IFAB

Institute for applied fire safety research

Report

Water Mist - an alternate solution to Sprinkler in building fire protection

Phase 1 - Determination of fire test protocols for the protection of buildings with automatic water mist nozzles

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IWMA Research Project / Step 1

The work conducted by IFAB as reported in " Water Mist - an alternate Solution to Sprinklers in Building Fire Protection / Step 1 - Determination of Fire Test Protocols for the Protection of Buildings with automatic Water Mist Nozzles" has been initiated, financed and supported by IWMA. However, it may not represent the opinion of all members of the IWMA or even of all members of the IWMA board of directors.

The main conclusions from the report can be outlined as:

- Determination of fire test protocols have shown that a great variety of fire test protocols exists
- Different fire test protocols are not well comparable due to the different approaches of test methods
- A chance to harmonize might be to organize and enhance them in order to fulfil the requirements of the superior standard to testing laboratory ISO/IEC 17025
- Whenever characteristics of a certain system shall be determined by measuring, this standard demands a validated standardized test method that creates reproducible results
- Accredited test laboratories should follow the requirements of the ISO/IEC 17025
- At present none of the investigated fire test protocols fulfil the requirements of the ISO/IEC 17025 completely

Development of future water mist fire test protocol should address the above considerations.

Ragnar Wighus

(Chairman of the IWMA board of directors)

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List of abbreviations

Following abbreviations are used in this report (see Table 1).

Table 1: Abbreviation

Abbreviation	Description
CNPP	Centre national de prévention et de protection in France
VDS	VdS Schadenverhütung GmbH in Germany
CEN	European Committee for Standardization
HC	Hazard category
OH	Ordinary hazard
LH	Low hazard
ST	Storage
FM	Factory Mutual
NFPA	National fire protection association
UL	Underwriters laboratories

1 AIM OF THE RESEARCH

The aim of this research project is to assess the fire test protocols and the pass/fail criteria to apply to the performance verification of water mist systems using thermally activated (sprinkler like) nozzles for the protection of buildings according to the current status of knowledge, suggesting also future developing of the matter.

The object of the study was based on the following milestones that included in this report to survey relevant fire test protocols, its pass/fail criteria and evaluation:

- Complete research study of all fire test protocols with automatic[i] water mist nozzles
- Cataloguing of relevant fire test protocols
- Determination of fire test protocols and its pass/fail criteria

IFAB was authorised by the International Water Mist Association Scientific Council to carry out this research project.

2 CURRENT SITUATION

The protection of buildings with sprinkler systems has been used for almost two centuries and its validity is now confirmed by a big collection of positive results in terms of actual fires controlled by the correct operation of sprinkler systems installed in accordance with the available international standards. A series of tests were carried out to assess the design criteria of the sprinkler systems in the past, but nobody now remember how they were defined and which pass fail criteria was applied.

In the last few decades a fire protection technology using water in small droplets to fight fires has been developed; one of the way of using such a new technology for fire fighting is based on the use of nozzles closed with a thermal released mechanism that is individually activated upon reaching a predetermined temperature, discharging water onto the fire. This technology has been proposed for the protection of building occupancies although a problem immediately arose about the acceptance criteria to follow.

When the water mist technology is used for extinguishment purpose (applicable mainly to class B fires) the acceptance criteria to be used for the system is quite clear: extinguishment! But when the technology is applied to class A fires and it is used with the above mentioned closed nozzles approach, the acceptance criteria are a bit more complex, not existing a clear definition of fire control or fire suppression for these kind of fires.

[i] Automatic – thermally activated

The comparison with the sprinkler systems as a reference system that is normally required for the same hazard has been extensively used for a few years to provide a simple and clear pass/fail parameter. But with the continuous development of the water mist technology and the new applications being considered, the initial approach is showing all its limits. Indeed the effects of water mist are not the same as for Sprinklers; the cooling based on small droplets' heat absorption is different from the wetting of the sprinkler drops, the mixing of the combustion gases resulting by the mist discharge is not comparable with the falling drops of the sprinkler systems, and so on…

3 OVERVIEW OF FIRE TEST PROTOCOLS

At first a data base "Perinorm[1]" was used to search for norms and standards. Standards marked with [*] were found in this database and are general standards. At second fire test institutes, carrying out such fire test, have its own developed or adopted standards available on its web pages or were contacted if they have such a fire test protocol available. At last supplier and manufacturer of water mist industries were contacted to provide such fire test protocols or to give information. However, only a few guidelines are found and were available containing fire test protocols (see Table 2). These ones are investigated and discussed in this report. Table 20 in the Annex (7.1) show information from other countries how they proceed. Basically, they follow one of the standards marked with [*] in Table 2 with or without variations.

Table 2: Overview over relevant standards with fire test protocols

Country	Guideline with fire test protocol	Occupancy	Name of the fire test protocol
EU	DIN CEN 14972*	Ordinary hazard (OH 1) office[2]	Fixed fire fighting systems - Water mist systems - Design and installation
		Ordinary hazard (OH 3) storage[3]	
US	FM 5560*	Small compartment[4]	Water Mist Systems for Fire Protection
		Large compartment[4]	
		Open space[4]	
US	UL 2167***	Small (cabin)[5]	Standard for Safety for Water Mist Nozzles for Fire-Protection Service
		Small (corridor)[5]	
		Large[5]	
		Public space[5]	
		Ordinary hazard[5]	
		Residential[5]	
		Light hazard[5]	
UK	DD 8458*	Residential/domestic compartment[6]	Fixed fire protection systems. Residential and domestic water mist systems. Code of practice for design and installation
UK	DD 8489-7*	Small compartment[7]	Fixed fire protection systems. Industrial and commercial water mist systems. Tests and requirements for water mist systems for the protection of low hazard occupancies
		Large compartment[7]	
		Open space[7]	
		Workshop[7]	

Continued: Table 2

Country	Guideline with fire test protocol	Occupancy	Name of the fire test protocol
FR	CNPP T2**	Double room[8]	Règles techniques, spécifications et méthodes d'essais
		Double room (sidewall)[8]	
		Single room (wardrobe)[8]	
		Archive[9]	
DE	VDS**	Ordinary hazard (OH 1) office[10]	Fire tests office (OH1)
DE		Ordinary hazard (OH 1) hotel[11]	Fire tests hotel (OH1)
DE		Ordinary hazard (OH 1) false ceiling[12]	Fire tests false ceilings (OH1)
DE		Ordinary hazard (OH 2) garages[13]	Fire tests parking garages (OH2)
DE		Ordinary hazard (OH 3) storage compact[14]	Fire tests for department stores (OH3)
		Ordinary hazard (OH 3) storage shelf[14]	

* General Standard
** Laboratory developed standard fire test protocols
*** Maritime standard fire test protocol

Standards ISO 6182-9[15], MSC 265(84) Annex 14[16] and UL 2167[5] are actually related for a shipboard protection and are similar among each other. However, UL 2167[5] includes the most fire test protocols for the protection with automatic water mist nozzles. Therefore, it was chosen as a representative for all the other shipboard applications to discuss its fire test protocols as it obviously does not matter if cabins of ships or buildings get protected by automatic water mist systems.

VdS and CNPP standards are laboratory developed fire test protocols, are adjusted and updated regularly as fire tests get carried out.

There are probably more laboratory developed fire test protocols existing and were not available for this determination.

4 DETERMINATION OF FIRE TEST PROTOCOLS

In order to show similarities and differences between different fire test protocols, it was necessary to develop a way to compare different important aspects with each other.

4.1 Comparison by fire hazards

The first approach to compare fire test protocols with each other was to list them by its identified fire hazard.

There are basically two types of fire hazards recognised in the listed fire test protocols that shall be protected by an automatic water mist systems: low hazards and ordinary hazards. High hazards are not considered in any of the fire test protocols.

However, fire hazards are defined differently in the world. Two different definitions for such fire hazards are found to define them (see Table 3 and Table 5). The fire test protocols are developed in a way following one or another definition as shown in Table 4 and Table 6.

4.1.1 Fire hazards according to EN 12845

According to EN 12845[17] fire hazards are divided in Table 3.

Table 3: Overview over fire hazard classes in fire test protocols (EN 12845)[17]

Classification of fire hazards	Examples
Low hazards (LH)	School rooms, jails, offices: rooms < 126 m^2
Ordinary hazards (OH 1)	School rooms, offices: rooms > 126 m^2, hotels, hospitals
Ordinary hazards (OH 2)	Parking garages, laboratories, breweries
Ordinary hazards (OH 3)	Warehouses, furniture industries, show industries

The following fire tests protocols are related to the fire hazard as shown in Table 4.

Table 4: Fire test protocols categorised according to fire hazards (EN 12845)[17]

Country	Guideline with fire test protocol	Name of scenario	Fire hazard (EN 12845)		
			Ordinary hazard		
			OH 1	OH 2	OH 3
EU	DIN CEN 14972	Ordinary hazard (OH 1) office	x	-	-
	DIN CEN 14972	Ordinary hazard (OH 3) storage	-	-	x
FR	CNPP T2	Double room	x	-	-
	CNPP T2	Double room (sidewall)	x	-	-
	CNPP T2	Single room (wardrobe)	x	-	-
	CNPP T2	Archive	-	-	x
DE	VDS	Ordinary hazard (OH 1) office	x	-	-
DE	VDS	Ordinary hazard (OH 1) hotel	x	-	-
DE	VDS	Ordinary hazard (OH 1) false ceiling	x	-	-
DE	VDS	Ordinary hazard (OH 2) garages	-	x	-
DE	VDS	Ordinary hazard (OH 3) storage compact	-	-	x
	VDS	Ordinary hazard (OH 3) storage shelf	-	-	x

4.1.2 Fire hazards according to NFPA 101 and FM 5560

According to standard NFPA 101 A[18] and FM 5560[4] fire hazards are divided in Table 5.

Table 5: Overview over fire hazard classes in fire test protocols (NFPA 101[18] and FM 5560[4])

Classification of fire hazards	Examples
Low hazard[ii], Hazard category 1 [HC 1]	apartments, schools, hospitals, museums, offices, residential facility
restricted areas	enclosed spaces < height of < 2,4 m
unrestricted areas	open spaces > height of < 5 m
Ordinary hazard, Hazard category 2 [HC 2]	Parking garages, mercantile areas, theatres

The following fire tests protocols are related to the fire hazard as shown in Table 6.

[ii] Low hazard: formerly light hazard areas.

Table 6: Fire test protocols categorised acc. to fire hazards (NFPA 101[18], FM 5560[4], FM 3-26[19])

Country	Guideline with fire test protocol	Occupancy	Fire hazard (NFPA 101 / FM 5560)		
			Low hazard		Ordinary hazard
			HC 1 restricted	HC 1 unrestricted	HC 2
US	FM 5560	Small compartment	x	-	-
	FM 5560	Large compartment	x	-	-
	FM 5560	Open space	-	x	-
US	UL 2167	Small (cabin)	x	-	-
	UL 2167	Small (corridor)	x	-	-
	UL 2167	Large	x	-	-
	UL 2167	Public space	-	x	-
	UL 2167	Ordinary hazard	-	-	x
	UL 2167	Residential	x	-	-
	UL 2167	Light hazard	x	-	-
UK	DD 8458	Residential/domestic compartment	x	-	-
UK	DD 8489-7	Small compartment	x	-	-
	DD 8489-7	Large compartment	x	-	-
	DD 8489-7	Open space	-	x	-
	DD 8489-7	Workshop	x	-	-

Additionally, in standard FM 5560, chapter 1.2.3.7 it is written that HC 2 and HC 3 shall not be protected by water mist systems. Hazard categories (HC 1 – 4) are defined in FM 3-26[19].

4.1.3 Result

As there are at least two different definitions of the fire hazard categories existing and used in fire test protocols, it is not possible to group fire test scenario by the definition of fire hazards in order to compare further aspect within these hazard groups (see chapter 4.1.1 and 0.)

In these categories, certain occupancies can be related to different fire hazard categories, e.g. hotel is low hazard (HC1) or ordinary hazard (HC2). According to FM 5560, occupancies related to ordinary hazards, such as garages, archives, warehouses etc., shall not be protected by an automatic water mist nozzles. This is contrary to all the other existing fire test protocols of CEN TS 14972, UL 2167, DD 8458-1, DD 8489-7, of CNPP and of VDS.

Basically, 4 hazard categories are recognised among the fire test protocols as shown in Table 7.

- Nonstorage: small area, height < 2,4 m
- Nonstorage: large area, height < 2,4 m
- Nonstorage: large area, height > 5 m
- Storage: large area, height > 5 m

Some fire test protocols did not define any minimum applicable area or height (n.d. – not defined). It means that a certain area or height tested in fire tests is the maximum applicable one for the real installation.

Table 7: Categorised fire test protocols by fire hazards

Guideline with fire test protocol	Occupancy	Fire hazard		Evaluation of area		
				Small	Large	High
		Non storage	Storage	< 12 m²	> 12 m²	> 5 m
FM 5560	Small compartment	x	-	x	-	-
UL 2167	Small (cabin)	x	-	x	-	-
UL 2167	Small (corridor)	x	-	x	-	-
DD 8489-7	Small compartment	x	-	x	-	-
FM 5560	Large compartment	x	-	-	x	-
UL 2167	Large	x	-	-	x	-
UL 2167	Residential	x	-	-	x	-
UL 2167	Light hazard	x	-	-	x	-
DD 8489-7	Large compartment	x	-	-	x	-
DIN CEN 14972	Ordinary hazard (OH 1) office	x	-	-	x	-
CNPP T2	Double room	x	-	-	x	-
CNPP T2	Double room (sidewall)	x	-	-	x	-
CNPP T2	Single room (wardrobe)	x	-	-	x	-
UL 2167	Public space	x	-	-	x	(x)
DD 8458	Residential/domestic compartment	x	-	-	x	(x)
FM 5560	Open space	x	-	-	x	x
DD 8489-7	Open space	x	-	-	x	x
DD 8489-7	Workshop	x	-	-	x	x
VDS	Ordinary hazard (OH 1) office	x	-	-	x	n.d.
VDS	Ordinary hazard (OH 1) hotel	x	-	-	x	n.d.
CNPP T2	Archive	-	x	-	x	-
DIN CEN 14972	Ordinary hazard (OH 3) storage	-	x	-	x	(x)
UL 2167	Ordinary hazard	-	x	-	x	x
VDS	Ordinary hazard (OH 2) garages	-	x	n.d.	n.d.	n.d.
VDS	Ordinary hazard (OH 3) storage compact	-	x	n.d.	n.d.	n.d.
VDS	Ordinary hazard (OH 3) storage shelf	-	x	n.d.	n.d.	n.d.
VDS	Ordinary hazard (OH 1) false ceiling	-	x	n.d.	n.d.	-

(x) More than one height is defined
n.d. Not defined: can be any size or height

4.2 Fire scenarios

Nonetheless, the grouping of fire test protocols by its hazard category as shown in Table 7 is not useful for further comparison, e.g. to compare fire scenario/mock-up. A new order was carried out following the type of fire scenario/mock-ups (see

Table 8).

There were similar mock-ups identified among the listed fire scenarios from the fire test protocols as shown as sketches in Annex 7.2, Table 21:

- Small compartment: 2 bunk beds
- Large compartment: Simulated furniture
- Open space: 4 sofas
- Offices/Workshop: 2 desks
- Storage: Cartons with cups
- Specific: Specific applications

Table 8: Fire test protocols in accordance to fire scenario/mock-up

Guideline with fire test protocol	Occupancy	Fire scenario/mock-ups					
		2 bunk beds	Simulated furniture	4 Sofas	2 desks	Carton and cups	Specific
FM 5560	Small compartment	x	-	-	-	-	-
UL 2167	Small (cabin)	x	-	-	-	-	-
DD 8489-7	Small compartment	x	-	-	-	-	-
FM 5560	Large compartment	-	x	-	-	-	-
UL 2167	Large	-	x	-	-	-	-
UL 2167	Residential	-	x	-	-	-	-
UL 2167	Light hazard	-	x	-	-	-	-
DD 8489-7	Large compartment	-	x	-	-	-	-
DD 8458	Residential/domestic compartment	-	x		-	-	
UL 2167	Public space	-	-	x	-	-	-
FM 5560	Open space	-	-	x	-	-	-
DD 8489-7	Open space	-	-	x	-	-	-
VDS	Ordinary hazard (OH 1) hotel	-	-	x	-	-	-
DIN CEN 14972	Ordinary hazard (OH 1) office	-	-	-	x	-	-
DD 8489-7	Workshop	-	-	-	x	-	-
VDS	Ordinary hazard (OH 1) office	-	-	-	x	-	-
DIN CEN 14972	Ordinary hazard (OH 3) storage	-	-	-	-	x	-
UL 2167	Ordinary hazard	-	-	-	-	x	-
VDS	Ordinary hazard (OH 3) storage compact	-	-	-	-	x	-
VDS	Ordinary hazard (OH 3) storage shelf	-	-	-	-	x	-
UL 2167	Small (corridor)	-	-	-	-	-	x
CNPP T2	Double room	-	-	-	-	-	x
CNPP T2	Double room (sidewall)	-	-	-	-	-	x
CNPP T2	Single room (wardrobe)	-	-	-	-	-	x
CNPP T2	Archive	-	-	-	-	-	x
VDS	Ordinary hazard (OH 2) garages	-	-	-	-	-	x
VDS	Ordinary hazard (OH 1) false ceiling	-	-	-	-	-	x

The grouping by its fire scenario/mock-up was used for further comparisons. However, the scenarios grouped as "Specific application" are not comparable with any other one and differ strongly from others.

4.3 Fire loads

The following materials and items are required for the following test scenarios listed according to fire scenarios (see chapter 4.2). Only burnable materials are listed in Table 9.

Table 22 - Table 27 in the Annex 7.3 show different materials in detail used for fire scenarios and its definitions. All materials and items are defined by its sizes in the fire test protocols and are not additionally listed.

Table 9: Fire loads

Fire scenarios	Fire loads	Materials
2 bunk beds	Mattresses/Pillows Fabric covers	Polyether Cotton
Simulated furni-ture	Plywood Foam cushions	Wood Polyether
4 sofas	Mattresses/Pillows Fabric covers	Polyether Cotton
2 desks	Plywood Table, drawers, chair Folders, Papers Cushions, Folders Fabric covers Others	Wood Chipboard Paper, cardboard Polyether, polyurethane Cotton Other synthetic materials
Cartons and cups	Cardboard Cups	Cardboard Polystyrene
Specific	Folders, Papers Furniture Mattresses, pillows, Fabric covers, Tissues Cars Cables	Paper, cardboard Chipboard, veneer Polyether, polyester Cotton Other synthetic materials

4.4 Ignition sources

Table 10 show different materials used as ignition sources. Sketches of ignition sources are shown in Annex 7.2, Table 21. Table 22 - Table 27 in the Annex 7.3 show ignition sources in more detail. Basically the following ignition sources are identified.

Table 10: Ignition sources

Fire scenarios	Ignition source	Standard
2 bunk beds	Fibre board/ n-heptane in plastic bag	IMO Res. A. 800[20]
Simulated furni-ture	Wood crib/ n-heptane	IMO Res. A. 800[20]
4 sofas	Fibre board/ n-heptane in plastic bag	IMO Res. A. 800[20]
2 desks	Burner + wood crib/ n-heptane Wood-plastic crib/ white spirit	EN 45545 (Square burner)[21] -
Cartons and cups	N-heptane in pool	IMO Res. A. 800[20]
Specific	Burner	EN 45545-2 (Square burner)[21] or ISO 12952-2[22]

However, ignition sources correlate to standardised ignition sources (see column "standard" Table 10).

4.5 Variety of test duration

Table 11 shows the fire scenarios in dependency of the test duration:

- Counted after the ignition: 10 min or 30 min
- Counted after the activation of water mist system: 10 min or 30 min

Table 11: Fire test protocols in accordance to its test duration

Guideline with fire test protocol	Occupancy	Mock-up	Duration of fire test			
			After ignition		After activation of water mist system	
			10 min	30 min	10 min	30 min
FM 5560	Small compartment	2 bunk beds	x	-	-	-
UL 2167	Small (cabin)		-	-	x	-
DD 8489-7	Small compartment		-	-	x	-
FM 5560	Large compartment	Simulated furniture	x	-	-	-
UL 2167	Large		x	-	-	-
UL 2167	Residential		-	x	-	-
UL 2167	Light hazard		-	-	x	-
DD 8489-7	Large compartment		-	-	x	-
DD 8458	Residential/domestic compartment		-	-	X (domestic)	X (residential)
UL 2167	Public space	4 Sofas	-	-	-	-
FM 5560	Open space		x	-	-	-
DD 8489-7	Open space		-	-	-	x
VDS	Ordinary hazard (OH 1) hotel		-	-	x	-
DIN CEN 14972	Ordinary hazard (OH 1) office	2 desks	-	-	-	x
DD 8489-7	Workshop		-	-	-	x
VDS	Ordinary hazard (OH 1) office		-	-	-	x
DIN CEN 14972	Ordinary hazard (OH 3) storage	Carton and cups	-	-	-	x
UL 2167	Ordinary hazard		-	-	x	-
VDS	Ordinary hazard (OH 3) storage compact		-	-	x	-
VDS	Ordinary hazard (OH 3) storage shelf		-	-	x	-
UL 2167	Small (corridor)	Specific	-	-	x	-
CNPP T2	Double room		-	-	-	x
CNPP T2	Double room (sidewall)		-	-	-	x
CNPP T2	Single room (wardrobe)		-	-	-	x
CNPP T2	Archive		-	-	-	x
VDS	Ordinary hazard (OH 2) garages		-	-	-	x
VDS	Ordinary hazard (OH 1) false ceiling		-	-	x	-

4.6 Variety among scenarios

Table 12 shows the scenarios and its variety, which are grouped by identified fire scenarios/mock-ups. It shows even with a similar fire scenario/mock-up for the same, fire tests are carried under different conditions:

- Position of mock-up changes during fire tests (e.g. at the wall or in the centre of the test room)
- Position of ignition sources changes during fire tests (e.g. at different position on the mock-up, at wall or in the centre of the test room)
- With or without ventilation
- Amount of nozzle in test room (e.g. under one nozzle, between 2 or 4 nozzles)

Table 12: Fire test protocols in accordance to its variety among fire scenario

Guideline with fire test protocol	Occupancy	Fire scenario/ Mock-up	Variety among fire scenarios				
			Position of mock-up	Position of ignition source	Ventilation	Amount of nozzles	Others
FM 5560	Small compartment	2 bunk beds	-	-	-	-	-
UL 2167	Small (cabin)		-	x	-	x	x
DD 8489-7	Small compartment		-	-	-	-	-
FM 5560	Large compartment	Simulated furniture	-	-	-	-	-
UL 2167	Large		-	-	-	-	-
UL 2167	Residential		x	-	-	-	-
UL 2167	Light hazard		-	x	-	-	-
DD 8489-7	Large compartment		-	-	-	-	-
DD 8458	Residential/domestic compartment		x	-	x	-	x
UL 2167	Public space	4 Sofas	x	x	x	-	x
FM 5560	Open space		x	-	-	-	-
DD 8489-7	Open space		-	x	-	-	-
VDS	Ordinary hazard (OH 1) hotel		-	-	-	x	-
DIN CEN 14972	Ordinary hazard (OH 1) office	2 desks	-	-	-	x	-
DD 8489-7	Workshop		-	x	-	-	-
VDS	Ordinary hazard (OH 1) office		-	-	-	x	-
DIN CEN 14972	Ordinary hazard (OH 3) storage	Carton and cups	-	-	-	x	-
UL 2167	Ordinary hazard		x	-	-	-	-
VDS	Ordinary hazard (OH 3) storage compact		-	-	-	x	-
VDS	Ordinary hazard (OH 3) storage shelf		-	-	-	x	-
UL 2167	Small (corridor)	Specific	x	-	-	-	x
CNPP T2	Double room		-	-	-	-	-
CNPP T2	Double room (sidewall)		-	-	-	-	-
CNPP T2	Single room (wardrobe)		-	-	-	-	-
CNPP T2	Archive		-	x	-	-	x
VDS	Ordinary hazard (OH 2) garages		-	-	-	x	-
VDS	Ordinary hazard (OH 1) false ceiling						

4.7 Test repetition

Table 13 shows which of the fire scenarios are defined to be repeated with and/or without any changes of test conditions as shown in Table 12. Some of the scenarios only need to be carried out once.

Table 13: Fire test protocols in accordance to its defined repetition

Guideline with fire test protocol	Occupancy	Fire scenario/ Mock-up	Test repetition	
			Conditions changed	Same test repeated
FM 5560	Small compartment	2 bunk beds	-	(x)
UL 2167	Small (cabin)		x	-
DD 8489-7	Small compartment		-	x
FM 5560	Large compartment	Simulated furniture	-	(x)
UL 2167	Large		-	-
UL 2167	Residential		x	x
UL 2167	Light hazard		x	-
DD 8489-7	Large compartment		-	x
DD 8458	Residential/domestic compartment		x	-
UL 2167	Public space	4 Sofas	x	-
FM 5560	Open space		x	(x)
DD 8489-7	Open space		x	-
VDS	Ordinary hazard (OH 1) hotel		x	x
DIN CEN 14972	Ordinary hazard (OH 1) office	2 desks	x	-
DD 8489-7	Workshop		x	-
VDS	Ordinary hazard (OH 1) office		x	x
DIN CEN 14972	Ordinary hazard (OH 3) storage	Carton and cups	x	-
UL 2167	Ordinary hazard		x	-
VDS	Ordinary hazard (OH 3) storage compact		x	x
VDS	Ordinary hazard (OH 3) storage shelf		x	x
UL 2167	Small (corridor)	Specific	x	-
CNPP T2	Double room		-	-
CNPP T2	Double room (sidewall)		-	-
CNPP T2	Single room (wardrobe)		-	-
CNPP T2	Archive		x	-
VDS	Ordinary hazard (OH 2) garages		x	x
VDS	Ordinary hazard (OH 1) false ceiling		-	-

(x) It is not compulsory to repeat the same test scenario.

4.8 Measurements

Table 14 shows the measurement variables that are defined in the fire test protocols and need to be recorded during the fire tests.

Temperature measurements and the determination of fire damages need to be analysed in almost all cases. Furthermore, some fire test protocols require gas analyses, measurement of water pressure and flow rates, radiation, video recording as well as a comparison with a reference fire fighting system (Sprinkler).

Table 14: Fire test protocols in accordance to its defined measurement variables

Guideline with fire test protocol	Occupancy	Fire scenario/ Mock-up	Measurement variables						
			Temperature	Burning damages	Gas concentration (O_2, CO, CO)	Water pressure	Water flow rate	Reference system	Others
FM 5560	Small compartment	2 bunk beds	x	x	-	-	-	-	-
UL 2167	Small (cabin)		x	x	-	x	x	-	-
DD 8489-7	Small compartment		x	x	x	x	x	-	-
FM 5560	Large compartment	Simulated furniture	x	-	-	-	-	-	-
UL 2167	Large		x	-	-	x	x	-	-
UL 2167	Residential		x	-	-	-	-	-	-
UL 2167	Light hazard		-	x	-	-	-	-	-
DD 8489-7	Large compartment		x	x	x	x	x	-	-
DD 8458	Residential/domestic compartment		x	-	x	x	x	-	-
UL 2167	Public space	4 sofas	x	x	-	-	-	-	-
FM 5560	Open space		x	x	-	-	-	-	-
DD 8489-7	Open space		x	x	x	x	x	-	-
VDS	Ordinary hazard (OH 1) hotel		x	x	-	x	x	x	-
DIN CEN 14972	Ordinary hazard (OH 1) office	2 desks	x	x	-	x	x	x	Video
DD 8489-7	Workshop		x	x	x	x	x	-	-
VDS	Ordinary hazard (OH 1) office		x	x	-	x	-	x	Radiation
DIN CEN 14972	Ordinary hazard (OH 3) storage	Cup and cartons	x	x	-	x	x	x	Video
UL 2167	Ordinary hazard		x	-	-	-	-	-	-
VDS	Ordinary hazard (OH 3) storage compact		x	x	-	x	x	x	Radiation
VDS	Ordinary hazard (OH 3) storage shelf		x	x	-	x	x	x	Radiation
UL 2167	Small (corridor)	Specific	x	-	-	x	x	-	-
CNPP T2	Double room		x	x	O_2	x	x	x	-
CNPP T2	Double room (sidewall)		x	x	O_2	x	x	-	-
CNPP T2	Single room (wardrobe)		x	x	O_2	x	x	-	-
CNPP T2	Archive		x	x	O_2	x	x	-	-
VDS	Ordinary hazard (OH 2) garages		x	x	-	x	x	x	Radiation
VDS	Ordinary hazard (OH 1) false ceiling		x	x	-	x	x	x	-

4.9 Evaluation criteria

There are basically two systems of evaluation a water mist fire fighting system (Table 15):

- Pass/fail criteria according to limit values for temperatures and burning damages
- Pass/fail criteria by comparison of reference system: fire damages and temperatures shall be lower than of the reference system

Table 15: Fire test protocols in accordance to its evaluation criteria

Guideline with fire test protocol	Occupancy	Fire scenario/ Mock-up	Type of criteria			
			Reference system		Limit values	
			Temperatures	Damages	Temperatures	Damages
FM 5560	Small compartment	2 bunk beds	-	-	x	x
UL 2167	Small (cabin)		-	-	x	x
DD 8489-7	Small compartment		-	-	x	x
FM 5560	Large compartment	Simulated furniture	-	-	x	-
UL 2167	Large		-	-	x	x
UL 2167	Residential		-	-	x	-
UL 2167	Light hazard		-	-	-	x
DD 8489-7	Large compartment		-	-	x	-
DD 8458	Residential/domestic compartment		-	-	x	-
UL 2167	Public space	4 sofas	-	-	x	x
FM 5560	Open space		-	-	x	x
DD 8489-7	Open space		-	-	x	x
VDS	Ordinary hazard (OH 1) hotel		x	x	-	-
DIN CEN 14972	Ordinary hazard (OH 1) office	2 desks	x	x	-	-
DD 8489-7	Workshop		-	-	x	x
VDS	Ordinary hazard (OH 1) office		x	x	-	-
DIN CEN 14972	Ordinary hazard (OH 3) storage	Cups and cartons	x	x	-	-
UL 2167	Ordinary hazard		-	-	x	x
VDS	Ordinary hazard (OH 3) storage compact		x	x	-	-
VDS	Ordinary hazard (OH 3) storage shelf		x	x	-	-
UL 2167	Small (corridor)	Specific	-	-	x	-
CNPP T2	Double room		x	x	-	-
CNPP T2	Double room (sidewall)		-	-	x	x
CNPP T2	Single room (wardrobe)		-	-	x	x
CNPP T2	Archive		-	-	x	x
VDS	Ordinary hazard (OH 2) garages		x	x	-	-
VDS	Ordinary hazard (OH 1) false ceiling		x	x	-	-

Table 16 shows these measurement variables and its limit values that are defined in the fire test protocols. The following parameters differ:

- Diameter of thermocouples
- Summarising temperatures by mean values
- Position of thermocouples used as evaluation criteria
- Limit values of temperatures
- Fire damages and its definitions how it is measures
- Limit values of oxygen
- Comparison to a reference system

Table 16 also shows which results from the fire tests are compared to the results of the reference systems. In this case, the tested water mist fire fighting system shall have better results in fire damages and temperatures than the reference system. No other limit value is then defined (except the fire scenario "double room" from CNPP).

Table 16: Fire test protocols in accordance to its definition of evaluation criteria

Guideline with fire test protocol	Occupancy	Fire scenario/ mock-up	Measurement variables as evaluation criteria							
			Thermocouple	Temperature				Determination of burning damages	Gas concentration	Reference system*
			Type K (alu-nickel-chrome)	Mean values	Ceiling gas [°C]	Ceiling surface [°C]	Elsewhere			
FM 5560	Small compartment	2 bunk beds	Ø 0,36 mm	-	315	260	-	By volume or dry weight	-	-
UL 2167	Small (cabin)		Ø 0,5 mm	x	360	320	x	n.d.	-	-
DD 8458-7	Small compartment		Ø 0,5 mm		360	260	-	By volume or dry weight	x	-
FM 5560	Large compartment	Simulated furniture	Ø 0,36 mm	-	315	265	-	-	-	-
UL 2167	Large		Ø 0,5 mm	x	315	260	-	-	-	-
UL 2167	Residential		Ø 0,5 mm		315	260	-	-	-	-
UL 2167	Light hazard		n.d.		-	-	-	n.d.	-	-
DD 8459-7	Large compartment		Ø 0,5 mm		315	260	-	By volume or dry weight	x	-
DD 8458	Residential/domestic compartment		n.d.	-	360	260	x	-	x	-
UL 2167	Public space	4 sofas	Ø 0,5 mm		360	220	-	n.d.	-	-
FM 5560	Open space		Ø 0,36 mm	-	315	260	-	By volume or dry weight	-	-
DD 8459-7	Open space		Ø 0,5 mm		315	260	-	By volume	x	-
VDS	Ordinary hazard (OH 1) hotel		Ø 0,5 mm	x	x	-	-	n.d.	-	x
DIN CEN 14972	Ordinary hazard (OH 1) office	2 desks	Ø 0,5 mm	x	x	-	-	n.d.	-	x
DD 8459-7	Workshop		Ø 0,5 mm		80	-	-	n.d.	x	-
VDS	Ordinary hazard (OH 1) office		Ø 0,5 mm	x	x	-	-	n.d.	-	x
DIN CEN 14972	Ordinary hazard (OH 3) storage	Cups and cartons	Ø 0,5 mm	x	x	-	-	n.d.	-	x
UL 2167	Ordinary hazard		Ø 0,5 mm		360		x	-	-	-
VDS	Ordinary hazard (OH 3) storage compact		Ø 0,5 mm	x	x	-	x	n.d.	-	x
VDS	Ordinary hazard (OH 3) storage shelf		Ø 0,5 mm	x	x	-	x	n.d.	-	x
UL 2167	Small (corridor)	Specific	Ø 0,5 mm	x	-	-	x	-	-	-
CNPP T2	Double room		Ø 1,5 mm		50	-	x	n.d.	O_2: 18 Vol%	x
CNPP T2	Double room (sidewall)		Ø 1,5 mm		50	-	x	n.d.	O_2: 18 Vol%	-
CNPP T2	Single room (wardrobe)		Ø 1,5 mm		50	-	x	n.d.	O_2: 18 Vol%	-
CNPP T2	Archive		n.d.		60	-	x	n.d.	O_2: 17 Vol%	-
VDS	Ordinary hazard (OH 2) garages		Ø 0,5 mm	x	x	-	-	n.d.	-	x
VDS	Ordinary hazard (OH 1) false ceiling		Ø 0,5 mm	x	x	-	x	n.d.	-	x

5 DISCUSSION

5.1 General

The determination of fire test protocols show that a suitable evaluation of fire test protocols is not possible. Fire test protocols differ too much from each other to compare them. It might be difficult to harmonise fire test protocols and to design a superior fire test protocol including all occupancies, scenarios of all existing ones.

As an option to get an order into a system, a more abstract base shall be found. Such a base might be the superior guideline ISO/IEC 17025[23] forcing any test laboratory to verify measurements and validate testing methods in a defined testing field. This standard could offer advantages if it is implemented in a reasonable way as it is explained in chapter 5.2.

5.2 Normative requirements

It becomes more and more obligatory to be accredited as a fire testing laboratory. The superior norm for such laboratories is ISO/IEC 17025[23] in general. This norm specifies the competence of a testing laboratory to carry out tests for a specific testing area, e.g. proof of non-combustibility, approval of water mist systems for machinery spaces etc..

It ensures qualitative correct results for testing in this particular testing field. This covers testing of standard, non-standard[III] and laboratory-developed methods such as:

- Examples for standard methods:
  - DIN CEN/TS 14972:2011-9, ANNEX F: Fire test procedure for certain occupancies; Ordinary hazard group OH3[14]
  - FM 5560: 2012, APPENDIX G: Fire Tests for Water Mist Systems for the Protection of Non-Storage Occupancies, Hazard Category 1 (HC-1) [formerly Light Hazard Occupancies] [4]
- Examples for laboratory developed methods:
  - CNPP *T2* Règles techniques, Annex 1 Hotel[8]
  - VdS *Test set up and requirement – OH 2 (parking garages)*[13]

Any accredited standardized method has to be developed and validated in a way that results are comparable and being independent from the test laboratory. In this case, test scenarios must produce reproducible results, e.g. a fire test protocol for the automatic water mist application in office occupancies must lead to the same results in different, but accredited laboratories. The following methodical aspects of a fire test protocol influence the reproducibility:

[III] Non-standard method: a standard method adapted due to specific requirements, e.g. by the client.

- Safety objectives
- Mock-up
    - Fire loads
    - Ignition sources
- Duration of test
- Measurement system
- Evaluation criteria

In order to have reproducible fire test scenarios, such test parameters shall be kept simple and be well-defined, because the fire process itself appears often randomly:

- Size of room
- Size of item
- Clear definition of the materials, duration and procedures
- Clear definition of measurement variables including definition and retraceability
- Clear definition of evaluation criteria

Therefore, you can ask the following questions:

- How shall a fire test protocol for water mist applications look like that fulfils the requirements of ISO/IEC 17025[23]?
- How shall existing fire test protocols be discussed to which extent these requirements are already considered?

Furthermore, it is compulsory for a testing institute to verify measurements and to participate on ability tests in a way that certain accredited laboratories carry out the same fire test of a certain fire test protocol and the result must be similar. If the results are not similar, it might have one of the following reasons:

- either the accredited standard method is not well-developed and must be revalidated
- or the accredited testing laboratories do not comply to the requirements of ISO/IEC 17025[23] and are re-examined due to its working procedures.

In order to develop a standard method for automatic fire fighting system in buildings that shall fulfil the requirements of the ISO/IEC 17025[23], the above mentioned criteria have to be introduced.

5.3 Compliance with the normative requirement

In order to receive an accreditation in accordance to this standard, a testing laboratory must define the testing field in conformity by a standardised and validated method. This method, e.g. new harmonised standard for water mist fire fighting applications in buildings, must ensure reproducible and comparable results independently from the testing institute. One way of designing such a standardised method is to investigate the fire test protocols by its reproducibility in contrary to its representativeness.

Reproducibility means that the test procedures always lead to the same result within an accepted range of tolerance. This feature ensures, the fire tests and its results can be checked and reproduced by others. Reproducibility is often required on tests with a scientific or technical background; it is a must in the fundamental research. The ISO/IEC 17025[23] focuses therefore strongly on the aspect of reproducibility. Representativeness of a test method reflects on the characteristic to represent particular details or a group of details from the reality, e.g. hazards, room size, ventilation conditions. The representativeness of a standardized test method ensures to meet the requirements of a particular field of application, e.g. fire hazards in office occupancies, fire hazards in machinery spaces of certain size. It is assumed that the investigated fire test protocols include a sufficient and reasonable amount of representativeness.

However, both aspects are important and it depends on the right balance among them.

The following aspects shall be taken into account:

- Clear definition of occupancy and fire hazard
- Definition of effective area and height
- Definition of fire scenario
    - Simple and abstract mock-up
    - Fire loads shall have a reasonable and limited variation and materials shall be defined and standardised
    - Ignition sources shall have a limited variation and materials shall be defined and standardised (see Table 10)
- Definition of test procedure:
    - Start ignition
    - Duration of test, Definition of start/stop fire fighting system
- Definition of the measuring method:
    - Type of sensor (e.g. Thermocouple Type K, diameter 1,5 mm, gas analysers, reference system)
    - Definition of position of sensors

  - Measurements made by the laboratory shall be retraceable to an international system of units (e.g. calibration, determination of derivation):
    - Method to measure temperatures, gases, water pressures and – flow rates
    - Method to determination of fire damages
    - Method to compare to a reference systems
- Repetition of a fire test with the same parameters shall give a similar result for the recorded measurements.
- Definition of evaluation criteria: correlation to standards
  - Where do the limit values come from (320°C, 316°C etc.)?
  - Why shall an automatic water mist system be compared to this particular reference system?

In order to determine fire test protocols by its compliance with the IEC/ISO 17025[23], it's obvious that at the moment none of the investigated fire test protocols fulfils the above mentioned necessary criteria completely. Especially the following parameters might need more improvement to comply with the IEC/ISO 17025[23], which is discussed in more detail by its reproducibility:

- Definition of fire scenario
- Definition of the measuring method

5.3.1 Reproducibility of fire scenario

Table 9 - Table 10 as well Table 22 - Table 27 in more detail show how differently fire loads and ignition sources are defined. Some fire test protocols define the exact burnable materials, number of items, location of items, others do not. Even within an exact definition of materials, fire test protocols correlate often to different parameter variables, e.g. polyether materials defined by foam density, heating values or weight, wooden materials defined by type, burning characteristics or thickness (see also Table 17). None of the fire test protocols specified its ignition source to a standard as listed in Table 10, even if they are already standardised and well defined.

Table 17: Burnable materials and its defined parameters

Burnable materials	Variations	Defined parameter
Synthetical materials	Polyether Polyurethane Polystyrene Polyester	Standard (burning characteristics) Foam density Heating values Weight
Wooden materials	Plywood Chip board* Crib wood	Type of wood Standard (burning characteristics) Heating values Weight Thickness
Paper materials	Cardboard* Carton* Paper	Area weight Total weight
Cotton	Cotton fabrics	Area weight Amount of layers
Burnable liquids*	N-heptane White spirit	Chemical name or CAS-Number Purity level
Burnable gases	Propane	Heating values
Specific*	Furniture Cars Cables Plastic	-

* not defined in none of the fire test protocols

Furthermore, fire loads and ignition sources were ranked and scored due to its material and how they are defined in the fire test protocols (see Table 22 - Table 27). All fire loads have well defined sizes. A cross (x) marks a well-defined material in the above mentioned tables, which was defined by:

- the exact material (name of wood or synthetic material without any choice among materials)
- the density of foam
- the size and area weight of paper
- the gas burner by its gas and its HRR
- the ignition source by its material
- no differentiation between materials of fire load and ignition source

It can be stated that test methods achieving good reproducibility need well-defined fire loads. That does not mean in reverse conclusion that every well-defined fire load leads to a reproducible test method (DIN CEN 14972, Annex A.3). It also depends on the extent of complexity in the entire test arrangement. It can be assumed that the more materials and items are used the less the reproducible the test method is. The two aspects, definition of fire load and complexity, have to be investigated and evaluated in the development process of a standardised method. The quality of definitions can be ranked easily. The complexity of a fire scenario shall be determined by the experimental standard deviation, which shall be analysed in fire tests.

The following Table 18 shows exemplarily, how a ranking could look like if the above made assumptions are true. It is the extract from Table 22 - Table 27 in the Annex 7.3. It refers to the quality of definition of fire load materials. A relation between the number of well-defined materials and the total amount of materials is calculated and ranked as shown in Table 19.

Table 18: Fire test protocols in accordance to its evaluation of fire scenarios

Guideline with fire test protocol	Occupancy	Fire scenario/ mock-up	Amount of burnable materials	Amount of well-defined materials	Ranking fire scenario %	Scores
FM 5560	Small compartment	2 bunk beds	5	3	60	2,75
UL 2167	Small (cabin)		6	3	50	3,00
DD 8489-7	Small compartment		5	3	60	2,75
FM 5560	Large compartment	Simulated furniture	5	4	80	1,75
UL 2167	Large		4	4	100	1,00
UL 2167	Residential		4	4	100	1,00
UL 2167	Light hazard		2	2	100	1,00
DD 8489-7	Large compartment		5	2	40	3,50
DD 8458	Residential/domestic compartment		4	3	75	2,00
UL 2167	Public space	4 sofas	6	1	17	4,25
FM 5560	Open space		5	3	60	2,75
DD 8489-7	Open space		5	3	60	2,75
VDS	Ordinary hazard (OH 1) hotel		5	3	60	2,75
DIN CEN 14972	Ordinary hazard (OH 1) office	2 desks	15	6	40	3,50
DD 8489-7	Workshop		7	3	43	3,50
VDS	Ordinary hazard (OH 1) office		12	5	42	3,50
DIN CEN 14972	Ordinary hazard (OH 3) storage	Cups and cartons	5	1	20	4,25
UL 2167	Ordinary hazard		5	0	0	5,00
VDS	Ordinary hazard (OH 3) storage compact		3	1	33	3,75
VDS	Ordinary hazard (OH 3) storage shelf		4	1	25	4,00
UL 2167	Small (corridor)	Specific	4	2	50	3,00
CNPP T2	Double room		14	2	14	4,50
CNPP T2	Double Room Sidewall nozzle		14	2	14	4,50
CNPP T2	Single room (wardrobe)		>10	0	0	5,00
CNPP T2	Archive		> 5	0	0	5,00
VDS	Ordinary hazard (OH 2) garages		>4	1	0	5,00
VDS	Ordinary hazard (OH 1) false ceiling		> 3	1	0	5,00

Table 19: Ranking and scores of fire scenarios

Ranking		
Ranking [%]	Score	Comment
100%	1	Reproducible
88%	1,5	
75%	2	
68%	2,5	
50%	3	-
38%	3,5	Not reproducible
25%	4	
13%	4,5	
0%	5	

5.3.2 Retraceability of measurement system

Table 16 shows that especially the method how to determine the fire damages is not defined in a way that it produces reproducible results. A standardised method of counting shall be used.

Furthermore, if a reference system is used as evaluation basis, it also has to give retraceable results. That means after the reproducibility of the fire scenario was determined, the reference system has to proof its reproducibility in the same scenario as well, e.g. activation times, ceiling temperatures and damages have to be within a defined deviation.

If limit values for temperature and gas concentration are used as evaluation criteria, it shall be defined where this limit values is correlated to, e.g. temperatures related to concrete spalling, to ignition temperatures of wooden materials, gas concentrations related to self-evacuation. A standardised method for the derivation of limit values shall then be used.

6 SUMMARY

The determination of fire test protocols for the protection of buildings and shipboard applications by automatic fire fighting systems have shown that a great variety of fire test protocols exists to evaluate such fire fighting systems. However, fire test protocols are not well comparable due to the different approaches of test methods. A chance to harmonise such fire test protocols might be to organise and enhance them in order to fulfil the requirements of the superior standard to testing laboratory ISO/IEC 17025[23]. Whenever characteristics of a certain system shall be determined by measuring, this standard demands a validated standardised test method that creates reproducible results. However, accredited test laboratories must follow the requirements of the ISO/IEC 17025[23] anyway. At present none of the investigated fire test protocols fulfil the requirements of the standard completely. A future water mist fire test protocol shall consider this, too.

7 ANNEXES