

Magnus Arvidson

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# An overview of fire protection of Swedish wooden churches

Brandforsk project 500-061

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## Abstract

The main objective of the project has been to summarise lessons learned and practical experience from some of the fire sprinkler installations in heritage buildings in the Nordic countries, with a special focus on the installations made in Sweden in recent years. Most of the installations have been made in small or intermediate sized wooden churches.

To provide input to the project, a case study involving six wooden churches in Sweden, recently protected with active fire protection systems, was undertaken. The report summarises the author's impressions after visits to these churches. Furthermore, the installers, the fire consultants and the inspectors of the system installations were interviewed. Finally, input was also gained from the users.

This work has resulted in a list of issues where additional research, testing or development work is desired.

Another part of the project has focused on relevant fire statistics and examples of illustrative fires or attempts to start fires. This information illustrates relevant fire scenarios and may form background material for forthcoming fire tests or fire test procedures.

**Key words:** Heritage buildings, churches, sprinkler systems, water mist systems, fire protection, case studies.

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## Preface

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The project was conducted in close co-operation with a group consisting of the following persons:

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All photos, except where noted, by the author of the report.

# Sammanfattning

(Executive summary in Swedish)

Projektet var inriktat mot att studera sprinklersystem i kulturbyggnader, med särskilt fokus på mindre och medelstora kyrkor eller andra kulturbyggnader i trä och skall ses som en förstudie.

## Projektets målsättning

Målsättningen var att dokumentera utförda sprinklerinstallationer i några representativa kyrkor, sammanställa kunskap och erfarenheter från dessa installationer och att identifiera områden för vidare forskning. Utöver detta har även erfarenheter från i första hand Norge sammanfattats i rapporten. Dessutom redovisas tillgänglig brandskadestatistik såsom brandorsak, tid på dygnet branden inträffar och var bränder normalt startar. Några bränder och brandtillbud har även studerats lite mer detalj för att illustrera hur en brand kan uppstå och vilka konsekvenser den kan få.

## Brand är historiskt sett den vanligaste orsaken till skada

En sammanställning visar att totalt 524 kyrkor eller kapell i Sverige förstörts av brand, krig, plundring, oväder, svåra sprickbildningar, konstruktionsfel, etc. under nära 800 år (1193 – 1984). Av dessa förstördes 447 (85%) av brand, varav 106 genom åsknedslag. De återstående 77 (15%) skadades på andra sätt. Sammanställningen omfattade 2890 kyrkor eller kapell. Tyvärr revs dessutom många medeltida kyrkor på 1700- och 1800-talen, oftast för att de var för små eller mörka. Till exempel revs mer än en tredjedel av Skånes medeltida kyrkor under 1800-talet.

## Anlagd brand vanlig – troligen mer frekvent i kulturbyggnader än i andra byggnader

Engelsk statistik visar att två tredjedelar av alla bränder i kulturbyggnader är anlagda och det har blivit vanligt att brand anläggs för att förstöra spår i form av DNA. Detta kan jämföras med brittisk storskadestatistik där ungefär 40% av alla bränder är anlagda. Kulturbyggnader är alltså relativt sett mer utsatta för anlagd brand än andra objekt. Noterbart är även att över 80% av alla bränder i brittiska kulturbyggnader startar nattetid. Någon tillförlitlig svensk brandskadestatistik som enbart omfattar kulturbyggnader finns för närvarande inte, men för kyrkor kan sägas att i snitt en kyrka per år förstörs vid brand. Svensk statistik visar en generell trend att anlagd brand ökar, särskilt anlagd brand utomhus. År 2005 var cirka 13% av alla bränder i svenska byggnader anlagda, men det finns ett stort mörkertal så den egentliga andelen är förmodligen högre.

## Detaljstudie av utvalda bränder och brandtillbud

Några bränder och brandtillbud har studerats lite mer detalj för att ge en bild av hur brand kan uppstå. Den mest välkända branden, förutom den i Katarina Kyrka, är kanske den i Södra Råda kyrka år 2001. Branden anlades av en psykiskt sjuk man och var planerad i förväg. Mannen anlade branden invändigt i kyrkan, men från utsidan genom ett fönster med bensen. Utan mannen erkännande hade troligen detta brott aldrig klarats upp.

Branden i Ledsjö kyrka år 2004 är ett annat exempel på anlagd brand. Här användes brännbar vätska och tidningar som placerades i kyrkans vapenhus, mot den (låsta) innerdörr som leder in till kyrkan. Med hjälp av teknisk bevisning, bland annat DNA och fingeravtryck, kunde en man knytas till brottet. Mannen dömdes till fängelse för grov mordbrand i tingsrätten men friades så småningom helt i hovrätten.

Pelarne kyrka utanför Vimmerby hade troligen varit totalförstörd i brand om inte en observant kyrkvaktmästare tagit en extra sväng i kyrkan sent en augustikväll 2005. Hon observerade att ett ljus saknades i en av kandelabrarna i sakristian och fattade misstankar att något inte stod rätt till. Detta ljus hittades – brinnande – omvirat med hushållspapper i en mindre skrubbe som innehåller kyrkan elcentral. Förmodligen var det arrangerat för att det skulle se ut som om branden startat i elanläggningen. Samma natt brann Östersjö Handpappersbruk från 1777 och Emils snickarbod utanför Vimmerby till grunden. Det är svårt att tro att något annat än anlagd brand varit orsaken till dessa två bränder.

En annan incident är den i S:ta Gertruds kyrka i Västervik en lördag i september 2005. En entreprenör hade täckt över en elradiator vid måleriarbeten. Ovetande om detta satte en vaktmästare på värmen i kyrkan inför ett dop och ett bröllop samma dag. Det brännbara materialet fattade eld, brandlarmet aktiverade och tack vare en snabb insats från räddningstjänsten släcktes branden innan den hann sprida sig till andra delar av kyrkan.

### **Studiebesök i några svenska kyrkor med sprinkler**

Från år 2004 och fram till idag (2006) har sprinklersystem installerats i knappt tio svenska kyrkor. Dessutom finns några exempel på kyrkor där sprinklersystem installerats i delar, vanligen vind eller torn, av kyrkan. Inom ramen för projektet besöktes kyrkorna i Hedared, Frödinge, Habo, Älgårås, Fröskog och Skållerud för att studera hur man installerat sprinkler i just dessa kyrkor. Dessutom intervjuades personer som projekterat, besiktigat eller installerat systemen i dessa eller andra kyrkor. Erfarenheter från Norge har också sammanställts. Där har sprinklersystem installerats i ett större antal kyrkor under den senaste tjugoårsperioden.

Att skydda kulturbyggnader mot brand kräver särskilda hänsyn. Sprinklersystemet måste installeras med så liten åverkan på byggnaden som möjligt och installationen måste vara diskret. Rör och munstycken ska smälta in i miljön utan att vara ögonfallande. Många äldre byggnader saknar värme och elektricitet vilket innebär att särskilda tekniska lösningar måste användas, som torrörsystem eller system där frysskyddsmedel tillsätts vattnet. Studiebesöken visar att en oerhörd möda har lagts ned på utformning och installation av systemen. Även om vissa typlösningar går igen kräver varje objekt speciallösningar. Visserligen har mycket värdefull kompetens byggts upp hos de personer som projekterat och installerat systemen, men flera av dem efterlyser mer kunskap och forskning.

- Systeminstallationerna är relativt komplexa: Några av kyrkorna som besöktes är skyddade med "vattendimma" invändigt och traditionell sprinklerteknik utvändigt, det vill säga två system som inte har en enda gemensam komponent, mer än möjligen vattentanken. Dessutom kan flera olika systemlösningar förekomma inom ett och samma objekt, våtrörsystem med frysskyddsmedel, torrörsystem och gruppaktiveringssystem. Det gör systemlösningarna komplexa och underhållskrävande, samtidigt som tillförlitligheten kan äventyras. En erfarenhet från Norge är att sofistikerade lösningar och "modern" teknik ställer högre krav på underhåll och att de ofta är dyrare. Enkla lösningar är därför eftersträvarvärda.
- Regelbunden funktionskontroll är viktigt: Ofta krävs en hel kedja med moment (detektering av brand, signalöverföring, öppning av ventiler, start av pump, etc) för att ett system skall fungera. Flera fall där system inte fungerat vid funktionskontroll dokumenterades i projektet. Regelbunden funktionskontroll krävs därför för att upptäcka fel. I rapporten föreslås även att regelbunden kontroll av automatiska



munstycken görs.

- Flera fall av oavsiktliga aktiveringar: Anmärkningsvärt många fall (sex fall i totalt nio olika kyrkor) där sprinklersystemet aktiverat oavsiktligt finns dokumenterade. I samtliga fall är det sprinklersektioner för utvändigt skydd, fasader eller tak, som aktiverat. Den direkta orsaken varierar men kan i samtliga fall hänföras till branddetektionssystemet.
- Dränering av rörsystemen är viktigt: Torrörssystem måste gå att dränera, annars finns risk att kvarstående vatten fryser eller bidrar till invändig korrosion. Om rörkopplingar eller munstycken fryser sönder kan det innebära att systemet aktiveras oavsiktligt. I några av kyrkorna används därför tryckluft för att blåsa rören fria från kvarstående vatten. Försök visar att rörsystemen går att få torra på det sättet men praktisk erfarenhet saknas.
- Användningen av frysskyddsmedel kan diskuteras: Dels gör det systemen mer komplicerade och underhållskrävande, dels finns risk att vissa frysskyddsmedel skadar känsliga ytor om läckage uppstår. Ett fall av läckage och skada dokumenterades.
- Installationerna är diskreta och väl utförda: Gemensamt för samtliga de kyrkor som besöktes inom ramen för projektet är att installationerna är mycket diskreta och väl utförda. Det är sannolikt att den normale kyrkobesökaren inte lägger märke till installationen överhuvudtaget. Stora hänsyn har också tagit vid installationerna för att undvika skador på byggnaderna.
- Kontroll, provning och underhåll: Statistik visar att regelbunden kontroll, provning och underhåll är nyckeln till hög tillförlitlighet. Men det kräver tid, utbildning och engagemang från anläggningsskötaren. Arbetsgivaren måste vara beredd att ställa tid till förfogande för detta arbete.
- Erfarenhetsutbyte efterlyses: Sprinklersystem har installerats i ett flertal svenska kyrkor. Flera anläggningsskötare som intervjuades efterlyste kontakt och erfarenhetsutbyte kyrkorna emellan.

### **Framtida insatser – var behövs mer kunskap?**

En central del av projektet var att utreda vilka frågeställningar som kräver fortsatta insatser. Sammanfattningsvis kan man säga att mer kunskap behövs för att ett objekt skall kunna skyddas på ett så enhetligt och enkelt sätt som möjligt. För att nå dit föreslås att bland annat följande frågor studeras i eventuella kommande projekt:

- Dimensionering av system för invändigt skydd: En återkommande fråga är hur systemen skall dimensioneras avseende vattentäthet och verkningsyta, inte minst för att anlagd brand är den vanligaste brandorsaken.
- Dimensionering av system för skydd av fasader och yttertak: Det är fördelaktigt om samma typ av system kan användas för både det inre och yttre skyddet. I vilken utsträckning är det möjligt att använda ”vattendimma”? Hur skall systemen dimensioneras?
- Branddetektionssystem för fasader och yttertak: De flesta av de kyrkor som studerats använder ”värmekabel” för att detektera utvändigt brand. Det finns dock branddetektionssystem som ger snabbare detektering, till exempel

differentialvärmedetektorer. Den mest lämpliga detektionsprincipen för fasader och yttertak bör studeras.

- Övertändningskontroll: Dimensionering av system som förhindrar övertändning är en vanlig förekommande fråga. Behov finns att använda denna typ av system på oinredda vindar. Kommande projekt bör fokusera på att vidareutveckla de teoretiska modeller som finns och genomföra verifierande försök.
- Systemens inverkan på vägg- och takmålningar: Många av de vägg- och takmålningar som finns i äldre kyrkor är målade med limfärg och är troligen mycket känsliga för vatten. Försök bör genomföras där påverkan av vattenspray på målade trätor studeras.
- Vattenströmning genom kalla rör: Försök genomförda i Norge indikerar att det finns risk att vatten som strömmar in i torrör- eller gruppaktiveringssystem fryser om rören är nedkylda. Sannolikt är system med "vattendimma" extra känsliga eftersom munstyckensöppningarna är små. Frågan borde utredas i mer detalj.
- Val av frysskyddsmedel: Användning av frysskyddsmedel är ett alternativ till torrörssystem men flera frågor kräver mer utredning. Kan man acceptera ett visst energitillskott till branden? Sprinklersystemens rörsystems volym - och därmed den totala volymen frysskyddsmedel är ofta låg. Hur påverkar frysskyddsmedel känsliga ytskikt och byggnadsmaterial?
- Torrörssystem: Här kan finnas anledning att utreda fördröjningstider för systemen och hur fördröjningstiden påverkar systemets prestanda.
- Tillförlitlighet: Oavsiktliga aktiveringar är extra angelägna att undvika i kulturbyggnader men å andra sidan är en hög tillförlitlig vid en brand eftersträvarsvärd. Tillförlitligheten för olika systemtyper och systemlösningar bör utredas.
- Alternativa vattenkällor: Vattenkällan svarar ofta för en hög andel av den totala kostnaden för ett sprinklersystem. Dessutom är det viktigt att den har en hög tillförlitlighet. Alternativa vattenkällor, till exempel hydrofor eller trycktank med drivgasbehållare bör studeras.

# **1 Background and scope of the project**

## **1.1 Background**

The list of heritage premises in Sweden partly or completely destroyed by fire is long, but not limited to: the Katarina church (1990), Trönö church (1998), Sura church (1998), Bäckaby church (2000), Södra Råda church (2001), Ledsjö church (2004), Zorn's Gammelgård (2005), Gästgivarehagen (2005), Ösjöfors hand-made paper mill (2005) and Mattisgården (2005). Many of the fires in the list were deliberately started.

In recent years, the fire protection of many historically valuable buildings, especially old churches has been improved, with the installation of fire detection systems and fire sprinkler systems, not to mention the fire prevention measures associated with improved burglar protection, lightning protection and video surveillance. Examples include, but are not limited to, the stave church in Hedared, the churches in Älgårås, Habo, Frödinge, Fröskog and Skållerud, Gunnebo Castle, the cathedral in Växjö and the towers of Storkyrkan, Klara church and S:t Jakob's church in Stockholm.

The installation of fire sprinklers can in many cases be the best measure for improving the fire protection. However, there are several aspects with sprinkler systems that need to be considered, including but not limited to the risk for water damage (due to leakage, accidental activation or actual activation), their intrusive nature, the expected life-time of the installation and the cost. The effect of water may be particularly important in the case of vulnerable interior wall- and ceiling paintings that may be especially susceptible to water damage. In addition, the choice of sprinkler system is often discussed, i.e., should a traditional sprinkler or a water mist system (low- or high-pressure) be used?

## **1.2 The scope of the project**

Fire protection for heritage buildings is an extensive task and a clear definition of the boundaries and limitations of this study must be made in order to limit the scope of the project. Several studies have been conducted previously, as summarised in Section 2. These studies have been reviewed in order to learn more and provide input to the project, and to avoid covering the same ground.

The objective of the project, as covered by this report, is to summarise lessons learned and practical experience from some of the fire sprinkler installations in the Nordic countries, with special focus on the installations made in Sweden during the last few years. Most of the installations have been made in small or intermediate sized wooden churches.

A central part of the project was the investigation of issues where additional research, testing or development work is needed. This work was based on practical experience and requests geminating from the sprinkler installations.

Another part of the project has focused on relevant fire statistics and examples of illustrative fires or attempts to start fires. This information illustrates relevant fire scenarios and may form background material for forthcoming fire tests or fire test procedures.

Protection of archives, antique collections, libraries, and similar, while naturally important, all contain special requirements not directly related to those of heritage buildings and have not been covered by this project.

## 2 Background information

### 2.1 Introduction

There are many publications, reports and papers dealing with fire and fire protection measures in heritage premises. Within the scope of the project, a short literature review was undertaken in order to summarise literature relevant for sprinkler protection. The literature covers issues such as experience with sprinklers, recommendations, case studies, technical solutions as well as cost-benefit analyses. This literature may also be a starting point for the interested reader of this report who would like to know more.

This part of the report also contains a description of different sprinkler system types, as different systems types are discussed throughout the report. During the work with the report it became clear that there is widespread confusion and misunderstanding concerning different system types. It is not uncommon that the function of “dry-pipe systems” is confused with the function of “deluge systems”, especially the fact that dry-pipe systems employ automatic sprinklers or nozzles while deluge systems do not. This will help clarify relevant terminology and application.

### 2.2 Compilation of historical Swedish church fires

The report “Kyrkbränder i Sverige” [1] contains a compilation of churches and chapels in Sweden damaged by fire, war, plundering, collapse, storm, snow, etc. during almost 800 years, 1193 – 1984. The compilation includes 524 damaged churches or chapels. In total, 447 (85%) were damaged or destroyed by fire. A total of 106 of these fires occurred due to lightning. The remaining 77 (15%) churches were damaged in other ways, for example action from war, storm, severe cracks or construction failures. The compilation included 2890 churches or chapels, excluding those built after 1950 or churches suffering only minor damage.

There are examples of fires starting under the ceremony causing fatalities or injuries. Here are some examples:

- A fire started in the church at Riddarholmen in Stockholm on August 10, 1694 and “fatalities were reported”.
- The church in Sexdrega was built from natural stone in 1810. The year after, lightning struck with the result that three people died and approximately 200 people were injured.
- The church in Rasbo, built in the 13<sup>th</sup> century, was struck by lightning in 1702 and “several people died”.
- Alva church in Visby was struck by lightning 1752 and the vicar was injured.
- In 1902, the church in Hackvad burnt, but people escaped the fire.
- There are also tragic cases of arson where the fire setter has died, for example, the fires in the churches of Kumla in 1968 and Järna in 1978.

Cathedrals have been suffering from fires, more often, than other churches. The cathedral in Västerås was damaged by fire in 1380, 1390, 1521, 1691 and 1702. The cathedral in Luleå was damaged by fire in 1653, 1657, 1716 and 1887. Växjö Cathedral was damaged by fire in 1277, 1570 and 1740. Gustavi Cathedral in Gothenburg was damaged in 1719 and 1865. The remaining Swedish cathedrals have been damaged by fire at least once,

with the exception of the cathedral in Härnösand, built in the 1840's, so far without any fire damage.

Although a church fire may occur any day, some church fires have occurred on particularly unsuitable occasions, e.g.:

- The cathedral in Strängnäs burnt down on its inauguration in 1291.
- The church in Umeå city burnt down on Christmas Eve in 1887.
- The church in Strängnäs, built 1875, burnt down on New Years Eve 1893.
- Ringamåla church started to burn during a ceremony on Whitsunday 1904 and burnt to the ground.
- The church in Möne burnt to the ground on Easter Day 1947.

### **2.3 Review of seventeen Swedish church fires**

During the last 100 years, approximately one church per year has been destroyed by fire in Sweden. When a church is lost to a fire, invaluable artefacts vanish, both material and immaterial. Churches are important symbols and the culture-historical value is in most cases very high. The grief and regret after a church is lost to a fire is vast, and even if the building can be re-constructed it can only be a copy and the inventories can usually not be copied. The report "Kyrkan brinner! Vad händer sedan?" [2] contains a review of seventeen Swedish church fires and the result of an investigation on how the loss of a church was dealt with by the congregations. The intent of the work was to provide guidance after a fire and to inspire improvements of fire protection measures in churches.

Table 1 summarises the cause of fire for the seventeen churches that were contained in the study. Seven of the fires were deliberately started, a couple of them by 'Satanists'. Two others were tragically suicides. Five of the fires have cited technical failures as the cause, primarily in the electrical systems. For four of the fires, the cause could not be determined, although, the fire in Ryssby church is suspected arson and one theory is that the fire in Trönö church started when the newly painted floor self-ignited. The seventeenth fire, the fire in Ransäters church, was started during restoration work.

Eight of the seventeen churches were originally constructed from wood, the others from natural stone or bricks. From the study, it was not possible to draw any clear conclusion concerning the fire damage to the building itself, the interior and the inventories. In general, however, it can be concluded that the wooden churches have been more or less completely destroyed by fire and that the fire damages to the other churches were more varied.

In those cases where the wooden churches have not been completely destroyed, the building construction have been so severely damaged by fire, smoke and water that the remains were demolished afterwards. For the other churches, the brickwork usually survived the fires such that it could be included in a new construction.

*Table 1 The cause of fire in seventeen Swedish churches (in Alphabetical order), from 1959 - 2001.*

Church	Built	Burnt	Cause of fire			
			Arson	Unknown	Technical failure	Restoration work
Aspeboda	1609	1959		x		
Brunskog	1876-78	1972			x	
Bäckaby (old)	1326, 1600's, 1700's	2000	x			
Järna	1822	1978	x			
Katarina	1739	1990			x	
Kumla	1829-34	1968	x			
Lundby (new)	1882-86	1993	x			
Munkfors	1919-20	1984			x	
Ransäter	1600's, 1740	1983				x
Ryssby	1748-49	2001	(x)	x		
Rörbäcksnäs	1909	1992			x	
Salabacke	1958	1993	x			
Skaga chapel	1957-58	2000		x		
Sura (old)	1671	1998	x			
Södra Råda (old)	1300's, 1600's	2001	x			
Trönö (new)	1893-95	1998		x		(x)
Umeå	1508	1986			x	

The sacristy is an important part of the church as it usually contains valuable documents and inventories. The sacristy is often equipped with a solid door, and if properly closed, it can prevent fire from spreading there. In two of the fires in wooden churches, the sacristy survived the fire (Aspeboda and the old church in Sura).

Of the seventeen churches, two of the churches have been re-constructed principally to their original appearance. Nine churches have been rebuilt with re-constructed exteriors and new interiors. Two churches have been rebuilt having a new appearance and two of the churches were not rebuilt at all, the old church in Sura and Bäckaby church. Instead, memorial groves were arranged. The new church in Trönö differs from the other churches as a new, and smaller, building was built inside the ruin. Additionally, to make the list complete, the intent is to rebuild the Södra Råda church.

## **2.4 Lessons learned from actual fires in Finland, Norway and Sweden**

The report "Can we learn from the heritage lost in a fire? Experiences and practises on the fire protection of historic buildings in Finland, Norway and Sweden" [3] contains a comprehensive compilation on fire protection of historic buildings and wooden towns, case studies, suggested fire prevention and fire protection measures and lessons learnt from actual fires.

There are many common aspects related to fire protection of heritage buildings in all these countries; a large proportion of the buildings are made of wood, there are historic wooden towns that are densely packed and where the threat from fire is high, some buildings are located in rural areas where the winters are cold and the summers are hot

which corresponds to a high risk of fires (summer time) and problems associated with fire protection and fire-fighting (winter time).

The report provides the following basic recommendations for choosing the proper fire protection methods and equipment for heritage buildings:

- Consider that each building is unique and therefore requires unique and innovative solutions.
- Try low cost methods first, complete with installations.
- Choose fire protection methods that do not involve interference with the building.
- If interference is unavoidable, keep it to the minimum, and it must be reversible.
- New installations must be accessible for maintenance and detachable without causing damage as they usually have a much shorter lifespan than the building itself.
- Technical installations and information signs must be discrete.
- Good solutions require co-operation between the owner, the fire protection engineer and the heritage inspector.

Prior to any improvement of the fire protection measures in a historic building, an overall strategy should be prepared. Usually, a combination of organisational and technical fire safety precautions is needed. Often, a proper organisation can reduce the need for technical adaptations.

Technical installations include fire prevention measures such as burglar protection, burglar alarm, lightning protection and video surveillance. Fire protection installations include fire detection systems, equipment for manual fire-fighting and fire suppression systems.

It should be recognized that technical installations need space for central control units, pump units, water tanks, etc. and this space often needs to be quite large. In addition, someone must always be responsible for the technical equipment and the regular control and maintenance thereof.

## **2.5 Water mist protection of heritage, experience from Norway**

The report "A White paper on Water Mist for Protection of Heritage" [4] is a state-of-the-art compilation concerning water mist protection of heritage buildings. The report provides information on the basics of water mist systems, including fire extinguishment mechanisms, water spray and nozzle characteristics, system types, regulations and standards, etc. In addition, it summarises results and conclusions from tests as well as practical experience and challenges from actual installations in heritage buildings.

The following list of issues that need additional research, testing or development work is given in the report, rationale given in *Italics* is provided by the author of the original report:

- Water mist application in freezing temperatures. *Non-heated areas are typical in heritage buildings and protection of exterior surfaces such as facades and roofs are common.*
- Flashover suppression systems. *These type systems are inexpensive, unobtrusive and the secondary damage is small.*
- Small stand-alone water mist systems. *These type systems are inexpensive and unobtrusive.*

- Mobile water mist equipment. *Fast intervention, effective, small amounts of water, etc.*
- Open water mist systems with fire department connection. *These types of systems are inexpensive and unobtrusive. Effective trade-off for other expensive and obtrusive measures.*
- Water mist for listed multi-storey townhouses. *To retain building construction, and allow use as is.*
- Dripping from nozzles before and after activation at full pressure.
- Total amount of water applied. *How beneficial is less water? Time to shut-off.*
- Adoption of water mist systems approved for other markets. *Which standards may be relevant?*
- Less obtrusive nozzles and fittings.
- System reliability. *No systematic or specific research on how to improve system reliability has been made.*
- Cost-effectiveness.
- Evaluation of alternative fire protection systems. *A comparison that includes parameters like risk for secondary damage, reliability, aesthetics, cost, maintenance, space requirements, etc.*

## 2.6 Sprinkler protection of heritage (Scotland)

Historic Scotland has published a series of Technical Advice Notes (TAN) on practical and technical issues concerned with the care and conservation of historic buildings and monuments in Scotland. Several of these publications are focused on fire protection measures:

- TAN 11 – Fire protection measures in Scottish Historic buildings [5]
- TAN 14 – The installation of automatic sprinkler systems in historic buildings [6]
- TAN 22 – Fire risk management in heritage buildings [7]
- TAN 23 – Fire safety management in heritage buildings [8]

These publications are very comprehensive, covering issues ranging from fire risk assessment and fire safety management for both property and contents to advice concerning practical fire protection measures such as fire detection, fire alarms and fire suppression systems.

Technical Advice Note no. 14, “The installation of automatic sprinkler systems in historic buildings” is intended to introduce the concept of sprinkler installations, outline how they work and how they may be installed in historic buildings. The publication covers several aspects, including a description of the purpose of automatic sprinkler installations, different system types, the components of a system and the codes of practices used for design and installation. In addition, it introduces owners of historic buildings to the components and engineering decisions that will be necessary to enable an installation suitable for a specific property to be designed.

A separate chapter presents the details relating to the practicalities of installing a system within historic buildings and illustrates how many of the difficulties can be overcome in practical ways with minimum intrusion into the building. Proper care and maintenance of a system, including the importance of staff training and action in the event of a fire, is also discussed within a separate chapter.

Two case histories are described within a separate appendix, the installation of a sprinkler system in the Duff House and the Coleridge Cottage, respectively. The appendices also



cover a list of major historic building fires in Scotland and a list of organisations where further information can be obtained.

The publication briefly discusses water mist systems as an alternative to sprinkler systems for historic building due to lower water storage needs and reduced pipe-work sizes.

## 2.7 Fire protection measures in Røros (Norway)

There are more reports than discussed here that document practical experience from Norway. The report “Byen brenner!” [9] summarises current know-how and practical experience from fire protection installations made in Røros. Røros was founded in the 17<sup>th</sup> century as a copper mining town and its layout has been preserved to the present day. Most of the buildings are from the early 19<sup>th</sup> century and both the wooden city centre and a larger area around the town are on The World Heritage List.

The report is very comprehensive and an exceptional source of information for practical fire protection solutions for wooden towns and states that “Wooden towns - with buildings very close to each other - require specific fire protection measures in addition to what is required for single buildings, in order to prevent a large city fire”. The report also puts emphasise on the fact that the overall level of fire safety relies both on technical and organisational solutions and that they are closely connected and dependent on each other.

Its content covers aspects such as regulatory requirements, standards and responsibilities, fire prevention and protection strategies, fire statistics, a discussion of different fire detection techniques, as well as passive and active fire protection measures. One chapter deals entirely with the specific measures taken in Røros.

The main objective for the fire protection improvements made in the city of Røros is to prevent a devastating city fire. In addition to a number of fire prevention measures, linear heat detection wires have been installed on the exterior of the buildings and on the inside attics. The fire protection of the attics is especially important in order to prevent a fire from spreading from building to building. Therefore, *flashover suppression* systems were installed in the attics of the buildings. The systems are simple, consisting of nozzles on a pipe-work with a fire department connection on the facade of the building.

The winters in Røros can be cold and one potential problem with the solution described above is that the water that is pumped into the piping may freeze on its way to the nozzles or at the actual nozzles. Nozzles with small orifices may be especially sensitive to freezing. In order to investigate the specific system design, two tests were conducted in a climate chamber at SINTEF. The tests were conducted at -37°C and -32°C, respectively and showed that there is a risk that nozzle orifices can be blocked by ice slurry. Therefore, the following recommendations were given in order to secure the function of the system during wintertime:

- 1) Delay the application of water until the attic has been heated by the fire.
- 2) Use an antifreeze solution, temporarily or continuously.
- 3) Use flexible hoses instead of risers made from steel to the first nozzle, thereafter rigid steel pipes. Note: The fire integrity of the hose may be a problem.
- 4) Use heated water (+40°C) in order to pre-heat the pipe-work and the nozzles, thereafter water having a temperature of for example +4°C is fine.
- 5) Use large diameter piping and reduce the mass of the nozzles.
- 6) Use higher water pressures.
- 7) Use a by-pass valve and pre-heat the pipe-work and the nozzles with non-heated water (i.e. water directly from the municipal water supply).

For Røros, solutions 1 to 5 were chosen. The water in the fire trucks are heated to +40°C during wintertime and the intention is to delay the pressurization of the system until hot gases are filling the protected attic.

An important conclusion of the report is that the ‘best’ technical solutions do not necessarily need to be the most technically sophisticated or expensive solutions. Expensive solutions are often complex, require more control and maintenance than simpler solutions and are often the solutions that are most obtrusive.

## **2.8 Risk analysis of the wooden town of Kungsbacka (Sweden)**

The report “Brandteknisk riskanalys av Kungsbacka trästad” [10] contains a quantitative risk analysis of the historical buildings in Kungsbacka in Sweden. The old part of the city includes 14 quarters, primarily with wooden building. Most of the wooden buildings were built during the second half of the 19<sup>th</sup> century. The city burnt in 1846 and only two buildings from the time period before the fire still exist. After the fire the city plan was changed in order to try to prevent the spread of fire between the quarters. However, since 1932 there have been seven larger fires which have been isolated to within a single quarter. The analysis covered five fire safety strategies that were analysed using the fault tree technique:

- Systematic fire safety management,
- Systematic fire safety management, including education and training of the occupants,
- The installation of a fire detection system throughout all buildings,
- Improvements of passive fire protection measures, and,
- The installation of a fire sprinkler system throughout all buildings.

Based on the analysis it could be concluded that improvements of the passive protection measures and the installation of a fire sprinkler system would improve the level of fire safety the most. However, improvements of the passive fire protection are difficult to achieve without influencing the historic values of the buildings.

An additional cost-benefit analysis revealed that an investment in systematic fire safety management would pay-off immediately. The installation of a sprinkler system, which is far more expensive but improves the fire safety level more, has a pay-off time of approximately one year.

The overall conclusion of the report is that all buildings in the old parts of Kungsbacka should be protected by fire sprinklers. Although the cost of the investment is high, it is less than the cost of a fire with the magnitude experienced in Jönköping in 2001. This fire involved three properties within a city block that were more or less completely destroyed by the fire or by the water used to control the fire.

Remark: During the finalisation of this report, a disastrous fire occurred in the inner city of Kungsbacka. The fire was discovered at 3 a.m. on Saturday morning, September 16, 2006. The fire involved a two storey block building from 1868, built around an inner square. More than 70 fire-fighters were involved in fighting the fire and in order to stop the fire from spreading, parts of the building had to be demolished using excavators. Fifteen apartments and several commercial occupancies were completely destroyed. The fire started in a garbage room and the police have found signs that indicate that the fire

was deliberately set. No fatalities or injuries were reported, however, approximately 40 people lost their homes in the fire [11, 12, 13].

## 2.9 Different sprinkler system types

Different sprinkler system types are discussed throughout the report. A list of different system types as defined in the 2002 edition of NFPA 13, “Standard for the installation of sprinkler systems” [14], is given below, with some additional information concerning how each system functions:

**Wet-pipe systems** are designed for applications where the temperature is maintained above freezing and employs sprinklers attached to a piping system containing water under pressure. The water discharges immediately as one or more sprinklers are activated by the heat from a fire.

**Dry-pipe systems** employ automatic sprinklers attached to a piping system containing air or Nitrogen under pressure. The activation of one or more sprinkler permits the water pressure to open a valve, known as the dry-pipe valve. The water then flows into the pipe-work and out of the opened sprinklers. It is essential that the dry-pipe valve is installed in an area not subject to freezing. It is also important to prevent condensation inside the pipe-work, in order to avoid ice build-up. This is made by a number of measures, including de-humidifying the compressed air from the air supply. It is also essential that the system piping is pitched and that provisions are made to drain all parts of the system in order to prevent dormant water inside the sprinkler piping.

**Pre-action systems** uses automatic sprinklers attached to a piping system that contain air that may or may not be under pressure, with a supplemental fire detection system installed in the same areas as the sprinklers. Pre-action systems are commonly used for areas where there is a danger of serious water damage as a result of damaged automatic sprinklers or broken piping. There are three types of pre-action systems:

- 1) Single-interlock systems, which admit water to the sprinkler piping upon operation of the fire detection system. With a rapid fire detection system, water may be discharged as quickly as the discharge from a wet-pipe system for this particular type of pre-action system. Single-interlock systems are not as suitable as double-interlock systems in areas subject to freezing, see the discussion below.
- 2) Non-interlock systems, which admit water to the sprinkler piping upon operation of the fire detection system or the automatic sprinklers. For a non-interlock system containing a dry-pipe valve, pressure drop or activation of the detection system would trip the valve, in a manner similar to the ‘combined dry-pipe and pre-action system’ (see below). For a non-interlock system containing a deluge valve, a separate detection system would trip the valve, but loss of a low system monitoring pressure could also be used to trip the system.
- 3) Double-interlocked systems admits water to the sprinkler piping upon operation of both the fire detection system and the automatic sprinklers, i.e. in order to activate, two independent events, caused by a fire condition, must occur. The sprinkler system piping must lose air pressure due to the operation of one or more sprinklers and a solenoid valve must open upon the operation of a fire detection system. If a sprinkler head is intentionally or unintentionally damaged, or if just the solenoid valve accidentally opens, this will only cause an alarm and will not trip the system or flood the sprinkler system piping. Double-interlocked systems are therefore safer than single-interlock systems in areas subject to freezing, as the sprinkler piping will not

fill up due to a failure of the fire detection system. The time delay, from the activation of the system until full discharge at the sprinkler, requires that this specific type of pre-action system is designed with a 30% increase in area of operation.

**Combined dry-pipe and pre-action systems** are constructed such that failure of the fire detection system does not prevent the system from functioning as a conventional automatic dry-pipe system. Systems are also constructed such that failure of automatic sprinklers does not prevent the fire detection system from properly functioning as an automatic fire alarm system.

**Deluge systems** employ open sprinklers<sup>1</sup> or spray nozzles<sup>2</sup> attached to a piping system. The system is connected to a water supply through a deluge valve. This valve is opened by the operation of a fire detection system installed in the protected area. When it opens, water flows into the piping system and discharges from all sprinklers or nozzles. The deluge valve needs to be installed in an area not subject to freezing. A deluge system has a time delay between detection of a fire and the discharge of water due to the time required to operate the valve and to fill the piping network with water.

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<sup>1</sup> An open sprinkler is a sprinkler that does not have actuators or heat-responsive elements.

<sup>2</sup> An open spray nozzle is an open water discharge device that will distribute the water in a specific, directional pattern. Spray nozzles are typically used in applications requiring special water discharge patterns, directional spray, or other discharge characteristics.

## **3 Fire statistics**

### **3.1 Introduction**

This section contains fire statistical information that is relevant for heritage buildings. Fire statistics specific for heritage buildings are rare, however, some statistics from the United Kingdom have been found and these statistics could be related to large loss fire statistics, as well as compared with Swedish fire statistics. Additionally, fire statistics from Germany provides information on cause of fire and place of origin for church fires.

### **3.2 Fire statistics from the Swedish Rescue Services Agency**

Fire statistics from the Swedish Rescue Services Agency are based on reports from the local fire services. These statistics cover every fire where the fire department was called, whether the fire was outdoors, inside a building or involved a vehicle.

From the statistics that cover fires in buildings it is possible to determine the type of building (apartment building, private house, cottage, etc), where the fire occurred and its cause. From 2005, fires in heritage buildings are a separate category, so it is possible to determine how common fire is in heritage buildings as compared to the building population in general. However, two major fire departments did not report such fires so the statistics are incomplete, but despite this fact a total of 81 fires were reported. A very small fraction compared to the total amount of approximately 10 300 fires that occurred in buildings in 2005 [15, 16]. This number is slightly higher than the number for 2004, but in general, there is a decreasing trend. Among the 10 300 fires that occurred in a building, 1350 fires (13%) were deliberately started. As the cause of approximately 2000 building fires (19%) were unknown, it is likely that that arson is even more common than indicated by the statistics.

### **3.3 Serious fires in heritage premises – fire statistics from the UK**

The Fire Protection Association in the United Kingdom have compiled incidence of serious fires in heritage premises, i.e. those involving fatalities or causing losses of more than £100,000, during the period from 1999 to 2003 [17].

The causes of serious fires are summarised below. From these statistics it can be concluded that deliberate ignition is by far the most common cause (67,8%) of fire, followed by electrical causes (6,5%). The total number of fires was 62 which would make it a reliable statistical population.

Table 2 *The supposed cause of serious fires in UK heritage premises from 1999 to 2003.*

<b>Supposed cause</b>	<b>No. of fires</b>	<b>Percentage</b>	<b>Estimated loss [£]</b>
Deliberate ignition	42	67,8%	19 067 851
Hot work	3	4,8%	2 490 184
Electrical	4	6,5%	1 790 000
Spontaneous combustion	1	1,6%	120 000
Smoking materials	1	1,6%	60 000
Under investigation	2	3,2%	22 170 000
Unknown	9	14,5%	4 754 500
<b>Total</b>	<b>62</b>	<b>100%</b>	<b>50 452 535</b>

The place of origin and time of these serious fires are given in the table below. From these figures it is clear that the vast majority of fires, 50 of 62 fires (80,6%) started during the night. It can also be concluded that many of the fires started either externally, inside roof spaces or in store rooms. This is interesting as people probably have limited access to such spaces. It is also noticeable that almost all fires that started in areas where people normally have access, like classrooms, lecture rooms and other accessible spaces started during the night.

Interesting to note is also that the number of fires in areas that would be expected to have a high likeliness for fire, like boiler rooms, workshops or kitchen areas, is in fact small.

Table 3 *Place of fire origin and time of serious fires in UK heritage premises from 1999 to 2003.*

<b>Place of origin</b>	<b>Daytime (06:00 – 17:59)</b>	<b>Night (18:00 – 05:59)</b>	<b>Total</b>
External structure	3	8	11
Roof space	3	5	8
Store, stockroom	-	6	6
Classroom, lecture room	-	5	5
Access area	-	3	3
Places where people assemble	1	2	3
Refuse and waste	1	2	3
Assembly hall	-	2	2
Boiler room	1	1	2
Kitchen	-	1	1
Production/maintenance area	1	-	1
Workshop	-	1	1
Common room	-	1	1
Ducts and flues	-	1	1
Fuel store	-	1	1
Bedroom, bedsitting room	1	-	1
Unknown	1	11	12
<b>Total</b>	<b>12</b>	<b>50</b>	<b>62</b>

The number of fires per year has been fairly constant over the period, as indicated in Table 4. In addition, this table provides a comparison of all serious fires in the UK for the same period of time. This comparison indicates that the relative number of serious fires in heritage premises is also fairly constant.

*Table 4 Comparison of serious fires in UK heritage premises with all serious fires from 1999 to 2003.*

<b>Year</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>
No. of serious fires in heritage premises	11	10	16	12	13
Total no. of all serious fires	346	339	353	346	310
<b>No. of serious fires in heritage premises as a % of all serious fires</b>	<b>3,2</b>	<b>2,9</b>	<b>4,5</b>	<b>3,5</b>	<b>4,2</b>

### 3.4 Large loss fires - fire statistics from the UK

Currently, a large loss fire in the UK is defined as a fire resulting in a loss over £50,000 or incidents involving multiple fatalities and reference [18] summarises current statistics. The data is interesting from many perspectives; however, the focus within this report is the comparison of the cause of fire relative to the statistics given for heritage premises in section 3.3. Table 5 shows a ten-year review, from 1994 to 2003, of the total number of (large loss) fires and the number of arson fires during each year.

*Table 5 Total number of large loss fires in UK from 1994 to 2003 and the number of arson fires.*

<b>Year</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>
No. of large loss fires	509	514	439	411	465	424	466	434	316	325
No. of arson fires	257	219	202	176	170	146	198	165	119	153
<b>Percentage [%]</b>	<b>46</b>	<b>43</b>	<b>46</b>	<b>43</b>	<b>37</b>	<b>34</b>	<b>41</b>	<b>38</b>	<b>38</b>	<b>47</b>

It is noteworthy that the number of serious fires in recent years has been declining. Nearly half (47%) of all large fires in 2003 resulted from deliberate or possible deliberate ignition, a much larger proportion than the 38% recorded for 2002. Looking at the overall ten-year period, no general trend is observed, there are years where the relative number of arson fires were as high as in 2003, and other years when the relative number of arson fires were lower. The average percentage of arson fires is 41%.

The comparison of these figures with the statistics for heritage premises in the UK is interesting as they indicate that arson fires are more common for heritage premises. As mentioned, there are no specific Swedish fire statistics relevant for heritage buildings. However, in general, it seems that arson is not as common in Sweden as indicated by the statistics from the UK. Still, arson is considered a major problem in Sweden and the trend that the number of deliberately started fires is increasing is alarming.

### 3.5 Fire statistics from Germany

There are fire statistics available from Germany that cover church fires from 1900 to 1984 [19] and from 1949 to 1991 [20]. These statistics are interesting as they provide information on the point of origin and cause of fire. However, as the statistics partly cover different periods of time, they are not completely analogous.

*Table 6 Cause of fire based on fire statistics available from Germany, covering 104 church fires from 1900 to 1984.*

<b>Cause of fire</b>	<b>Number of fires</b>	<b>Percentage</b>
Lightning	12	11,6%
Heating devices	6	5,8%
Chimney fires	6	5,8%
Arson	1	1,0%
Unknown	79	76,0%
<b>Total</b>	<b>104</b>	<b>100,0%</b>

*Table 7 Place of fire origin based on fire statistics available from Germany, covering 150 church fires from 1949 to 1991.*

<b>Place of origin</b>	<b>Number of fires</b>	<b>Percentage</b>
Attic, roof or tower	33	22,0%
Interior	17	11,3%
Sacristy	9	6,0%
Church tower	8	5,3%
Alter	6	4,0%
Balcony (with church organ)	4	2,7%
Side spaces, chapels	3	2,0%
Boiler rooms	2	1,3%
Unknown	68	45,4%
<b>Total</b>	<b>150</b>	<b>100,0%</b>

When studying the statistics, there seems to be a relationship between the fact that most fires starts in the attic or tower and the fact that lightning is the most common cause of fire. Arson fires are very rare (1,0%) according to the statistics, which is contradictory to the information from other sources presented in this report, although it should be observed that the number of unknown reasons are very high (76,0%). It is not unlikely that many arson fires are hidden in the latter number.



## 4 Illustrative examples of fire incidents

### 4.1 Introduction

By reviewing some of the fires and fire incidents in Swedish heritage buildings it is possible to gain an understanding of how a fire can start and its consequences. The examples given here illustrate how broad the cause of a fire can be, difficulties faced by manual fire fighting, problems associated with investigations and prosecutions, and how disastrous fires in heritage buildings really are.

### 4.2 The fire in Södra Råda church

An aspirating smoke detection system was under installation when a fire completely destroyed the old, medieval church of Södra Råda early in the morning on November 12, 2001. The fire detection system was therefore not fully functional at the time of the fire.

The church was made from timber and the timber frame from the 14<sup>th</sup> century was very well preserved. The interior had unique paintings on the walls and the ceiling, and particularly those in the chancel, from 1323, were of highest artistic quality.



*Figure 1 The Södra Råda church was completely destroyed in a fire in November 2001. Photo: Swedish National Heritage Board.*

The fire spread very rapidly and it was not possible to save any interior objects in the church. Only a few pieces of timber remained after the fire and these were numbered and saved. Due to the intensity of the fire and the strong wind, a farm house positioned several hundred meters from the church caught fire. However, the fire damages to the farm house were limited. Although a careful fire investigation was made, the cause of the fire was not determined, and arson could neither be verified nor excluded [3].

Subsequently, in the autumn of 2003, a 26-year old man voluntarily confessed to arson during interrogation for an unrelated crime concerning the murder of a child. The

arsonist, who was mentally disturbed, claimed he got the inspiration to start the fire from a TV-programme presenting old wooden churches in Sweden.

There was no technical evidence that linked the man to the crime; however, he gave a detailed story of the action and a description of the church that could be verified. The fire was started from outside, a window was broken with a hammer and a total of approximately 6,5 L of gasoline was poured on the wall inside and on the outside. The fire was then ignited with a lighter. The fire developed rapidly and the man left the scene immediately. From data recording from the smoke detection system that was under installation (but not connected to the fire department), it could be determined that the fire had been burning for at least 25 minutes before it was discovered by the neighbours that alerted the fire department. The fire department arrived to the church approximately 50 minutes after the start of the fire.

According to the man, the action was planned in advance and not impulsive. In fact he travelled several hours from his home to the church. His intention was to start the fire at a date that gave reference to the “9/11” terrorist attacks exactly two months earlier. During the interrogation he confessed that the church fire gave him a sense of relief and that his internal turmoil diminished for a time after the fire [21].

The Södra Råda church was unusually well documented and soon after the fire the decision was made to try re-building the church in its original appearance. The reconstruction is expected to be finished in 2008 [22].

### **4.3 Attempt to start fire in Pelarne church**

Pelarne church is situated outside Vimmerby. The church is a well visited road church and is normally open during summertime for passing groups of tourists. The church is also popular for weddings. The early history of the church has not been entirely explained but typical Roman characteristics of, for example, the eastern chapel wall are clearly very old, most likely from the beginning of the 13<sup>th</sup> century. The church is constructed of horizontally-laid pine. On the northern side, the wall is covered with profiled weatherboard oak planks. The other walls are covered with oak chips with a pointed short side. The chip coverings are on the east wall and the year 1781 is engraved on it. The vestry was put up in 1812 [23].

On the evening of Friday, August 26, 2005 an arson fire was avoided thanks to an observant church caretaker named Margit Andersson. At about 7 p.m. she visited the church to lock it for the night. She took a walk inside to ensure that everything was in proper order. However, back home she wondered if she shouldn't go back for another check, she reminded herself about talks the day before concerning a burglar in the nearby Djursdala church. Therefore, she went back at about 10 p.m. After unlocking the door to the church she made the observation that a key wasn't in its intended position, it should have been on a nail in a hidden place. She also made the observation that a candle was missing from one of the candelabra placed on a table in the sacristy.



Figure 2 Pelarne church, where an attempt to start fire was made in August 2005.

When she opened the door to a small space where the fuse box for the church is positioned, she discovered a lit candle wrapped in tissue paper on the floor. It is likely that the candle had been lit for some while and would have burned for a few more hours before the tissue would have caught fire. It is probable that the candle was deliberately placed near the fuse box to make the fire look like an electrical failure [24].

Later the same night two of Vimmerby's primary tourist attractions burnt to the ground, the Ösjöfors hand-made paper mill and "Emils snickerbod", belonging to Astrid Lindgren's World. It was also discovered that a window to the famous writer Astrid Lindgren's native home was smashed. On the table inside the open window, the tablecloth was crumpled up and positioned close to two candles. The candles were not burning when discovered and it is not clear whether they had been burning or had been extinguished by the wind draft from the open window [25].

Ösjöfors was Sweden's oldest hand-made paper mill, preserved in its natural setting with original functioning equipment. The paper mill was started in 1777 and was in uninterrupted operation until 1926, when it was shut down. This industrial building was unique even in a world-wide perspective, but it is not expected that it will be re-built [23].

It is likely, but not proven, that both the fires and the attempts to start fire in Pelarne church and at Astrid Lindgren's native home was the action of the same person.

## 4.4 Fire incident in St Gertrud's church

Not all fires and fire incidents in churches are due to arson. One illustrative example of this occurred in St Gertrud's church in Västervik on Saturday, September 10, 2005. The church dates back to 1433 and contains a unique and invaluable organ, constructed in 1748 by the internationally renowned Johan Wistenius.

The windows of the church were under restoration and the painter had covered the electrical heat radiator under a window with a blanket and a rag-carpet, in order to protect it from paint spill. However, this particular Saturday, a baptism and a wedding were going to take place and the caretaker of the church turned on the heat in the morning, without noticing that one of the heat radiators was covered. After a while, the combustible material ignited and caught fire. Fortunately, the church was equipped with a fire detection system and the fire department was alerted. As the door to the church was unlocked, their action was fast, but the fire had almost spread to the balcony with the organ at the time they arrived. The whole church and the church tower were filled with combustion gases and the fire department had to use mobile fans to ventilate the building [26, 27]. Thanks to the alarm from the fire detection system and the fast action from the fire department, the fire and smoke damage were limited.

## 4.5 The fire in Ledsjö church

The fire was discovered by a police patrol looking for a wrongly parked car, on the night to Monday, December 6, 2004. When discovered, the fire involved the church porch.

Even though the local fire department quickly attended the scene, the church was completely destroyed by the fire, only the stone walls remained. The wind was strong during the night and the portal through the bulwark around the church prevented the fire engines from approaching the building. The church tower, the roof of the church and the bells collapsed. Some inventories could be saved, a crucifix from the 12<sup>th</sup> century, the baptismal font and various textiles. Parts of the church dates back to the 13<sup>th</sup> century but the church was re-built and extended in 1776. The church was used for a wedding on the weekend prior to the fire and is regularly used for services. The capacity of the church was 200 persons [28].

The chronology of the fire and the action of the fire department was documented as follows [29, 30]:

- 00:42        The fire is discovered by a police patrol and the fire department is alerted.
- 00:55        The fire departments arrives at scene. Upon their arrival, the church porch is fully involved in the fire and the fire has spread to the tower and attic. It is estimated that the fire has been in progress for approximately half an hour.
- 00:57        The fire fighting starts. However, the task is difficult as it is impossible to come close to the church with the fire engines, but ladders are positioned against the wall and attempts are made to reduce the fire inside the attic from the outside. Some inventories are saved, with the help from civilians, but as there is a risk for collapse of the inner ceiling people have to retreat. The inner ceiling collapses a few minutes later.

02:00 Visible fire at the church tower as the fire breaks through the windows and the walls.

02:30 The roof of the church burns through.

During the manual fire-fighting, the police discovered a burglary in an adjacent building, used for the caretakers of the church. A window was smashed and someone had broken in. Inside the building, the police found fingerprints, footprints and it was also found that the burglar had drunk a cup of coffee and something was written on a piece of paper. DNA from the burglar could be secured on the coffee cup [31]. In addition, material that may have been used to start a fire, a steel can that contained 1,5 L of paint thinner and a cardboard carton containing waste newspapers, was missing inside the building. Remains of these items were found after the fire, on the outside of the door between the church porch and the church. This door was closed and locked, but burnt through and spread the fire to the inside of the church [32].

Based on the available evidence, a 41-year old man was prosecuted and sentenced to six and a half years in prison plus damages, for deliberately starting the fire. The man denied the crime and an appeal was raised against the decision. During the second trial the man was acquitted, according to the court it was not possible to exclude the fact that someone else could have started the fire [33]. It has been decided that the church will be re-built and the intention is to re-construct the exterior in its original design but modernise the interior [34].

## **4.6 Suspected attempt to start fire in Sandarne church**

At 10:10 p.m. on Wednesday, July 5, 2006 the fire department was called to Sandarne church after someone spotted smoke coming out of the roof of the sacristy. The fire, which was small and involved combustible insulation material (sawdust), was reached through a hatch from the outside and was manually extinguished with limited damages. A piece of paper that was half-burnt were found outside the church and the police suspect that the fire was deliberately started [35]. There is a fixed ladder that leads to the top of the roof which is easily accessible. This could be used to access an unlocked hatch and enter the attic space. The incident shows how important it is to keep any doors or hatches locked in order to prevent access of unauthorised people and that fire detection systems are installed in concealed spaces.

## 5 System installation case studies

### 5.1 Introduction

To provide input to the project, a system installation case study involving six wooden churches, recently protected with sprinklers, was undertaken.

Presently, approximately ten churches in Sweden are fully protected with automatic sprinkler systems. The majority of these churches use high-pressure water mist systems, in some cases combined with traditional sprinklers for the exterior (facades and roof). There are at least two churches that are fully protected with traditional sprinkler systems. However, by request of the owner, these churches have not been included explicitly in the case study, although the fire protection consultants and the installers were interviewed.

In addition to the churches discussed here, there are examples of churches that are partly protected with sprinklers, primarily spaces like attics or bell towers. Some of the installations use automatic systems, some are manually activated.

The following churches were studied:

- Hedareds stave church
- Frödinge church
- Älgårå church
- Habo church
- Fröskog church
- Skålleruds church

Full descriptions of the first four buildings and the installations are provided in Appendices A to D, with a short summary given below. The installations of churches in Fröskog and Skållerud were not documented in detail, but the installations are similar to those present in the other four churches.

#### 5.1.1 Hedareds stave church

Hedareds stave church is Sweden's only preserved late medieval stave church. The church is quite small and is fully protected (interior and exterior) with a high-pressure water mist system. The system is activated in sections through a separate fire detection system. The pump unit consists of a gas driven pump (GPU) that is positioned inside a separate, newly built, building just outside the church yard.

This church was the first Swedish church completely protected by sprinklers. The system was put in to service in 2004.

#### 5.1.2 Frödinge church

Frödinge church is protected using two different and separate (except for the water reservoir) systems, an automatic high-pressure, dry-pipe system that utilizes automatic nozzles for the interior and the attic and a traditional low-pressure, deluge system for the facades. The roof of the church is covered by steel plates and, therefore, does not need sprinkler protection. The adjacent bell tower is protected in the same fashion as the church. The pump units, a diesel generator and the water reservoir for the system will be

positioned in a separate, newly built, building just outside the church yard. The installation of the system was not fully completed at the time for the study visit and will be put in service beginning of 2007.

### **5.1.3 Älgårås church**

Älgårås church is reasonably small and fully protected (interior and exterior) with a high-pressure water mist system. Inside the church and in the attic and church tower, an automatic dry-pipe system that utilizes automatic nozzles is installed. The facades and the roof are protected by deluge sections with open nozzles, activated by a linear heat detection system. The pump unit for the system is fed from the municipal electrical network, with extra support from a diesel generator. The equipment is positioned in a separate, newly built, building just outside the church yard, along with the water reservoir.

### **5.1.4 Habo church**

The church is sometimes called “The Wooden Cathedral” and is unique in that the architecture resembles a cathedral, but is built entirely from wood. This church was the largest of the churches that were studied within the project and the ceiling height inside the church is fairly high. Because of its size, it had the largest number of nozzles installed and the system installation was probably the most complex. The installer expressed that; “An installation of this kind will probably never be made in Sweden again”, referring to both the specific nature of the church and the installation as such.

The interior, the attic and the tower of the church are protected with a high-pressure, wet-pipe system (with antifreeze). The facades and the adjacent bell tower utilize a traditional sprinkler system, with deluge sections with open nozzles, activated by a linear heat detection system. The pump unit for the high-pressure system consists of a gas driven pump (GPU). The traditional sprinkler system is supplied by two independent centrifugal pumps supported by a diesel generator. The equipment and the water reservoir are positioned inside a separate, newly built, building just outside the church yard.

### **5.1.5 Fröskog church**

Fröskog church is fairly small and fully protected (interior and exterior) with a high-pressure water mist system. Inside the church and in the attic, an automatic dry-pipe system that utilizes automatic nozzles is installed. The facades and the roof are protected by deluge sections with open nozzles, activated by a linear heat detection system. The pump unit for the system is fed from the municipal electrical network, with extra support from a diesel generator. The equipment is positioned in a separate, newly built, building just outside the church yard, along with the water reservoir.

### **5.1.6 Skålleruds church**

Skålleruds church is also quite small and is protected in the same fashion as the church in Fröskog; however, the roof is covered by (non-combustible) slate and is therefore not protected.



*Hedareds stave church*



*Frödinge church*



*Älgårås church*



*Habo church*



*Fröskog church*



*Skålleruds church*

*Figure 3 The churches that were studied in the project.*

## **5.2 Experience and lessons learned from the installations**

### **5.2.1 Introduction**

This section of the report summarises the authors impressions after visits to the churches included in this study. Furthermore, the installers, the fire protection consultants and the inspector [36] of the systems were interviewed and input was also gained from the users.

The viewpoints and experience have been catalogued and labelled, see the sections below. It should be pointed out that not all of the issues identified below were from the churches that were studied, although most were. During discussions with people associated with the six churches included in this study, experience from other churches in



Sweden was also brought up by the people interviewed. No distinction has been made between relevant information from the churches studied in detail and that pertaining to other similar buildings discussed in the interviews. The various issues raised have been considered equally important to document and discuss.

### 5.2.2 Separate buildings house the water supply

For all the churches studied, a separate building containing the water reservoir, pump unit, diesel generator, air compressor and any other equipment necessary for the system has been built. The buildings have been discreetly designed and positioned just outside of the church yards.



*Figure 4 Buildings built close to the churches that contain the water reservoir, pumps and associated equipment. To the left is the building for Habo church and to the right the building for Älgårås church.*

The total required volume of water is usually based on the amount of water needed for the activation of at least two sections of the system, multiplied by the desired discharge duration time. This time is based on the response time of the fire department, with a certain safety factor and is usually in the order of 30 to 60 minutes. In some cases, water is reserved for manual fire-fighting, further increasing the total volume. For the churches studied, the total amount of water varied from 5,5 m<sup>3</sup> (with automatic re-filling of the tank from the municipal water supply), as used in Älgårås church, to 100 m<sup>3</sup> (where 50 m<sup>3</sup> is reserved for the fire department), as used in the churches in Habo and Frödinge.

### 5.2.3 The level of system complexity is high

Modern technology offers technically sophisticated solutions, but in some cases, despite all the possibilities that modern technology offers, there is a risk that simpler and more straightforward solutions may be overlooked.

The mixing of different systems, usually traditional sprinklers for exterior parts and water mist nozzles for the interior is unfortunate as the level of complexity of the system and system installation increases. The only common part of the systems may be the water reservoir, all other components are dissimilar, the nozzles, piping, valves, the pump unit(s), the controls, etc. It is obvious that the same type of system for all parts of a building is preferable, for reasons of simplicity and reliability.

The level of complexity further increases as different system types may be used for different parts of the building, although it is understood that the nature of the building and the fire risks may require such solutions in certain cases. One part may utilize a wet-pipe system (with antifreeze), a second part a dry-pipe system and a third part a deluge system. This will make the control and maintenance of the system unnecessarily difficult, and as

discussed in other parts of this report, proper control and maintenance are vital for proper reliability of the system.

Different fire detection techniques are also commonly used in the studied objects. This may be required to address different environments or risk scenarios in different parts of the building, but it increases the complexity of the system.

#### 5.2.4 Drainage of the system is important

The importance of proper system drainage depends on the type of system. Wet-pipe systems tend to be drained only if the system is modified. However, dry-pipe or pre-action systems have to be drained every time the system activates or trips [37].

Proper drainage is especially important during winter time, when the ambient temperature goes below freezing point. Otherwise the system may need to be dismantled and re-installed or be out of service until the weather is warmer. Or, alternatively, if not all parts of the system are properly drained, freezing may occur, leading to the separation of a joint and an accidental activation of the system.

For this reason, some of the installations utilize the possibility to manually flush the system with compressed air after the water is turned off. However, it should be pointed out that it is important that flushing of the system should be undertaken immediately after system shut-down, if the ambient temperature is low. Complete flushing requires a special nozzle connection. Instead of a traditional T-connection a Y-connection is used. This connection limits the amount of standing water at the inlet of the nozzles. Each of the ends, respectively, of the branch lines of the system is equipped with a ball valve. This valve is opened and the pipe is flushed with compressed air from the other end.



*Figure 5 Y-connections are used to limit the amount of standing water at the inlet of the nozzles. To the left is shown an automatic nozzle inside the attic of Frödinge church. To the right, an automatic nozzle protecting the interior of Fröskog church, is shown.*

For deluge sections, typically used on facades or roofs, standing water is flushed out through the open nozzles.

There is no actual field experience with the concept described above, as the installations are so new. Future experience will show whether the concept will prevent problems associated with freezing or not. However, testing has proven that the system piping is

indeed very dry after flushing. The technique requires a high air compressor capacity, for the studied churches the capacity was approximately 700 – 900 L/min at 10 bar.

For systems without this technical solution, it is essential that all branch lines and mains are pitched and that a sufficient number of drainage valves are installed. During the inspection of one of the installations in the churches studied it was observed that parts of the pipe-work were pitched away from a drainage valve, rather than towards it. It was also concluded that a sufficient number of drainage valves were not installed.

### **5.2.5 Delay times should be minimised**

The delay time, from the detection of a fire (for deluge systems) or from the activation of the first automatic sprinkler (for dry-pipe or pre-action systems), until water discharge may be substantial. Especially as the valves are often located in a separate building, a certain distance from the protected property. One alternative solution may be to position the valves in a small cabinet that, relatively discretely, can be placed close to the protected building. Such a solution is used for Hedareds stave church.

In some cases, it is possible to find a discrete and suitable location for the valves inside the church, such in the case of Habo church.

Common practice for traditional sprinkler systems is that the maximum required delay time is 60 seconds. This has been the criteria applied for the installations studied in this report, but as discussed elsewhere in the report, the fire risks of heritage buildings may require the use of a stricter criterion. When measured, the maximum delay time for dry-pipe systems in the churches studied, has been around 50 to 60 seconds.

### **5.2.6 The use of antifreeze solutions may be questioned**

The use of an antifreeze solution increases the complexity of the system and the required maintenance work. Another drawback is that antifreeze solutions may leak and are definitely distributed during the activation of the system. The interior and items inside heritage buildings are especially vulnerable to any damage from the antifreeze solution, as documented during the installation in the Habo church. A small leakage of the antifreeze solution, consisting of a mixture of organic salts, left an intimidating spot on the wooden flooring, see figure 6.



*Figure 6 A spot on the floor at the Habo church caused by the leakage of the antifreeze solution used for (parts of) the sprinkler system.*

### **5.2.7 Aesthetical aspects important**

Installation of sprinkler systems in heritage buildings requires careful planning, installation and documentation. The position of a nozzle/sprinkler is repeatedly a compromise between fire protection demands and aesthetical demands and the routes of the sprinkler pipe-work frequently require discussions with conservation officers and conservers. As one installer expressed: “Drilling a hole may take half a day.”, based on the fact that minimisation of changes to heritage buildings is paramount. Small diameter piping and discrete nozzles are therefore desired.

There are of course examples from all the churches studied where aesthetic considerations may have been given too high priority relative to the fire protection demands. But the examples are few and it should be underlined that the installations are impressively discreet, without interfering with the fire protection demands. There are often other equipment inside the churches that are more indiscreet than the fire protection system, like light fixtures, heat radiators and speakers.



*Figure 7 An automatic high-pressure water mist nozzle in Älgårds church. The position of a nozzle is often a compromise between fire protection, cultural historical and aesthetical demands.*



*Figure 8 Sometimes, the sprinkler piping can not be concealed, but with the smaller diameter piping associated with high-pressure water mist systems, the installation can be made very discreet as in Habo church.*

A good example of how discreet an installation can be is illustrated by a question made by a church visitor during the first of advent; “When will the installation of the sprinkler system start?”. The correct answer was, “It is already complete!”

### 5.2.8 The installation work must be very careful

Heritage buildings are very sensitive and the installation work must be conducted carefully. Furthermore, new installations must be accessible for maintenance and detachable without causing damage as they usually have a much shorter lifespan than the building itself. The installations must be reversible; in Habo church all core samples were collected and archived.

Interference with the building is probably unavoidable, but must be kept to a minimum. There is one example where installation work inside the attic of a church is believed to have damaged the inner ceiling. The distance between the top of the organ and the inner ceiling seems to have been reduced after installation. However, further investigation is needed to resolve this issue.

For system installation inside attics, the construction of permanent working platforms is recommended. This will help prevent damage to the church, facilitate the system installation and will make future inspection, tests and maintenance a lot easier. Another good reason for working platforms is the improved working safety. The figures below show working platforms at low and high level, respectively, inside the attic of Fröskog church. The platforms were installed in such a way that interference with the building was minimised and with the understanding that any future dismantling should be easily achievable.



Figure 9 Permanent working platforms inside the attic of Fröskog church. The platform flooring at the top level was built under the beams, to allow full standing height. Photo: Jan G Andersson.

It should be remembered that permanent working platforms increase the fire load and that it may be necessary to install nozzles below platforms at high elevations, as they may obscure the water spray from nozzles above.

### **5.2.9 Functional tests essential**

One general experience from inspections of the installations in the churches described above as well as from other installations is that functional tests are exceptionally important in order to uncover any functional problems associated with the system.

It should be noted that such functional tests should be conducted regularly, not only prior to the commissioning of the system. Further, a functional test should be a test where activation of the system is simulated, e.g. the systems inspectors test valve is opened, a fire detection device is activated, etc and one confirms that the pump unit starts and runs properly, that the system pipe-work is pressurised and, if practically feasible, that water is distributed properly from the sprinklers.

Here are some examples of functional problems occurring at functional tests in Swedish heritage buildings:

- The activation of a pneumatic linear heat detector was simulated, however, the pressure drop inside the line was not high enough to open the deluge valve and the sprinkler system pipe-work was not filled with water.
- A smoke detector, used with a pre-action system was activated, however, due to an electrical failure in a component, the solenoid valve never opened and the sprinkler system pipe-work was not filled with water.
- The activation of a dry-pipe system was simulated with the opening of the inspectors test valve. The air pressure dropped inside the pipe-work and the dry-pipe valve opened properly, however, the pump had to work so hard to fill the pipe-work with water that the motor protector of the electrical motor activated and stopped the pump.
- One of the deluge sections valves for a system protecting the facades and the roof of a church did not open during a functional test. Another deluge valve did not close properly after the test. In both cases, there were mechanical problems with the valves, and they were changed.

It is also the opinion of the author, that periodic inspection and, preferably, functional tests of dismantled samples of automatic sprinklers or nozzles should be undertaken. This is especially important if an antifreeze solution is used with the system, due to an increased risk for corrosion and clogging. This type of functional tests should be conducted at a fire test laboratory, measuring parameters like thermal sensitivity, activation temperature, water distribution and variation in the discharge coefficient (K-factor).

### **5.2.10 Unintentional activations**

A total of six unintentional activations were documented within the project. This is a surprisingly high number, given that the total number of installations is small (approximately ten churches). In most cases, the unintentional activations have occurred shortly after the commissioning of the system. Given below is a list of cases and the suspected reasons. Fortunately, only little or very limited water damage has been reported.

A deluge section protecting one of the facades of Hedareds stave church has falsely activated twice, for the following reasons:

- 1) Rain water was flowing along the wire of the linear heat detection system at the facade and into an electrical junction box. This problem has been solved by improving the encapsulation of the junction box and by changing the run of the wire to avoid water flow, along the wire.
- 2) Unknown cause, but was probably due to an electrical spike in the fire detection alarm panel, perhaps caused by lightning. The reliability of the alarm panel has been improved by requiring two relays (in serial connection) to operate before activating the deluge section valve.

There have been at least four other unintentional activations in Swedish churches. In fact, three activations occurred at the same, unusually hot summer day in July 2006, in three different churches. The reason in all three cases was an unintentional fire alarm from the linear heat detector systems on the facades, having wires rated 68°C. After these incidences, the position of the wires has been changed in order to avoid direct sun light and “pockets” under the eave of the facades where warm air could gather. Note: Alternatively, wires with a higher temperature rating could be used, with the disadvantage that the fire alarm will be slightly delayed.

The fourth unintentional activation is especially interesting as it occurred during wintertime, under freezing conditions. The particular system is supplied by a gas driven pump unit (GPU) with a water supply sufficient for a discharge duration time of 10 minutes. A deluge section of the system protecting one of the facades activated, probably due to a manufacturing defect of a component in the fire alarm panel. Water was discharged until the water reservoir was empty and the remaining gas flushed the system piping dry. This was an unexpected benefit of this specific type of pump unit. The system was put back into service by refilling the water reservoir and changing the Nitrogen gas cylinders. There was no damage or no formation of ice on the facade.

### **5.2.11 Unintentional fire alarms**

Several cases of unintentional activations of fire detection systems, other than the cases associated with the unintentional system activations described above, have been documented. In some cases, the reason can be determined; in other this is not possible. Problems are usually most frequent soon after commissioning the system and are less frequent after these initial problems have been dealt with.

One case is worth of mentioning: a small leakage occurred during the hydrostatic test of the sprinkler system pipe-work. This water found its way down the building and inside a smoke detector, which was not noted. This particular detector activated several weeks later and alerted the fire department.

Another experience is that immediate feedback from the fire department is important. In one case, the fire department was alerted several times to a church, which should have been an indication that something was wrong with the fire detection system. Instead, the system was just re-set, without any real error analysis.

For one of the churches that uses an aspirating smoke detection system inside the attic, the system detected smoke from an intentional fire outdoors. Leaves were burnt - but too close to the church. The fire department was alerted.

There is another example, other than the three cases described in the previous section, involving an unintentional fire alarm from a linear heat detector systems installed on the facades of a church. Also in this case, the wires were rated 68°C, which was too low



when they were exposed in direct sun light. After this incidence, all wires were changed to wires rated 105°C. At the time of the incidence, the installation of the sprinkler system was not finalised, therefore, the specific deluge section never activated, as would have been the case if the system had been in service.

### **5.2.12 Miscellaneous problems and solutions**

Given below is a list of miscellaneous problems and their solutions. The list is a mix of problems having been discovered either during installation, at the inspection of the system or after the system was put into service.

- There has been one case where a high-pressure pump unit started, for an unknown reason, and was running for several hours without discovery, as the B-alarm (trouble signal) was not distributed to the user. The routine was changed such that these signals were transferred to the user.
- Leakage of air in a pneumatic linear heat detection line made the connected air compressor to start more often than intended. The leakage was traced and repaired and an additional air compressor was installed in order to increase the capacity of compressed air.
- A temperature regulator, set at +5°C, was installed at the top part of two fire hose reel cabinets. During a cold winter night, both ball valves inside the cabinets froze and were damaged. After this incident, the temperature regulator was moved to the bottom part of the cabinets.

### **5.2.13 The lack of installation guidelines is a concern**

The lack of installation standards is a concern during the inspection carried out prior to the commissioning of the system. This inspection is usually undertaken by an independent third party and the installation and status of the system is compared with requirements set out in an installation standard.

As no specific installation standard exists for heritage buildings, the objective of the inspector is limited to a comparison of the actual system installation with its order specification. In other words, the inspection is focused on whether or not the end-user got what he paid for, rather than a control that the system fulfils any installation requirements.

### **5.2.14 Inspection, tests and maintenance**

There are indications that the maintenance of sprinkler systems installed in heritage buildings (the majority being old churches) often is poorer in than in other objects.

The reason may be a lack of people, time, or training or any other reason but stresses the importance that a contract is made by the end-user and a professional fire service company that regularly inspects, test and maintain the system.

It is of course important that the user can handle the daily supervision and service, however, one of the employees (users) complained that he has not been given any extra time for his duties with the system. He also recommended that at least two employees are fully trained to handle the system.

### **5.2.15 Exchange of practical experience is desired**

As described within this report, several old churches in Sweden have been protected with sprinklers. One end user that was interviewed suggested that exchange of practical experience from the different installations would be valuable. The people involved with the daily service and supervision of the systems should meet and share their thoughts and experience.

This viewpoint highlights the importance of documenting problems, incidences and solutions. Another end user that was interviewed admitted that no such strict documentation was kept; “We never expected to have as many incidences as we have, in fact, experienced”.

## **6 Additional research, testing or development needs**

### **6.1 Introduction**

A central part of this project is the discussion of issues where additional research, testing or development work is desired. This discussion is provided within this section of the report, along with additional information and experience relevant for the specific issue.

The issues are given without any particular order of importance.

### **6.2 Water discharge densities and design areas**

#### **6.2.1 General**

One of the main issues related to sprinkler protection of heritage buildings is water discharge densities and design areas. Given below is a short summary of relevant criteria in EN 12845:2004 and NFPA 13, the sprinkler installation standards used in Europe and the USA, respectively. A comparison of the recommended water discharge densities, design areas and duration times, is provided.

For water mist systems, the relevant installation guidelines do not provide any design criteria. Usually, system design criteria are based on fire tests. A short summary of relevant fire test procedures is, however, given.

#### **6.2.2 Sprinkler systems**

In EN 12845:2004, the European Standard for the design, installation and maintenance of sprinkler systems, occupancies with low fire loads are typically classified as Light Hazard occupancies<sup>3</sup>. Examples of Light Hazard occupancies include certain areas in schools and other educational institutions, certain areas in office buildings and prisons. The water supply for sprinklers installed in Light Hazard occupancies shall be designed for a water density of at least 2,25 mm/min and an area of operation of 84 m<sup>2</sup>. This design is only allowed for wet-pipe systems, and corresponds to a total water flow rate of a minimum of 190 L/min. It is, however, rare that sprinkler systems are designed in accordance with the Light Hazard requirements. Usually they are designed for at least OH1, as discussed below.

Occupancies with a medium fire load are classified as Ordinary Hazard Group 1 (OH1) occupancies<sup>4</sup>. Examples of OH1 occupancies include hospitals, hotels, libraries (excluding book stores), restaurants, schools and offices. Heritage buildings are not particularly mentioned, but would probably fall under this occupancy category. The water

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<sup>3</sup> Chapter 6.2.1 of EN 12845:2004 defines Light Hazard occupancies as follows; “Occupancies with low fire loads and low combustibility and with no single compartment greater than 126 m<sup>2</sup> with a fire resistance of at least 30 minutes.”

<sup>4</sup> Chapter 6.2.2 of EN 12845:2004 defines Ordinary Hazard occupancies as follows; “Occupancies where combustible materials with a medium fire load and a medium combustibility are processed or manufactured.”

supply for sprinkler installed under OH1 shall be designed for a water density of at least 5,0 mm/min and an area of operation of 72 m<sup>2</sup>. Theoretically, this corresponds to a total water flow rate of a minimum of 360 L/min. Dry-pipe systems shall have a design area of at least 90 m<sup>2</sup>.

In NFPA 13, the standard for installation of sprinkler systems primarily used in the USA, occupancies with low fire loads are classified as Light Hazard occupancies<sup>5</sup>. The water supply for sprinklers shall be calculated from density/area curves given for the specific occupancy hazard, where the calculation shall satisfy any point on the curve. The most common design point for Light Hazard occupancies is 4,1 mm/min with an area of operation equal to 139 m<sup>2</sup>. Theoretically, this corresponds to a total water flow rate of a minimum of 560 L/min. When listed quick response sprinklers are used, a percent reduction of the design area of 25% to 40% is permitted. However, in order to allow for this reduction, a number of conditions should be satisfied, for example that the system is of the wet-pipe type and that the maximum ceiling height is 6,1 m.

For dry-pipe and double-interlock, pre-action systems, the area of sprinkler operation shall be increased by 30%. The maximum water delivery time for Light Hazard occupancies under NFPA 13 is 60 seconds.

Table 8 summarises the recommended water discharge densities, design areas and discharge duration times in EN 12845:2004 and NFPA 13. It can be concluded that NFPA 13 requires a larger total amount of water as compared to EN 12845:2004. However, with the allowed design area reduction permitted with quick response sprinklers, the total flow rate of the two standards is comparable.

*Table 8 Summary of recommended water discharge densities, design areas and discharge duration times in EN 12845:2004 and NFPA 13.*

Standard / Occupancy classification	System type	Water discharge density [mm/min]	Area of operation [m <sup>2</sup> ]	Water supply duration [minutes]	Total amount of water [L]
<u>EN 12845:2004</u>					
Light Hazard	Wet-pipe	2,25	84	30	5 670
Light Hazard	Dry-pipe	Not applicable	Not applicable	Not applicable	Not applicable
Ordinary Hazard (OH1)	Wet-pipe	5,0	72	30	10 800
Ordinary Hazard (OH1)	Dry-pipe	5,0	90	30	13 500
<u>NFPA 13</u>					
Light Hazard	Wet-pipe	4,1	139*	30	17 097**
Light Hazard	Dry-pipe	4,1	181	30	22 226
<u>NFPA 13D</u>					
Dwellings	Wet-pipe	2,05	2-sprinklers	10	~550
<u>NFPA 13R</u>					
Residential occupancies	Wet-pipe	2,05	4-sprinklers	30	~3 295

\*) May be reduced with 25% to 40%, i.e. to between 104 m<sup>2</sup> and 83 m<sup>2</sup>, if quick-response sprinklers are used.

\*\*\*) Will be reduced to between 12 823 L and 10 258 L under the conditions in the note above.

<sup>5</sup> Chapter 5.2 of NFPA 13 defines Light Hazard occupancies as follows; "Light hazard occupancies shall be defined as occupancies or portions of other occupancies where the quantity and / or combustibility of contents is low and fires with relatively low rates of heat release are expected." Examples of such occupancies include churches, libraries (except large stack rooms), museums and unused attics.

NFPA 13D and 13R contain installation guidelines for residential sprinklers. These sprinkler systems are intended for improved protection against injury, loss of life, and property damage in residential occupancies. A sprinkler system installed in accordance with the recommendations is expected to prevent flashover (total involvement) in the room of fire origin and to improve the chances for occupants to escape or to be evacuated.

NFPA 13D was specifically written to cover the installation of residential sprinklers in one and two-family dwellings and manufactured homes. To make sprinkler systems economically practical for dwellings, NFPA 13D permits omission of sprinklers from certain building areas where NFPA 13 would require sprinklers. NFPA 13D also permits a two-sprinkler design area so as to accommodate limited domestic water supplies. The minimum discharge density should be 2,05 mm/min. Where water is stored, the minimum quantity of the water supply shall equal the demand rate times 10 minutes.

NFPA 13R covers the design and installation of automatic sprinkler systems for occupancies up to and including four stories in height and is therefore more stringent than NFPA 13D. NFPA 13R requires a minimum discharge density of 2,05 mm/min to the design (listed) sprinklers, where the number of design sprinklers includes all of the sprinklers, up to a maximum of four, that require the greatest hydraulic demand. The water supply shall be capable of supplying the system demand for at least 30 minutes.

As shown in Table 8, the typical total flow rates associated with NFPA 13D or 13R systems are significantly less than those of Light Hazard systems.

### **6.2.3 Water mist systems**

FM Global has developed fire test procedures for Light Hazard applications, as contained in Appendix I of their Approval Standard for water mist systems [38]. The fire test procedures are partly based on fire test procedures for accommodation and service space on board ships, contained in IMO Resolution A.800(19) [39] and developed by the International Maritime Organization. The fire test sources simulate small and larger sized passenger cabins and public space areas. The combustible material includes foam mattresses, combustible wall linings and upholstered sofas constructed from foam mattresses.

Within the CEN standardisation body in Europe, a Technical Specification for the installation of water mist systems will soon be published. The document contains fire test procedures for Ordinary Hazard Group 1 (OH1) occupancies. The fire test source consists of a set-up that simulates an office interior, with an office desk, a drawer, an office chair, etc arranged adjacent to two walls with combustible lining.

As per the discussion in the previous section of this report, sprinkler design criteria for Light Hazard occupancies per NFPA 13 and Ordinary Hazard Group 1 (OH1) occupancies per EN 12845:2004 are reasonably similar. The correlation between the fire test procedures described above is, however, unknown and has not been tested.

Another noteworthy observation is that all the described fire test procedures are intended for wet-pipe water mist systems.

**Additional research, testing or development work**

Large-scale fire test procedures should be developed that better simulate conditions relevant to heritage buildings. From the experience presented in this report it seems essential that arson fires are reflected in the fire test procedures, including ignition with flammable liquids, and that the procedures are applicable to both wet-pipe as well as dry-pipe systems.

### **6.3 Sprinkler protection of facades and roofs**

The combination of different system types, traditional sprinklers for exterior parts and water mist nozzles for the interior is counter productive as the level of complexity of the system and system installation increases. The same type of system for all parts is preferable from a practical standpoint.

Sprinkler pipes on outside facades are difficult to hide, especially if the height of the facade requires multiple levels of nozzles. From an aesthetic aspect it is desirable to use pipes that are as small as possible, which encourages the use of water mist systems. Alternatively, the piping could be arranged inside the building, with piping to the individual nozzles penetrating the wall.

The area of the facades and roof may be large and if the whole portion of a facade or even several facades is to be protected simultaneously, the water demand will be high as will be the capacity of the sprinkler system pump unit. This would, on the other hand, encourage the use of a traditional sprinkler system in order to reduce the electrical power demand. Although some ad hoc testing has been conducted [40], indicating that water mist systems may provide good protection of wooden facades, no systematic research has been undertaken. Parameters to be studied would include the influence of external wind, the height of the facade, type of wall panelling and the relevant and realistic fire exposure to a facade or roof.

All the installations made for the protection of facades or roofs that are described within this report utilize deluge systems, where a whole section, typically covering one facade is activated from the signal from a separate linear heat detection system. It is therefore essential that testing of any such concept needs to involve both the fire detection and the sprinkler system.



*Figure 10 Protection of the facades and the roof of Älgårds church using a water mist system. Photo: Jan G Andersson.*

None of the installations studied use wet-pipe (with antifreeze) or dry-pipe systems for the protection of facades or roofs. Such systems may be preferred as they are independent of a separate fire detection system. The drawback may be that sprinkler spacing may need to be short, in order to ensure that the sprinklers are activated prior to fire spreading through any ventilation gap between the wall and the roof.

#### **Additional research, testing or development work**

There are several benefits of being able to use the same type system both for the protection of the interior and the exterior of a building. This is why the protection of outside facades and roofs is a topic for further investigations. Furthermore, the surface area of facades and roof may be large. If a whole portion of a facade or even several facades is to be protected simultaneously, the water demand will be high as will be the required capacity of the sprinkler system pump unit. The lower the water discharge density – the lower the total water demand. It is suggested that any investigation include large-scale fire tests varying parameters like:

- Height of the facade.
- Type of wall panelling.
- Influence of external wind.
- Type of system (wet-pipe, dry-pipe, pre-action or deluge).
- Type of fire detection system (relevant for pre-action or deluge type systems).

## 6.4 Fire detection systems for facades and roofs

Fire detection systems for facades and roofs closely relate to the issue in the previous section, as the fire protection system usually is activated by a separate fire detection system. Figure 11 shows linear heat detection wires at the facade of Hedareds stave church. Figure 11 shows linear heat detection wires at the facade of Hedareds stave church.



*Figure 11 Linear heat detection wires at the facades of Hedareds stave church (left hand photo) and Fröskog church (right hand photo). Note the high-pressure water mist nozzle shown in the left hand side photo.*

A research project [41] looking at the use and installation of linear heat detection wires on facades was recently undertaken at SP Fire Technology and the experience gained from this project may be valuable for heritage buildings. The test included two different heat detection technologies: electrical linear heat detector wires with fixed alarm temperature ratings of either 68°C or 105°C and a pneumatic ‘rate-of-rise’ detector. However, most of the tests were conducted with thermocouples at different positions on the facade wall and under the eave. The findings included:

- Wires, especially those with a fixed temperature rating, should be positioned as low as possible, although not less than approximately 1 m above the likely position of a fire. Note that the risk for sabotage needs to be considered if the wire can be reached from ground level.
- If the facade is high, typically in excess of 5 to 6 m (two-storey buildings), additional wire(s) need to be installed at lower levels, in order to speed up the response time. Detector wires at lower levels usually need a higher temperature rating than wires positioned under the eave, as they may be exposed to direct sun light.
- Wires should not be run ‘in the shadow’ caused by the building structure.
- Wires should not be installed directly against the surface on which they are mounted, i.e., performance is improved when the wire is mounted a small distance from the facade. This is to avoid cooling of the wire from the wall and to place the wire in the plume gas flow.
- Wires fitted below eaves should be run close to the facade, and not further out than half the width of the eaves. With underlying secondary panels, it makes no great difference whether the wires are fitted between the panels or on a board, provided that they are relatively close to the facade wall. Alternatively, wires can be fitted to the facade wall fairly close to the eaves.
- The response time is considerably delayed if the wire is run in a conduit, which should therefore be avoided. It is better to run the wire inside perforated metal, or to protect it from sabotage by netting.



- The effects of a perforated sheet etc on the activation time should be tested in a component test.

It could be concluded that the pneumatic ‘rate-of-rise’ detector wire tested responded, under equal test conditions, significantly faster than the detector wires with a fixed alarm rating tested. However, it is important to point out that in order to decide whether a specific linear heat detector will detect a particular fire, it is necessary to know the wire’s thermal sensitivity, which can be determined by a component test. It is also the case that the sensitivity of the pneumatic ‘rate-of-rise’ detectors can be adjusted.

In a Norwegian study [42], four different linear heat detection wires systems were compared: two pneumatic ‘rate-of-rise’ detectors and two fixed alarm detector wires. The comparison included an evaluation of fire response time and the risk for false alarms. The reason for the latter is that concerns have been raised that rates of temperature rise above alarm thresholds of ‘rate-of-rise’ detectors can be experienced under normal operating conditions. For example if the wire is exposed to direct sunlight or positioned above a doorway or window to a heated building, where the door/window is opened (during wintertime).

The fire tests indicated that the two tested pneumatic ‘rate-of-rise’ detectors responded faster to the test fires than the two fixed alarm detector wires, under equal test conditions. Tests were also conducted where the wires were installed above a window to a heated room. The window was opened and it was determined whether the wires responded to the sudden temperature rise. One of the two pneumatic ‘rate-of-rise’ detector wires did activate during this particular test, but after the sensitivity was adjusted, unintentional alarm was prevented.

Reference [43] contains an extensive compilation of different fire detection techniques and their suitability for heritage buildings and museums. The report summarise the results from several series of evaluation tests and practical experience from installations in Norway.

#### **Additional research, testing or development work**

As discussed elsewhere in the report, the choice and position of the linear heat detection systems for facades and roofs have been a problem for the churches studied under this project. There have been several cases of unintentional alarms and system activations.

Most of the churches use wires with a fixed alarm rating; however, as described above, pneumatic ‘rate-of-rise’ detectors may respond faster to a fire and wires at different height levels at the facade may not be needed. It is suggested that any additional investigation is focused on evaluating fast and reliable fire detection systems for facades and roofs.

## **6.5 Flashover prevention systems**

A flashover occurs at the stage of a fire when all surfaces and objects within a compartment have been heated to their ignition temperature, and ignition of pyrolysis gases occurs at once over the surface of all objects in the compartment. The gas temperature is typically between 500°C and 600°C, although flashover temperatures can peak at about 1100°C.

After flashover occurs, access to oxygen controls the heat release rate. This stage is known as the fully developed compartment fire. When all the combustible material inside

the compartment starts to become consumed by the fire, the heat release rate decreases. This stage is known as the decay period [44].

Flashover prevention system has been used in several Norwegian churches, as discussed elsewhere in this report. Furthermore, a number of fire tests have been conducted and theoretical models to explain flashover suppression have been developed [45, 46]. Special focus has been given to the protection of attics, where systems designed to prevent flashover of the attic despite fully developed fires in the ground floor of a building [47, 48] have been developed and tested.

In this context, it could be mentioned that small droplets evaporate faster than larger droplets and the overall surface area in relation to their volume is larger. The cooling of hot combustion gases is therefore typically better with smaller droplets. On the other hand, larger droplets penetrate hot gas layers or fire plumes better than smaller droplets and water that hits burning surfaces decreases the rate of pyrolysis.

#### **Additional research, testing or development work**

It is suggested that any additional investigation is focused on developing methods to evaluate the efficiency of flashover prevention systems to determine proper design criteria.

## **6.6 Water exposure to vulnerable paintings and décor**

Walls and ceilings inside many old churches are often decorated with valuable paintings, artefacts and décor. The paint may be water-soluble and therefore very sensitive to the exposure from a water spray from a sprinkler.

The Norwegian Directorate for Cultural Heritage has recommendations for the installation of water mist nozzles inside churches with water-soluble décor, in order to avoid or reduce the likeliness for water damage [49]. These recommendations suggest that low impulse water mist nozzles are installed at the ceiling combined with strategically located medium impulse nozzles at a low level of the compartment. The intention is that the nozzles at the ceiling provides cooling of the hot gas layer, thereby preventing flashover and that the nozzles at the lower level will suppress a fire at floor level.

For systems where the fire protection objective is fire control or fire suppression, rather than flashover prevention, nozzles with larger droplets or higher momentum are used and the amount of water is typically higher. Such nozzles need to be carefully positioned in order to avoid a direct hit on sensitive surfaces or objects.



*Figure 12* Examples of valuable wall and ceiling paintings from the Södra Råda church, to the right is a detail of one of the paintings. As discussed within the report, the church was completely destroyed in a fire in November 2001. Photos: Swedish National Heritage Board.

The recommendations contain a note of caution. Optimization of a system to avoid secondary damage to paintings or artefacts generally leads to water mist systems with low water discharge densities. Even though flashover of the protected compartment is prevented, initial fires, shielded fires or small fires may remain unaffected by the system. It is advised that such systems are primarily used where the intervention time of staff or the fire department is short, in order to reduce fire and smoke damage which can be as devastating as water damage.

The importance of providing wetting of walls in order to reduce fire damage is illustrated on figure 13. The photos show fire damage to two corner walls with an outer layer of 3 mm plywood. The nozzle used in the photo on the left hand side had wall wetting capabilities superior to the nozzle used in the photo on the right hand side. The parts of the walls that were wetted or not wetted by the water spray are clearly distinguished. If a fire spreads up a combustible wall, the size of the fire and the associated fire damage can be large if no water, or very little water, reaches the wall.



*Figure 13* Illustrative results from two fire tests, where the nozzle used in the photo on the left hand side had wall wetting capabilities superior of the nozzle used in the photo on the right hand side. The fire source consisted of a 100 kW propane gas burner positioned close to the corner walls (not shown in the photos).

Reference [50] contains the results from an examination of the impact on artefact material from smoke and extinguishing media. It is concluded that agents containing chemicals (foam and emulsifying agents) extensively affected surfaces of the material samples. Excessive water increases mechanical and wetting damage to samples. Powder agents will result in considerable costs in the follow-on cleaning and conservation of the materials. It also causes corrosion on iron. The cooling effect of Carbon Dioxide (CO<sub>2</sub>) causes damage to certain material. However, it was also concluded that the damage caused by the fire itself will always be greater than the damage caused by the extinguishers, their agents or hardware. Thus, more valuable material is saved by resolute rather than careful extinguishment of the fire.

#### **Additional research, testing or development work**

The issue is a balance between damage from water and damage from a fire. The more water that is used, the more a fire will be suppressed. It is suggested that any additional investigation relating to water exposure to valuable paintings, artefacts and décor are focused on questions like the damage from the water spray of different sprinklers or nozzles and the corresponding fire damage.

## **6.7 The use of antifreeze**

The cold climate in the Nordic countries almost always require that parts of the sprinkler system used for the protection of heritage buildings is of the dry-pipe or deluge system type or that an antifreeze solution is used.

The use of antifreeze in sprinkler systems is a complex issue due to one or more of the following reasons: the increased viscosity of the extinguishing medium that requires different hydraulic calculation techniques and may require larger pipe sizes, material compatibility issues, increased risk for leakage, the potential flammability of the solution, environmental aspects, health issues, increased system complexity and increased cost.

For the protection of refrigerated and cold storage warehouses, sprinkler system concepts with antifreeze solutions have been developed and practical experience has been obtained. Reference [51] describes a sprinkler system concept for such applications where a 50%/50% propylene glycol and water antifreeze solution is used. The part of the piping system subject to freezing is filled with the pressurised antifreeze solution maintained from a pressure pump system, connected to a small antifreeze solution tank, which controls and maintains the desired antifreeze solution pressure.

In addition to the antifreeze solution tank, the system requires a reclaim tank for drainage of the system and for pressure control on the system riser. Any increase in temperature in the freezer will increase the pressure in the system piping and the tank is used to collect any solution vented from the system due to this temperature expansion. Once the pressure in the system normalizes, a digital pressure switch re-sets the solenoid drain valve to close and stop the flow to the reclaim tank. The reclaim tank is sized for the largest single system capacity.

If the system piping pressure is too low, due to the temperature in the freezer being lowered, additional antifreeze solution is automatically pumped into the system from the antifreeze solution tank.

The system requires one system isolation valve, an alarm valve and two check valves downstream from the alarm valve. All valves should be positioned in a heated area and the pipe volume from the first check valve onwards is filled with the antifreeze solution.

The reason for this arrangement is the high thermal conductivity<sup>6</sup> of the antifreeze solution. Experience gained from previous systems which only had an alarm valve between the antifreeze solution and water, has shown that a thermal transfer system was set up within the antifreeze system pipe-work where colder, denser solution from inside the warehouse flowed towards the alarm valve was capable of removing enough energy from the warmer water beneath the alarm valve to cause it to freeze and form an ice plug (effectively taking the system out of operation). This occurred because of the density difference between the cold solution inside the freezer and the warmer solution outside the freezer. Current systems employ two check valves and a pre-action control valve to maintain an air gap between the antifreeze solution and water, removing the possibility of ice plug formation.

In 1999, a study of the combustibility of antifreeze for sprinkler systems was conducted [52] at SP Fire Technology. Concerns had been raised as to whether or not some antifreeze recommended for sprinkler systems contributed additional energy to an established fire upon sprinkler activation. This could potentially result in an excessive number of sprinklers being activated. The study was made in intermediate scale using oxygen depletion calorimetry. The results were compared with water only and revealed that only two of the antifreeze solutions tested were comparable to or better than water only, namely calcium chloride and potassium acetate. The other antifreeze solutions (ethanol, glycerine, methanol, propylene glycol and urea) resulted in a significant increase of the heat release rate of the fire source. All the results correlated well with theoretical calculations.

Antifreeze solutions may leak and are definitely distributed during the activation of the system. The interior and items inside heritage buildings are especially vulnerable to any damage from the antifreeze solution, as documented during the installation in the Habo church, as per the discussion in another section of this report.

#### **Additional research, testing or development work**

It is clear that a wet-pipe system containing an antifreeze solution is more complex than a dry-pipe system. Such a system needs a number of features, like an antifreeze solution tank, a reclaim tank for drainage and measures to handle any temperature expansion due to temperature changes that a dry-pipe system does not. In addition, leakage of the antifreeze solution may damage vulnerable material and surfaces. The advantage is that the delay time, from the activation of the system until water / antifreeze is applied is shorter than the delay time associated with a dry-pipe system. It is, however, important to weigh any benefit over a dry-pipe system in this respect against the contribution of the antifreeze solution to the intensity of the fire. If the antifreeze solution increases the intensity of the fire, no real benefit is applicable.

It is suggested that any additional investigation related to the use of antifreeze solutions are focused on questions like:

- Damage from the antifreeze solution on vulnerable material and surfaces.
- Contribution from the antifreeze solution to the intensity of the fire, as a function of the amount of solution used for the system.
- Contribution from the antifreeze solution to intensity of the fire, dependent on the droplet sizes i.e. a comparison between traditional sprinklers and water mist systems.

<sup>6</sup> For comparison, the thermal conductivity for water is 0,60 W/(m·K), the thermal conductivity for a 50%/50% solution of propylene glycol and water is approximately 0,32 W/(m·K) and the thermal conductivity for steel is approximately 45 W/(m·K).

## 6.8 System reliability

### 6.8.1 Sprinkler system reliability - data from USA

Based on data from the National Fire Incident Reporting System (NFIRS) in USA, an analysis [53] has been made of automatic sprinkler system reliability. The analysis is interesting as it is based on current data from 1999 – 2002 and because the version of the reporting system (Version 5.0) that was used, provided much better estimates of sprinkler reliability than previously possible.

The data shows that sprinklers activated in 93% of the fires large enough to activate them. The percentage varies from a high 98% for apartments to a low 86% for storage properties.

Wet-pipe systems accounted for 75% of all systems in the analysis, dry-pipe systems for 11%. For storage properties, wet-pipe accounted for 68% and dry-pipe systems for 29%.

Two-thirds (65%) of the sprinkler systems failures to operate were because the system had been shut off. Another 16% occurred because manual intervention defeated the system, for example by shutting it off before the fire was completely extinguished. Lack of maintenance accounted for 11% of the sprinkler failures to operate and 5% because the wrong type of system was present. Nearly all failures occurred entirely or primarily due to human error. Only 3% involved damage to system components.

When the sprinkler system operated as intended, they were effective in 96% of the fires (for all type properties). For the remaining 4% of the cases they were not effective, over half the time (55%) was because the water did not reach fire. Most of the other cases of ineffective performance (31% of the total) occurred because not enough water was discharged. Inappropriate systems accounted for 7% of the cases, system component damage for 5%, and manual intervention for 2%.

There is a clear trend that the effectiveness of the sprinkler system is associated with the number of sprinklers activated. When only one sprinkler operated, the performance effectiveness was 95%. The effectiveness fell to 94% when two sprinklers activated, 91% for three sprinklers, 89% for 4 – 10 sprinklers, and down to 81% for more than 10 sprinklers.

Based on the data given above, the combined reliability of a sprinkler system can be calculated to be **89%** (93% system activation reliability  $\times$  96% system performance effectiveness). This figure is an overall number that includes data from all type of properties and both wet-pipe and dry-pipe systems as well as pre-action and deluge systems.

As indicated from the data from NFIRS, proper inspection, testing and maintenance of a sprinkler system are important for its function. FM Global reports [54] that a concerning trend has evolved during the last ten years with the regards to the inspection and maintenance of fire pumps. A number of factors seem to be contributing to this, including a lack of trained on-site maintenance personnel and poor service by contracted vendors responsible for the task.

## 6.8.2 Unintentional sprinkler activations - data from Norway

The report “Analysis of sprinkler failures in listed heritage buildings...” [55] contains an analysis of accidental activations of water based fire protection systems in Norwegian heritage buildings.

During the period from 1986 to 2005, 27 accidental activations have been recorded and the contributing factors have been listed and analysed within the report. The ten dominating factors causing accidental activations given in the above report are (by decreasing order):

1. Human error.
2. Indispensable vital part added (not addressed by installation standards) to serve need related to heritage.
3. The system design requires more skill to operate than offered by local maintenance staff.
4. Condition required by heritage application (not addressed by installation standard).
5. Complicated system, installation or procedures.
6. Fault in manufactured part.
7. Fault in system installation.
8. Fault in system engineering design.
9. Freezing.
10. Unexpected conditions, unforeseen and unlikely to reoccur at such building.

Two main factors causing accidental activations are discussed in more detail within the report, i.e., freezing and system complexity.

Problems directly or indirectly associated with freezing are many, even though the problem is covered in sprinkler installations standards. For buildings or areas subject to freezing, usually a dry-pipe, a pre-action or a deluge system (the terminology is explained in section 2.9 of the report) is used.

Freezing may cause water leakage when ice is formed inside the sprinkler piping, breaking a pipe joint or rupturing the pipe. Dormant water inside the system pipe-work is either caused by poor drainage of the system or condensation. It is essential that the system piping is pitched and that provisions are made to drain all parts of the system.

Freezing may also cause unintentional operation of the fire detection system. This is the cause of several accidental activations of deluge systems, mainly protecting facades. Some line heat detection or actuating systems are pneumatic, hence several incidents relate to freezing of condensed water inside these. In at least one case, white frost caused multiple spot detectors to operate, activating the sprinkler system.

The report concludes that systems installed in heritage buildings are generally more complex than systems for other applications. Inevitably, complexity translates to reduced reliability. The demand for proper inspection, testing and maintenance is therefore high and requires trained personnel.

It is interesting to notice that the reported water damages from the accidental activations were either none or limited. One reason is probably that most of the activations were related to deluge systems protecting facades. Another noteworthy observation is that only one of the activations was because someone tampered with the system. In the case in question, the glass bulb of a water mist nozzle was intentionally broken.

### **Additional research, testing or development work**

A reliable system should activate properly under fire conditions and unintentional activations should not occur. The latter is especially important for heritage buildings, where the building itself and the inventories are vulnerable to water damage. However, there is a contradiction between these two requirements. The more conditions that need to be fulfilled before activation of the system, the higher the likelihood that the system will not function as intended in a fire.

For traditional sprinkler systems, nearly all failures occur entirely or primarily due to human error. After more than 100 years on the market, shut off valves are still the classical and dominating reason for failures. Manufacturing defects to system components is rare. Periodic inspection, test and maintenance by trained personnel are therefore the key to a high reliability.

As indicated in this report, water mist systems are commonly used for the protection of heritage buildings. The technology is new, and there is limited or no reliability data available. Often, “non-approved” system components are used, simply because there are few component approval standards available. This makes periodic inspection, test and maintenance as important or more important for water mist systems as for traditional sprinkler systems.

The issue of avoiding unintentional activation and still keeping a high reliability under fire conditions is crucial. It is therefore suggested that further investigations should be focused on this particular issue.

## **6.9 Alternative water supplies**

For all the churches studied within the project a separate water reservoir is required as the water flow rate from the municipal water supply was too low in the areas where the churches are situated.

For smaller buildings or for cases where the desired discharge duration time can be short, limited water supply alternatives may be considered, for example pressure tank systems. The standard pressure tank system uses a pressure rated tank filled to 70% capacity with water. The remaining 30% capacity is filled with compressed air of 5,2 bar (75 psi), plus the head pressure required for the difference in elevation between the discharge outlet of the tank and the topmost sprinkler. Some limited water supplies use Nitrogen gas stored in cylinders to provide the discharge pressure for the water flow to the sprinklers. This requires a pressure regulating valve between the cylinders and the pressure tank [56]. One advantage of this solution is that the pressure tank can be almost completely filled with water, i.e. allowing the use of the full capacity of the tank and that the pressure remains constant during the discharge of water. A drawback is that the pressure cylinders need to be changed after any activation of the system.

Presently, there are approximately 30 installations in Sweden with relatively large pressure tanks, ranging from 20 m<sup>3</sup> to 100 m<sup>3</sup>, pressurised by Nitrogen gas stored in cylinders [57]. All the installations have been made in industrial applications, such as saw mills or manufacturing industries. So far, no installations have been made in heritage buildings. The figure below shows a pressure tank used in an industrial application. The outlet of the tank is connected, via a wet alarm valve, to a sprinkler system at the ceiling that protects parts of the factory that are considered vital to the production. The following



parameters are continuously supervised: the pressure of the gas cylinders, the water level and water pressure inside the tank and the system valves.



*Figure 14 A 20 m<sup>3</sup> pressure tank used in an industrial application. The Nitrogen gas cylinders and the wet alarm valve are positioned at the bottom part, underneath the tank, with access through a steel door. Photo: Robert Linde.*

An analysis of the reliability of alternative water supplies for sprinkler systems have shown that pressure tanks (either using compressed air or Nitrogen) have a higher reliability than pumps driven by an electrical motor or a diesel engine [58]. The technology can therefore also be considered interesting for heritage buildings.

#### **Additional research, testing or development work**

Usually, a relatively large portion of the total cost of a sprinkler installation is associated with the water supply, especially if a diesel generator is required to secure the electrical power. The pressure tank systems that are discussed here have the advantage that they are more or less independent of electrical power, which is a desired feature for buildings in rural areas with less reliable power supply.

It is therefore suggested that further investigations into the use of alternative water supplies for heritage buildings are initiated, with the objective of decreasing the cost but maintaining a high degree of reliability.

## 6.10 Streaming of water in cold sprinkler piping

The system pipe-work of dry-pipe or deluge systems may be exposed to freezing temperatures during wintertime, when installed to protect building exteriors or attics. When the system activates, water will stream through cold piping and there is a risk for the formation of ice slurry inside the pipe, with an associated risk for blocking of the sprinkler orifice(s).

It is likely that the risk for formation of ice and blockage of nozzles is higher for water mist systems; due the smaller diameter piping that is used and the nozzles orifice(s) which may be very small, sometimes less than a millimetre.

### **Additional research, testing or development work**

Investigations of the risk for the formation of ice slurry dependent on the size of the pipe, the pipe length, the orifice size, ambient temperature, water temperature, etc. Any work should be preceded by the development of a theoretical model concerning streaming and cooling of water in cold pipes.

## **7 Summary and conclusions**

### **7.1 General**

The main objective of the project has been to summarise lessons learned and practical experience from some of the fire sprinkler installations in heritage buildings in the Nordic countries, with special focus on the installations made in Sweden during the last few years. Most of the installations have been made in small or intermediate sized wooden churches.

This work has resulted in a list of issues where additional research, testing or development work is desired.

Another part of the project has focused on relevant fire statistics and examples of illustrative fires or attempts to start fires. This information illustrates relevant fire scenarios and may form background material for forthcoming fire tests or fire test procedures.

### **7.2 Fire scenarios and fire statistics**

During almost 800 years, 1193 – 1984, a total of 524 churches and chapels in Sweden were damaged by fire, war, plundering, collapse, storm, snow, etc. In total, 447 (85%) were damaged or destroyed by fire. A total of 106 of these fires occurred due to lightning. The remaining 77 (15%) churches were damaged in other ways, for example action from war, storm, severe cracks or construction failures. Churches or chapels built after 1950 are not included in the compilation; neither are churches suffering only minor damage. From a historical perspective, it can therefore be concluded that fire is the main cause for damage to churches and chapels.

In general, arson is a common cause for fire and according to Swedish fire statistics there are tendencies that the number of fires started deliberately increases, especially fires outdoors. However, there is no specific Swedish statistics for heritage buildings prior to 2005 and the statistics from 2005 are incomplete.

From statistics from the United Kingdom it can be concluded that deliberate ignition is by far the most common cause (67,8%) of fire in heritage buildings, followed by electrical causes (6,5%). The vast majority of fires (80,6%) started during the night. It can also be concluded that many of the fires started either externally, inside roof spaces or in store rooms. This is interesting as people probably have limited access to such spaces. It is also noticeable that almost all fires that started in areas where people normally have access, like classrooms, lecture rooms and other accessible spaces started during the night.

From the statistics from UK cited within this report is not known to what extent the particular heritage buildings were used as a residence or not.

Some fires and fire incidents in Swedish heritage buildings were reviewed in order to gain an understanding of how a fire can start and its consequences. The examples illustrate how broad the cause of a fire can be, difficulties faced by manual fire fighting, problems associated with investigations and prosecutions, and how disastrous fires in heritage buildings really are. Several of the fires in heritage buildings in Sweden have been deliberately started, and (although not discussed in detail within this report) the same person could be responsible for a series of fires.

### **7.3 Experience documented from the case studies**

To provide input to the project, a case study involving six wooden churches in Sweden, recently protected with active fire protection systems was undertaken. The report summarises the authors impressions after visits to the churches included in this study. Furthermore, the installers, the fire protection consultants and the inspector of the system installations were interviewed. Finally, input was also gained from the users.

It should be pointed out that not all of the issues identified were from the six churches that were studied, although most were. During discussions with people associated with the churches included in this study, experience from other heritage buildings in Sweden was also brought up by the people interviewed. No distinction has been made between relevant information from the churches studied in detail and that pertaining to other similar heritage buildings discussed in the interviews. The various issues raised have been considered equally important to document and discuss.

The main impression from the study is that all the system installations exhibit impressive performance and the installations are very discreet. However, in some cases it can be concluded that the level of system complexity is very high, especially for the churches where different system technologies have been used for the protection of the interior and the exterior. Modern technology offers technically sophisticated solutions, but in some cases, there is a risk that simpler and more straightforward solutions may be overlooked.

There are at least six cases of unintentional system activations. An alarmingly high number relative to the small number of (approximately ten) system installations and the short total time they have been in service, from 2004 to present. The reason for all these activations can be traced back to the fire detection system and three of the cases occurred as the temperature rating of the linear heat detection wires was too low as they were, at least partly, exposed to direct sun light. Fortunately, only little or very limited water damage has been reported. All cases involved the accidental activation of deluge sections on the outside of the buildings.

A number of unintentional fire alarms, for miscellaneous reasons, were documented. Some are 'typical' for fire detection systems installations, some are not. One case where leakage from the sprinkler system found its way in to a smoke detector and caused an unintentional fire alarm was documented.

Functional tests are exceptionally important in order to uncover any functional problems associated with the system. Several cases where systems failed to operate during testing were documented. It should be noted that such functional tests should be conducted regularly, not only prior to the commissioning of the system. Further, a functional test should be a test where activation of the system is simulated, e.g. the systems inspectors test valve is opened, a fire detection device is activated, etc and one confirms that the pump unit starts and runs properly, that the system pipe-work is pressurised and, if practically feasible, that water is distributed properly from the sprinklers.

The cold climate in the Nordic countries almost always requires that parts of the sprinkler system used for the protection of heritage buildings are of the dry-pipe or deluge system type or that an antifreeze solution is used. Experience from installations in Norway indicates that freezing is one of two main factors causing accidental activations of systems. The other reason is system complexity. Several of the churches that were studied utilize the possibility to manually flush the system piping with compressed air after the water is turned off. However, it should be pointed out that it is important that flushing be undertaken immediately after system shut-down, if the ambient temperature is low. The

technique requires a high air compressor capacity. For the churches studied the capacity was in the order of 700 – 900 L/min at 10 bar.

The use of an antifreeze solution increases the complexity of the system and the required maintenance work. Another drawback is that antifreeze solutions may leak and are definitely distributed during the activation of the system. The interior and inventories in heritage buildings are especially vulnerable to any damage from the antifreeze solution, as documented during the installation in the Habo church.

## **7.4 Additional research, testing or development needs**

A central part of this project has been the discussion of issues where additional research, testing or development work is desired. The following issues should be investigated in more detail:

- Water discharge densities and design areas relevant for heritage buildings.
- The protection of outside facades and roofs.
- Fire detection for facades and roofs.
- Flashover prevention systems.
- Water exposure to vulnerable paintings and décor.
- The use of antifreeze.
- System reliability.
- Alternative water supplies.
- Streaming of water in cold sprinkler piping.

The list is given without any particular order of importance. Additional information and experience relevant for the specific issue is given within the body of the report.

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## Appendix A: Hedareds Stave Church

### A general description of the church

Sweden's only preserved medieval stave church is situated in Hedared, in the Sandhult municipal area approximately 15 km outside of Borås. The characteristics of stave churches are the building construction that consists of vertical timber that are cut or planks. For the oldest churches, the lower part of the timber was buried in the ground. Stave churches were mainly used in Sweden and Norway as heirs to pre-Christian cult temples and shrines using similar methods of construction, but isolated stave churches was also built in Denmark and on Iceland, although none is preserved.

The church was for many years considered as being from the early Middle Ages (1200 to 1400 centuries) as the construction represents an older, slightly more primitive, style. However, a dendrochronological investigation of the timber has shown that it was cut somewhere between 1498 and 1503, with 1501 as the most likely year. This dating is corroborated by a Bishops letter from 1506 where the construction of the church is mentioned. It is, however, likely that there was a stave church in Hedared already during the early Middle Ages, that due to damages from wood rot was replaced by a new church built with the same construction technique. In conjunction with the construction of the church in Sandhult in the 1830's, the existence of the stave church was threatened, due to a decree from Stockholm. But the parishioners refused to tear down the church and continued untiringly to repair and maintain it.

The church was fitted with a new facade and windows in 1781 and a church porch was built. However, during a restoration of the outer parts of the church in 1901 the outer facade and the porch were removed, with the intent, to as far as possible, re-establish the origin. In addition, the outer roof made from hand-splinted pine wood was changed. During a restoration in 1934-35, a medieval altar-piece painted directly on the wall was discovered. The painting visualised the coronation of the Virgin Mary. The painting was assumed to be from the end of the 1300's and was probably covered during a restoration of the interior in 1735. The church porch was reconstructed as soon as 1996 – 97 and the facade was boarded and a new roof was laid. The church still contains medieval relics and beautiful, old paintings.

### The system installation

<b>Year of installation</b>	2003 – 2004
<b>General description</b>	<p>The church is fully protected, including the interior, the attic as well as the outer facades and the roof with a high-pressure (80 bar) system of the deluge type (open nozzles).</p> <p>The system consists of a water supply in a separate, adjacent (new built) building, connected to a ground main that supplies the section valves of the system. The deluge section valves are installed in a small, insulated and heated cabinet situated close to the church, from which smaller piping leads to different parts of the church. This piping is exposed and therefore subject to freezing.</p> <p>Activation is achieved through a separate fire detection system connected to solenoid operated section valves. This function has been chosen to provide an early activation, thereby limiting fire and smoke damages. The choice of having this type of activation was supported by the small size of the church.</p> <p>Sprinkler nozzles are also positioned under the overhang of the roof. The intention is to wet the facade walls and particularly important to block heat under the overhang, to prevent fire from spreading to the attic. In addition, sprinklers were installed on top of the wooden roof with the intention to distribute water over the roof.</p>

<b>Number of sections</b>	The system consists of a total of eight sections, as per follows: Interior: One section. Attic: One section. Facades: Four sections, one section for each facade. Roof: Two sections.
<b>Fire detection system</b>	Different parts of the church utilize different fire detection techniques that activate the corresponding sprinkler section: <u>Interior:</u> Smoke detection with single spot detectors and an aspirating system for early smoke detection. <u>Exterior:</u> Linear heat detection wires under the roof overhang and on the roof.
<b>Piping and tube</b>	The ground main consisted of a 30 mm tube. Ø25 mm piping was used for feed lines with Ø12 mm piping to the sprinklers. All piping was made from stainless steel and joined with compression ring fittings, which enabled the installation to be carried out without hot works.
<b>Type of nozzles</b>	Non-automatic (open) nozzles.
<b>Water supply</b>	The pump unit is situated in a (newly built) building outside the church yard. The building is insulated and heated. In this building a water tank is installed. The pump unit consists of a gas driven pump (GPU), using pressurised air. The pressurised air is stored in 50 L pressure cylinders pressurized to 200 bars.  The amount of water is enough for a continuous discharge duration time of at least 30 minutes.
<b>Power supply</b>	As the pump is powered by pressurised air, no secured electrical power supply is needed for system operation.
<b>Approvals</b>	The sprinkler system, including system components is type approved by VDS for Ordinary Hazard 1 occupancies.
<b>Manual fire-fighting</b>	A fire hose reel with semi-rigid hose is positioned inside the cabinet for the system section valves.
<b>System make and system installer</b>	Marioff HI-FOG, Marioff Corporation Oy

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**Selected photos**



*Hedareds stave church.*



*The new built building outside the church yard that contains the gas driven pump (GPU) and the water reservoir.*



*The insulated and heated cabinet containing the section valves of the system and a fire hose reel.*



*The inside of the cabinet containing the section valves and a fire hose reel. Photo: Anders Lönnermark.*



*Insulated and heated cabinet containing a fire hose reel.*



*The interior of the church.*



*The medieval alter-piece inside the church that is painted directly on the wall.*



*One of the high-pressure water mist nozzles and a fire detector at the ceiling.*



*Visible but discreetly installed piping inside the church.*



*The attic of the church. Photo: Anders Lönnermark.*





*High-pressure water mist nozzle and pipe-work inside the attic of the church. Photo: Anders Lönnermark.*



*High-pressure water mist nozzle and linear heat detection wires on one of the facades.*



*Functional test of one of the sections that protects the facades of the church. Wind velocity was high during the test; however, the water spray from the nozzles was not significantly affected. Note: The water spray provided a more uniform and higher degree of wall wetting than indicated by the photo. Photo: Anders Lönnermark.*



*Functional test of one of the sections that protects the facades of the church. Photo: Anders Lönnermark.*

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## Appendix B: Frödinge Church

### A general description of the church

The church is situated in Frödinge, approximately 10 km east of Vimmerby in Småland. The current church was built in 1739, but it is likely that the building was preceded by two other churches. The first was probably destroyed by fire at the end of the 1300's and the second church was built soon after. However, this building was severely damaged by wood rot and was replaced by the existing building in 1739.

The interior is octagonal with a rectangular sanctuary facing East, and has a flat, horizontal inner ceiling. The outer roof was constructed from hand-splinted pine wood. The interior ceiling and walls were decorated with paintings.

A church porch was built in 1757 on the West side of the church. This part was also built from wood and covered with hand-splinted pine wood. The church was maintained and repaired during the 1800's and the first major restoration was made in 1904. In 1939 plans to restore the church to its original conditions were drawn up, but it was not until 1950 that a vast reverential restoration took place. Under the first part of the 1990's another larger restoration was undertaken. The paintings on the walls and ceiling in the sanctuary, sacristy and church porch were conserved. The exterior of the church was restored in 1994, when the roof was repaired and painted, drainpipes and gutters changed, windows and doors painted red instead of grey, etc. In 2003 – 2004 the work of improving the fire- and burglar protection was initiated.

### The system installation

<b>Year of installation</b>	2005 – 2006
<b>General description</b>	<p>The church is fully protected; the interior, the attic, the outer facades as well as the separate bell tower. The roof of the church is, however, covered by steel plates and is therefore not protected.</p> <p>Two different, separated and independent systems are used:</p> <ol style="list-style-type: none"> <li>1) A high-pressure (100 bar) automatic dry-pipe water mist system with automatic nozzles that protects the interior and the attic, and,</li> <li>2) A low-pressure (sprinkler system) with deluge sections with open sprinklers for the facades and for exterior of the separate bell tower. The interior of the bell tower utilize a dry-pipe system with automatic sprinklers.</li> </ol> <p>The water supply is placed in a separate, adjacent (new built) building, connected to a ground main that supplies the section valves of the system.</p> <p>The section valves are installed in the adjacent building that is insulated and heated, from where smaller piping leads to different parts of the church. This piping is exposed and therefore subject to freezing. A dry-pipe valve is installed in the separate bell tower.</p>
<b>Number of sections</b>	<p>The system consists of a total of six sections, as per follows:</p> <p>Interior and attic: One section (i.e. the high-pressure part of the system)</p> <p>Facades: Four sections, one section for each of the facades and one section for the bell tower (i.e. the low-pressure part of the system).</p>
<b>Fire detection system</b>	<p>Different parts of the church utilize different fire detection techniques:</p> <p><u>Interior:</u> An aspirating system for early smoke detection inside the church room combined with a smoke detection system with single spot detectors for the other parts of the church.</p> <p><u>Exterior:</u> Pneumatic heat detector lines under the roof overhang. This system</p>

	activates the deluge sprinkler system valves when the air pressure is reduced as the plastic line burns through and provided a fire alarm.
<b>Piping and tube</b>	The ground main consists of a 22 mm tube. Ø12 mm piping to the sprinklers. All piping is made from stainless steel and joined with compression ring fittings, which enabled the installation to be carried out without hot works.
<b>Type of nozzles</b>	<u>Interior:</u> Automatic, K=2,0, K=1,3 or K=0,8 nozzles, utilizing 57°C, 2 mm glass bulbs. <u>Exterior:</u> Non-automatic (open), K=38 or K=80 sprinklers, dependent on the height of the facade.
<b>Water supply</b>	The pump unit and a water tank are situated in a newly built building close to the church. The building is insulated and heated. The water tank capacity is 100 m <sup>3</sup> and is automatically re-filled from the public water main when the level of water goes below a certain level. Half of the capacity of the water tank (50 m <sup>3</sup> ) is reserved for the fire department.  <u>High-pressure pump unit:</u> The high-pressure pump unit consists of two high-pressure pumps and two electrical motors, respectively.  <u>Low-pressure pump unit:</u> Two electrically driven centrifugal pumps.  The quantity of water in the fresh water tank is by itself sufficient for a continuous discharge duration time of at least 60 minutes. Note that the separate building for the water supply not was built at the time of the visit.
<b>Power supply</b>	The pump units are fed from the public electrical network. However, this is not sufficient for feeding all pump motors; therefore a separate diesel generator is installed.
<b>Compressed air supply</b>	The air compressor for the dry-pipe pipe sections of the system is installed inside the separate building described above. The air is de-humidified to prevent freezing.
<b>Approvals</b>	The sprinkler system, including system components, is type approved by different marine classification societies.
<b>Manual fire-fighting</b>	One cabinet with fire hose reels with semi-rigid hoses is positioned close to the church. The water is supplied from the one of the sprinkler sections.
<b>Special features</b>	System activation at ambient freezing temperatures may make the system inoperable when the water is turned off. Therefore, all parts of the system piping can be flushed with compressed air. The part of the system with automatic nozzles is further divided into smaller sections, where the end of the system piping has a ball-valve. This valve is opened during flushing. For the deluge sections on the facades, no additional valves are needed; remaining water is flushed out through the open nozzles.  Complete flushing required a special nozzle connection. Instead of a traditional T-connection, a Y-connection was developed. This connection limits the amount of standing water at the inlet of the nozzles.
<b>System make and system installer</b>	Ultra Fog AB Installationsbolaget Sprinkler AB

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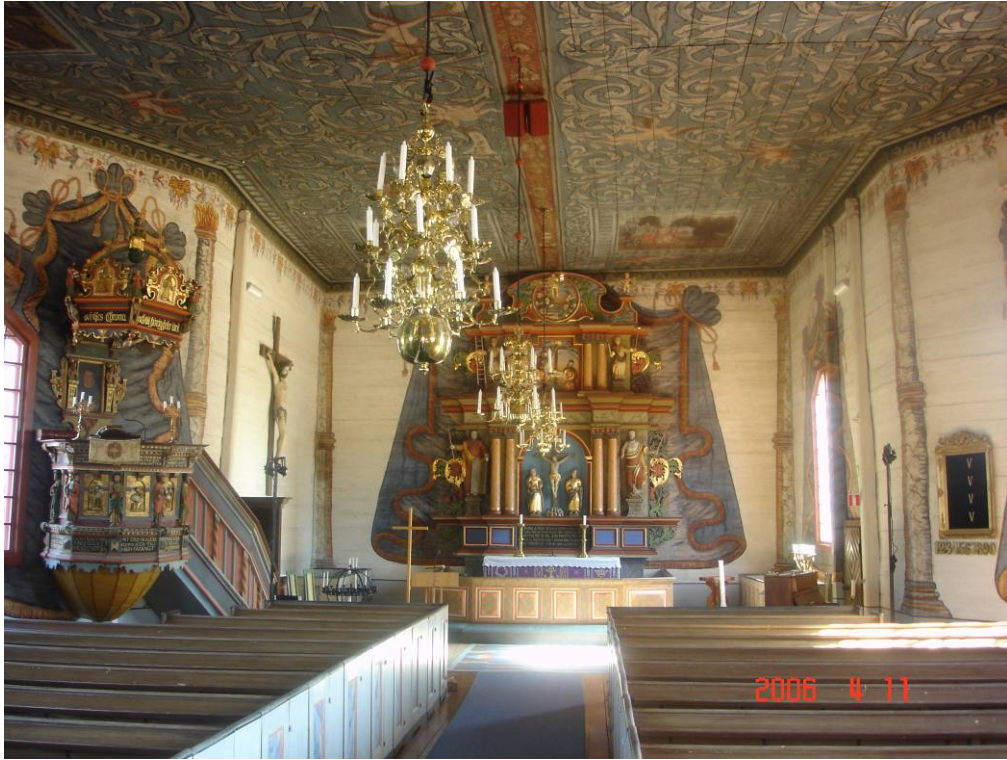
**Selected photos**



*The Frödinge church.*



*The separate bell tower.*



*The interior of the church. The nozzles at the ceiling are almost impossible to discover from the floor level.*



*Visible, but discretely installed high-pressure piping.*



*Close-up photo of one of the high-pressure water mist nozzles at the ceiling.*



*One of the high-pressure water mist nozzles at the ceiling, seen from a distance.*



*High-pressure water mist nozzles protecting the attic of the church. Note that Y-connection is used instead of a traditional T-connection. This connection limits the amount of standing water at the inlet of the nozzles and improves the possibilities to flush the piping with compressed air after an activation.*



*Pipe-work, inside the attic of the church, for the sprinklers protecting the facades. A stainless steel main pipe connects to the copper piping on the outside of the building.*





*The copper sprinkler piping for the sprinklers protecting the facades. Note: The colour of the pipe will become darker with time, making the pipe less visible, which is the reason for choosing copper over stainless steel. Standard (upright) spray sprinklers, positioned horizontally, are used.*

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## Appendix C: Älgårås Church

The church in Älgårås is situated approximately 20 km south-east of Hova in Västergötland. The church is a red-painted, shingled timber building with a squared east end. The western part of the church is medieval, dating from 1460-1469. It was extended eastwards in 1684 and the ridge turret was added in 1735. The interior, especially the inner ceiling, has paintings covering the whole chancel. These paintings were made in 1735. The sacristy was erected in 1706 and restored in 1966.

An extensive restoration was undertaken in 1929 where the interior paintings were conserved. During excavations underneath the church, made in 1979, foundations of the presumably oldest church on the site were found, dating from the 13<sup>th</sup> century.

### The system installation

<b>Year of installation</b>	2005
<b>General description</b>	<p>The church is fully protected with high-pressure (100 bar) automatic water mist system, including the interior, the attic and ridge turret as well as the outer facades and the roof.</p> <p>For the interior a dry-pipe system that utilizes automatic nozzles is used. The exterior is protected by deluge sections with open nozzles.</p> <p>The system consists of a water supply in a separate, adjacent (new built) building, connected to a ground main that supplies the section valves of the system. The section valves are installed in the sacristy that is insulated and heated, from which smaller piping leads to different parts of the church. This piping is exposed and therefore subject to freezing.</p>
<b>Number of sections</b>	<p>The system is divided into a total of eight sections, as per follows:</p> <p>Interior, attic and ridge turret: One section (i.e. one alarm valve) with automatic nozzles.</p> <p>Facades and roof: Seven sections (i.e. seven deluge section valves).</p>
<b>Fire detection system</b>	<p>Different parts of the church utilize different fire detection techniques:</p> <p><u>Interior:</u> Smoke detection with single spot detectors and an aspirating system for early smoke detection.</p> <p><u>Exterior:</u> Linear heat detection wires under the roof overhang and on the roof. The fire detection system activates the corresponding system section valve.</p>
<b>Piping and tube</b>	<p>The ground main consists of a 42 mm tube. Ø28 or Ø22mm piping is used for feed lines with Ø12 mm piping to the sprinklers. All piping is made from stainless steel and joined with compression ring fittings, which enabled the installation to be carried out without hot works.</p>
<b>Type of nozzles</b>	<p><u>Interior:</u> Automatic, K=1,3 or K=0,8 nozzles, utilizing 57°C, 2 mm glass bulbs.</p> <p><u>Exterior:</u> Non-automatic (open) nozzles. K=2,0 nozzles for the higher parts of the facades and K=1,6 nozzles for lower parts.</p>
<b>Water supply</b>	<p>The pump unit and a fresh water tank are situated in a (newly built) building close to the church. The building is insulated and heated. The water tank capacity is 5500 L and is automatically re-filled from the public water main when the level of water goes below a certain level. The quantity of water in the fresh water tank is by itself sufficient for a continuous discharge duration time of at least 10 minutes.</p>
<b>Power supply</b>	<p>The pump unit is fed from the public electrical network. However, this is not sufficient for feeding all four pump motors; therefore a separate diesel generator is installed.</p>
<b>Compressed air supply</b>	<p>The air compressor for the dry-pipe pipe section of the system is installed inside the separate building described above. The air is de-humidified to prevent freezing.</p>
<b>Approvals</b>	<p>The sprinkler system, including system components is type approved by different marine classification societies.</p>
<b>Manual fire-fighting</b>	<p>Two cabinets with fire hose reels with semi-rigid hoses are positioned close to the church. The water for these hoses is taken from the public water main.</p>

<b>Special features</b>	<p>System activation at ambient freezing temperatures may make the system inoperable when the water is turned off. Therefore, it is possible to flush all parts of the system piping with compressed air. The part of the system having automatic nozzles is further divided into two smaller sections, looped back to the sacristy, where the end of the system piping have a ball-valve. This valve is opened during flushing. For the deluge sections at the facades and the roof, no additional valves are needed; remaining water is flushed out through the open nozzles.</p> <p>Complete flushing required a special nozzle connection. Instead of a traditional T-connection a Y-connection was developed. This connection limits the amount of standing water at the inlet of the nozzles.</p>
<b>System make and system installer</b>	<p>Ultra Fog AB Installationsbolaget Sprinkler AB</p>

### Sources of information

Erland Lagerlöf, "Älgårås kyrka", andra reviderade upplagan, 2005 (in Swedish)

Personal communication with Anders Kjellberg, Ultra Fog AB, Jan G Andersson, Elplanering Väst  
Jan G Andersson AB and Conny Nabrink, Installationsbolaget Sprinkler AB.

**Selected photos**



*Älgårds church (facade towards West).*



*Älgårds church (facade towards South).*



*The newly built building close to the church that contains the pump unit, diesel generator and the fresh water tank. The building is insulated and heated.*



*The high-pressure pump unit and the diesel generator (in front). Photo: Jan G Andersson.*



*The section valves and the valves (at the right hand side wall) that are opened when flushing the system pipe-work with compressed air. All equipment is installed in the sacristy. Photo: Jan G Andersson.*



*One of the cabinets that contains a fire hose reel. Indicator lamps on the cabinet show which part of the church was the source of the fire alarm.*



*The interior of the church.*



*One row of automatic nozzles positioned close to a wall. These nozzles have a smaller  $K$ -factor as compared ( $K=0,8$ ) as compared to the other nozzles used for the interior, in order to limit the amount that hits the walls paintings.*



*Two of the nozzles installed to protect the facade; the nozzle to the right is directed towards the corner in order to achieve additional protection against fire spread up the corner walls. The piping has been painted red to make the pipe as discreet as possible. Note the linear heat detector wire.*



*The picture shows a functional test of the system, where several sections that protects the facades and the roof was simultaneously activated. Photo: Jan G Andersson.*

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## Appendix D: Habo Church

### A general description of the church

The church is situated in Habo, approximately 20 km north-west of Jönköping in Västergötaland.

The parish of Habo dates back to the middle ages. The first missionaries came to the area in the 11<sup>th</sup> century and it is believed that the first church was built in the 12<sup>th</sup> century. Since then the church has been rebuilt several times. The baptismal font dates from 1250 and the alter-piece is from the 14<sup>th</sup> century. During the 17<sup>th</sup> century the church had a cruciform shape and a parochial seal from 1622 shows the church with a central tower, flanked by ridge turrets. This church is, therefore, at least partly medieval. The church was rebuilt in 1680. The western part of the church was then given its present form.

The present church is one of the largest timber churches in Sweden and was built in 1723. The church is sometimes called “The Wooden Cathedral” and is unique in that the architecture resembles a cathedral, but is built entirely from wood. There are no bells in the church tower; it is only an ornament. The bell tower in the church yard was built in 1760 and contains three bells. The two larger bells are presumably from the 16<sup>th</sup> century and have both been recast, the small bell was cast in Jönköping in 1760. The church was restored in 1872, 1908 and during the 1950's, but no major alternations have been made.

### The system installation

<b>Year of installation</b>	2005 – 2006
<b>General description</b>	<p>The church is fully protected, including the interior, the attic, the church tower as well as the outer facades. In addition, the adjacent bell tower is fully protected. The roof of the church is not protected as it is covered by non-combustible material, i.e. steel plates.</p> <p>Two different, separated and independent systems are used:</p> <ol style="list-style-type: none"> <li>1) A high-pressure (80 bar) automatic wet-pipe (with antifreeze) water mist system with automatic nozzles that protects the interior, the attic and the church tower, and,</li> <li>2) A low-pressure (sprinkler system) with deluge sections with open sprinklers for the facades of the church and the exterior of the separate bell tower. In addition, parts of the interior and the bell tower are protected with a dry-pipe system with automatic sprinklers.</li> </ol> <p>The system consists of a water supply in a separate, adjacent (new built) building, connected to a ground main that supplies the section valves of the system. The dry-pipe and deluge section valves of the low-pressure (sprinkler) system are installed in space under the church from where smaller piping leads to different parts of the church. A dry-pipe valve is installed in the separate bell tower. The section valve for the high-pressure system is installed inside the church.</p> <p>Activation is either automatic (the wet-pipe and dry-pipe sections of the system) or is achieved through a separate fire detection system that operate the deluge section valves.</p>

<b>Number of sections</b>	The system consists of a total of eight sections, as per follows: Interior, attic and church tower: One section. Facades of the church: Four sections, one section for each wall. Church tower: One section. Bell tower: One section.
<b>Fire detection system</b>	<u>Interior:</u> Smoke detection with single spot detectors. <u>Exterior:</u> Pneumatic heat detector lines under the roof overhang and on the roof. This system activates the deluge sprinkler system valves when the air pressure is reduced as the plastic line burns through and provides a fire alarm.
<b>Piping and tube</b>	The ground main for the high-pressure system consisted of a 30 mm tube and the ground main for the low-pressure (sprinkler) system of a 150 mm tube.  All piping for the high-pressure system was made from stainless steel and joined with compression ring fittings. For the low-pressure (sprinkler) system, all piping in excess of Ø65 mm was made from stainless steel, welded together. Copper pipes, joined with compression ring fittings, were used for smaller pipe dimensions.
<b>Type of nozzles</b>	High-pressure system: Automatic, K=2,0 nozzles, utilizing 57°C, 2 mm glass bulbs. Low-pressure (sprinkler): Non-automatic (open), K=80 sprinklers and automatic, K=80 sprinklers, utilizing 68°C, 5 mm glass bulbs.
<b>Water supply</b>	The pump units are situated in a newly built building outside the church yard. The high-pressure pump unit consists of a gas driven pump (GPU), using pressurised air. The pressurised air is stored in 50 L pressure cylinders pressurized to 200 bars. Two separate and redundant centrifugal pumps with electrical motors are used for the low-pressure (sprinkler) system.  The building does also contain the water reservoir for the system, containing 100 m <sup>3</sup> of water. Half of this amount is reserved for the fire department, the remaining amount of water is enough for a discharge duration time of at least 60 minutes.
<b>Antifreeze</b>	An antifreeze solution, consisting of a mixture of organic salts, is used for parts of the system.
<b>Power supply</b>	As the high-pressure pump unit is powered by pressurised air, no secured electrical power supply is needed for system operation. The centrifugal pumps are backed-up by a diesel generator.
<b>Approvals</b>	The sprinkler system, including system components is type approved by VDS for Ordinary Hazard 1 occupancies. The low-pressure (sprinkler) system components are approved by VDS, LPC, etc.
<b>Manual fire-fighting</b>	A fire hose reel with semi-rigid hose is positioned outside the church.
<b>System make and system installer</b>	Marioff HI-FOG, Marioff Corporation Oy AT Brandskydd AB

### Sources of information

”Medeltida träkyrkor II”, av Erland Lagerlöf (1985)

”Habo church, A guide book”

Personal communication with Didrik Tollander, Marioff Skandinavien AB, Jan G Andersson, Elplanering Väst AB and Alf Thors, AT Brandskydd AB.

Selected photos



*The Habo church.*



*The Habo church.*



*The separate bell tower.*



*The newly built building close to the church that contains the pump units, the diesel generator and the fresh water tank. The building is insulated and heated.*



*The gas driven pump (GPU) used for the high-pressure water mist system.*



*The electrical centrifugal pumps used for the low-pressure (sprinkler) system.*



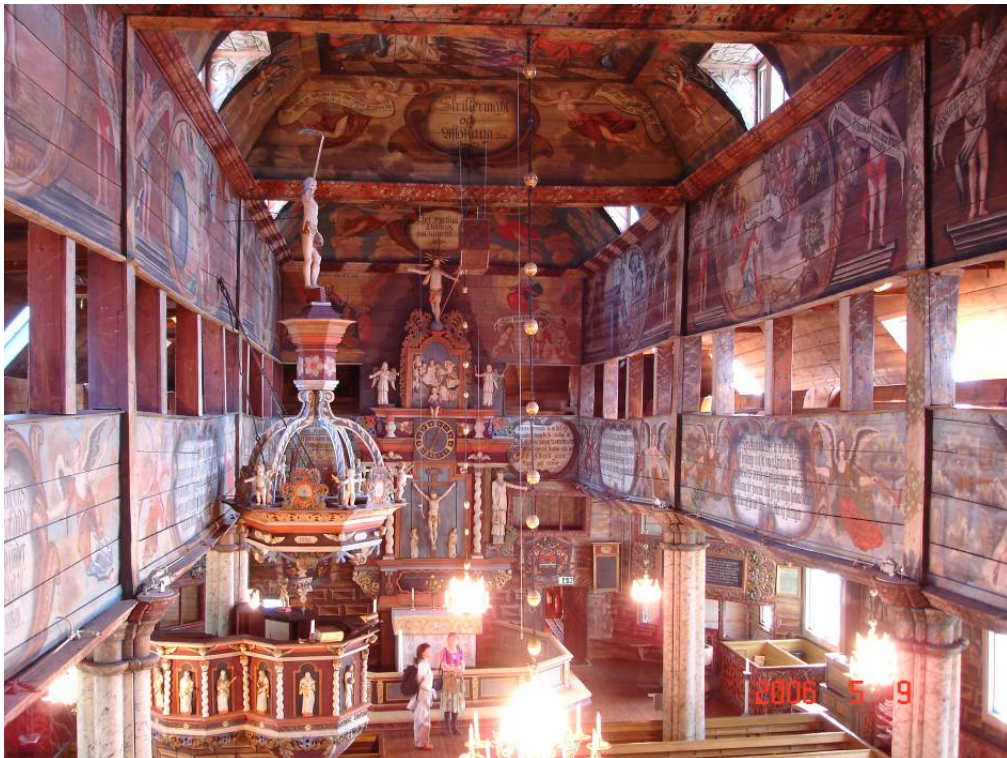
*The diesel generator.*



*The deluge and dry-pipe valves used with the low-pressure (sprinkler) system. This equipment is positioned inside the church.*



*The section valve for the high-pressure water mist system.*



*Interior of the church. Note the sprinkler piping on each side of the balconies. The high-pressure water mist nozzles at the ceiling are not visible from floor level.*



*Discreet installation of a high-pressure water nozzle.*



*The high-pressure water mist nozzle pictured above, with its piping.*





*Some of the piping could not be concealed, but are discretely installed.*



*The small diameter piping typically used with high-pressure systems offers the possibility of discreet installations.*



*Installation of the high-pressure system inside the attic of the church. The activation of a group release valve (at the top) activates one nozzle on either of the vertical branch lines. In addition, a separate, automatic, pendent nozzle may activate independent of the group release valve.*



*Photo from inside the attic. The copper piping connects to the pipe-work for the sprinklers protecting the facades. The smaller copper piping connects to the pneumatic linear heat detection system for the facades.*



*One of the (open) sprinklers used to protect the facade.*



*Sprinkler (open) used to protect the facade, with the pneumatic linear heat detection lines.*



*Sidewall sprinkler inside the church installed using copper piping.*



*Functional test of the deluge system that protects the bell tower.*

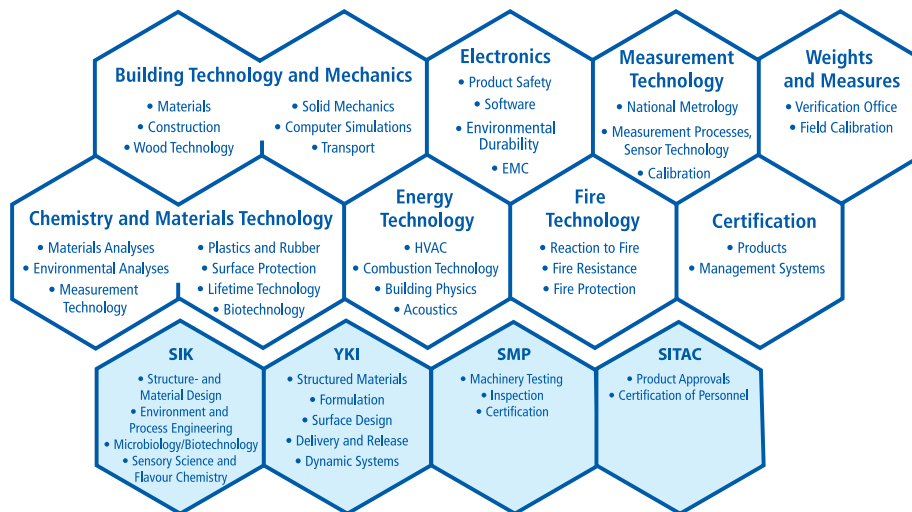


*Functional test of the deluge system that protects the bell tower.*

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