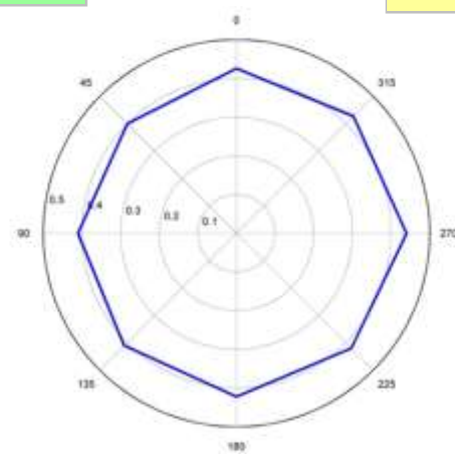


Detector type 2



Detector type 3

Detector type 4



Detector type 5

Tests with old detectors

Directional Dependence

50 % of the old detectors of each detector type

➥ 4 measurements of the RTV of each detector
after each measurement the detector was turned by 90°

➥ Measurements include the angle with the lowest sensitivity (m_{max}) of a new detector

➥ 1 repetition for each measurement

Reproducibility & Repeatability

50 % of the old detectors of each detector type

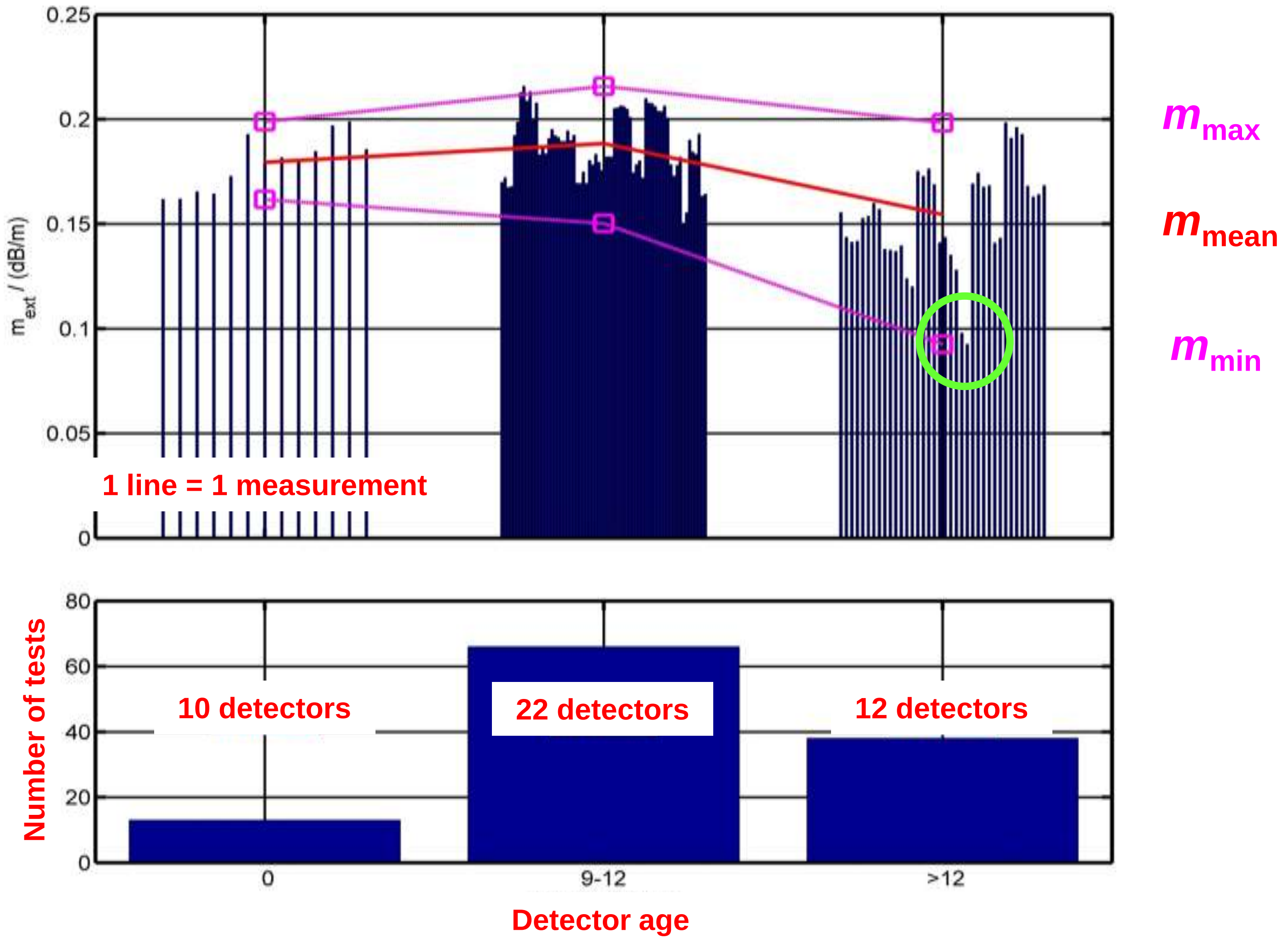
➥ 3 measurements of the RTV of each detector
at the angle with the lowest sensitivity (m_{max}) of a new detector

Total number of measurements depending on the operating life

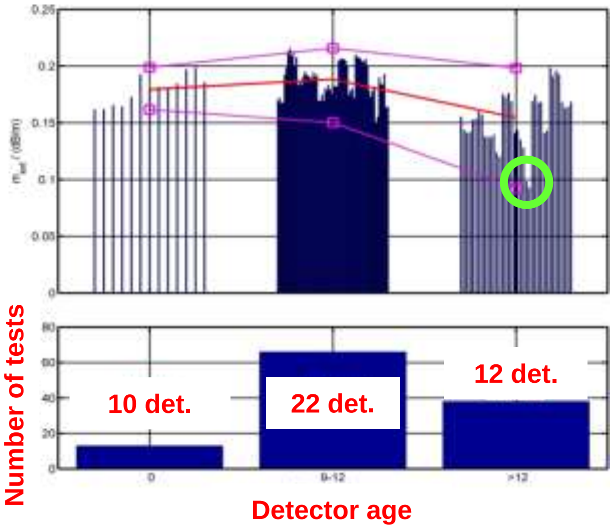
	New detectors	Detectors with 2 - 5 years of operating life	Detectors with 6 - 8 years of operating life	Detectors with 9 - 12 years of operating life	Detectors with more than > 12 years of operating life	Number of tests
Detector type 1	21	-	-	132	68	221
Detector type 2	21	24	80	60	-	185
Detector type 3	20	24	92	144	60	340
Detector type 4	20	24	48	68	-	160
Detector type 5	14	8	16	-	-	38
Total number of measurements depending on the operating life	**96**	**80**	**236**	**272**	**128**	**944**

- A total of 944 measurements of new and old detectors were collected
- The directionality and RTV tests were done repeatedly with identical configuration
- The scattering result values were averaged

Measurement of response value of detector type 1, angle 45°



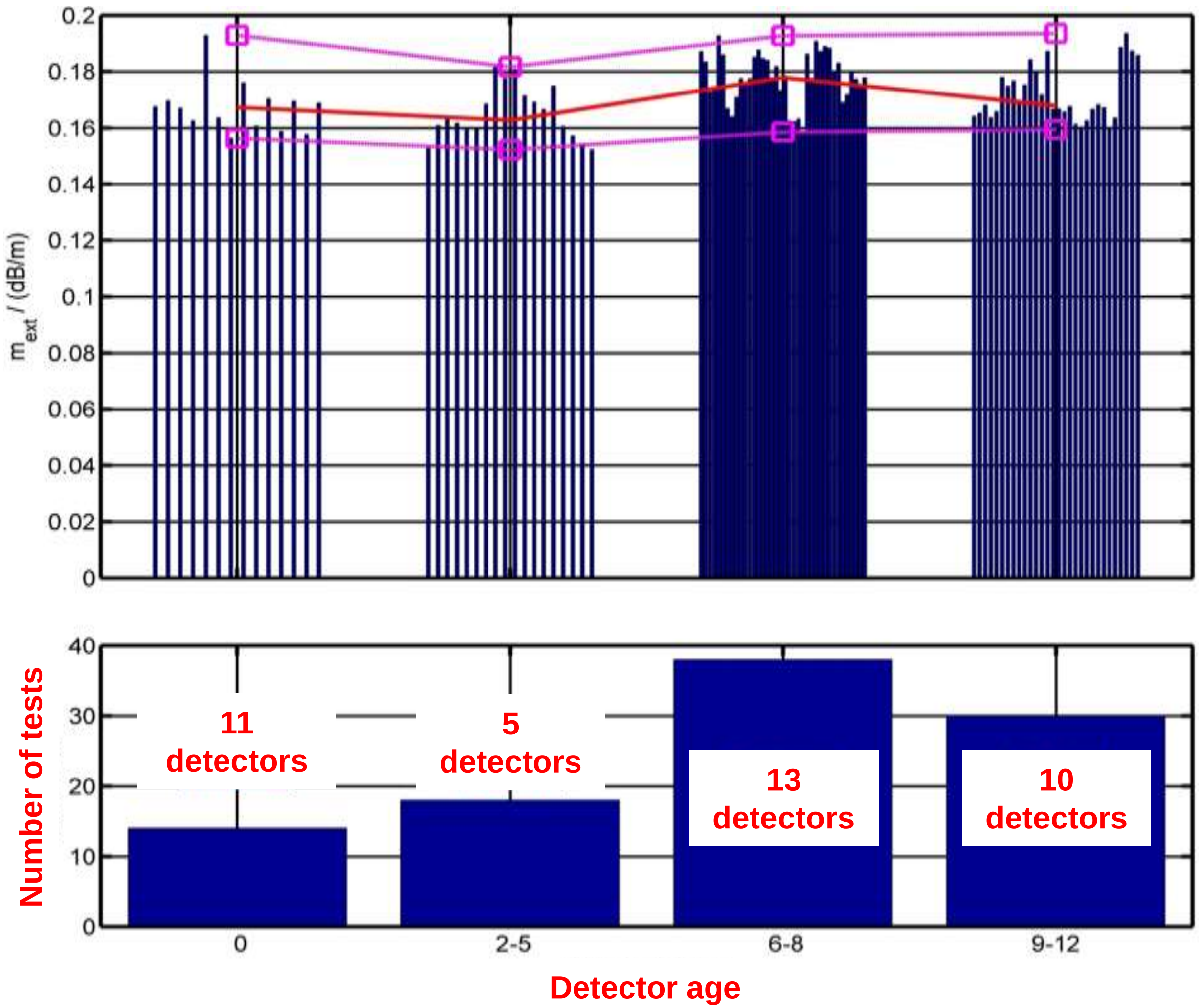
Measurement of response value of detector type 1



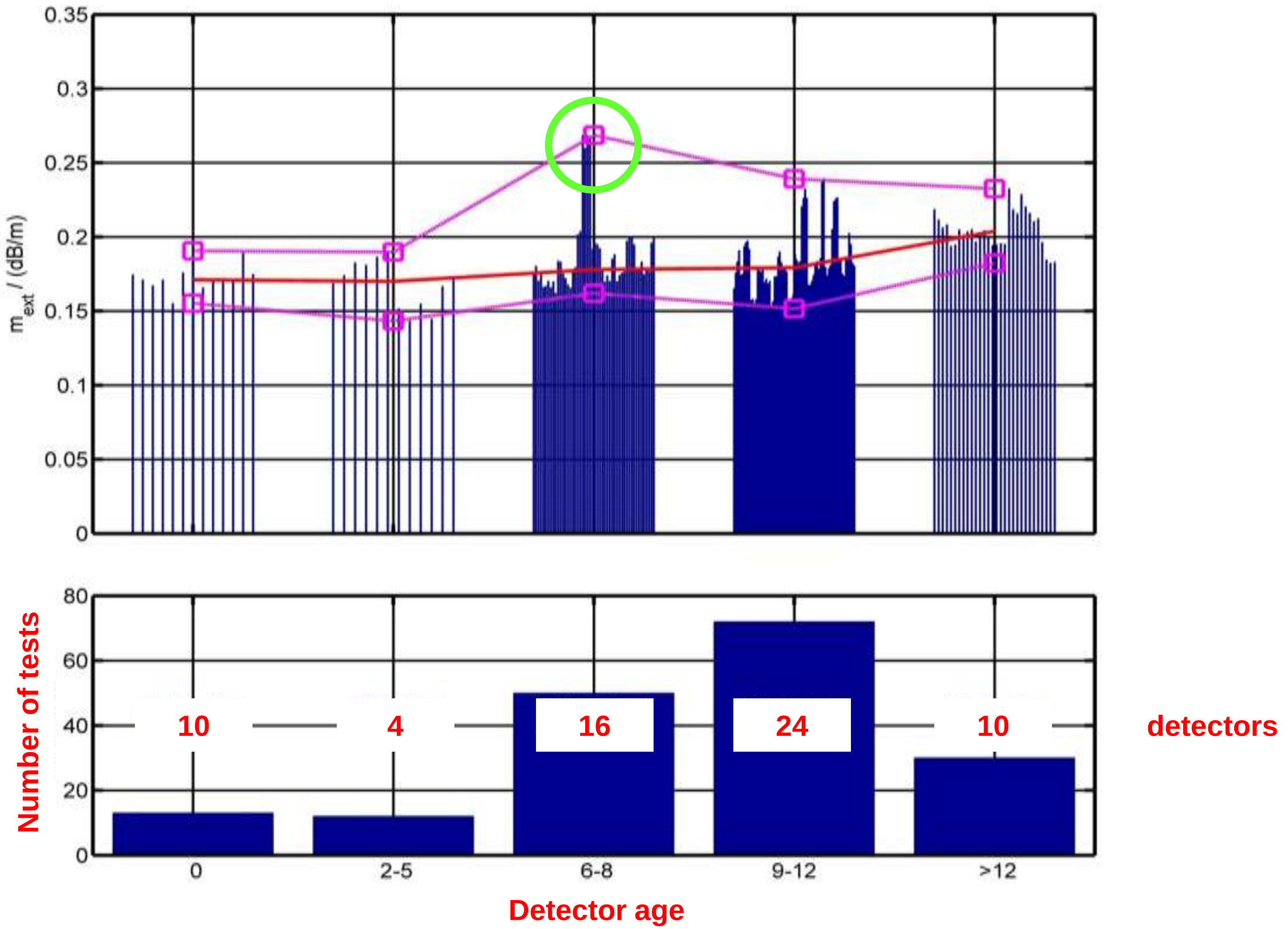
- Angle with the lowest sensitivity of a new detector type 1 is 45°
- 1 of 12 detectors is more sensitive
- 2 of 38 measurements
- Higher sensitivity = more false alarms
- ≈ 97 % of the old detectors type 1 have passed the test for new detectors

Detector type 1	EN54	new detector	2-5 years	6-8 years	9-12 years	> 12 years
m_{min}		0.162	-	-	0.150	0.093
m_{max}		0.199	-	-	0.216	0.155
m_{mean}		0.179	-	-	0.188	0.154
m_{max} / m_{mean}	≤ 1.33	1.11	-	-	1.15	1.29
m_{mean} / m_{min}	≤ 1.5	1.11	-	-	1.25	1.66

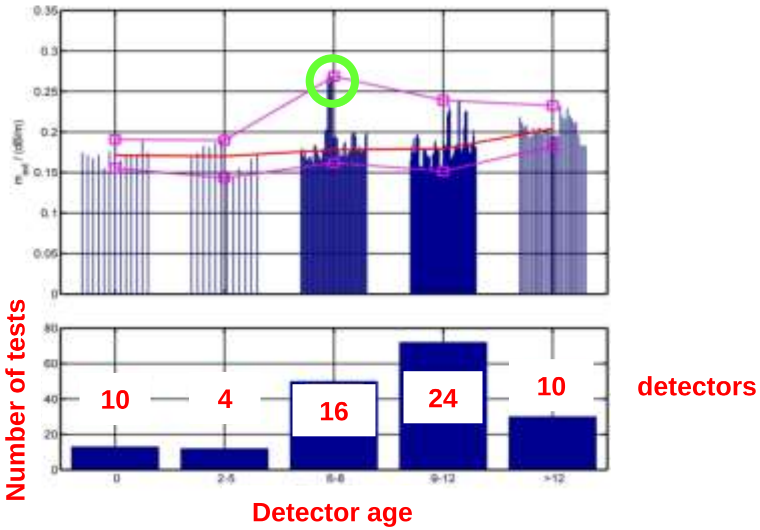
Measurement of response value of detector type 2, angle 90°



Measurement of response value of detector type 3, angle 135°



Measurement of response value of detector type 3, angle 135°

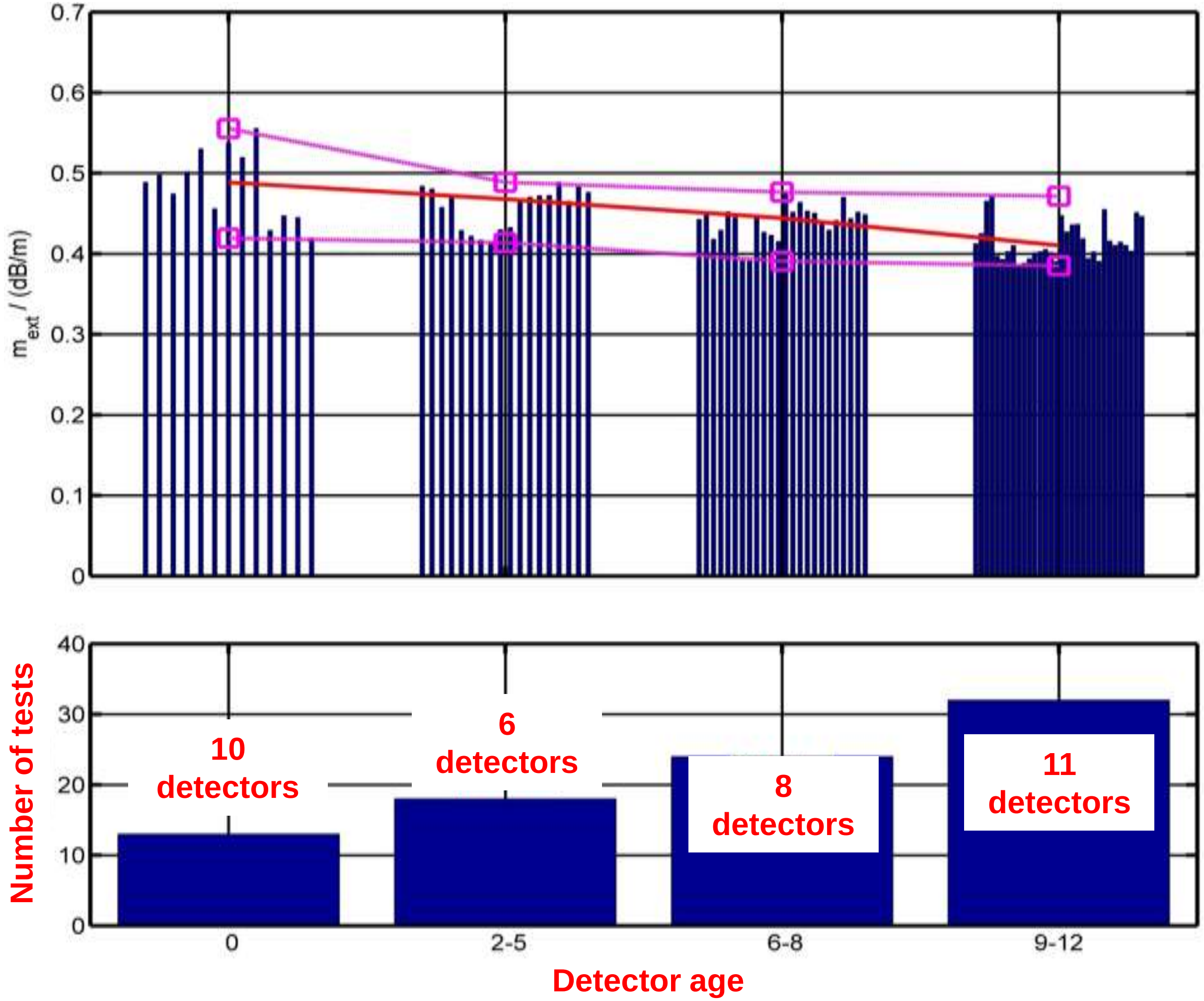


- Angle with the lowest sensitivity of a new detector type 3 is 135°
- 1 of 16 detectors is less sensitive
- 4 of 50 measurements
- A lower sensitivity increases the probability that a possible fire will be detected too late

- 98 % of the old detectors type 3 have passed the test for new detectors

Detector type 3	EN54	new detector	2-5 years	6-8 years	9-12 years	> 12 years
m_{min}		0.155	0.143	0.162	0.152	0.182
m_{max}		0.191	0.190	0.269	0.239	0.233
m_{mean}		0.172	0.168	0.187	0.184	0.204
m_{max} / m_{mean}	≤ 1.33	1.11	1.13	1.43	1.30	1.14
m_{mean} / m_{min}	≤ 1.5	1.11	1.17	1.16	1.21	1.12

Measurement of response value of detector type 4, angle 270°



Summary

- Key aspect of the study was the verification of the behavior of new and old optical smoke detectors with respect to the defined EN54 requirements
- A total of 944 measurements of 45 new and 143 old optical smoke detectors were collected and analyzed
- The old detectors were collected from office buildings (relatively clean areas)

Summary

Directional Dependence

- No conspicuous features
- The EN 54 requirement $m_{max} / m_{min} < 1.6$ was met by all tested detectors even after more than 12 years of operating life
- However, it can be observed that
  the angle with the lowest sensitivity of detector type 4
  has changed from 270° to 90°
  - ➥ Detector with 9 - 12 years operating life
    compared with a new detector

Summary

Reproducibility and aging effects

- The production spread of new smoke alarms has to be within the limits $m_{max} / m_{mean} \leq 1.33$ and $m_{mean} / m_{min} \leq 1.5$
- To show possible indications of e.g. aging of the detectors these values were calculated for each of the 4 age groups

Summary

Reproducibility and aging effects

- The production spread of new smoke alarms
  has to be within the limits $m_{max} / m_{mean} \leq 1.33$ and $m_{mean} / m_{min} \leq 1.5$
- To show possible indications of e.g. aging of the detectors
  these values were calculated for each of the 4 age groups
- Only minor changes with two exceptions
- A general trend to lower or higher RTV as a function
  of the operating age could not be determined
- A minor age-dependent variation may be determined
  depending on the detector type

Summary

Reproducibility and aging effects

- 2 detector types may be more sensitive with advancing age
- Detector type 1 changes of m_{mean} ≈ 14 % (age > 12 years)
- Detector type 4 changes of m_{mean} ≈ 15 % (9-12 years old)
- Higher sensitivity
  - ⇨ more false alarms
  - ⇨ no problem
  - ⇨ the detector will be exchanged

Summary

Reproducibility and aging effects

- 2 detector types may be more sensitive with advancing age
- Detector type 1 — changes of m_{mean} ≈ 14 % (age > 12 years)
- Detector type 4 — changes of m_{mean} ≈ 15 % (9-12 years old)
- Higher sensitivity
  - ⇨ more false alarms
  - ⇨ no problem
  - ⇨ the detector will be exchanged
- Detector type 3 — trend to lower sensitivity
  - changes of m_{mean} ≈ 9 % (age < 12 years)
  - changes of m_{mean} ≈ 19 % (age > 12 years)
- Detector type 2 — no trend to higher or lower sensitivity
- Detector type 5 — no trend to higher or lower sensitivity

Summary

- It can be shown that the age limit of 8 years (DIN 14675) is not an insurmountable problem.
- It should be stressed that the study should not be valued as absolute proof.
- The performed investigations show first important details for a possible review of the defined age limit.
- The study represents only a very small sample of detectors.
- A scientifically sound statement requires a significantly larger number of smoke alarms from different manufacturers and different areas of application.

Outlook

Sensitivity test after **???** years at regular intervals during operation, e.g. with ”trutest”**?**

- ”trutest” provides a linear increase of the aerosol concentration.
- The light obscuration is measured in %/ft.
- The result is not comparable with EN54 smoke tunnel tests due to a different areosol.
- In new installations the RTV of each smoke alarm has to be measured.

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- In new installations the RTV of each smoke alarm has to be measured.

Cost-benefit analysis:
What is more expensive, the replacement after 5 resp. 8 years or further re-testing**?**

➥ Discussing the matter with the standardization bodies

Extension to 8 + **X** years? ➔ Define **X**

No hard deadline for replacement, but a risk analysis**?**

Companies with an own fire service make a decision by themselves**?**

The predicted life time**?**
Current smoke alarms are equipped with a 10 year battery.

The behavior of multisensor detectors (e.g. with a CO-sensor)**?**

The behavior of detectors with integrated pollution compensation**???**

➥ Measurements with a larger number of smoke alarms from different manufacturers and different areas of application.

Thank you for your attention!

http://nts.uni-due.de

Wolfgang Krüll, Lea Marcius, Thorsten Schultze & Ingolf Willms

Publications

- Wolfgang Krüll, Thorsten Schultze, Robert Tobera & Ingolf Willms
  Characterization of Dust and Water Steam Aerosols in False Alarm Scenarios
  - Design of a Test Method for Fire Detectors in Dusty and in Highly Foggy Environments
  SupDET 2015, Orlando, Florida, U.S.A., March 2015
- W. Krüll, T. Schultze, R. Tobera & I. Willms
  Apparatus for the test of fire detectors in dusty environments
  15th International Conference on Automatic Fire Detection, AUBE '14, Duisburg, Germany, October 2014
- R. Tobera, W. Krüll, T. Schultze & I. Willms
  Apparatus for the test of fire detectors in high foggy environments
  15th International Conference on Automatic Fire Detection, AUBE '14, Duisburg, Germany, October 2014
- W. Krüll, T. Schultze, R. Tobera & I. Willms
  Characterization of dust aerosols in false alarm scenarios
  15th International Conference on Automatic Fire Detection, AUBE '14, Duisburg, Germany, October 2014
- W. Krüll, T. Schultze, R. Tobera & I. Willms
  Analysis of dust properties to solve the complex problem of non-fire sensitivity testing of optical smoke detectors
  9th Asia-Oceania Symposium on Fire Science and Technology, AOSFST, Hefei, China, October 2012.
- W. Krüll, T. Schultze, I. Willms & A. Freiling
  Developments in Non-Fire Sensitivity Testing of Optical Smoke Detectors - Proposal for a New Test Method
  10th International Symposium on Fire Science, University of Maryland, College Park, Maryland USA, June 2011
- W. Krüll, T. Schultze, I. Willms & A. Freiling
  Development of a test installation to determine false alarm susceptibility of smoke detectors
  International s+s report, number 1, 4/2011, page 10 – 15, VdS, Cologne, Germany, 2011
- W. Krüll, T. Schultze, I. Willms & A. Freiling
  Test Apparatus for the Evaluation of the Behaviour of Smoke Detectors in non-fire Situations
  2010 International Symposium on Safety Science and Technology, 2010 ISSST, Hangzhou, China, October 2010
- I. Willms & W. Kruell
  Developments in Non-Fire Sensitivity Testing
  EUSAS Conference on "Fire Detection: State of the Art and Future Development", Zug, Switzerland, June 2010