Fire performance of escape route doors in cultural heritage buildings A state-of-the-art review

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A state-of-the-art review

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Abstract

The aim of this project was an inventory of the upgrading of old wooden doors for improved fire performance, to identify the key issues and find possibilities for the future.

Expected benefit was an update of knowledge, as a preparation for reworking guidelines for improvement of fire resistance of old paneled doors as important parts of historic interiors.

Technical solutions for fire rating as well as matrix-based risk assessment approaches for fire performance of timber doors in cultural heritage buildings are presented. A thesis that question the established interpretation of the fire safety regulations by looking into the cost-benefit ratio of upgrading is also presented.

Further fire-testing of doors can serve as a basis for a revision of guidelines. Also, the implementation of a more risk-based approach to fire threats in old apartment houses and further investigations of the numbers behind interpretations of regulations - which fire safety measures that give the best effect/cost-benefit ratio – could be useful for the fire safety work in stairwells in the old apartment buildings.

The results of the project are highly relevant at a regional and national level.

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Table of contents

1 Introduction

The purpose of this report was to get an overview of the state-of-the-art of fire performance of old timber doors and their weaknesses as presented in Norwegian reports and fire tests; of guidelines used for upgrading, and of laws and regulations relevant to the upgrading of existing doors.

The project is of value to the culture heritage management, authorities responsible for building quality and fire safety, respectively, fire and rescue services, the consulting industry, building owners, residents and the public in general.

2 State of the art

2.1 Type of doors

The doors which this report concerns are original stairwell doors in older brick apartment houses of cultural heritage value, which can be found in the larger cities of Norway. The old brick apartment houses have walls of load-bearing bricks, wooden beams and roof structures in wood and many of them are categorized as cultural heritage. In Oslo there are around 4000 such buildings, of which many still hold preserved original stairwell doors, and Trondheim, Bergen and Ålesund also have many old brick apartment buildings. In addition Trondheim, Oslo and Bergen have several wooden apartment buildings with the same kind of doors [1]. Because of their construction the old apartment buildings are vulnerable to fire and need fire protection upgrades. The stairwell doors are critical elements to prevent fire spread and to keep evacuation routes safe, so their function and condition are important to the level of fire protection in the building.

Rich decorations and the large glass fields against common areas make these doors a major part of the architectural expression of an older apartment building [2]. In the brick houses that still have the original stairwell doors between apartments and stairwells, these are usually nicely decorated wooden filling doors. The lower part of the door leaf has a wooden panel, while the upper part of the door leaf is often fitted with glass panels. Many doors also have a glass panel above the door leaf. The glass panel originally used ordinary glass, often with an "acid-etched" decorative pattern. Such glass had very poor fire resistance, which was made visible by several serious fires in Oslo in the 1920s and early 1930s. In 1936 a supplement to the Fire Act led to a large-scale process were the old glass was required to be replaced with wired glass [3].

2.2 Laws, regulations and guidance documents

The fire protection of buildings in Norway is regulated by the Fire and Explosion Prevention Act brann- og eksplosjonsvernloven) [4], the Planning and Building Act (plan- og bygningsloven) [5] and the Internal Control Regulations (internkontrollforskriften) [6].

According to § 18 in the Regulations on Fire Prevention (forskrift om brannforebygging), which entered into force in Norway in 2016, audits are required to be performed and prioritized on the basis of the 1) risk of loss of life and health, 2) risk of loss of material and cultural historical values, 3) risk of societal consequences, 4) risk of breach of preventive duties and 5) on the basis of the effect of audits as compared to other fire preventive measures [7].

To ensure a minimum level of safety for all existing buildings, the Regulations on Fire Prevention require the owner of a building to provide the necessary fire protection measures, [7]. The owner of a building is required to upgrade the safety level in the building so that it at least

corresponds to the level stated in Building Regulations 1985 (BF85)/ Building Regulations 15. november 1984 nr. 1892, or later building regulations. The safety of older buildings should be upgraded to the same level as for newer buildings, as far as possible within a practical and economically viable framework.

The Planning and Building Act [5], sets requirements for the technical construction of the building. The law comes into force in the event of building changes that are subject to application. Regulations on technical requirements for construction works (TEK17) [8] shall apply to those parts of the building covered by the change.

The most relevant points related to old stairway doors in The Planning and Building Act are §20-1 *Measures requiring application and permission* and chapter 31 *Requirements for existing construction works* (Dyrseth, 2014) [9]. Fire improvement of existing stairwell doors is not subject to application. However, if the doors are replaced, the measure is considered an intervention in fire separating structure and will trigger application obligation after the Planning and Building Act §20-1 (Korsaksel, 2009) [10].

A typical measure that has been implemented in many old brick apartment buildings in Oslo is the conversion of attic to dwelling. In such cases the requirements of the Planning and Building Act and TEK17 must be complied with, which leads to upgrading of escape routes and the installation of fire alarm systems in the building [9].

The preservation of cultural heritage buildings is governed by the Cultural Heritage Act [11] and the Planning and Building Act [5]. The Municipal Cultural Heritage Management Office has legal authority only in the stairwells in buildings protected by § 15 of the Cultural Heritage Act, and this applies to only a few dozen old brick apartment buildings in Oslo. For the rest of the buildings in question, the Oslo Municipal Cultural Heritage Management Office does not have direct influence on the choice of measures for upgrading. Most older brick buildings in Oslo are part of the Oslo Municipal Cultural Heritage Management Office's so-called "Yellow list", with a protection status as "conservation worthy". This protection status mainly imposes restrictions on changing the facades and does not necessarily impose restrictions in relation to interior alterations.

In the document “the Attic guidance” (Loftsveilederen) [12] it is stated that “in all older buildings, the main access to each apartment has a representative design. Entryways and stairwells, with all their details, from the entrance door and up to the ceiling, belong to the public part of the building. A roof extension might result in a penetration of the stairwell ceiling, and thereby a need for additional fire protective measures. It is important to avoid that cultural heritage values and details representing an epoque of the past are being removed or otherwise destroyed. Instead, the interventions should be made as small as possible, and the preservation of original elements should be ensured by compensatory measures, such as upgrading of existing doors and installation of fire alarms and fire extinguishers.”

If the original appearance of the stairwell shall be preserved, it put restrictions to building changes, and conservation interests may conflict with fire safety considerations [9]. Not

unexpected, there is a strong desire from the Oslo Municipal Cultural Heritage Management Office that original interior details are preserved. There is also a strong interest in preserving original interior details among many owners and occupants [2].

2.3 Fire protective measures for doors

As the original doors can perform poorly with regard to fire resistance properties, including smoke spread, they have formerly often been replaced by new fire rated doors. Using pre-accepted solutions such as changing the old doors to new fire rated doors may require less planning, though in many cases it will result in larger and more expensive interventions than necessary. If upgrading is done solely on the stairwell doors, the upgrading must be more extensive than if other measures are used. For buildings with antiquarian values an alternative analysis is recommended, where all conditions are considered in context. The chosen solution shall, overall, ensure a sufficient level of fire safety (“Veileder i forbindelse med branntilsyn”/ “Supervisor in connection with fire supervision”, Trondheim Municipality, 2020) [13].

Establishing a modern fire alarm system will often be the simplest measure to increase the level of safety of the occupants of the building. External fire escape stairways can be considered, however, since this means measures on the façade, this is not the first choice of the cultural heritage authorities [10].

Upgrading of existing doors can be done without losing the antiquarian values, and this is always recommended by cultural heritage authorities for old stairwell doors. From an antiquarian perspective, newly made "old style" doors cannot replace the aesthetic and historical qualities of an original door. Figure 2-1 shows an example where an original door has been replaced by a simple fire-rated door.

Figure 2-1 An example of replacement of unknown original door by a simple fire-rated door. Photo: B. Wedvik, NIKU, 2017.

Intumescent strips or smoke seals can be mounted in the edge of the door leaves and in the frame. The functionality of hinges, locks and handles must be considered. Most often the old details can be improved and customized. Glass panels over doors can be preserved by mounting fire rated glass on the inside. Other viable solutions include establishing an internal fire partition inside the entrance door, creating a front room, in order to preserve the existing door [13].

One way to keep the doors is by improving their fire performance through technical solutions to approximately 30 minutes of fire resistance, which is the desired goal achievement in the SINTEF Building Detail Sheet 734.503 (Byggdetaljblad) [14] and the withdrawn guideline from Oslo municipality [15].

However, the implementation of technical solutions to reach the required fire safety level still is a challenge to both fire safety and conservation interests since it would require e.g. replacing

original glass panels with fire rated glass, or covering decorated wood filling with materials of better fire resistance as well as using fire retardant paint that may alter the look of the door. Therefore, in order to achieve a "conservation-friendly" fire protection of the old apartment buildings, it is necessary to re-think about the choice of technical solutions.

The fire protective measures chosen for the door leaves are important for the keeping of the doors as cultural heritage. Measures that have great impact on the visual presentation of the doors are presented below:

Fire insulating board

This is a fire-technical improvement of old wooden filling doors where the door side to the apartment is covered by a fire-insulating board when parts of the door - most often mirrors, friezes or glass - do not meet the safety requirements, while the door side towards the stairwell is preserved as it is. An insulating board of plywood, chipboard or plaster is installed on the apartment side of the stairwell door, as is depicted in the left hand picture in Figure 2-2. The right hand picture in Figure 2-2 shows an example where the entire door area is covered by fire insulation boards. The original handle, hinges and astragal moulding are kept. In other examples of upgrading given in the SINTEF Building Detail Sheet 734.503 only the door lite and thinner wooden parts as panel and panel profiles are covered.

Figure 2-2 The picture to the left shows an example of door upgrading following The SINTEF Building Detail Sheet 734.503, stairwell side. The picture to the right is an example of door upgrading following The SINTEF Building Detail Sheet 734.503, apartment side. Photo: B. Wedvik NIKU, 2017.

Fire rated glass panels

Fire rated glass instead of insulating panels covering the light opening will make both sides of the original door visible and light penetration and space experience will be retained in the stairway. This can be done by replacement or by addition of fire rated glass to the original glass panel. Figure 2.4 shows a door set (righthand side) that is upgraded with fire rated glass by replacement of the old glass panes. However, the way of mounting new panes of glass in old timber doors has been given little attention in Norwegian reports and guidelines and should be looked further into with respect to the fire performance. Fire rated glass panes are normally heavier and thicker than the original glass panes. This can affect both method for mounting the glass panel in the rebate, and the size or number of door hinges to hold the door leaf. Tight mounting of the glass in the light opening and of the door leaf in the door frame is important to avoid smoke penetration. One example that shows concern about new fire rated glass panels in old wooden doors is a guideline from Intumescent Fire Seals Association. The guideline mentions challenges concerning tensions when mounting new glass panes in old glass openings: *Many monolithic clear glasses are incompatible with timber beaded constructions because they cannot accept the amount of insulation protection that a timber bead provides with the result that they break in the early stages of exposure. It is vital when selecting glass to ensure that it has test evidence in timber doors with beads of the size to be used* [16].

Fire retardant paint

Fire retardant (FR) paint applied to the thinner wood elements can increase the burn-trough time, so that panels decorated with woodwork such as elaborate profiles can remain exposed on both sides of the door. However, before using FR paints and varnishes it is important to clarify whether the FR paint products are documented effective for the type of application in question, for example on top of existing paint. The Norwegian Building Authority (DiBK) established a supervisory case for FR coating products in 2016, due to misleading marketing and lack of certifications [17]. For the keeping of the door's cultural heritage qualities, preserving the old layers of paint is preferred if possible. If the old paint must be stripped off down to bare wood before treatment with FR-paint, this could be done only where necessary, for example on the inside of the door and only on the thinner parts of wood. There is also a need for a way to measure and control that the correct amount, weight or thickness of FR paint required to achieve the required fire class is applied. Finally an inspection and maintenance plan for the paint should be implemented in the maintenance plan for the building [18]. A quality control system has been suggested for application of FR paint on-site by drilling small holes and measure the depth, according to Östman [19]. Figure 2.4 shows a door set (righthand side) that is upgraded by application of intumescent paint on all wooden parts on both sides of the door.

Additional measures

"Timber panelled doors and fire - upgrading the fire resistance performance of timber paneled doors and frames" [20] includes an appendix which describes different solutions for upgrading of only the joint area between panel and framing on door leaves, because those parts often are the thinnest parts and will be burnt through first. Solutions presented are with intumescent paste and heat resisting adhesive in the joints, fire resisting boards, steel fixing springs, glass board, intumescent sheet, intumescent coating and intumescent paper. In "Upgrading the fire resistance of floors and doors in heritage buildings" [21] solution with steel strips placed in slots in a moulded panel is presented.

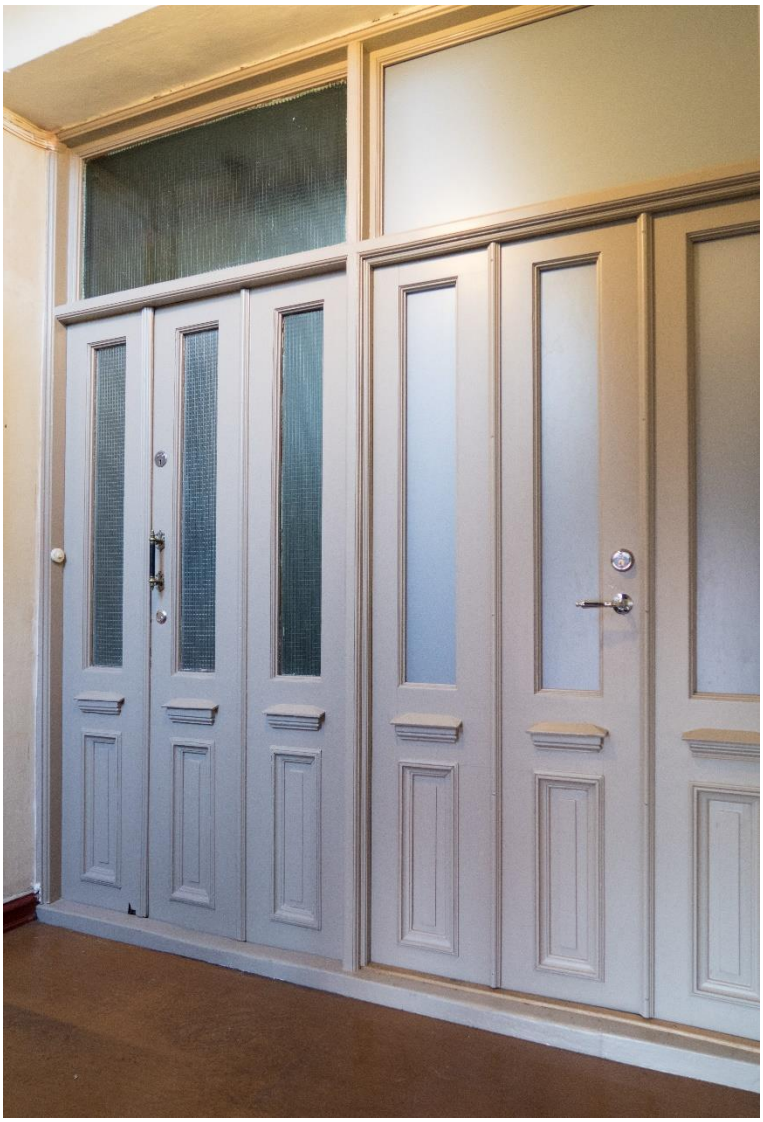

Figure 2-3 An example of door upgrading following the Oslo Municipal`s guide, stairwell side. The door set on the lefthand side is not upgraded but supplied with a fire safe inner door. The door set on the righthand side is upgraded by application of intumescent paint on all wooden parts on both sides of the door, and with fire rated glass with frosted films for privacy, mounted on the stairwell side. Photo: B. Wedvik NIKU, 2017.

2.4 Guidelines

In Norway two guidelines for the upgrading of old and historically important doors has been available from 2015, until the withdrawal of Oslo municipality's guideline in 2019. The guidelines are very similar; the main differences concern technical solutions on the door leaves.

The SINTEF Building Detail Sheet 734.503 "Fire-technical improvement of old staircase doors (SINTEF Byggdetaljblad 734.503 "Brannteknisk forbedring av gamle trefyllingsdører") first version published in 1983; current version from 2016 [14]:

SINTEF's guidelines describe a fire-technical improvement of old wooden filling doors; "Improvement is necessary for stairwell doors in older apartment houses where craftsmanship, aesthetic considerations and cultural heritage value make it desirable to keep existing doors." The guide shows technical solutions where one or both door sides are covered by a fire-insulating board when parts of the door - most often panel, moulding or glass - do not meet the safety requirements. SINTEF's guidelines also mention alternative solutions such as inserting fire-rated glass and painting with fire-retardant paints.

Oslo municipality's guideline was a consequence of the recognition by Oslo Municipal Cultural Heritage Management Office and others that a more conservation-friendly approach was needed, to be able to keep the glass panels, giving transmitted light in the stairways, and to take better care of the wooden details. The new guideline published by Oslo Municipality was written by Oslo Municipal Cultural Heritage Management Office and the Oslo Fire and Rescue Service. Oslo municipality's information sheet "Fire-technical improvement of conservation worthy staircase doors" (Brannteknisk forbedring av bevaringsverdige trapperomsdører) published in 2015, withdrawn 2019:

While SINTEF proposes, as the primary solution, the use of an insulating board (gypsum, plywood, chipboard) on the residence side of the door to increase the fire performance of old wood filling doors - also for doors with glass panels – Oslo municipality does not present this solution as an alternative. For increased fire resistance of thin wood, fire-retardant paint is proposed. For doors with fixed glass panels which do not have a satisfactory fire performance it is suggested to insert fire rated glass in the frame inside the old glass, or to upgrade by replacing the old glass with a fire rated glass.Those solutions are part of the reason for withdrawal of the leaflet, as they, in 2019, were considered to be too prone to human error by one of the co-writers, the Oslo Fire and Rescue Service. Other objections were that the information sheet does not take account of the overall fire safety of the building, and that compensatory measures for doors with less than 30 minutes of fire resistance are not considered.

In January 2020 The Trondheim Municipal Cultural Heritage Management Office published a supervisor to be used in connection with fire supervision [13]. This guideline will not be reviewed here as it does not give technical solutions for upgrading of doors. However, it should be mentioned as it states the need for a comprehensive fire strategy when finding solutions for the stairways in old brick- and wooden houses, and lists compensatory measures.

2.5 Review of previously reported studies

2.5.1 Studies on apartment brick buildings stairways and their doors

There are a few reports on apartment brick buildings and their stairways, this review focuses on what those reports say about the doors. The material presented is limited to Norwegian sources.

The Oslo Fire and Rescue Service's "Final report for the project "Fire safe town houses"" (Sluttrapport for prosjekt brannsikker bygård) [2]:

The aim of the project was to define the fire risk in the older brick town houses in Oslo, and to introduce fire engineering solutions for the older brick buildings that would provide both a satisfactory level of safety and which safeguarded the preservation interests associated with original building parts to a greater extent than pre-accepted solutions would do. The report states that the lack of fire safety measures in stairwells, including the use of original doors between stairwells and apartments, is the most serious fire-technical weakness in these buildings. Replacement of stairwell doors to doors with fire rating B30 (now EI 30) is the most common fire safety measure in older brick town houses to meet the fire safety requirements. Fire testing of an original stairwell door from an older brick town house was performed according to NS 3907 [22]. The purpose of the test was to compare the characteristics of the original door with the characteristics of a representative fire classified door of fire rating B30. The results of the test are presented later in this report.

The summary outlines two main upgrading principles:

1) Replacement of stairwell doors with fire rated doors with door pumps and installation of fire alarm systems where there is only one stairwell available from each apartment.
2) Installation of sprinkler systems in the building in order to be able to preserve original building parts and stairwell doors to a greater extent.

In the report it is stated that if the report were to be written again, the conservation interests would be even more emphasized. Sprinkler systems and other fixed extinguishing systems would have been more discussed to meet the need for fire protection of cultural heritage.

"Fire Protection - Stairwells in brick houses" (Brannsikring - Trapperom i murhus)[23]: This report is a literature review commissioned by the Norwegian Directorate for Cultural Heritage where the fire safety in connection with stairwells in brick buildings in the cities of Oslo, Bergen and Trondheim has been assessed.

In the report it was concluded that the design of stairwells in brick houses has less significance for the outcome of fire damage than what is assumed by regulations, guidance and general opinion. The decisive factor is the number of stairwells; if there are two separate or only one. Fire alarm systems are considered as the most important and most cost-effective measure, as first documented by Stenstad [3]. It is also said, based on the material reviewed, that the

common belief that safety increases substantially when upgrading stairwell doors to EI 30 or EI 60 is likely to be flawed. Jensen et al. suggests a broader survey to quantify the effect of those measures in practice, i.e. the level of fire safety achieved by such measures in stairwells in older brick houses [23]. This conclusion and proposal for further investigation was followed-up by Dyrseth in her master thesis:

”Upgrading the fire safety of older brick town houses” (Oppgradering av brannsikkerheten i eldre murgårder) [9]:

Dyrseth discusses what *upgrading within a practical and economically viable framework* means. Regulations on Fire Prevention [7] require that the safety of older buildings should be upgraded to the same level as for newer buildings as far as this can be done within a practical and economically viable framework. Dyrseth states, however, that there is no clear definition of which safety measures that can be included within this framework. In her thesis fire fatality risk has been converted to a FAR value[i] in order to assess the risk level against probabilistic acceptance criteria. Based on the results, it is argued that upgrading the fire safety level of the old brick apartment houses is not economically viable since large fatal fires are a relatively rare phenomenon. In fact, none of the evaluated fire safety measures are economically viable to implement. Sprinkler systems were the measure that gave the greatest reduction in risk, but this alternative has very high costs compared to other fire protection options. In order to reduce the risk in the brick apartment houses to an acceptable level, it is recommended that as a minimum solution a fire alarm system is installed in the building and smoke sealing strips are mounted on the doors. This will provide long enough available egress time and improve the safety for persons in the apartment of the fire origin. This solution also maintains the stairwell’s original appearance, and hence its antiquarian value.

According to Dyrseth, upgrading of the doors to EI 30 is not necessary; smoke sealing strips would be sufficient if there is a fire alarm system installed. Apartment buildings with above average number of residents and apartment buildings with only one accessible stairwell should be prioritized in the fire protection work.

2.5.2 Risk-based matrix for upgrading of doors

In the United Kingdom efforts have been made to develop matrixes for a risk-based approach for the upgrading of doors in cultural heritage buildings. The fire engineering report “Upgrading the Fire Resistance of Existing Historically Significant Doorsets - A Risk Assessed Approach” aims at providing evidence to support the ‘risk assessed’ approach for the assessment of the need to upgrade the fire resistance of existing historic doorsets. This is done to reduce the interference with the existent structure or materials), whilst ensuring safe evacuation and reasonable levels of fire separation within the built heritage. In the report it was suggested that further research may be used to prepare a matrix that would relate the onset of flashover to ventilation, room

[i] The fatal accident rate (FAR) is the expected number of fatalities per 100 million hours of exposure.

size and fire loads, so that a reduction in fire performance compared to a standard fire door may be allowed for [24]. In “The Upgrading of Fire Safety in Historic Buildings” a matrix developed by English Heritage (now Historic England) is described, intended as an assessment tool so that historic doors can be individually assessed for their effectiveness in resisting the passage of fire and smoke. The level of upgrading required on historic doors was determined by the effect of room size on fire growth [25,26].

In “Fire Protection - Stairwells in Brick Houses” (Brannsikring - Trapperom i murhus)[23], an upcoming project “Assessing fire resistance of timber doorsets” was mentioned. The development of a calculation tool to determine fire resistance of existing doors without dismantling them, especially with a view to preservation, was planned. The research project started in 2005, and a draft layout for the final report has been presented [27], however, the project was not finished. In 2015 the same company, COWI, made a check list for owners of old stairwell doors in buildings with a need for upgrading the fire safety. The aim of the check list is to assess the fire resistance of the door without inspecting it on site [28].

2.5.3 Fire- and smoke curtains

Fire- and smoke curtains have been used for upgrading a staircase room in Oslo, see Figure 2-5. This is a non-invasive solution and should be considered.

Two papers on historic buildings describe the use of fire- and smoke curtains. In "Innovations in conservation of heritage museums and libraries from fire hazards," [29] innovative solutions for establishing compartment lines in historic buildings are discussed. Smoke- and fire curtains are described as a high-performing solution. Five main types of smoke control curtains are listed here - elevator, vertical, horizontal, perimeter and draft. They are made of micronized aluminium polymer coated on both sides of the fabric and offer fire protection for 1-4 hours depending upon the grade of anodizing.

Curtains are also presented in “The Upgrading of Fire Safety in Historic Buildings” [25]: where examples of establishment of compartment lines by curtains in historic buildings are given. The examples given are curtains that are closed every night. It is also mentioned that automatic deployment of fire curtains can be linked to the fire alarm system.

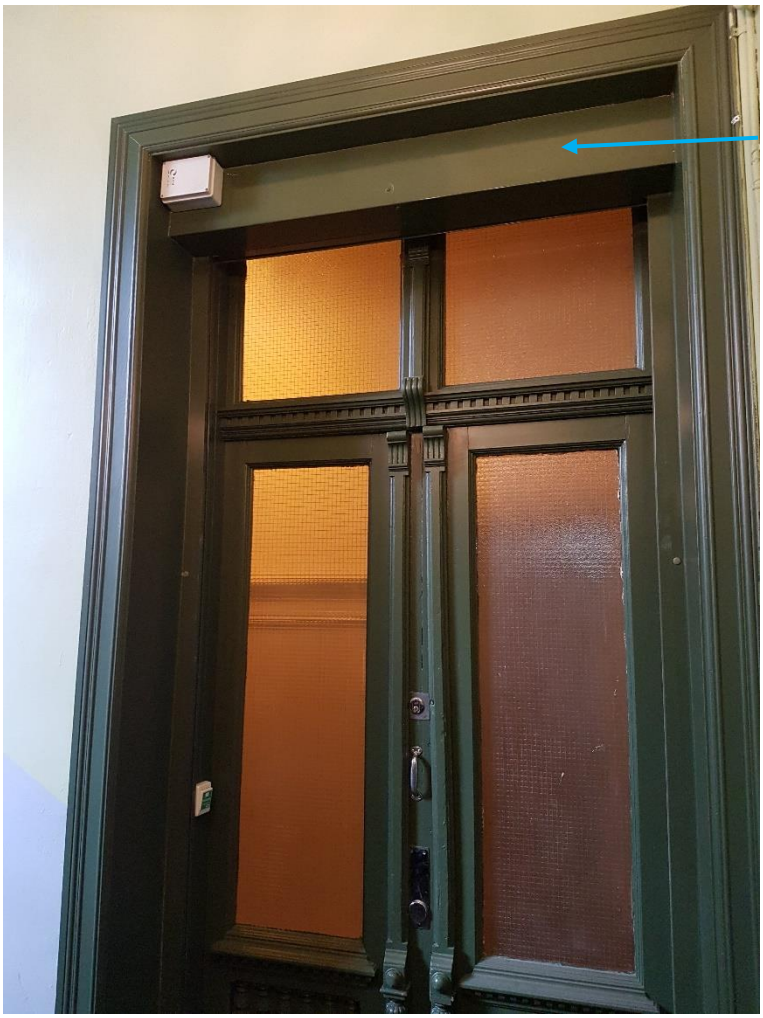

Figure 2-4 Fire curtains in front of stairwell door, Oslo. The fire curtain is inside the horizontal green box on the upper part of the door, see blue arrow. Photo: A. Korsaksel, Byantikvaren, 2018.

2.6 Fire testing of original doors

2.6.1 Fire classification

The pre-accepted perfomance of class EI_2 30 for doors means that they pass the requirements in EN 13501-2 [30] for integrity and thermal insulation for 30 minutes when tested according to EN 1634-1 [31].

E, Integrity: the doors ability to withstand fire exposure of one side only, without the transmission of fire to the unexposed side as a result of the passage of flames or hot gases.

The assessment of integrity is generally made on the basis of:

- Cracks or openings in excess of given dimensions
- Ignition of a cotton pad

- Sustained flaming on the unexposed side

I_2, Thermal insulation for doors: thermal insulation is the door's ability to withstand fire exposure on one side only, without the transmission of fire as a result of significant transfer of heat from the exposed side to the unexposed side. For a door, when I_2 is used, it means that the mean temperature rise on the unexposed face of the door leaf shall be limited to 140 °C above the initial mean temperature, with the maximum temperature rise at any point of the door leaf limited to 180 °C. No temperature measurements shall be taken into account on the door leaf within 100 mm from the border line of the visible part of the door leaf. The temperature rise at any point on the frame shall be limited to 360 °C, measured at 100 mm from the visible edge (on the unexposed face) of the door leaf.

If the door fails the integrity criterion it is also considered to have failed on thermal insulation, even if has not exceeded the temperatures mentioned above.

Some key differences between the test methods NS 3907 [22] and EN 1634-1 [31]:

- Requirements on the exposure direction, the direction of the door swing in or out of the furnace.
- Requirements on the supporting construction in which the door is installed during test.
- Instrumentation requirements, position of thermocouples.
- Test criteria, mainly temperature.
- Mechanical conditioning before test, e.g. opening/closing sequences and measurements of clearance between door leaf and frame.
- Use of plate thermocouple for oven control in EN 1634-1, encapsulated thermocouples in NS 3907, making exposure conditions difficult to compare.

2.6.2 Door tests reviewed

We have found only a small number of test reports where original doors have been tested and where results are published. These are mainly Norwegian. From Sweden, we have been informed that it is very unusual to document this issue by means of fire testing, and that fire safety engineers generally evaluate the fire safety level provided by the doors analytically with basis on the assumed fire safety level rendered by the fire protective paint.

"Fire testing of an original stairwell door with wired glass from an 1890-building/old building according to NS 3907)" (Brannteknisk prøving av en original trapperomsdør med trådglass fra en 1890-gård / eldre murgård i henhold til NS 3907) [32]: An original stairwell door from an "1890-building" was tested. Some deviations were made in the test set-up with regards to thermocouple positions at assumed weak spots on the door. Summary of test results: Smoke penetration in connection to the glass window, after only 30 seconds into the test, and large amounts of smoke from around the door after 90 seconds. The glass (original) cracked and was thus a weak spot. From this area there were also some visible flames (although initially no

sustained flaming). The test was interrupted after 23 minutes (with sustained flaming after 10 minutes into the test) due to integrity failure.

The bachelor thesis "Guides to estimate fire resistance on old wood filling doors" (Føringer for å anslå brannmotstand på gamle trefyllingsdører) [33]: Two doors, including door frames and mounted in a gypsum wall were tested simultaneously with basis in NS 3907. One of the doors was "upgraded" with different fire protection measures (expanding strips in milled tracks in the doorwing, a rubber seal on the door frame, fire protective coating on two of the four door shuts, and the other two door shuts were covered with 0.9 mm steel plates using ceramic insulation underneath, in the recesses of the door shuts. The opening between the steel plate and the edge of the door shuts were filled with a fire protective sealant (heat expanding type). The second door was tested in its original shape. Summary of test results: Early smoke penetration from both doors. Only the upgraded door reached the integrity requirement of 30 minutes. Thermal imagery shows that the upgrade with metal plate and ceramic insulation provided better heat protection than the fire protective coating. From pictures it appears that the fire protective coating protects the door from the heat radiation to some extent.

"Fire exposure experiments on wood filling doors" (Försök med brandpåverkan mot fyllningsdörrar) [34]: A report from tests, performed in Sweden, describes testing of original doors with and without fire protective coating, where the doors are mounted in the opening of a "fire room" (normally used for the reaction-to-fire room-corner test) and a where the fuel is placed on the floor in this room. It is difficult to compare the results from these tests with test results from fire resistance tests because of the differences in the test setup and testing conditions. However, it seems that the fire protective paint may have delayed burnthrough, which is indicated by the fact that burnthrough appears at different positions for treated vs. untreated door.

"Fire test of a two-leaf wooden door in a gas concrete wall" (Branntekninsk prøving av tofløya tredør i vegg av gassbetong) [35]: A two-leaf wooden door with a glass panel at the top from the late 1800's was tested based on NS EN 1634-1. The door was stated to have been improved according to the guidelines of Oslo Municipality from 2015. This included a countersinking in the frame ledge for sealant, fire resistant paint on all inward surfaces and edges (2 coats of fire-resistant acrylic paint covered with 2 coats of interior paint) and mounting of fire sealing fins. E 30 graded glass was mistakenly installed instead of the specified EI 30 graded glass. Summary of test results: Smoke penetration was visible 30 seconds into the test at the top of the doorwing. Integrity failure was reported after 9 minutes and insulation failure after 2 minutes when the average temperature passed 140 °C. The window areas appeared to be the weak spots.

Figure 2-5 Fire resistance test set-up for old stairwell door. Thermocouples are shown attached to de door, registering the temperatures on the unexposed side. Photo: B. Wedvik, NIKU 2019.

Figure 2-6 Fire resistance test. Glass panes have broken, smoke and flames are visible. Photo: B. Wedvik, NIKU 2019.

Figure 2-7 Fire resistance test. Test is ended. All glass panes are broken. Photo: B. Wedvik, NIKU 2019.

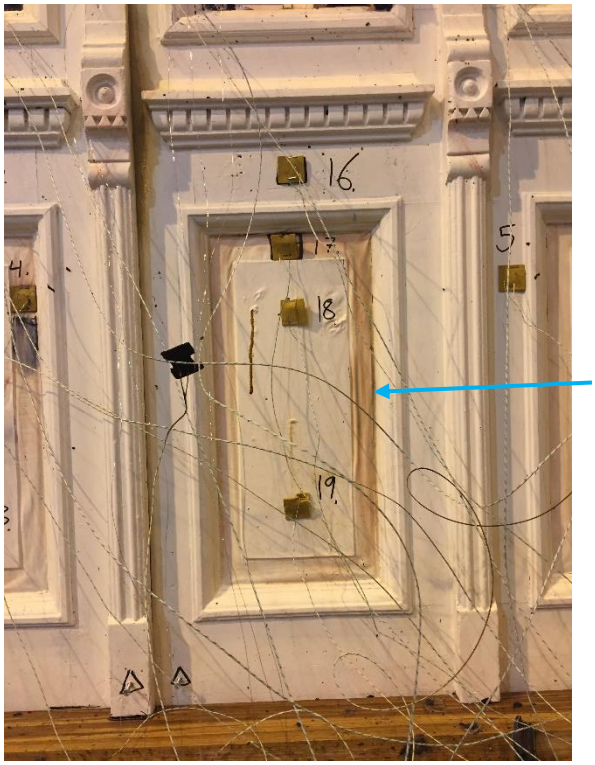

Figure 2-8 Fire resistance test. Test is ended. Area with thin wood protected with fire retardant paint on the unexposed side has turned brown, paint has loosened. See blue arrow. Photo: B. Wedvik, NIKU 2019.

3 Discussion

Main challenges for the withdrawn guideline of Oslo municipality:

The old doors in question have great variation in the design and characteristics, and very few fire tests on old wooden doors have been performed, both with and without upgrading. Documentation of the effect of the proposed solutions for upgrading of fire performance in the guideline had been asked for by the Planning and Building Services in Oslo Municipality. Other groups of fire safety experts[ii] have been critical to the prerequisites for the guideline, and to the suggestion of the use of fire-retardant paint.

Prior to performing new fire tests on old doors there is a need for a discussion, involving the relevant disciplines and authorities, to establish an agreement on how standard fire test methods can be used to document the required properties for these old doors, and how the results can be implemented in fire safety work. For example, according to the Oslo Municipal Cultural Heritage Management Office[iii] the guideline has wrongly been referred to for documentation in building matters (ceiling extensions) to show compliance with TEK17. This was not how it was meant to be used. The guideline was made to be used according to the fire legislation for older buildings based on the Building Regulations of 1985.

Concerning the technical methods for upgrading of the door leaf, both the method for mounting of new fire rated glass panes and the way of using fire retardant paint are aspects that needs further attention with regards to the reliability of the alleged upgrading of the fire performance. Testing of fire performance of the proposed solutions and new solutions, development of a more detailed technical guideline and more standardized craft work methods might be needed.

Main aspects/challenges based on review of reports:

In the summary from the final report for the project ”Fire safe town houses” [2] the Oslo Fire and Rescue Service recommends replacing stairwell doors with new, fire rated doors with door pumps, installation of fire alarm systems where there is only one stairwell accessible for each apartment, and installation of sprinkler systems for the preservation of original building parts and stairwell doors. While the Oslo Fire and Rescue Service recommends replacement of stairwell doors to fire rated doors where there is only one stairwell, Dyrseth shows that it can be debatable whether EI 30 fire rated doors, new or old, is a good improvement in safety when related to cost [9]. According to Dyrseth’s calculations, the installation of a fire alarm system, door closer and smoke seals should give sufficient time for safe evacuation. Sprinkler systems give the greatest reduction in risk but have very high costs. Those findings are very interesting concerning preservation of the doors and should be looked further into. However, Dyrseths study is limited to a cost/benefit calculation based on fatal fires only and it would be useful to

[ii] The Fire expert group in the Consulting Engineers’ Association (Rådgivende ingeniørers forening); the Fire engineering advisory forum (Brannteknisk rådgiverforum). Information given by the Agency of cultural heritage in Oslo.

[iii] Email correspondence 27.1.2020

include the damage to human health and loss of property in the cost-benefit calculations when evaluating the need for upgrading.

Examples of risk-based assessment matrix tools for doors in cultural heritage buildings have been given in the text. Fire testing of old doors is destructive on cultural heritage material, and there are limitations of the availability of data, due to the old doorsets' proprietary nature. Fire testing to achieve useful results is also expected to be expensive and time consuming. The relevance of developing a matrix as a tool for establishing the given fire performance of stairwell doors in old brick apartment houses should be looked further into and evaluated, considering aspects as reliability, cost/gain and practical utility.

Main aspects/challenges based the review of fire test reports:

A small number of tests have been found, but some learning points can be drawn. The tests reviewed showed that the original doors are weak regarding the required class of EI_2 30 and that there are (combinations of) measures that can increase the fire resistance of the doors sufficiently. In a few cases fire protective measures on the doors have been tested. However, since there are combinations of different measures it is difficult to conclude on which individual measure has which effect. Covering the surface with fire protective paint can improve the properties of the door but covering the surface with thermal insulation appears more efficient to increase the fire resistance. Intumescent seals or fins appear effective regarding preventing smoke from spreading through cracks or openings. The original glass is shown to be a weak spot and need to be addressed.

3.1 Content recommendations for an updated guideline for fire safety level of stairwell doors

Recommended tests

As basis for an updated guideline the following needs further attention.

Fire-rated glass panels

- Investigate the mounting of fire classified glass panels in timber doors. Such glasses are heavier and thicker than the original glasses. The way to mount the fire-rated glass must be described in detail, as this is expected to be critical for the fire behaviour. Fire testing should be done to find the best way to mount the glass without creating unwanted tension/pressure/other possible challenges.
- The mounting of a fire-rated glass panel on the inside of the existing door glass should be tested. Attention must be given to a higher load on the door leaf and to the aesthetics of the result.

Fire-rated insulation and panels

- In a UK guide [36], the covering with boards is presented as the preferred solution because it is a reversible process. Upgrading using insulation and panels on the inside, as described in SINTEF's guidance, should not be discarded. This recommended solution should also be fire tested to demonstrate its efficiency and reliability.
- Previous inspections by NIKU of upgraded doors demonstrated a need for more awareness of aesthetic and cultural heritage values when choosing this solution.

Fire-retardant paint/varnish

- Test if local stripping of old paint and treatment with FR-paint only on the thinner parts and only on one side of the door leaf will cause tensions/curves in the door.
- Test different methods for measuring that the right amount/weight/thickness of fire-retardant paint has been applied.

Smoke seals

- Different types and mounting of smoke seal strips could be evaluated and eventually tested since this is a measure that gives a great reduction in risk of smoke spread.

As is described in "Timber panelled doors and fire - upgrading the fire resistance performance of timber panelled doors and frames " [20] and "Upgrading the fire resistance of floors and doors in heritage buildings"[21] other solutions are available that can be effective for upgrading of the joint area between panel and framing on door leafs, e.g. using intumescent paste and heat resisting adhesive in the joints, fire resisting boards, steel fixing springs, glass board, intumescent sheet, intumescent coating, intumescent paper and solutions with steel strips placed in slots in a moulded panel is presented.

Fire- and smoke curtains

Fire- and smoke curtains can be a good solution in stairwells of cultural heritage importance, since this measure represents minor interventions in the original material. Automatic deployment of fire curtains can be linked to the fire alarm system. The use of fire and smoke curtains in stairwell cases should be looked further into, to find the best solutions for the type of room, occupants and fire scenarios in question.

Other future achievements for a guideline

- It must be made clear how the guideline is intended to be used, in accordance with relevant laws and regulations, and in agreement with relevant agencies and authorities.
- The guideline should take account of the overall fire safety of the building and mention compensatory measures for doors with less than 30 minutes of fire resistance.
- There should be a check list containing a detailed technical description of the suggested solutions for upgrading.
- A new guideline could include a step-by-step organizational process description for apartment house owners.
- There is a demand for the presentation of good examples of upgrading, with pictures of successfully upgraded doors and descriptions of measures undertaken to the owners of apartment houses.
- To ensure the maintenance of fire protection measures on the doors the need for an updated management- and maintenance plan for the building could be mentioned in a guideline.

Challenges related to upgrading

- It is a challenge for house owners to find fire consultants with the combined competence on fire upgrading of doors *and* caretaking of historic values. Possible solutions to this should be discussed.
- Automatic extinguishing systems can be a good solution but is expensive. It might be a challenge that the house owners that need it the most can often not afford it. The possibility of funding in such circumstances could be considered.

4 Conclusion and proposal for future work

There is a need for documentation of the fire performance of upgraded old door leaves. The purpose of new fire tests should be to provide a basis for the preparation of such documentation. The documentation should be useable to establish "pre-accepted" solutions or to create a template /set of criteria which fire consultants can use as a starting point / framework for designing more individual solutions, in accordance with the fire legislation and to current building regulations.

A work plan for fire-testing of fire protective measures for doors includes discussing the possibilities of testing fire protective solutions that may form the basis for a more general approval for the use on existing doors, and how to implement the results in guidelines. More specifically a test plan should be set up and suitable test specimens should be arranged for.

Other aspects than upgrades to the actual doors that deserve further investigation

- The use of fire- and smoke curtains in cultural heritage buildings.
- The relevance and usability of risk-assessment matrixes as a tool for assessing the fire performance related to the type of doors in question.
- The interpretation of regulations and possible definitions of *safety measures considered to be within a practical and economically viable framework.*

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