Water-mist systems for fire-protection of saunas

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• Increasing popularity of saunas in the built environment (e.g., hotels, recreation centers, resorts)
• Fire hazards:
  ➢ timber benches
  ➢ fabric (e.g., linen, towels)
  ➢ chemicals (e.g., detergents)
• Potentially high environmental temperatures (~ 90 °C), electrical heaters, incandescent stones
• Natural/forced ventilation that may emphasize fire evolution and spread
• Lack of knowledge about active fire-protection systems in the open literature
• Buildings already endowed with fire-protection systems vs. unprotected buildings (stand-alone solutions required)
• Support and inspiration from industry
**Sources:**

I. RC50. Fire Safety in the Construction and Use of Saunas, United Kingdom: Fire Protection Association (FPA) on behalf of RISC Authority, 2009


III. Zurich Insurance Group, Risk Topics, Fixed fire protection – Water mist – Saunas, 2015

- Generic reference to standard NFPA 750 for water-mist systems
- Use of a wood crib and a heptane pool as the ignition source and accelerant respectively
- Pre-heated sauna mock-up with forced ventilation
- Comparison between a sprinkler and a water-mist suppression system
Active fire-protection systems as those based on water-mist technology are to be combined with:

• Suitable and adequate passive fire-protection measures (e.g., fire-rated separations)
• Fire alarms (e.g., heat and/or smoke detectors)
• Use of automatically-operated fire dampers in any ventilation duct
• Measures against excessive drying out of the timber linings
• Requirements for heating and electrical installations
Ostia: incendio in una palestra in via Mare dei Sargassi, lunga colonna di fumo

Un incendio di vaste dimensioni si è sviluppato all'alba in una nota palestra di Ostia, la Virgin, in via Mare dei Sargassi. L'area che sta bruciando sarebbe di circa 6000 metri quadrati.

In via Mare dei Sargassi, nelle vicinanze dell'ospedale G.B.Grassi, a Ostia è andata a fuoco nella notte una nota palestra: la Virgin.

To grasp the disaster:

https://www.youtube.com/watch?v=GQcF8MsI18g
Objectives and Challenges

Main scope:
Development, design and implementation of a water-mist, stand-alone system dedicated to sauna fire protection

Objectives:
• Challenging a promising, discharge-based system against this fire scenario
• Identifying the main structural and physical mechanisms governing this fire configuration and water-mist control and suppression performance
• Development of a testing procedure to quantitatively evaluate suppression/extinction in sauna scenarios
• Evaluating water-mist capabilities within a real-scale facility and throughout an experimental test series towards a worst-case scenario

Challenge:
Need for consolidating a set of variable parameters – mainly related with geometric configuration and ignition – within a limited number of tests
An actual water-mist system for sauna fire protection consists of:

- High-pressure delivery unit that includes water-filled cylinders and inert gas cylinders to allow > 100 bar initial pressure
- Open water-mist nozzle set and stainless steel piping
- Detection system, notably heat detectors operating at fixed temperature threshold and connected to a control unit
- Fire alarm system including sounders and beacons
- Remote signaling of alarm, discharge and fault
Actual Installation

Moncalieri (Italy) Fitness center by Virgin Active
Discharge System and Limitations

CODE: NWMO014
MANUFACTURER: Bettati Antincendio S.r.l.
K-FACTOR: 1.4 L min\(^{-1}\) bar\(^{-0.5}\) (overall)
INJECTORS: 7 (6 peripheral, 1 central) pressure-swirl
AREA COVERAGE: 3.6 \(\times\) 3.6 m (1.8 m from the wall)
INSTALLATION HEIGHT: 2.4 m
OPERATIVE PRESSURE: 150 bar descending (nitrogen-pressurized)
CAPACITY OF CYLINDERS: 80 L (each)
No. OF WATER CYLINDERS: 3
No. OF N\(_2\) CYLINDERS: 1
MAX. COMPARTMENT AREA: 25 m\(^2\)
DISCHARGE TIME: > 10 min

Standard CEN/TS 14972:2011

‘Fixed firefighting systems – Watermist systems – Design and installation’

No specific guidance provided for sauna fires

Annex B

‘Guidelines for developing representative fire test procedures for watermist systems’

- Evaluation of fire hazard;
- Evaluation of the compartment conditions;
- Performance objectives;
- Anticipated worst-case scenario(s).

PASS/FAIL criterion: SUPPRESSION
Plan view of the test chamber: a) ignition source at the corner behind benches (configuration C1); b) ignition source at the center of the wall behind the benches (configuration C2). WMN: water-mist nozzle location; Riv: heat-detector (by Kidde-Fenwal Inc.) location.

<table>
<thead>
<tr>
<th>Test-chamber height</th>
<th>L1</th>
<th>L2</th>
<th>d</th>
<th>d_riv</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.4</td>
<td>5.9</td>
<td>2.3</td>
<td>3.6</td>
<td>1.0</td>
</tr>
</tbody>
</table>

L2/2 in all tests but the last one; d/2 in the last test.
Ignition Source

SCOPE:
Resembling an electric-heater fire

DESIGN CHOICE:
Wood-crib (2.9 kg) fire, accelerated by a manually-activated heptane (0.24 l) pool fire

Evaluation of peak Heat Release Rate (HRR) from the wood-crib fire as an estimate of fire size in the compartment:

\[ HRR = MLR \cdot \Delta h_c = C \cdot \left( \frac{S}{H} \right) \left( \frac{m_i}{t} \right) \cdot \Delta h_c \approx 230 \text{ kW} \]

MLR: mass-loss rate, \( \Delta h_c \): wood heat of combustion (= 12 MJ kg\(^{-1}\)), C: empirical constant (= 7.44 \times 10^{-4}), S: clear spacing between sticks in the same layer (= 50 mm), H: crib height, \( m_i \): initial mass, t: stick thickness

Temperature and Mass-Loss Evaluation

Set of 7 thermocouples (type K, 0.5 mm wire diameter, 1 Hz acquisition frequency):

- T_gas (3 probes): gas temperature 76 mm below the ceiling, at the symmetry axis of the ignition source, at the heat-detector location and symmetric to Riv
- T_crib: gas temperature at the center of the ignition-source top surface
- T_sts: surface temperature of the timber bench bottom surface, at the symmetry axis of the ignition source
- T_clg: surface temperature at the ceiling and at the ignition-source symmetry axis
- T_rad: associated with hot-plate thermometer and located at 500 mm height from the floor, close to the container exit

Load cell to measure damage ratio \((m_i - m_f)/m_i\) of wood crib and timber benches

The bench damage ratio was selected as the quantitative representation of the chosen pass/fail criterion.

As for moisture content of timber benches, it was monitored before each to have it lower than 5%; mass loss was measured after benches were let dry out.

HINT FOR THE FUTURE:
Measuring the moisture content right after discharge to evaluate quantitatively the consequences on timber benches, even those due to false alarms.
Hot-plate thermometry was employed to evaluate incident radiant heat flux as representative of HRR and overall fire evolution (Ingason H, Wickström U., Fire Saf J 42 (2007) 161-6).

Notably, the plate was placed in front of the presumed fire location, between the wood crib and the involved bench. So, it was set at 0.6 m height from the floor and at the corner next to the crib in both configurations.

\[
q = \frac{\varepsilon_{PT} \sigma T_{PT}^4 + (h_{PT} + K_{cond})(T_{PT} - T_{\infty}) + \rho_{st}c_{st}s(\Delta T_{PT}/\Delta t)}{\varepsilon_{PT}}
\]

- \(\varepsilon_{PT}\): plate-thermometer emissivity
- \(\sigma\): Stefan-Boltzmann constant
- \(T_{PT}\): plate-thermometer temperature
- \(h_{PT}\): convective heat-transfer coefficient
- \(K_{cond}\): conduction correction factor
- \(T_{\infty}\): room temperature
- \(\rho_{st}\): steel density
- \(c_{st}\): steel specific heat capacity
- \(s\): steel plate thickness
- \(t\): time
Test Matrix and Initial Conditions

The following parameters were identified and varied through the test series:

- Location of the ignition source
- Initial room temperature \( (T_i) \)
- Discharge activation time \( (\tau_{\text{act}}, \text{heat-detector threshold @ 165 °C}) \)
- Ventilation \((0.7 \times 1.9 \text{ m door})\)
- Distance between the nozzles and the wall behind benches \( (D) \)
- Presence of drywall boards attached to the back of the benches
- Distance between benches and the wall behind \( (\delta) \)

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Ignition source</th>
<th>( T_i ) [°C]</th>
<th>( \tau_{\text{act}} ) [s]</th>
<th>Ventilation</th>
<th>( D ) [m]</th>
<th>Drywall boards</th>
<th>( \delta ) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>corner (C1)</td>
<td>20 - 30</td>
<td>alarm + 5</td>
<td>NO</td>
<td>1.15</td>
<td>NO</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>center (C2)</td>
<td>20 - 30</td>
<td>alarm + 5</td>
<td>NO</td>
<td>1.15</td>
<td>NO</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>center (C2)</td>
<td>20 - 30</td>
<td>180</td>
<td>NO</td>
<td>1.15</td>
<td>NO</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>center (C2)</td>
<td>20 - 30</td>
<td>alarm + 5</td>
<td>NO</td>
<td>1.15</td>
<td>NO</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>center (C2)</td>
<td>20 - 30</td>
<td>alarm + 5</td>
<td>NO</td>
<td>1.15</td>
<td>YES</td>
<td>250</td>
</tr>
<tr>
<td>6</td>
<td>center (C2)</td>
<td>&gt; 80</td>
<td>alarm + 5</td>
<td>NO</td>
<td>1.15</td>
<td>NO</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>center (C2)</td>
<td>&gt; 80</td>
<td>alarm + 5</td>
<td>YES</td>
<td>1.80</td>
<td>NO</td>
<td>0</td>
</tr>
</tbody>
</table>
Example of the whole temperature/pressure dataset, with a reference to **wood-ignition temperature** (Babrauskas V., *Interflam* 2001, pp. 71-88)
Temperature and Pressure Trends (Test no. 2 – 4)

Temperature vs. Time (s)

- T_sts - Test no. 2
- T_elg - Test no. 2
- T_sts - Test no. 3
- T_elg - Test no. 3
- T_sts - Test no. 4
- T_elg - Test no. 4

Delayed Activation
Temperature and Pressure Trends (Test no. 5 – 7)

![Graph showing temperature and pressure trends over time for different tests.](image-url)
Incident Heat Flux

Discharge activation

RE-GROWTH in worst-case scenario
## Summary of Experimental Outcomes

<table>
<thead>
<tr>
<th></th>
<th>Test no. 1</th>
<th>Test no. 2</th>
<th>Test no. 3</th>
<th>Test no. 4</th>
<th>Test no. 5</th>
<th>Test no. 6</th>
<th>Test no. 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat-detector activation time [s]</td>
<td>91</td>
<td>100</td>
<td>107</td>
<td>143</td>
<td>179</td>
<td>107</td>
<td>129</td>
</tr>
<tr>
<td>Discharge activation time [s]</td>
<td>96</td>
<td>105</td>
<td>182</td>
<td>148</td>
<td>184</td>
<td>112</td>
<td>134</td>
</tr>
<tr>
<td>Smoldering materials at the end</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Overall suppression</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Wood-crib fire extinction time [s]</td>
<td>267</td>
<td>284</td>
<td>226</td>
<td>273</td>
<td>256</td>
<td>311</td>
<td>327</td>
</tr>
<tr>
<td>Initial wood-crib mass [g]</td>
<td>2813.2</td>
<td>2745.5</td>
<td>2750.5</td>
<td>2849.5</td>
<td>2907.5</td>
<td>3230.0</td>
<td>3175.5</td>
</tr>
<tr>
<td>Wood-crib damage ratio</td>
<td>12%</td>
<td>14%</td>
<td>11%</td>
<td>7%</td>
<td>12%</td>
<td>5%</td>
<td>12%</td>
</tr>
<tr>
<td>Initial bench mass [kg]</td>
<td>NM</td>
<td>NM</td>
<td>43.5</td>
<td>43.5</td>
<td>43.0</td>
<td>43.0</td>
<td>41.5</td>
</tr>
<tr>
<td>Bench damage ratio</td>
<td>NM</td>
<td>NM</td>
<td>3%</td>
<td>1%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
</tr>
</tbody>
</table>

NM: Not Measured
Conclusions and Recommendations

- A water-mist system was **designed** and **tested** as inspired by recognized standards for application in **sauna scenarios**
- The proposed system was capable of controlling and suppressing the fire in all tests (**timber-bench damage ratio ≤ 3%**)
- The **ignition-source location**, the **presence of drywall boards** behind timber benches and the presence of a **gap between benches and the wall** behind did **not** prove **critical** in determining system performance
- A **heat-detector-governed discharge** was **effective** in containing damage ratio, with respect to a fixed, longer activation time
- **Initial room temperature** does **not** appear to be **crucial** in determining system performance
- The **worst-case scenario** showed that **natural ventilation** and a **larger nozzle-to-bench distance** may imply **re-ignition** and **smoldering** materials at the end, yet damage ratio did not vary with respect to the other tested conditions
- The developed water-mist system may be considered suitable for enclosures endowed with **self-closing doors**
Acknowledgments and Q&A

Under the auspices of:

Virgin Active
STARPOOL

Big thanks to:

• Mr. Francesco Dignatici for technical advising
• Bettati Antincendio S.r.l. staff for their support throughout the experiments

Thanks for your kind attention.

Questions?

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IWMC 2017