MASTER THESIS

Fire prevention of typical civil buildings

- comparison between California and Austria

submitted to the

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Graz, March 16th, 2016 Signature:……………………..

Kurzfassung

Diese Diplomarbeit befasst sich damit die unterschiedlichen Weisen zur Herstellung eines Brandschutzkonzeptes in Kalifornien und Steiermark gegenüberzustellen. Der Schwerpunkt der Arbeit liegt im Vergleich von einem fiktiven Wohnbau beziehungsweise Bürobau. Diese Bauten werden anhand gesetzlicher Vorschriften, Richtlinien und Standards einmal in Österreich und in den USA gebaut.

Zu Beginn gibt ein kurzer historischer Rückblick Aufschluss über die Entstehung des Brandschutzes und der Brandschutzkonzepte. Weiters werden wichtige Grundbegriffe des Bauwesens und diverse Bauweisen erläutert. Der Beginn eines Brandes beziehungsweise die Brandentstehung, sowie die Brandentwicklung werden durch diese Arbeit genauer definiert, um einen detaillierten Einblick in die Entwicklung eines Brandes zu geben.

Nach Definition der wichtigsten Begriffe werden die einzelnen Klassifizierungssysteme im Bezug auf Brandverhalten gegenübergestellt. Einen weiteren Punkt stellt die Beschreibung einiger wichtiger Materialien dar, die großteils im Bauwesen zum Einsatz kommen. Nachdem der passive Brandschutz dargelegt wurde, folgen der aktive Brandschutz und deren Systeme. Abermals wird ein Vergleich der verschiedenen zum Einsatz kommenden Systeme geboten.

Die Arbeit gibt außerdem Aufschluss über die verwendeten gesetzlichen Vorschriften, Richtlinien und Normen, die für einen späteren Vergleich essenziell sind.

Der Fokus der Diplomarbeit liegt darin die Punkte der verschiedenen Brandschutzkonzepte zu definieren, um weiters einen Vergleich zu ermöglichen. Hier wird sehr spezifisch auf den Wohnbau und Bürobau eingegangen.

Der letzte Teil der Diplomarbeit erarbeitet mit den zuvor gewonnenen Informationen die einzelnen Bauten und vergleicht diese.

Den Schlussteil bildet ein Resümee über die erarbeiteten Unterschiede und soll die gewonnen Eindrücke darstellen und zugleich den Nutzen der Anforderungen hinterfragen.

Stichworte:

Brandschutzkonzept
Wohnbau
Bürobau
Brandentwicklung
OIB Richtlinie
Kalifornisches Baugesetzbuch

Abstract

This thesis deals with the different ways of creating a fire protection concept in California and Styria and juxtaposes them. The work is focused on the comparison of a fictitious residential building and an office building. These buildings are built based on the legal regulations, guidelines and standards in Austria and the United States.

At the beginning, a brief review of the history of each country throughout the origin of fire safety and fire protection concepts is provided. Further, the important basic concepts of construction and construction methods are explained. The beginning of a fire—called the ignition—the fire development and the decay period are defined more precisely to give a detailed overview of the whole developmental process of fire.

After defining the key words of the individual fire behaviour classification, the terms are compared. This comparison is followed by a description of the common and important materials in the building industry. The active and passive fire protection will be presented and is followed by a comparison of the different systems.

The work also provides information about the applied legal regulations, guidelines and standards, which are essential for a later comparison.

One of the most important parts of this thesis is to define the points of the various fire protection concepts to make it possible to compare them. Thereby the residential and office buildings are evaluated in detail.

The last part of the thesis contains the comparison of the obtained information.

The final part is a conclusion of the elaborated difference. Furthermore, it states the gained overall impressions and explores the importance of subsequently questioning benefits.

Keywords:

Fire protection concept
Residential building
Office building
Fire development
OIB Guideline
California Building Code

Declaration

“Obligatory signed declaration: I hereby declare that the present bachelor's thesis/diploma thesis/master's thesis was composed by myself and that the work contained herein is my own. I also confirm that I have only used the specified resources. All formulations and concepts taken verbatim or in substance from printed or unprinted material or from the Internet have been cited according to the rules of good scientific practice and indicated by footnotes or other exact references to the original source. The present thesis has not been submitted to another university for the award of an academic degree in this form. This thesis has been submitted in printed and electronic form. I hereby confirm that the content of the digital version is the same as in the printed version. I understand that the provision of incorrect information may have legal consequences.”

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Table of contents

1 Introduction

Within the last century, the topic "fire protection" became more and more relevant for insurance companies. Hence, several insurance companies decided to connect and develop codes for fire protection engineering. In further consequence, the topic becomes also more important for civil engineers.

Over the years, codes, guidelines and standards were revised and improved the effectiveness of the different documents.

This thesis aims to provide an overview of the development of fire protection and the different ways to classify materials according to their fire behaviour and fire resistance. The thesis includes information about the passive and active fire protection, whereby automatic sprinkler systems play a decisive role.

The fact that a lot of the knowledge about fire protection derives from the United States makes it interesting to compare it with Austria. Therefore, the federal states of California and Styria have been chosen for this paper.

In this thesis, the legal requirements and technical specifications of each country are investigated and applied to make a fire protection concept. Furthermore, the obtained information provides the basis for the case study, in which a residential building and an office building are designed.

The requirements for each building are compared and evaluated, which again contributes to the conclusion.

2 Development and history

2.1 Residential buildings

From 2010 to 2013 nearly 51,536 housing structures were built in California, which is an increase of 0.38 percentages of built structures. In comparison to that, Austria built 131,574 new housing structures which equals an increase of 5.8 percentages.

The developing of housing units in Austria has significantly increased in the last few years.

Nevertheless California has about 3,900,000 residential buildings with 3 or more units, whereas Austria has about 260,000. (2013)

However, the population of California is approximately 4.6 times greater than Austria. Comparing the size of the countries, California is 5 times bigger than Austria.[1,2]

Consequently, Austria has one residential building with 3 or more housing units every 0.43 square kilometre while California has one every 0.11 square kilometres.

This clearly proofs that California has a higher building density compared to Austria.

To summarize, residential buildings vary from country to country based on size and other constraints. Therefore, conflicting research is to be expected regardless of the research being from a reliable source. Many of the statistics are influenced by factors such as economy, developing/growing population and much more. [3,4,5,6]

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[1] Cf. http://data.worldbank.org/indicator/SP.POP.TOTL/countries/AT?display=graph

[2] Cf. http://mapfight.appspot.com/california-vs-at/california-us-austria-size-comparison

[3] Cf. http://quickfacts.census.gov/qfd/states/06000.html

[4] Cf. http://www.statistik.at/wcm/idc/idcplg?IdcService=GET_PDF_FILE&RevisionSelectionMethod=LatestReleased&dDocName=079522

[5] Cf. http://www.statistik.at/wcm/idc/idcplg?IdcService=GET_PDF_FILE&RevisionSelectionMethod=LatestReleased&dDocName=026021

[6] Cf. http://www.nationsonline.org/oneworld/countries_by_area.htm

2.2 Fire prevention

Fire prevention has its roots in Rome in 64 after Christ. Some of the first regulations were to build external walls out of fireproof materials to protect against fire. This regulation was set after Rome burned down in that year.

One of the first recorded fire services was established by Emperor Augustus. After the collapse of the Roman Empire, it took a long time until new technical improvements of fire protection emerged again.

In the 17th century, London had a large fire which nearly destroyed the whole city. Much of the city was made of stone and brick houses with fire-resisting party wall separations, as were defined in the regulations. In addition, the first hand-pumper fire apparatus was developed and is a good example for the development of fire prevention engineering.

One of the most important contributions in fire protection took place in the 18th century in Great Britain, during the industrial revolution. At this time Karl VI, imperator of Austria, established the extinguish regulations from 1722, which was the beginning of fire protection in Austria. In the early 19th century, the United States had many renewals concerning fire protection. The first fire departments were formed, accessible underground water supplies were created, the first hydrants were placed and the use of masonry, concrete and steel increased fire resistance.

During that century, many fires occurred in the different factories in the cities. The solution to this problem was the forerunner of a sprinkler system. The idea was to install a system of perforated pipes at ceiling level where water was able to directly extinguish the fire. Once these sprinklers were installed, fire engineers aimed to make this system automatic, which was accomplished at the end of the 19th century, by Henry S. Parmelee.

These improvements were mainly influenced by the insurance industry, which wanted to minimize property loss by fire and improve safety. The influence of the insurance industry in Austria also caused changes, for example, the forming of the first volunteer fire departments. The first fire service or company can be dated back in the 17th century in Austria and in the United States.

During the 20th century Austria’s development in fire protection progressed slowly, because it only gently progressed from the Second World War. After the dark ages of Austria, the fire service was re-established and fire prevention returned to a better recognition.

In this age more and more insurance companies emerged in the United States. Several companies linked/connected/combined, which also influenced the importance of protection of one's property. Also the body of knowledge in fire protection engineering continued to grow.

In the 20th century, buildings, fire codes, standards and guidelines became more important. They became the epitome of fire protection engineering for life safety and property protection. Codes, standards and guidelines were always revised to improve the regulations and effectiveness.

Professional societies for fire protection were established and the research of fire prevention gained more and more importance.

Fire dynamics was and still is one of the most complex factors in fire prevention. To know how materials ignite and burn or how the smoke makes its way through buildings or how the heat is transferred is very important for fire prevention research.

Austrian engineers also conduct research in fire dynamics, but a lot of the knowledge comes from the United States.

Today every country has its own standards, regulations and codes. In the past few years the knowledge of fire protection has been growing: most notably in how fire spreads, smoke development/movement predictions, extinguishing systems, and smoke alarm systems. Due to the fact that insurance has such a big influence on the fire protection of the property in the United States, they make sprinkler systems to minimize the property damage as the most important factor. On the one hand this guarantees a fast extinguish procedure, but on the other hand most of the extinguished parts of the property are destroyed. In comparison to that, Austrian fire engineers rather consider system sustainability and reuse after a fire. [7,8]

[7] Cf. http://www.bundesfeuerwehrverband.at/service/handbuch-zur-feuerwehrgeschichte/entwicklung-des-oesterreichischen-feuerwehrwesens/

[8] Cf. http://magazine.sfpe.org/professional-practice/history-fire-protection-engineering

3 Statistical distribution of building types

3.1 Single and double family houses

As a matter of fact, it is almost clear that most of the existing buildings are single/double family houses. Not only in Austria, but also in California a high amount of single/double family houses can be discovered. For example in Austria, two out of three buildings are single family houses, while in California the number of single family houses is approximately 60 percentage of all buildings.

Concerning fire prevention, it is not that difficult, because every new single or double family house does not have many requirements to meet. That is why this thesis will not be going into detail with this building type.[9]

3.2 Residential building

The number of residential buildings with 3 or more units increased in California to about 3,900,000 and in Austria to about 260,000 (2013). This amount of completed 3 or more unit residential buildings increased from 2010 to 2013 about 3 percentages. See Section 2.1.

3.3 Office building

The development of office buildings in Austria in the last year is nearly the same as lodging and hotels. The increase of newly built office buildings is about 1.5 percentage points of the stock of office buildings in Austria.

[9] Cf. http://www.statistik.at/wcm/idc/idcplg?IdcService=GET_PDF_FILE&RevisionSelectionMethod=LatestReleased&dDocName=026021

4 Structure types[10]

For each type of material, there are different types of structure which are used. The difference between structure types are often not as clear as it seems to be. Some of the structure types are very similar, for example, platform frame and frame construction. They can be divided into frame types, material types and into their building construction methods.

The most common and used structural systems in Austria are:

- Frame construction
- Skeleton construction
- Solid construction

In California, the common structural systems are:

- Post and beam construction
  - Platform framing
  - Balloon framing

This does not mean that these countries do not have the same structural systems. It only shows the different types and which ones are the most common. Each structural system has its own special characteristics with its associated advantages and disadvantages. Regarding the different materials, there are also limits in heights and different building requirements. The prefabrication of each structural type is as important as the determination of the material.

The frame construction has its roots in platform and balloon framing and established itself over the years. It consists of a bar-shaped skeleton, which takes care of the vertical loads and stabilizes planking, which again is responsible for the horizontal loads. One big advantage is the possibility of prefabrication; therefore it is feasible to assemble the parts immediately. This also saves cost and time. In this case, good machinery is needed to get the accurate and high quality parts. The next part which has to be taken into account is the dimensions of the prefabricated parts, which are limited because of different ways of transportation.

[10] Cf. Holzbau mit System pp. 38-65, 78-79, 82-83, 86-91, 106-135, 284-307

One of the main facts about frame constructions is that this structural system typically uses timber material. Timber is a renewable resource; therefore, it is a commonly used material.

Building with timber has its advantages and disadvantages, as every material has. Particular attention should be given to swelling and shrinking. For example, the one or two storey buildings do not have this big volume changes. As vertical and horizontal loads are increased with the use of timber, more attention should be given to swelling and shrinking.

Sometimes it is necessary to make use of constructive methods. To consider is the wood moisture, which should be at 12%, to keep the swelling and shrinking in limit (12 % represents the later ceasing equilibrium moisture content).

A very rare material used for frame construction is steel, because it is normally used in skeleton construction, where planking is not used as stabilization. The next figure gives an overview of a frame construction.

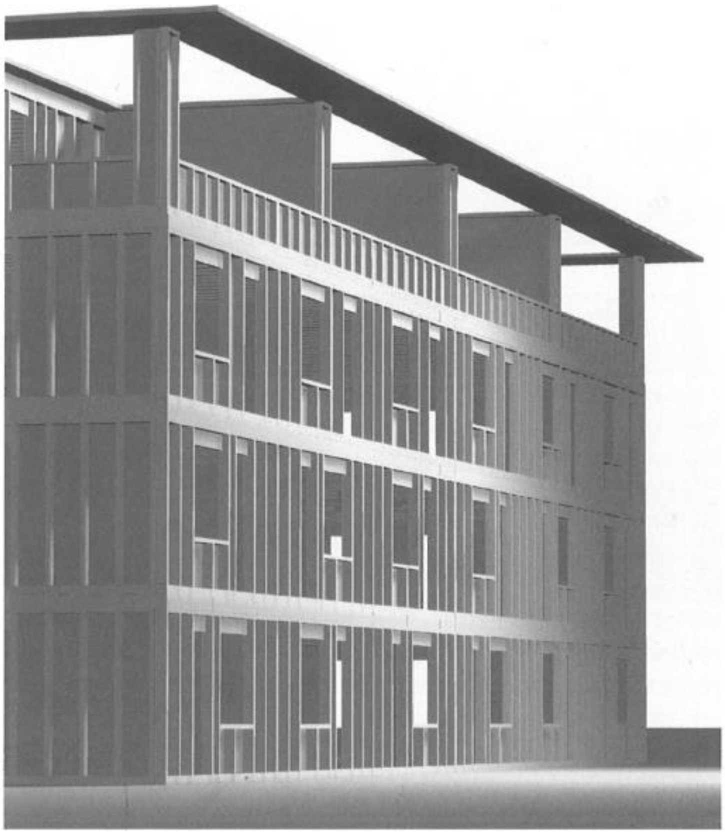

Figure 1: Timber frame construction[11]

[11] Holzbau mit System p. 39

Most commonly used materials for skeleton:

- solid timber
- glued timber
- steel

Common used materials for planking:

- Oriented strand board
- Plasterboard
- Triple layer panels
- Veneer plates

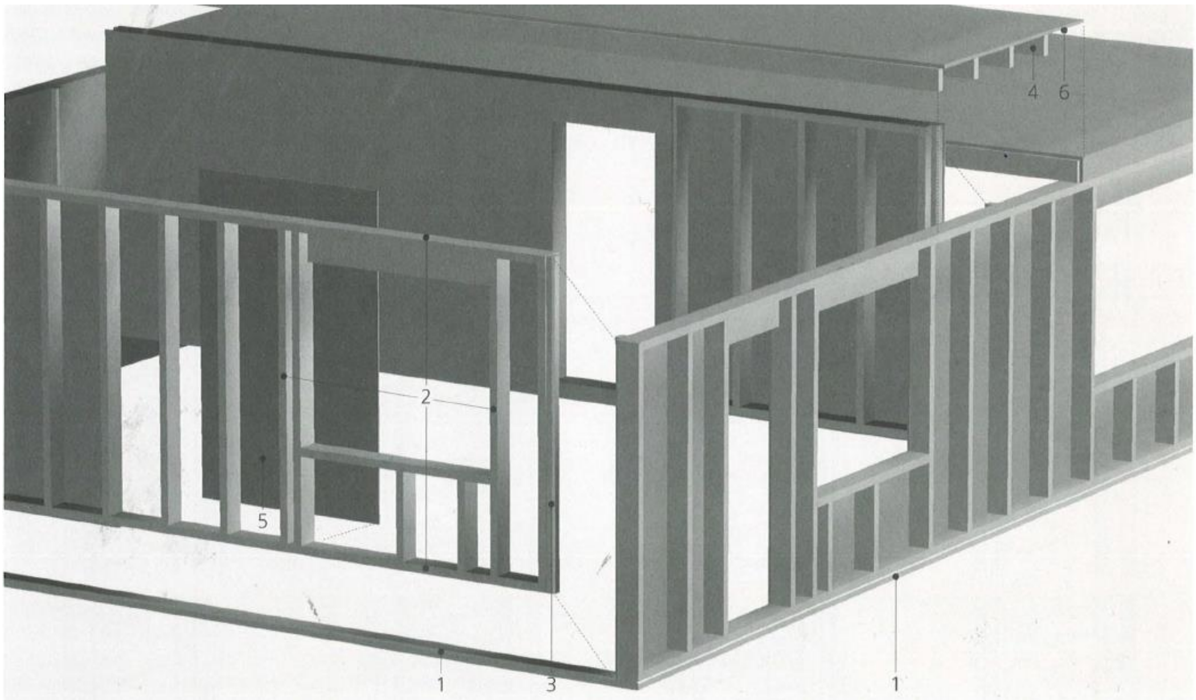

Figure 2: Construction parts – frame construction[12]

1	sill plate	2	frame (joist and stud)	3	connection timber
4	joist, beam	5	wall planking	6	ceiling planking

The typical/usual grid dimension is between 500 to 700 millimetre.

[12] Ibid. p. 64

4.1 Skeleton construction

Skeleton construction is one of the most used structural types and also one of the oldest structural types. This type of structure allows for increased structure height, compared to the low weight of the structure itself. Today most of the highest buildings use skeleton structure, not only because of the low weight, but also due to the grid dimension, which can span further than a frame construction. Different to other structure types, walls do not have to carry any load, which provides the possibility to use big glass windows or facades. The system consists of pillars, beams and bracing elements, which build a structure system and carry whole loads. The constant and relatively large grid dimensions also need to be mentioned, which are helpful for a better interior design.
Because of its individual ground plan and adaptable form, it is often used.

Timber, steel and reinforced concrete are the most common materials for this type of structure. The choice of material depends on the height and loads of the building. Regarding fire protection, there also specific requirements for the buildings, which are listed in the different codes, regulations and guidelines.

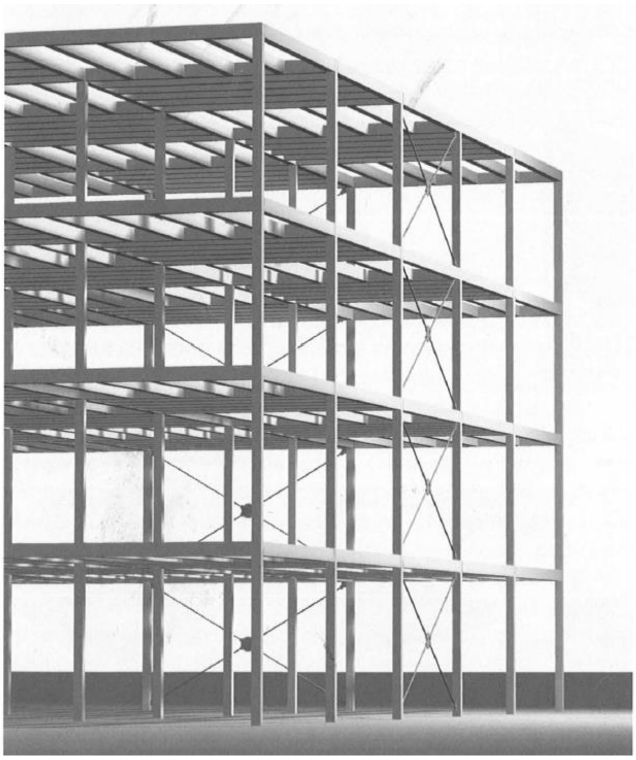

Figure 3: Skeleton construction[13]

[13] Ibid. p. 38

To carry horizontal loads, bracing elements are needed, which get tension loads by the impact of horizontal loads. Due to this fact the most common braces are made out of steel. Steel is known for its strength under tension. Because of that the bracings do not have to be as thick as other materials would have to be for the same bracing potential.

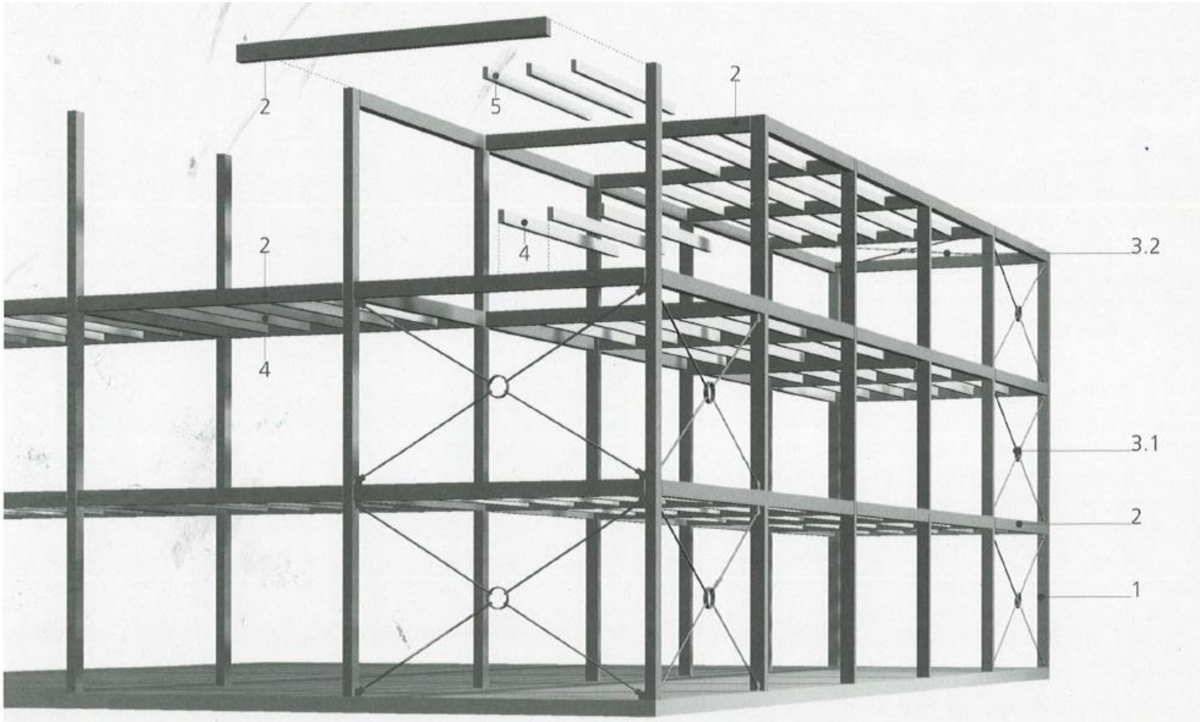

Figure 4: Construction parts – skeleton construction[14]

1 pillar	2 beam	3.1 vertical bracing
3.2 horizontal bracing	5 joist (ceiling elements)	6 rafter (roof elements)

Notice: 5,6 secondary support structure

As already mentioned, bracing is very important. To accomplish that, steel is often used as horizontal and vertical bracing. Materials like solid timber and other wooden slabs also find there usage.

Another very common method to brace buildings is to make a solid core out of reinforced concrete or other suitable materials.

Compared to frame construction, the pre-assembly is much lower, which deflects in the buildings fitting.

[14] Ibid. p.88

4.2 Solid construction

Today, solid constructions are very common. In Austria it is one of the most used types of structure. Due to the fact that this type of structure uses massive walls out of brick, reinforcement steel or wood, it is able to carry heavy loads. The system is always the same: the primary load carrying structure is massive, which means there are no bracings or any slabs or planking which braces the system. Different to other types of structure it is a plane construction, rather then a beam construction. The degree of prefabrication depends on which material is used. Solid wooden walls are often prefabricated. Concrete walls can be partly prefabricated. A prefabrication of walls out of brick are possible, but has not been established as common practice.

The biggest advantage in this case is not only the solidity of a structure, but the fact that there are no restrictions related to grid dimensions or modules.

As already mentioned in the chapters before, shrinking and swelling are the aspects of wood to which should be given the most attention. The advantage of building with timber is that there is the possibility of using cross laminated timber, which does not have the large shrinking and swelling measurements. That is preferable to transverse arrangement of the layer of the plates, which reduces the shrinking and swelling measurements in tangential directions.

Reinforced concrete is known for his high compressive strength and shaping possibility. One of its disadvantages might be the bigger dead load and higher heat conductivity compared to timber and brick.

One of the common used materials in Austria is brick, more specifically, vertical coring bricks. In the age of sustainability and insulation, it plays a vital role. Not only because of the fact of its low head conductivity, but also due to a good resistance against fire it is one of the most used materials in Austria.

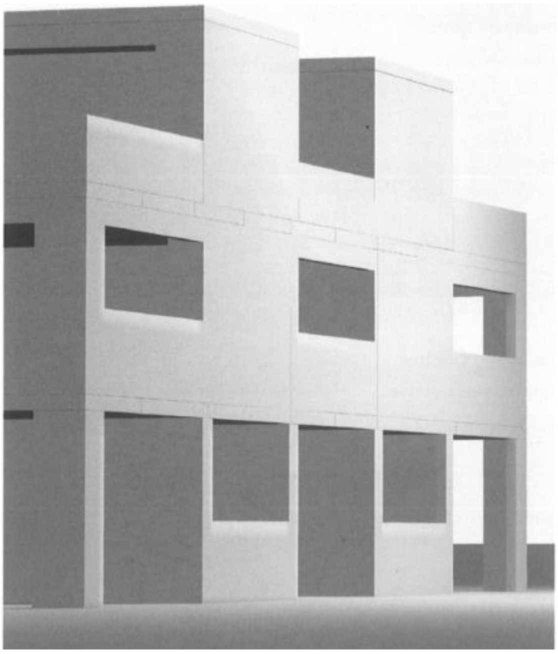

Figure 5: Solid construction[15]

Solid construction is a suitable structural type for more storey buildings, however, the fact of its dead load is the point why there are limits concerning building heights.

The next figure shows the construction parts, as an example of a solid wood construction.

[15] Ibid. p. 38

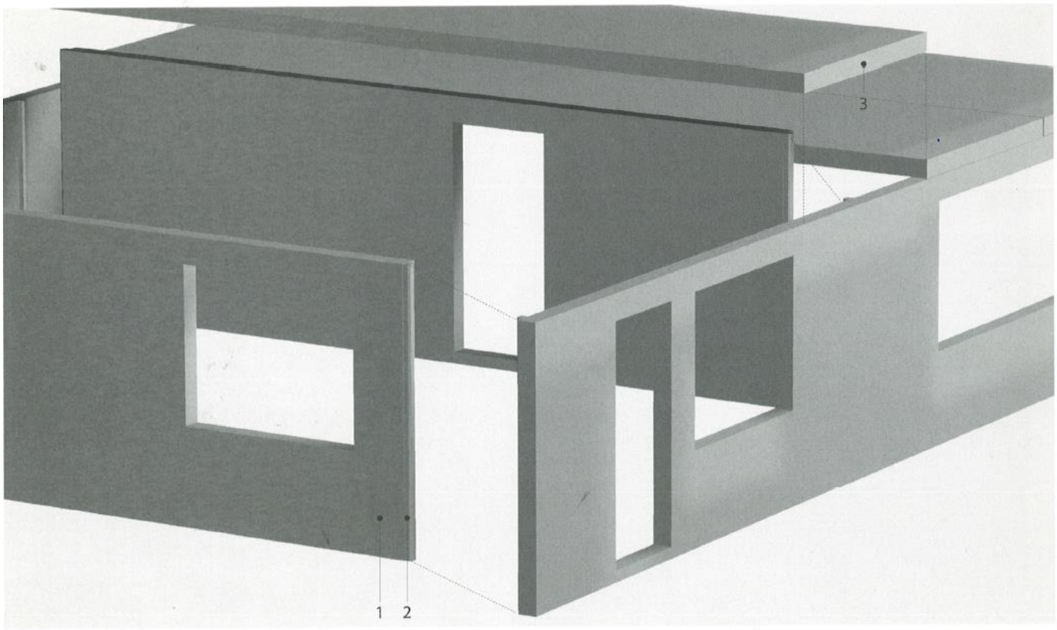

Figure 6: Construction parts – solid construction[16]

1 wall element
2 sill plate (only by wood constructions)
3 roof element

Wall elements can be made out of solid wood, cross laminated wood and other wood types. Reinforced concrete walls can be built with prefabricated elements or with in-situ concrete.

The wall can also be a masonry which is made out of bricks. In this case every notch has a reinforcement part on the top, for example a reinforced concrete beam.

[16] Ibid. p. 116

4.3 Platform framing & balloon framing

Definition of the structural elements

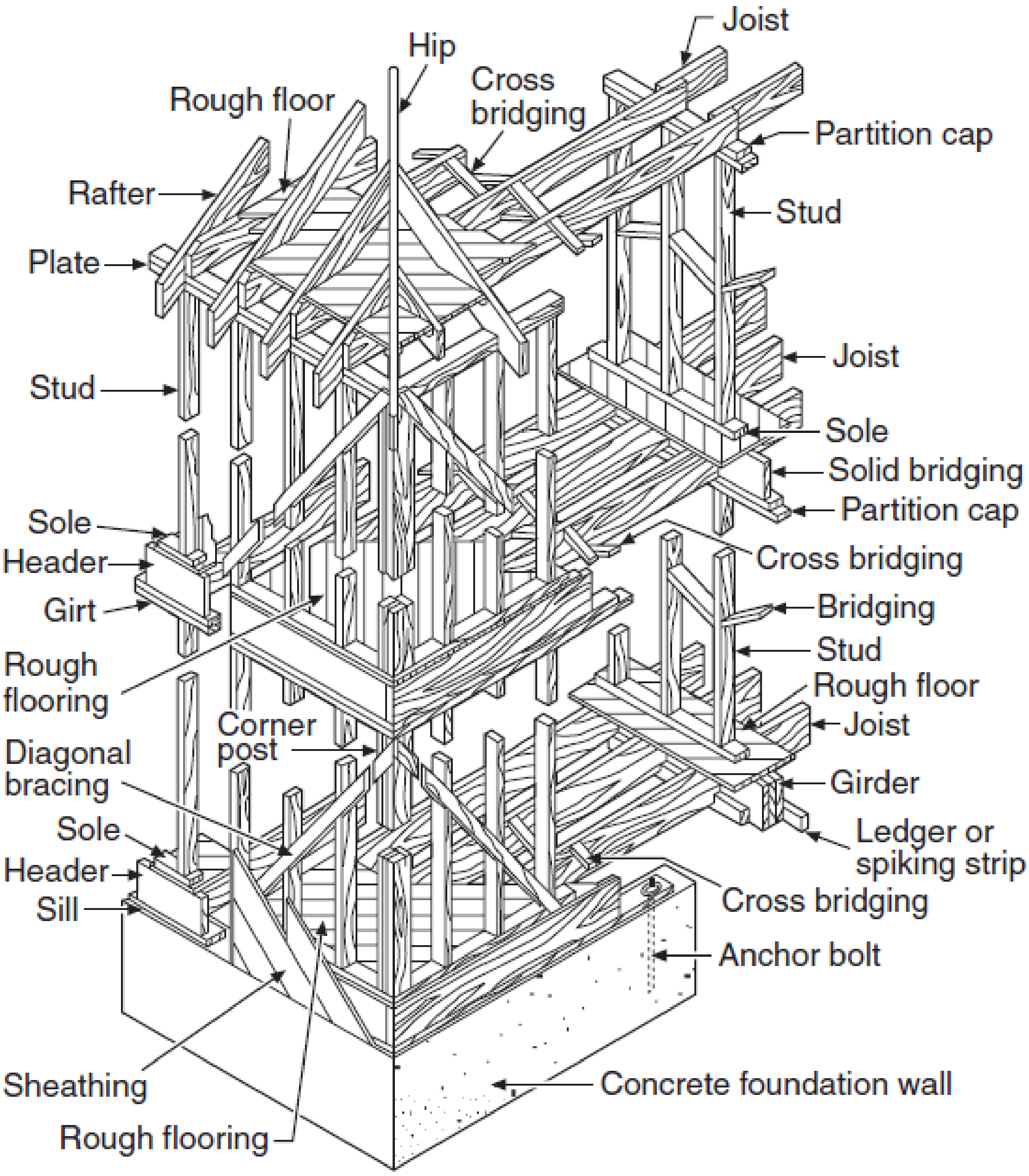

Figure 7: Wood-frame platform construction[17]

[17] Fire Protection Handbook sec. 19-18

Platform framing

Platform framing is an often used structural type in the United States. The Structure itself forms a platform on each storey and the parts of the structure are made out of wood. The studs go from one floor to the next floor and provide a work surface at each floor level. This type of structure is principally used in one or two storey home buildings. The bracing of the system is contrived over wooden plates, but also trusses are used for it.

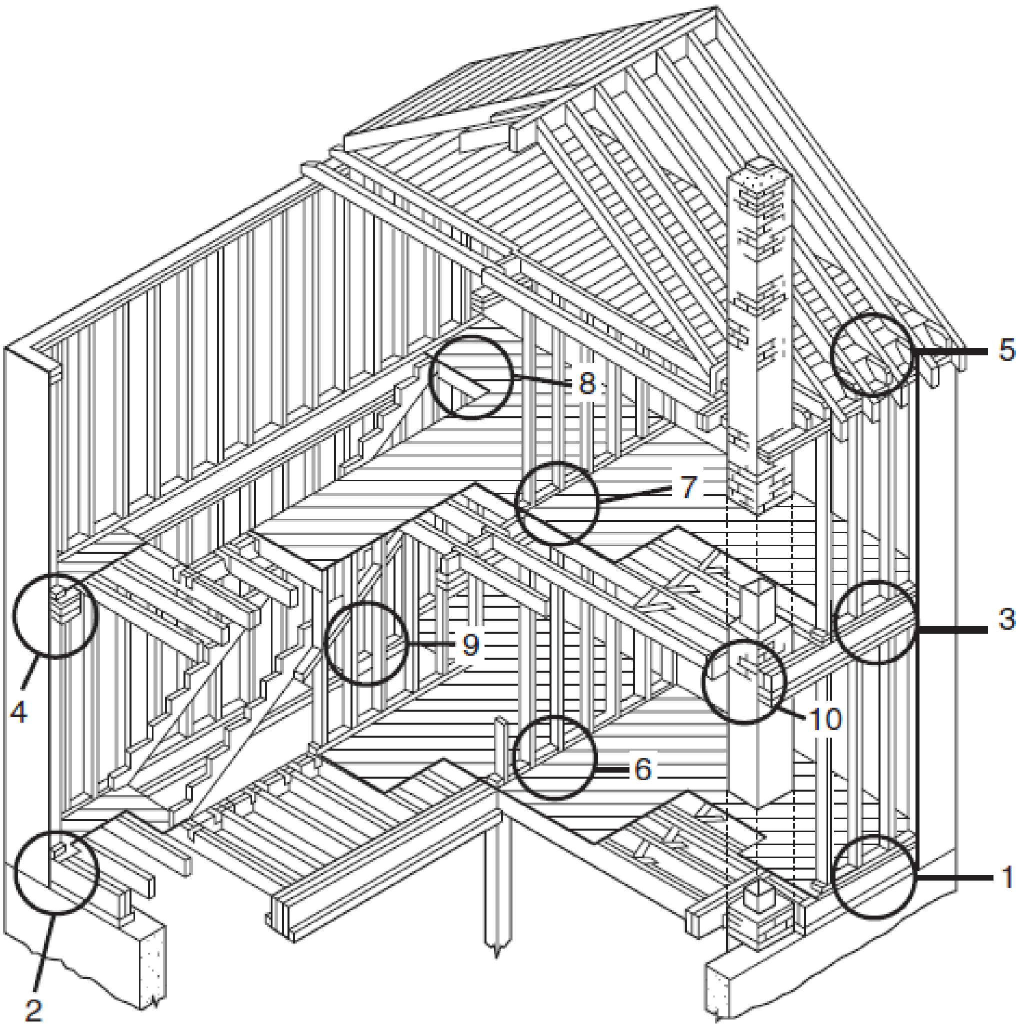

Figure 8: Wood platform frame construction showing points to be fire blocked[18]

[18] Ibid. sec. 19-19

Balloon framing

The specific attribute of balloon framing is that the stud goes over two or more storeys. The joists are anchored on the studs. One of the advantages of balloon framing is that it reduces distortions of openings in the interior load bearing partitions.

The issue with this type of construction is the required length of the studs and fire prevention, which is not easy to achieve by storey passing studs.

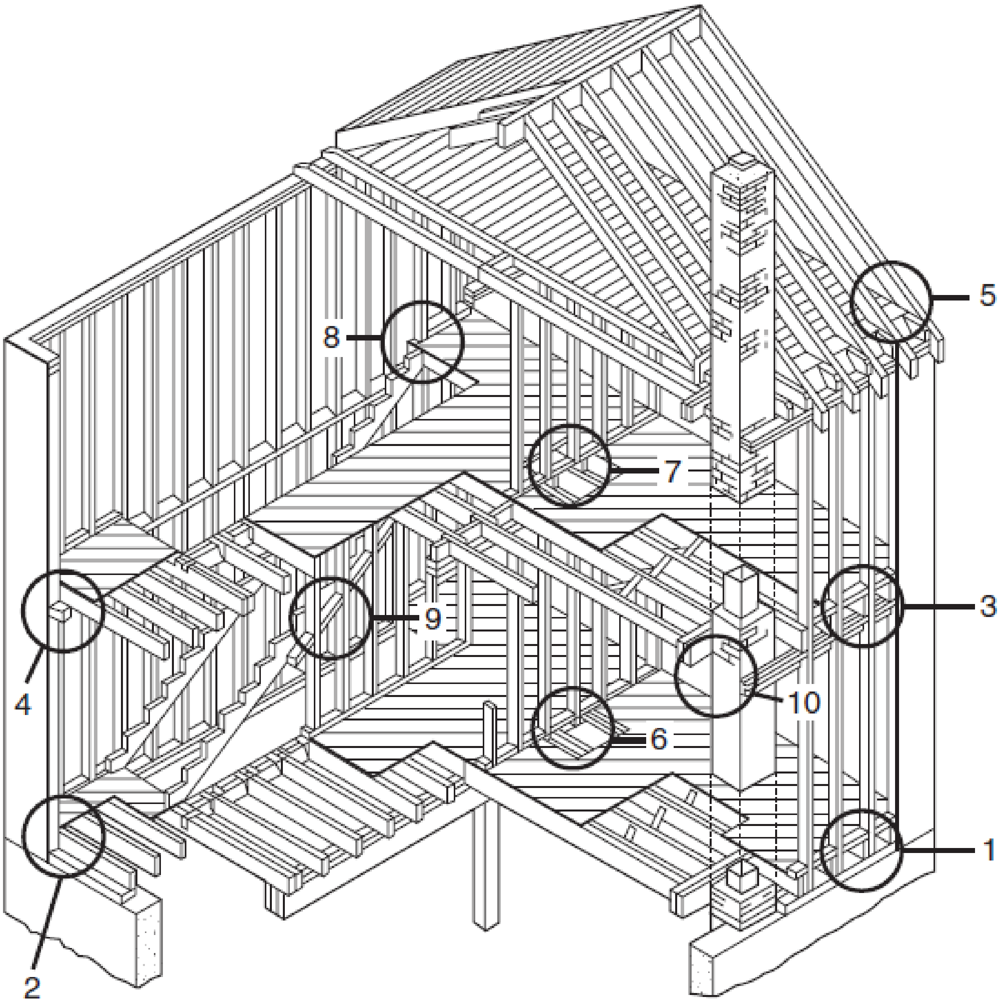

Figure 9: Wood balloon frame construction showing points to be fire blocked[19]

[19] Ibid. sec. 19-19

Fire blocking points

Materials which are used for fire blocking have to be non-combustible.

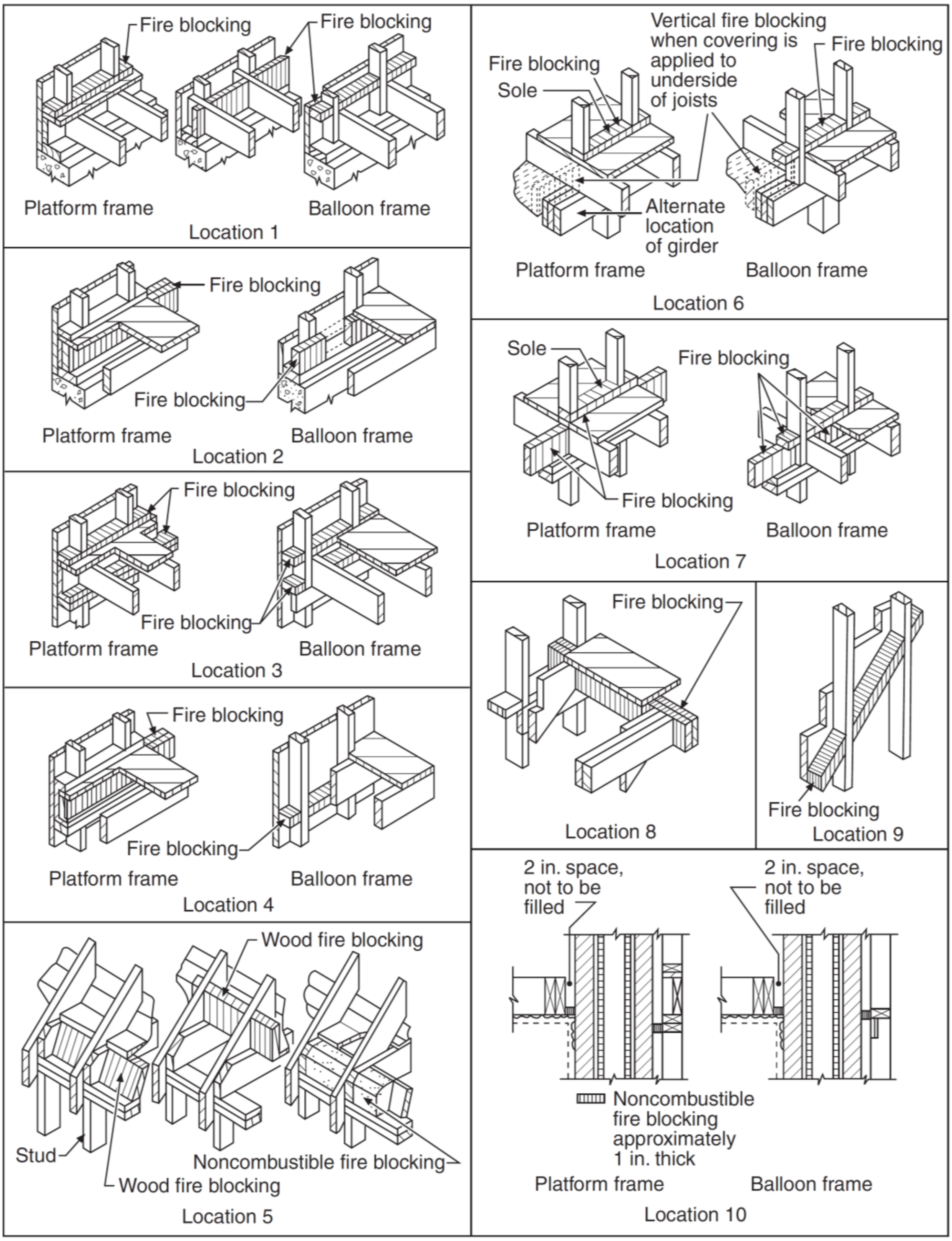

Figure 10: Details of the application of fire blocking to platform and balloon framing. Location numbers coincide with locations circled in Figure 8and Figure 9. For SI units: 1 in. = 25.4 mm[20]

[20] Ibid. sec. 19-20

5 Definition of Terms

5.1 Temperature

There are three different temperature units, which are generally used to describe the difference between the temperature of melting and boiling water at standard atmospheric pressure (1001.3 kPa). The first unit is Kelvin (K), which is especially used in physics to describe a specific heat. It is an approved SI Unit, which means that it is the most used system of measurement. Zero Kelvin defines the coldest point, which is compared to Celsius degree -273.15 °C. Celsius degree is the measurement system which is normally used in Europe. The zero point of Celsius is the point where ice begins to melt and 100 °C is the point where water begins to boil. The last temperature unit is Fahrenheit (°F). To convert this unit into Celsius, a formula is needed because the temperature scales are not absolute scales. For example 0 °C is equal to 32 °F but 100 °C is equal to 212 °F.[21]

5.2 Heat Units

Joule and Watt are the most frequently used measurement units to describe energy.

“Conventionally, the joule is defined as the energy (or work) which expands when unit forces moves a body through unit distance (1 m).” [22]

“The watt is a measure of energy release (or consumption). One watt is equal to 1 joule per second.” [23]

There is also an important dimension for describing heat. It is especially important for fire protection and for knowing how much heat a substance needs to increase its temperature by one degree. Furthermore, it is possible to find out the point at which a substance becomes dangerous. The fact that water is a good extinguishing agent is true because of its higher specific heat (4200 J/kg*K). The unit to describe specific heat is Joule per kilogram kelvin. [24]

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[21] Cf. Fire Protection Handbook sec. 2-4

[22] Ibid. sec. 2-4

[23] Ibid. sec. 2-4

[24] Cf. ibid. sec. 2-4

5.3 Heat release rate

"The amount of heat energy released during a particular period of time, such a second, is called the heat release rate and is expressed in J/s (joules per second) or W (watts)."[25]

5.4 Mass loss rate

This type of measurement describes the mass which is lost under a fire per time unit (kilogram per second). Relating to fire, it depends on many factors, as well as the influence of radiation, ventilation, type of material and some other circumstances. Also see 6.1.2.2 Smouldering stage.[26]

5.5 Flames

There are typically two types of flames, premixed flames and diffusion flames. As it already says, premixed flames are flames which occur when two gases are mixed and this causes the heat to ignite itself. Diffusion flames are basically flames formed under diffusion, which means that the fuel and the oxygen (air) are not mixed as much. For example, a candle: it has candle grease and a candle wick. The fuel of the candle is the candle itself, but there are two more factors needed for the candle to ignite and burn. These two factors are oxygen and an amount of heat. The candle grease is sucked up in the wick and it releases a gas, in combination with the oxygen. A reaction takes place, this process is called diffusion. Between the fuel layer and oxygen layer a reaction layer is built up, which is also called combustion zone. The diffusion flames are the type of flames fire-fighters have to tackle most of the time.

The diffusion flames can also split up in two types:

- Laminar diffusion flames
- Turbulent diffusion flames

Laminar diffusion flames are flames with typical low velocity and the oxygen and fuel mix constantly. In contrast, turbulent diffusion flames are flames where the velocity of the fuel is higher than the velocity of the oxygen itself. That is the reason why the flames are turbulent - the two gases are mixed up in a swirl.[27]

[25] Enclosure fires p. 40
[26] Cf. ibid. p. 42
[27] Cf. ibid. p. 46-64

5.6 Flame spread index (FSI)

“The normal output of the NFPA 255/ASTM E84 test is a flame spread index (FSI).This is a relative number based on the area under the flame spread distance versus time curve of the test, with an FSI of 0 assigned to cement board and an FSI of 100 (approximately) assigned to red oak flooring.” [28]

5.7 Smoke developed index (SDI)

“The smoke developed index for a test specimen is determined by comparing the reduction in light caused by the smoke from red oak flooring to the reduction of light by smoke from a test specimen. Red oak flooring is arbitrarily assigned a value of 100 and the cementitious board material is assigned a smoke developed index of 0. Therefore, a product achieving a 450 smoke developed index produces a curve of light attenuation versus time which has 4.5 times the area of the curve produced by red oak flooring (in comparison with the results for the cementitious board). In simplistic terms, one may think of a product having a 450 smoke developed index as one that produces 4.5 times the amount of smoke that red oak flooring generates during a 10 minute tunnel test.”[29]

5.8 Active fire protection

Active fire protection is everything which requires power to work; it doesn’t matter whether the power is electrical or mechanical. Good examples are sprinkler systems which are activated by a specific heat at the sprinkler head or a smoke control system, which can open automatically light domes when a fire is detected. [30]

5.9 Passive fire protection

The opposite of an active fire protection is the passive fire protection. This fire protection relies on construction and engineering details, for example, which type of material is used for which element of protection against fire. For this type of protection no energy is needed.[31]

[28] Fire Protection Handbook sec. 6-43-6.44

[29] Ibid. sec. 18-26

[30] Cf. ibid. sec. 2-59

[31] Cf. ibid. sec. 2-59

5.10 Fire wall

Austria-Styria

A firewall is decelerated as a wall, which has specific requirements in fire resistance. It is used for fire sections.[32]

United States - California

"A fire-resistance-rated wall having protected openings, which restricts the spread of fire and extends continuously from the foundation to or through the roof, with sufficient structural stability under fire conditions to allow collapse of construction on either side without collapse of the wall."[33]

Comparison

The definitions are basically the same; nevertheless the definition of Austria does not describe the part of fire resistance in detail.

5.11 Other wall types relating to fire prevention[34]

The following assembles are definitions out of the California Building Code, which are not applied in Austria. It also depends on the applied codes, as an example, fire partitions are only defined in the California Building Code, not in the NFPA Codes. The NFPA does not differ between a fire partition and fire barrier.

Fire barrier

"A fire-resistance-rated wall assembly of materials designed to restrict the spread of fire in which continuity is maintained."[35]

For example, a fire barrier is used to separate a single occupancy or mixed occupancy in different fire areas. They are also used for shaft enclosures, exit passageways or other exits.[36]

Fire partition

"A vertical assembly of materials designed to restrict the spread of fire in which openings are protected." [37]

[32] Cf. OIB Guideline: Definitions p. 3
[33] California Building Code 2013 p. 60
[34] Understanding Firewall Basics p.1-24
[35] California Building Code 2013 p. 60
[36] Cf. ibid. p. 247
[37] Cf. California Building Code 2013 p. 60

Fire partition walls are used to separate dwelling and sleeping units in the same residential building, as for an example Corridor walls too.[38]

Basically the difference between a fire barrier and fire partition is that the barrier is more stable and has a higher fire resistance than a partition. Usually those walls are non-load bearing walls. Another important fact is that barriers and partition are only vertical assemblies. Horizontal fire barriers or partitions are defined under horizontal assembly. See below.

Horizontal assembly

“A fire-resistance-rated floor or roof assembly of materials designed to restrict the spread of fire in which continuity is maintained.” [39]This can be a fire wall, fire partition and fire barrier, if the constructed horizontally.[40]

Smoke barrier

“A continuous membrane, either vertical or horizontal, such as a wall, floor or ceiling assembly, that is designed and constructed to restrict the movement of smoke.”[41]

5.12 Fire section or area

“Is an area which is separated from a part of a building by a fire section wall or fire section roof.” [42]

Note: Fire section walls are the same as fire walls.

5.13 Smoke section or area

A smoke section is a volume defined over an area under the ceiling, which is limited by up down reaching smoke draft curtains, smoke curtains to a certain height or by exterior or partitions walls of fire section or fire room. [43]

[38] Cf. Ibid. p. 125 212

[39] Ibid. p. 65

[40] Cf. ibid. p. 214, 215

[41] Ibid. p. 79

[42] Cf. OIB Guideline: Definitions p. 3

[43] TRVB S 125 97A p. 4

5.14 Sufficient clearance width

Sufficient clearance width describes the smallest width of a finished installed door.[44]

5.15 Sufficient clearance height

Sufficient clearance height describes the smallest height of a finished installed door.[45]

5.16 Evacuation level

"The evacuation level describes the height difference between the finished floor level of the highest over-ground storey and the average finished height of the bordering area of the building." [46]

5.17 Evacuation route

The evacuation route is the route which is used in a dangerous situation. It should provide a way to a safety place without outside assistance.[47]

5.18 Gross floor area

The gross floor area defines the complete area of a storey from one outside boundary surface to the other.[48]

5.19 Net floor area

By contrast, the net floor area consists of all useful areas without any covert areas by walls or other structural parts.[49]

[44] Cf. OIB Guideline: Definitions p. 4
[45] Cf. ibid. p. 4
[46] Ibid. p. 5
[47] Cf. ibid. p. 5
[48] Cf. Austrian Standard B 1800 p. 4
[49] Cf. ibid. p. 4

5.20 Gross and net volume

As described in 5.18 and 5.19 Net floor area, the differences are the same by volume. Additional to those areas, the gross volume gets multiplied with the complete height from structural parts – from the lower edge of the floor to the upper edge of the ceiling. The net volume in contrast gets multiplied with the sufficient clearance height.[50]

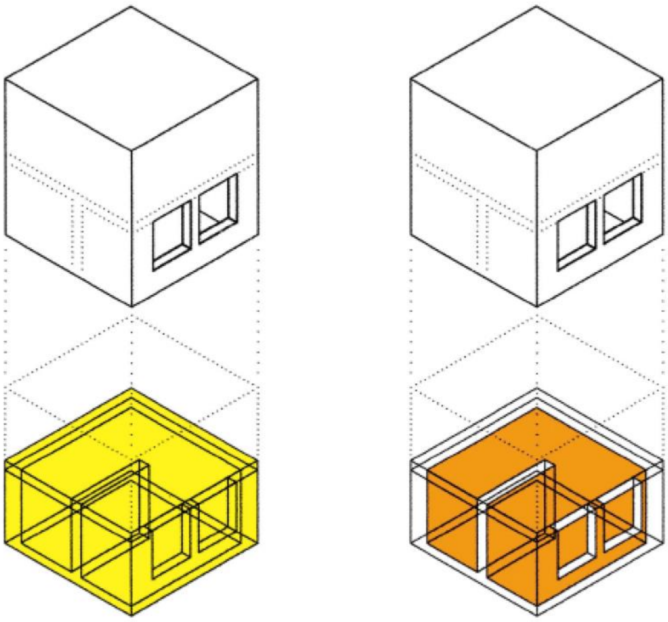

Figure 11: Volume per storey (left gross volume, right net volume)[51]

[50] Cf. ibid. p. 8-11

[51] Ibid. p. 8

6 Fire prevention

6.1 Reality fire – fire growth[52,53,54]

6.1.1 Overview of fire scenarios

It is very important to understand how a fire can break out and develop.

Usually there are many crucial factors, which contribute in developing a fire; it starts with the quantity of combustible materials, arrangement of the room and present amount of oxygen in a room. Hereby, it is important to know that a fire cannot develop without oxygen.

For example, a candle burns and gets covered with a glass: at the beginning the candle burns on, because the fire has enough oxygen left in the glass, but after a short time the oxygen is exhausted and no oxygen gets to the candle - the light goes out. But when the glass is taken off, the flame whirls for a few seconds and gets back to its normal size. That is due to the rapid change of the velocity of oxygen supply.

The same thing can be observed in a room. At the beginning of the fire development an open window can increase the heat/temperature. Regarding the increasing heat, the surface of the combustible materials can emit pyrolysis gas which can ignite itself by the influence of temperature. The ignition of pyrolysis gas is called a flashover, which is probably the most dangerous stage by a fire growth curve.

After that point, the fire development is dependent on access of oxygen. This stage is called the fully developed compartment fire. When everything burns for a long time, the material loses its mass and then the decay period begins.

If there is not enough oxygen in a room or other materials cannot be heated up to emit pyrolysis gases, the fire can also diminish before a flashover can occur.

Another dangerous scenario can occur when fire-fighters open a room which contains mostly exhausted oxygen. Opening the door results in new oxygen accesses to the room and causes a shoot out of flames, which might harm a fire-fighter. This shoot out of flames is a so called backdraught.

[52] Cf. Enclosure fires p. 11-106

[53] Cf. http://iaff266.com/flashover

[54] Cf. Fire Protection Handbook sec. 2.3-2.73

The next figure gives an overview of how a fire can develop in relation to temperature and time.

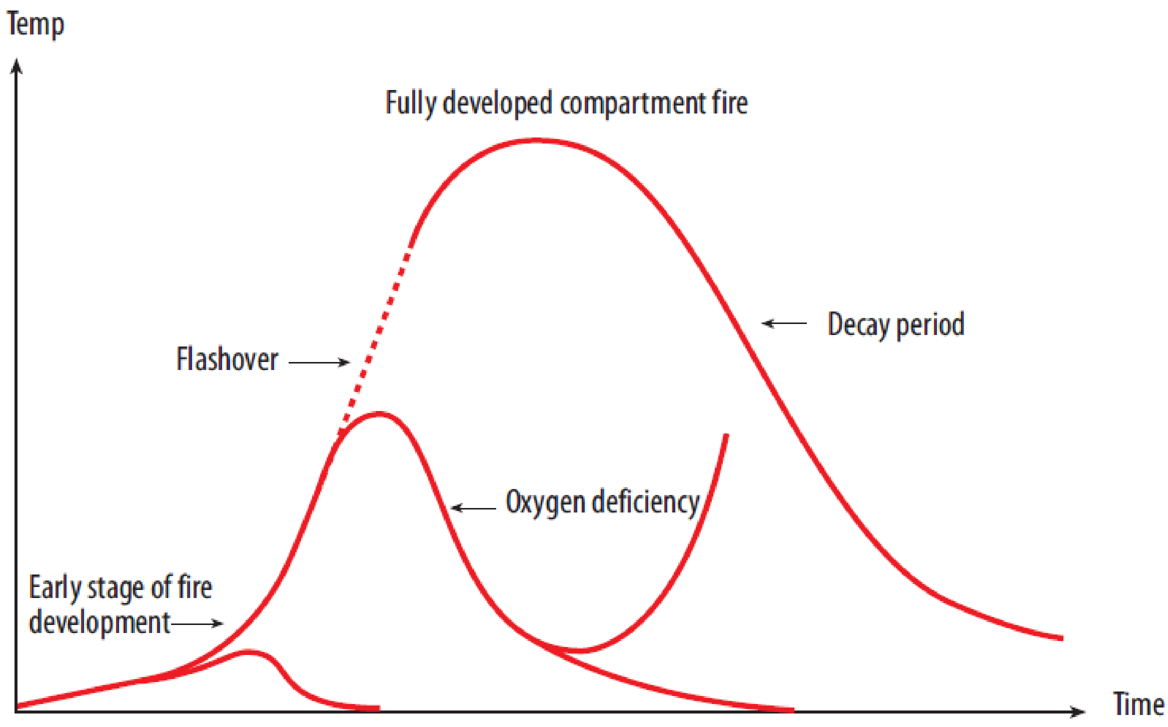

Figure 12: Fire growth curve featuring different types of fire behaviour[55]

It is necessary to know the underlying scenario, because it is crucial to the outcome of the operation. To sum up, it is important to avoid a flashover, because it risks human life to be put in danger. Therefore, everything should be set up to avoid it; this is the main fact why the fire growth curve with a flashover is the most used scenario at fire testing.

6.1.2 The four stages of fire development

As already mentioned there are different stages of fire development.

More specifically, fire development is divided into four stages:

- **Ignition stage** – how the fire starts and when it starts to burn
- **Smouldering stage** – early fire development accompanied with smoke gases
- **Flashover stage** – when the temperature rises up immediately
- **Fully developed fire and decay period** – where the maximum heat is reached followed by the cool down process

[55] Enclosure fires p. 12

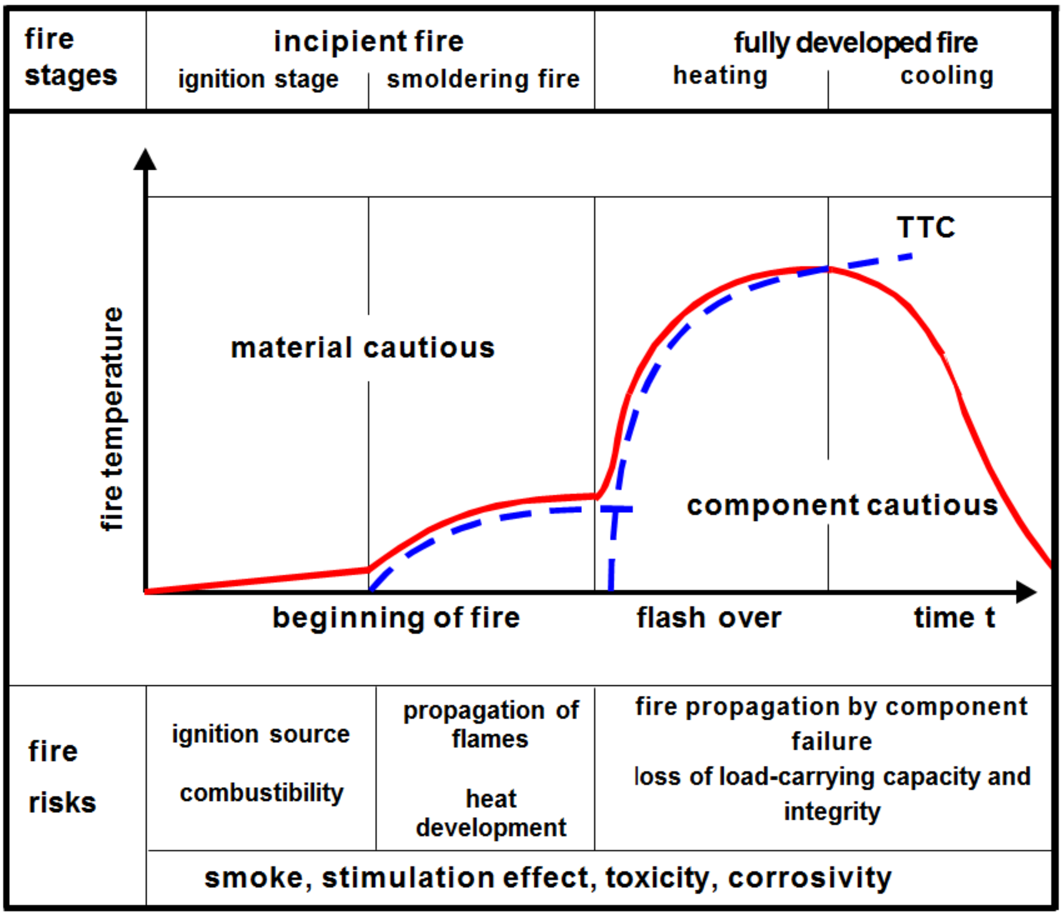

Figure 13: Fire developing categorized in stages in relation to their risks[56]

Figure 13 gives an overview of the risks which come with each stages and what their causes are.

TTC is the abbreviation for time temperature curve and it is dealt with in Section 6.2.

The aim of the next few pages is to give a detailed description of each stage.

[56] Brandverhalten von Baustoffen und Bauteilen p. 2

6.1.2.1 Ignition stage

Beginning with the ignition stage, it is important to know how a fire starts. There are two factors which are necessary to determine how a fire will grow - the ignition itself and the flame spread.

There are different causes of how a fire can start, typically there is an object which already produces heat or already burns – these objects are called fire triggers.

Fire triggers might be a hot pan with oil, a candle or one of the most common causes, cigarettes. The fire itself can grow or subside; this depends on the possibility to spread out. An initial fire can release the heat needed to ignite other objects. As an example wood based materials, porous materials or plastics can contribute to a quicker heat development.

The heat influence of a fire trigger, whether it is the direct flame or the radiation of a trigger, can cause a chemical reaction called oxidation, which makes the material pyrolyse. Thereby, combustible gases develop, which are necessary for the ignition itself. If there is not enough combustible gas, the material cannot ignite. Pyrolyse is defined as the chemical process of bigger molecules getting split up under heat. Additionally, the oxidation of oxygenic material can contribute to this chemical process. Concerning the pyrolyse itself, every material needs a certain amount of pyrolyse gas and oxygen to ignite. As an example, wood and paper need the double amount of gas to ignite compared to plastic, which is about $2g/m^2s$.

The gases accumulate in the upper part of the room; this smoke gas contains carbon monoxide, which can be deadly if inhaled.

Coming back to the flame spread, it is important to know that every material has its own thermal inertia, which defines its reaction to the influence of the heat. The larger the inertia, the more time is needed for a flame spread. The surface directions play a big role too, in relation to the flame spread rate, which is downwards slower than upwards. This depends on the fact that heat normally raises up.

6.1.2.2 Smouldering stage

The smouldering stage occurs when fuel oxidized procures; this causes pyrolyse gas to form, which is the principal constituent of smoke gas. The smoke gas accumulates on the ceiling and heats up the ceiling. As already mentioned the smoke gas includes carbon monoxide, which can be deadly if inhaled. At the beginning it is still okay to stay in the lower part of the room. Normally at this time the fire-fighters would arrive. The smoke layer can also contain other products like hydrogen cyanide (produced by not completely combust materials as wool, silk, polyurethane), Nitrogen dioxide (from fabrics), Ammonia (produced by materials as wool and silk) and hydrogen chloride (from cables and PVC), which can pose a risk to people and can cause death.

It is important to know which materials are present and if there is sufficient fuel and oxygen in the room.

The result of these gases—especially pyrolyse gases—accumulate at the ceiling and heat the whole room up: starting from the ceiling down to the attached walls and furniture and lastly reaching the floor. Everything gets heated and can start to accumulate new pyrolyse gases and eventually ignite. This can lead to ignition of smoke gases and the fire can then spread very quickly.

The reason why this happens is that the gases, which do not combust in the flame, are rising up to the ceiling. Those are so called unburned gases, which were already mentioned before. The issue is that the quantity of unburned gases in the smoke layer is dependent on the mixture of air with the fire plume itself. A sufficient oxygen supply, for example a door, means fewer unburned gas, as insufficient oxygen like a window. This is due to the fact that the combustion process is related to the access of the air, which has influence on the unburned gases in the smoke layer – also an incomplete combustion means a large amount of combustible gases in the smoke layer.3

It is important to know that the mass loss rate and combust efficiency stands in relation to the heat release and unburned gases. This is influenced by external radiation, for example, the heated ceiling caused by the flames itself and the heat conducted through the material.

The heat release and the forming of unburned gas also depend on the ventilation itself. That means that the combust efficiency is lower, if the ventilation itself is lower. This causes more unburned gas.

Additional gas properties should be considered, thus, why the hot gas goes up and accumulates under the ceiling. The reason is very simple: hot air always moves upwards because of the air’s molecular movements. The hot air’s density is less compared to the density of cold air. Hot air gets lighter, which can be explained by comparing hot air and cold air: the same area of space will show hot air having fewer molecules than cold air. In the upper part of the room, there is normally a positive pressure and at the lower parts a negative pressure. Positive pressure does not exert as much pressure on the earth as cold air would do.

The aim of the nature is to have equilibrium; this means a natural exchange of pressure. That is the reason, why hot gas in a high pressure environment always flows to an environment with less pressure. As long as the gas has a higher temperature and pressure, it wants to escape upwards. The so called neutral plane describes a condition where the pressure outside is the same as inside; this neutral plane is between the positive pressure in the upper part of the room and the negative pressure in the lower part of the room. When someone is talking about positive pressure, it is related to the pressure which is higher inside than outside on the same height. For example if the pressure, as shown in Figure 15, is higher inside than the pressure outside, the smoke gases escape over the neutral plane and new air gets sucked in. This example shows a room with an opening, a window or door, which is opened. When everything is closed, the situation is somewhat different. Usually every room with a door or window has a small leakage, but if there is theoretically no leakage the pressure would increase rapidly and would break the windows or doors. Figure 14, Figure 15 and Figure 16 give an overview when and why smoke gases escape.

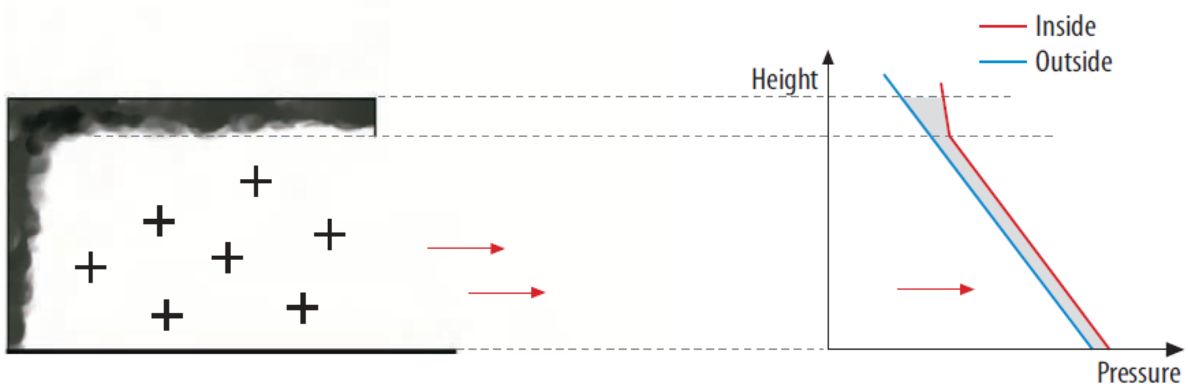

Figure 14: The pressure conditions in a fire room when there is still positive pressure in the whole room can be identified by the "Outside" pressure curve to the left of the "Inside" one. You should note that no smoke gases have escaped from the room up until this point. [57]

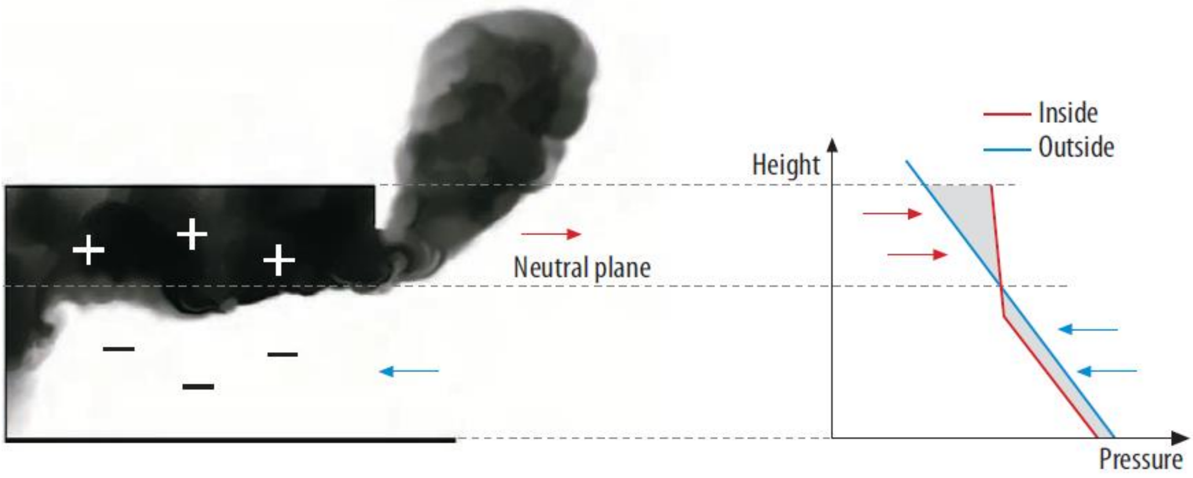

Figure 15: The pressure conditions in a fire room with a clear two-zone layer and a clear neutral plane. There is positive pressure above the neutral plane, i.e. the gases are escaping through the room. There is negative pressure underneath the neutral plane, which means that air is flowing into the room.[58]

[57] Enclosure fires p. 75

[58] Ibid. p. 75

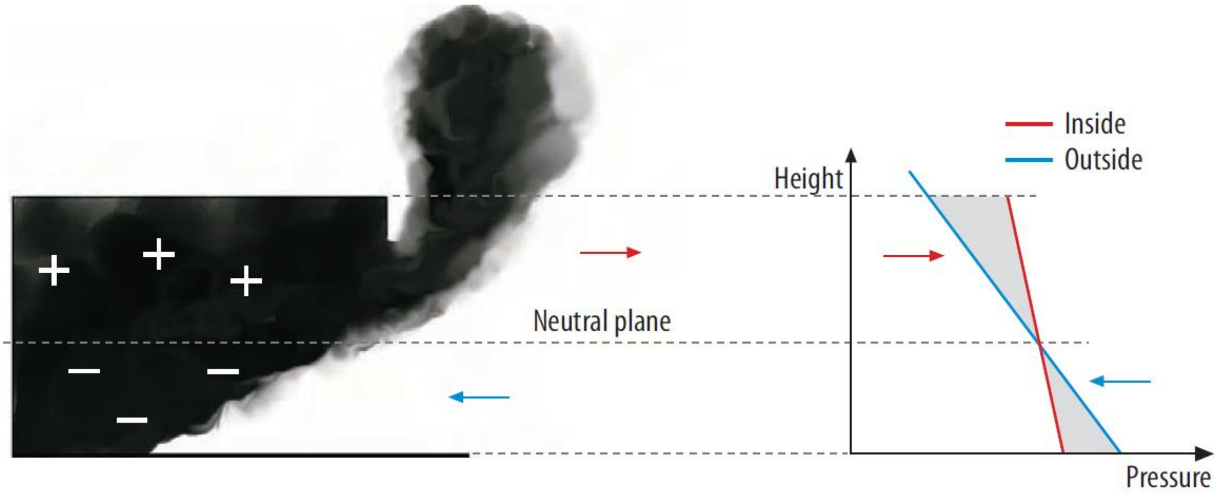

Figure 16: The pressure conditions in the opening to a fire room completely filled with smoke gases or where a flashover has occurred.[59]

6.1.2.3 Flashover stage

The worst case scenario concerning a fire is the so called flashover. As discussed before, an explanation of some points should be clarified here. A flashover occurs if the oxygen supply is ample- this is the case when the room has openings - but when there is a leakage of oxygen the fire intensity decreases and fire may go out or smoulder. There are many different definitions of how a flashover is described, but to sum up a flashover is defined as a fully developed compartment fire.

A more specified declaration comes from Lars-Göran Bengtsson, which is leant on an ISO definition:

“During a compartment fire a stage may be reached where the thermal radiation from the fire, the hot gases and the hot enclosure surfaces cause all combustible surfaces in the fire room to pyrolyse. This sudden and sustained transition of a growing fire to a fully developed fire is flashover.” [60]

In fact, a flashover can occur when the fire is ventilation controlled and not fuel controlled. This can be explained simply by the fact of not having enough oxygen supply which results in the inability of smoke gases or pyrolyse products to burn.

It is difficult to define at which time a flashover occurs, because it depends on many factors, like room situation, combustible materials with their self-ignition and also the oxygen supply.

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[59] Ibid. p. 76

[60] Ibid. p. 87

A general stated fact is that a flashover occurs if the temperature in the smoke layer is about 600°C or the radiation at the floor is over 20 kW/m². The issue of the flashover itself is that the heat and the pressure in the compartment increase very quickly; therefore, it is nearly impossible to survive it.

6.1.2.4 Fully developed fire and decay period

After a flashover the temperature in the room can reach about 800-900°C. The result is called a fully developed compartment fire. The heat in the room is temporarily that high, that nothing can resist this for a long time. How long the temperature lasts depends on the amount of fuel, which is left as well as on the access to oxygen, but it is not unusually that the temperature can hold on, up to several hours.

After that the decay period starts and normally the fire gets fuel controlled again. At this stage temperature drops.

As discussed before, the flashover is one of the most deadly/lethally situations/results/consequences of a fire. So are the gases which are inhaled, but one of the major causes is that the material loses its strength. This leads to the collapse of structural components. Furthermore, the collapsing of parts of the building is an area which becomes important, namely, to improve the resistance of the material itself and which material fits the best situation. Detailed information about materials is provided in Chapter 6.4.

6.1.2.5 Summary

At the beginning of every fire you need a specific amount of heat which can react with a surface of a material. This reaction is called oxidation, the material is heated up and its surface oxidizes. This causes pyrolysis gases, which are hot and accumulate at the ceiling. The ceiling gets heated up. The material itself ignites and also heats up other parts in the compartment. If the oxygen supply is sufficient, there are fewer unburned gases in the smoke layer at the ceiling,

At this stage everything in the room gets heated up. A flashover can occur if the heat in the smoke layer reaches 600 °C and the smoke layer auto ignites or if the radiation on the floor is above 20 kW/m² and most of the materials auto ignite. In addition, there has to be enough oxygen to burn on. The time where everything ignites is called flashover, at this time the pressure in the room and the temperature increases rapidly. After that the temperature can reach up to 900 °C which might last up to several hours, depending on the amount of fuel and oxygen access. Next to it the decay stage starts, normally the fire gets fuel controlled again and not on ventilation as before. Next to deadly gases and flashover, the materials start to lose their strength, which can lead to collapsing of different structural parts.

6.2 (Standard) time temperature curve

To test the fire resistance of a construction or material, the time temperature curve is used. The ISO834-1 standard is the normally used standard in Austria. In the United States the ASTM E 119 is used; these standards make it possible to categorize the fire resistance class for each material and make it comparable. The curve itself shows the fire stage after a flashover and does not include the ignition and developing of the fire before the flash over, That is the reason why it is not that easy to use it for the real fire developing time.

Every material gets tested in a standardised room under standardised boundary conditions. It is possible to measure the changes of the material itself in relation to the temperature and time. After some test schedules the material is ready to be categorized.

Figure 17 also gives an overview of the external exposure fire curve, which is used for simulating the influence of a fire, stepped out over a window, on an outside surface of a wall and the hydrocarbon curve, which is used for example in petrochemical facilities. These two curves are not relevant for this thesis.

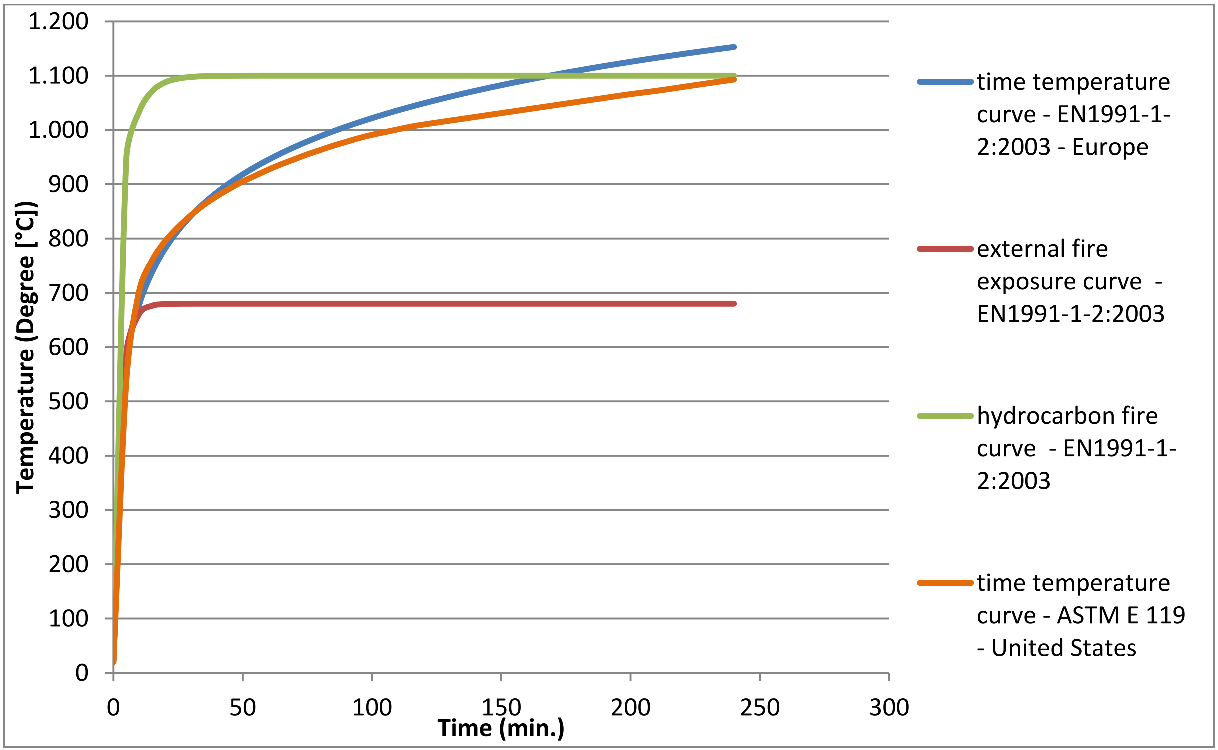

Figure 17: Different time temperature curve[61,62]

[61] Cf. Eurocode 1: Actions on structures – Part 1-2 p. 25-26

[62] Cf. ASTM E 119 – 00a p. 16-25

As already mentioned, the standards for the time temperature curve in Austria are the ISO834-1 and the EN 1991-1-2 standard and for the United States of America the ASTM E119.

The differences between the ISO 834-1 and ASTM E119 is, that “the ASTM E 119 furnace exposure is measured using shielded thermocouples, while the ISO 834 furnace exposure is measured using sheathed thermocouples.”

Note: The standard time temperature curve is a standardized fire development curve, which does not reflect the real fire development. It is a simulation model which can differ from the real fire. In fact, the standard time temperature curve is a unified system, which makes it comparable. The issue is the over- and under estimation of the temperature, which doesn’t fit the real fire load. (Other curves/Another curve should be used by for an example a gas fire) It also does not have a decay phase and deflects a constantly increasing temperature at a high level. [63,64,65,66]

[63] Cf. Fire Protection Handbook sec. 6-37
[64] Cf. Fire Resistance Testing For Performance-based Fire Design of Buildings p. 16-18
[65] Cf. Eurocode 1: Actions on structures – Part 1-2 p. 25-26
[66] Cf. ASTM E 119 – 00a p. 16-25

6.3 Fire resistance rating

“The fire resistance rating gives information about the time a building element can resist against a standard fire in a furnace test. In fact, it is the time which is needed to bring the material to failure. “Failure criteria are based on thermal penetration, integrity, or structural collapse.”[67]

6.3.1 Austria[68]

In Austria the terminology “REI” is used to define these three failure criteria. The abbreviation originally comes from French, “**R**” stands for **Resistance** – structure collapse, “**E**” stands for **Etanchéité** – integrity, “**I**” stands for **Isolation** – thermal penetration.

R – load bearing capacity

This means that structural elements can resist a standard fire without losing its stability. Stability is defined over the criteria of deflection, strain and compression.

E – enclosure of space/integrity

It stands for the tightness of a room dividing structural elements against fire and smoke, which means that the fire cannot spread from the flared side to the non flared side.

The enclosure of space failure criteria are:

- chink and gaps, with defined dimensions
- ignition of a cotton pad
- ongoing ignition on the unexposed side

I – thermal penetration

The thermal penetration is defined as the ability of a structural element to limit the transmission of heat and fire, so that material nearby the non-flared side cannot ignite and people near the heat are protected.

The abbreviations can be combined with each other. For load bearing structural elements the combinations of REI-time, RE-time and R-time can be used. RI does not exist, due to the fact that a structural element automatically fulfils the point of enclosed space when it has been provided a thermal penetration. When the structural element is non-load bearing, the abbreviations EI-time and E-time are used.

[67] Cf. Fire Protection Handbook p. 2-60

[68] Cf. Fire classification of construction products and building elements – Part 2 p. 15-20

Generally the following performance times are used to define a structural element:

15, 20, 30, 45, 60, 90, 120, 180, 240, 360.

As an example “REI 90” means that the structural element has to fulfil the requirements of load bearing capacity, enclosure of space and thermal penetration for at least 90 minutes.

Additional to that there are other abbreviations too:

W	thermal radiation
M	specific mechanical load
C	mechanical locking device
S	leakage rate for smoke

W-thermal radiation

It is the ability to limit the thermal radiation of a structural element through itself or on the non- flared side to avoid the thermal radiation on adjacent materials.

The radiation itself is not allowed to exceed 15 kW/m².

M- specific mechanical load

It describes the resistance of a structural element against an impact loading of any other structural element, which lost its load bearing capacity. The test itself is simple: after the material reached the target time, for example REI90 (90 minutes), the material gets a defined impact loading, which it has to resist. Then the material receives the classification M – REI – M 90.

C- mechanical locking device - self closing

Self-closing stands for the ability of an opened fire resistant door or a window that closes itself. This mechanism has to work without electricity to guarantee a closed door even in the case of an electricity failure. This classification has six subtypes C0-C5 and each subtype has a certain amount of closing cycles. This means that the fire door gets opened and closed for a defined amount of closing cycles. After that it is subjected to the fire testing.

S – leakage rate for smoke – smoke tightness

This abbreviation describes the ability to prevent gas or smoke coming from one side of the element to the other.

6.3.2 Differences to the United States

The system of the United States is very similar to the Austrian system. In fact the differences can be rather found in the terminology.

As an example R, E and I are not a terminology which is defined in a standard or code, but the failure criteria (thermal penetration, integrity, or structural collapse) are the same. Different to Austria, the United States have a value of an amount of hours, which is defined in the International Building Code or for example in California, in the California Building code. This doesn't mean that walls have to resist against thermal penetration, integrity and structural collapse for this amount of hours. The ASTM E 119 gives information about the requirements for each structural part, for examples it has to resist the passage of flames and gases hot enough to ignite a cotton waste, for the defined amount of hours or it has to resist for a certain amount of hours without a structural collapse.

In Austria there are guidelines which include the complete information about requirements.

To summarize, Austria defines the requirements in a guideline (Example: R 90 - the structural element has to resist 1 ½ hours without losing its stability); compared to the United States which define the time of fire resistance in a Code (Example: Exterior wall 1 ½ hours) and define the requirements of the structural element in the ASTM E 119 or UL 263. (Example: have to resist that time without structural collapse)

In fact the systems are very similar; the differences are more how each country provides its data.[69,70]

[69] Cf. California Building Code 2013 p. 60

[70] Cf. ASTM E 119 – 00a p. 2,3

6.4 Fire behaviour of materials

6.4.1 Classification of materials in Austria[71,72,73]

The classification of materials in Austria is defined in the standard EN 13501-1 and contains three main material specifications:

- Combustibility
- Smoke formation
- Droplet formation

Combustibility

Generally the material is split up in combustible materials and non-combustible materials, with different classifications.

- **Non-combustible materials**
  Non-combustible materials supply no contribution to the fire itself and have the abbreviation:
  - **A1**, which means that the fuel value is under 2,0 MJ/kg
    - Examples: concrete, glass, rock wool
  - **A2**, with a fuel value under 3,0 MJ/kg and criteria of B
    - **Examples**: gypsum plasterboard

- **Combustible materials**
  Combustible materials are classified by five abbreviations.
  - **B - very limited contribution to fire**
    After 30 seconds of flaming the material, the fire is not allowed to expand more than 150 millimetres in 60 seconds. The heat release rate has to be less than 120 W/s and the released heat is not allowed to be more than 7,5 MJ.
    - **Examples**: isolations panels[74]

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[71] Cf. Fire classification of construction products and building elements – Part 1 p. 17-34

[72] Cf.http://www.egger.com/downloads/bildarchiv/116000/1_116033_TM_Brandverhalten_DE.pdf

[73] Cf. http://www.egger.com/downloads/bildarchiv/116000/1_116034_TM_Brandverhalten_EUROCLASS-13501-1_DE.pdf

[74] Cf. http://www.hoesch-bau.com/uploads/tx_downloads/140909_GBTP_de_web_Update072015_kl.pdf p.9

- **C – limited contribution to fire**

  After 30 seconds of flaming the material, the fire is not allowed to expand more than 150 millimetres in 60 seconds. The heat release rate has to be less than 250 W/s and the released heat is not allowed to be more than 15 MJ.

- **D – acceptable contribution to fire**

  After 30 seconds of flaming the material, the fire is not allowed to expand more than 150 millimetres in 60 seconds.

  - **Examples**: construction timber, non-treated wood

- **E – acceptable fire behaviour**

  After 15 seconds of flaming the material, the fire is not allowed to expand more than 150 millimetres in 20 seconds.

  - **Examples:** fibre board with low density, extracellular polymeric substances (EPS)

- **F – non requirements**

  This includes all materials which cannot be assigned to the mentioned classes. The usage of these materials is not allowed.

Note: The examples mentioned in the individual classification are a rough guideline. From manufacturer to manufacturer, there can be considerable deviations.

Smoke formation

The smoke formation is split up into three abbreviations:

- **s1 – weak smoulder**

  The smoke production rate value has to be under 30 m^2/s^2 (squared metre per second squared) and the total smoke production has to be less than 50 m^2 (squared metre)

- **s2 – normal smoulder**

  Different to weak smoulder, the smoke production has to be less than 180 m^2/s^2 (squared metre per second squared)

- **s3 – heavy smoulder**

  All products which cannot be classified with s1 or s2 or which are not tested for smoke production

  Note: s stands for smoke

Droplet formation

As the smoke formation, the droplet formation is split up into three abbreviations:

- **d0 – non-dripping**

  Non fire dripping in a period of 600 seconds

- **d1 – dripping**

  No continuous fire dripping over 10 seconds in a period of 600 seconds

- **d2 – ignite dripping**

  This class defines every product, which is not tested or not classified with d0 and d1 or the filter paper, which is tested by the EN ISO 11925-2, ignites.

  Note: d stands for droplet

Example of a classification by the standard EN 13501-1:2009-12:

C – s0,d2

C means that the material has a limited contribution to fire and **s0** stands for a weak smoulder production from the material itself and **d2** defines that the material is not in droplet formation or didn’t get the classification d0 or d1.

Note: There are classifications of textile products itself, but they are not mentioned in this thesis.

6.4.2 Classification of materials in the United States[75,76,77]

The classification of the materials is generally divided in combustible and noncombustible materials.

The definition whether a material is noncombustible is defined in the California building code.

A noncombustible material is defined by two points:

1. The building construction material will not ignite and burn when it is subjected to fire or it passes the ASTM E 136 test.

   ASTM E 136 describes a fire test method where four specimens get preheated up to 750 °C in a furnace and are left there for a maximum of 30 minutes.

   After that, three of the four specimens have to pass these criteria:

   - "When the weight loss of the specimen is 50% or less, the recorded temperature of the surface and interior thermocouples shall not at any time during the test rise more than 30°C above the furnace temperature at the beginning of the test and there shall be no flaming from the specimen after the first 30 seconds.

   - When the weight loss of the specimen exceeds 50%, the recorded temperature of the surface and interior thermocouples shall not at any time during the test rise above the furnace temperature at the beginning of the test and there shall be no flaming from the specimen." [78]

2. A material having the structural base like mentioned in the first point and where the surfacing material is not over 3.2 mm thick and has a flame spread index not over 50. Tested in accordance with ASTM E 84.
   (This is intended for materials as gypsum, concrete and other composite materials – which are losing a significant amount of weight, due the release of chemically bounded water)

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[75] Cf. California Building Code 2013 p. 70

[76] Cf. http://ncdoi.com/OSFM/Engineering_and_Codes/Documents/whitepaper/Classification%20of%20Materials%20According%20to%20Combustibility%20Sept.%2020,%202011_.pdf

[77] Cf. http://www.ul.com/global/documents/corporate/aboutul/publications/newsletters/fire/fsa_issue_3_2008.pdf

[78] http://www.ul.com/global/documents/corporate/aboutul/publications/newsletters/fire/fsa_issue_3_2008.pdf

“Non-combustible does not apply to surface finish materials.

………

No material shall be classed as noncombustible which is subject to increase in combustibility or flame-spread index, beyond the limits herein established, through the effects of age, moisture or other atmospheric condition.”[79]

Examples:

Concrete, gypsum, brick masonry, metals except aluminium, sheet glass and rock wool.

Combustible materials

Combustible materials are consequently all materials which do meet the requirements of non-combustible material; it will ignite, burn and support the combustion.

Examples: Wood, extracellular polymeric substances (EPS), fire retardant treated wood

In addition to the differences between the combustion, there is always the possibility to improve the materials itself. The load bearing capacity of steel under fire can be improved by coatings. Wood can be improved with the impregnation of chemicals, but in fact it doesn’t change if they are combustible or non-combustible. This helps to improve the fire resistance and makes it possible to use materials, where they usually couldn’t be used. See Chapter 6.4.4.2 and 0.

> **Definition:** “Fire-retardant-treated wood is any wood product which, when impregnated with chemicals by a pressure process or other means during manufacture, shall have, when tested in accordance with ASTM E 84 or UL 723, a listed flame spread index of 25 or less and show no evidence of significant progressive combustion when the test is continued for an additional 20-minute period. Additionally, the flame front shall not progress more than 10 1/2 feet (3200 mm) beyond the centerline of the burners at any time during the test.”[80]

Furthermore, there is an extra classification for interior walls and ceiling finishes, which should be classified by the ASTM E84.

There are three types of classifications:

- **Class A -** The flame spread index is from 0 to 25 and the smoke developed index is from 0 -450.

[79] California Building Code 2013 p. 70
[80] Ibid. p. 300

- **Class B -** The flame spread index is from 26 to 75 and the smoke developed index is from 0 -450.
- **Class C -** The flame spread index is from 76 to 200 and the smoke developed index is from 0 -450.

6.4.3 Comparison of fire behavior classification

The differences between Austria and the United States are not as big as they might seem.

Generally, the materials have to be divided in combustible and non-combustible materials. In Austria there are subtypes of material classifications to border the usage of each material. In comparison to that, the United States (California) divide in combustible and non-combustible, except for the classification of interior walls and ceiling finishes. There are some sub-items, which make it possible to use materials, where they normally cannot be used. (Example: Fire retardant treated wood can be used in the construction Type II where only non-combustible materials are allowed.) See Section 7.4.2.3.

Additional to combustible and noncombustible materials there is also a classification for interior walls and ceiling finishes. This is comparable with the subtypes of non-combustible materials in Austria, where restrictions about fire spread of materials can be found as well.

6.4.4 Common structural materials

6.4.4.1 Concrete – Reinforced concrete

Concrete is one of the most common materials in civil engineering. It has the ability to resist a fire over 1 to 2 hours by only getting a moderate damage. The classification of concrete is A1-s0,d0 (non-combustible, non-smoke formation and non-droplet formation – Austrian declaration). It also does not contribute to the fire load itself and remains hard under the influence of heat. Those abilities make it one of the most suitable materials in relation to fire protection. In case of an intense and long-lasting fire, severe damage may occur in form of concrete spalling.

Another fact about concrete is the reinforcement, which is accomplished by structural steel. In a fire the concrete gets heated up and, therefore, the steel too. The problem with steel itself is that it loses its strength under a certain temperature. In addition to that, the dilatation of steel is bigger than of concrete; this causes stress in the concrete itself, which leads to concrete spalling. After such spalling, the covering of the structural steel might not be provided anymore and the steel is directly exposed to fire. The fact, that the steel mainly carries the tension forces in the concrete element can lead to the failure of the steel and subsequently to the collapse of the structural element.

A relative new and increasingly used material is the so called ultra-high performance concrete (UHPC). It differs from normal concrete in terms of cross section being minimized under the fact of strength improvements and lower dead loads. Tension forces are carried over polypropylene or steel fibres. A research indicates that the polypropylene fibres reduce the concrete spalling. The high density of the UHPC is a disadvantage relating to the fire resistance itself. Under the influence of heat, the pressure of the pore water in pore of the UHPC rapidly increases. Usually the pressure cannot increase that fast, but UHPC has, because of its high density, only a few pores. This causes concrete spalling on the surface of the structural element. To prevent the spalling itself, polypropylene instead of steel fibres is used, because polypropylene softens and melds under the influence of heat. Thereby, providing escape routes for trapped steam are made. [81,82]

Preventing of fire damage

Generally it is important to estimate the expected fire load and the definition of protective goals. Based on that, structural elements can be adjusted, in form of bigger cross sections with bigger concrete coverings or with the usage of coverage materials. Additional fire protection systems like smoke and heat extraction/exhaust systems or sprinkler systems can help to reach the protective goals.

6.4.4.2 Wood

Wood is one of the most common used building materials and also one of the oldest. However, it is usually referred to as a material which does not have a good resistance against fire. This might be due to the fact that it is commonly used as a fuel.

Wood is classified in Austria with the abbreviations D-s2,d0, which means that wood is a combustible material with an acceptable contribution to fire and it also has the characteristic

[81] Cf. Fire Protection Handbook sec. 2-61,2-66

[82] Cf. http://www.ductal.com/06_2002_fire_resistance_fr.pdf

of weak smouldering during the influence of a certain amount of temperature. The material itself does not drip under the influence of a fire.

The characteristics are the same as in the United States. Generally there are two aspects to consider when wood is exposed to fire. The first one is that wood loses its strength, because the material is burned away and second, it contributes to the heating up process, because of the release of energy by the burning process itself. To describe the relation between time and loss of material/strength, the term char depth is used.

Concerning the behaviour of wood during a fire, it is to say that wood ignites at a temperature of 275 °C; before that decomposition takes place at about 200 °C.

However, if a durability heating is given, the ignition can also take place at a temperature of 120 °C.

At 400 °C combustion with a flame takes place, by 500°C fire spreads out to the core direction of the wood and at over 700°C the pyrolysis layer starts to combust.

A standard value for the char depth is about 0,65 mm/min (millimetres per minute) for one dimensional slab and 0,80 mm/min for a beam, however, this depends on one hand on the material itself and on the other hand on sides which are influenced by fire.

An important fact of the behaviour of wood on/under fire is that when it burns a carbon layer is formed, which isolates the underlying load bearing wood fibres. This helps to maintain the building stability as long as possible and makes it assessable. In contrast to steel, wood is a combustible material, but if steel gets heated up high, it completely loses its carrying capacity and collapses, whereas wood loses its carrying capacity assessable and slow.

In Austria and the United States there are some restrictions which do not allow the usage of wood for some structural parts under certain circumstances. That is the reason why wood is not allowed to be used in some areas without any compensation measurements. An example of a compensation measure would be a sprinkler system or the enclosure of wood and the United States fire retardant treated wood is used. (During this process the wood gets impregnated with chemicals by pressure to improve its fire resistance) See Chapter 6.4.

Note: An enclosure of wood can be accomplished through a gypsum plaster fire protection board. Until the failure of the board the fire has no direct contact to the wood itself. This building measure can improve the fire resistance rate of the structural element and make it possible to use wood in areas, where it wouldn't be allowed.[83,84]

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[83] Cf. Eurocode 5: Design of timber structures Part 1-2 p. 26

[84] Cf. Fire Protection Handbook sec. 6-61 – 6-72

Preventing of fire damage

As already mentioned before, wood cannot be used in every situation, which is why some building measures or some active fire systems are needed to improve the performance of wood in case of a fire. It is necessary to know from how many directions the structural element is influenced by fire. Then char depth can be defined, which offers the possibility to adjust the cross section to resist against a fire and has enough strength to provide a collapse of the structural element itself.

6.4.4.3 Steel

Steel is a very commonly used material for skeleton construction and it is one of the most popular building materials. Although, the material itself is non-combustible, this doesn't mean that it has some weak points relating to its fire behaviour. The main issue with steel is its loss of strength, which suffers as temperature rises from 100°C to 700°C. At about 316 °C a significant loss of stiffness is noticeable and at about 539°C it loses significant strength.

Another important factor is thermal expansion, as when steel gets heated up it wants to expand and when the temperature increases the thermal coefficient increases too: at 600 °C the length increases 0.008 mm/mm.

Nevertheless, steel has the ability to sustain loads greater than calculated; this can be accomplished of its plastic flow, over redistribution of stresses in the material itself that are loaded close to the design limit. If the plastic moment of the material is reached, a plastic hinge is formed, which transfers the maximum moment of plasticity. But when the moment passes the maximum moment of plasticity the structure can collapse.

Generally, it is important to provide a direct exposure of fire on the structural element.

Therefore, many fire preventing measurements can be implemented and they can be split up in constructive fire preventing measurements, such as passive and active fire preventing measurements.

A constructive example would be an over dimensioning or dimensioning at warm state. A composite construction with concrete is useful too as it improves the load capacity and also the fire resistance. This can be accomplished over the ability of concrete: concrete has lower thermo conductivity and is a better heat accumulator than steel, also the material itself carries amount of the loads. Another method to improve the fire behaviour is to fill up the steel profiles with water. It is a closed system with pipes which are connected together, when water heats up, the density decreases; this causes pressure differences in the system which lead to a circulation of water.

As already mentioned there are other ways to improve the fire resistance, for example, one way is to enclose the structural element with materials like a gypsum plaster fire protection board. The second passive fire measure is coating: however, before steel can be coated it is important to remove chemical impurities, rust, fats and oil to achieve a good adhesion. This can be done with different methods like sand blasting, grinding or degrease.

The main reason why steel gets coated is to protect the steel from high temperature. The coat is swelling up to 20 times and saves the steel from an influence of high temperature. The chemical coating of steel (relating to fire) is fundamentally a replicate of the natural behaviour of wood, where a carbon layer is formed to isolate inner wood fibres from fire.

The reconstruction of coated steel elements is maybe more time consuming than the other protection measures, but its initial production saves time and is one of the easiest ways to improve the fire resistance of steel.

Active measures are generally the same as with other materials. Fire exhaust/smoke detectors or sprinkler systems can help to prevent or reduce the fire development.[85]

[85] Cf. ibid. sec. 6-163,6-164

6.5 Penetration sealing (Through-penetration firestop system)[86,87, 88]

Penetration sealing is as important as the fire resistance of a fire wall. It does not depend on how good the fire resistance of the wall itself is, because fire or smoke can still go through the openings. Penetration sealing is used for grommet, air supply and other pipe systems.

Therefore, it is important to use the right sealing system for different types of openings.

In Austria the categorization is the same as for the structural element itself. In fact the terminology “E” and “I” is used for the classification. See also Chapter 6.4.1.

In comparison, the United States (California Building Code) make use of the terminology “F”, “T” and “L”.

- **F-RATING (flame rating)** – “Evaluates the time that the system will withstand the passage of flame expressed in hours.” [89]
- **T-RATING (thermal rating)** – “Evaluates the time that the system will limit the temperature on the unexposed side to not more than 325 °F (163 °C) expressed in hours”[90]
- **L-RATING (leakage/smoke rating)** – “Evaluates the air leakage through the system at ambient and/or 400°F (204°C) at an air pressure differential of 0.30 in. of water (74.6 Pa) expressed in cubic feet per minute per square foot of opening (cfm/ft2); the test for L ratings is not a requirement of ASTM E814 and is optional in UL 1479” [91]

Note: It might be necessary to insulate items with a high heat transmission to fulfill the criteria of a T-Rating, and a F-Rating. (Example: metal pipes)

[86] Cf. Fire classification of construction products and building elements – Part 2 p. 53-55
[87] Cf. Vorbeugender baulicher Brandschutz: Dämmarbeiten/Ausführungsrichtlinie p. 8-27
[88] Cf. Fire Protection Handbook sec. 18-73 – 18-78
[89] Ibid. sec. 18-74
[90] Ibid. sec. 18-74
[91] Ibid. sec. 18-74

Basically, the process of choosing the right system is similar in California and Styria.

1. First of all it is important to have a look at the fire resistance rating of the structural element being penetrated.
2. Type of pipe, conduit or other item, which should penetrate the fire barrier
3. Type of construction - wall, floor or both
4. The required rating – Austria (“E” and/or “I”); California (“F” and/or “T” and/or “L”)
5. Selection of the penetration sealing with detail construction

The requirements in California are defined by the California building code and in Austria the OIB Guideline 2 is used.

There are many ways to prevent a flame or smoke coming through a grommet or a pipe lead-through. Basically, the requirements for a penetration sealing are the same as for the penetrated element (wall, floor). This applies for Austria as well as for California.

One way to accomplish it is to use materials which expand under the influence of heat and seal the air spaces between penetrated element and penetration item.

6.5.1 Cable sealing

When it comes to cable sealing it is important to know, that the recommended maximum cable assignment is only allowed to take in 60 percent of the opening.

Hard sealing

It uses a fire protection mortar, which consists of ingredients to reduce the heat transmission. That is why the flames cannot spread on the non-flared side and smoke cannot pass through. The mortar itself is based on cement or gypsum. An advantage of it is the possibility to conduct cables afterwards only by drilling through the mortar. This kind of sealing is commonly used when there are rather few cables. For a bigger amount of cables soft sealing is used.

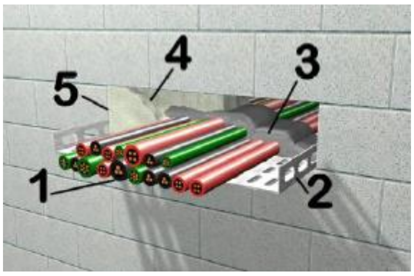

Figure 18: Hard sealing[92]

1 – cable 2 – cable tray 3 – sealing component

4 – certified formwork 5 – fire protection mortar

Soft sealing

A soft sealing includes two components: the first one is the fire protection plate, which is basically out of rock wool or glass wool, and the coating, which can be out of an intumescent paint or an ablation coating. The difference between the two coating types is that the intumescent paint increases in volume under a certain amount of heat and builds an insulation layer. In contrast, the ablation coating reacts under the heat, melts and builds ceramic, which acts as a thermal insulation.

[92] Vorbeugender baulicher Brandschutz: Dämmarbeiten/Ausführungsrichtlinie p. 11

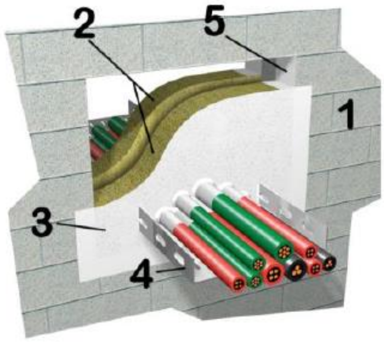

Figure 19: Soft sealing[93]

1 – masonry
2 – rock wool
3 – intumescent paint
4 – cable tray
5 – reveal coating

Module sealing

A module sealing uses a prefabricated steel frame with an expanding fire protection element. In case of a fire the modules expand and seal the air openings, thus, it guarantees that no smoke and fire can come through the penetrated element. The fixture of the fire protection elements is accomplished with anchor plates and chock seals.

Note: Cable trays are not allowed to be combined with module sealing.

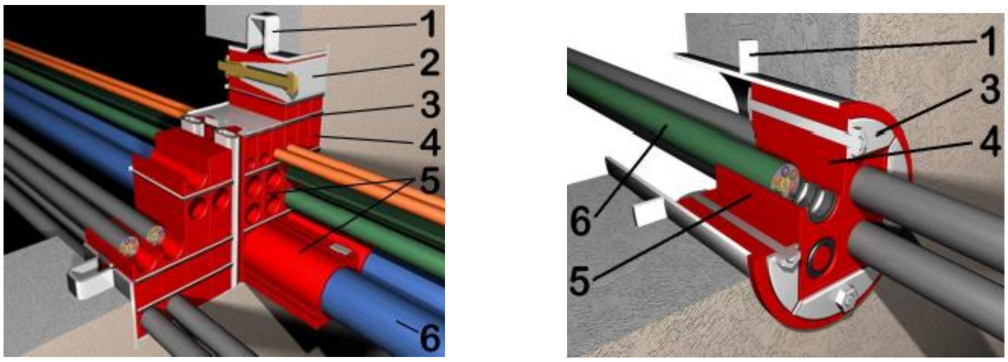

Figure 20: Module sealing[94]

1 – frame
2 – chock seal
3 – anchor plate
4 – fill module
5 – gap module
6 – cable

[93] Ibid. p. 10
[94] Ibid. p. 12

Cushion sealing

Similar to the module sealing, the cushion sealing uses expanding materials in form of cushions. It is used as a provisional solution in the building phase; it is often covered with steel grid, so nobody can divert it.

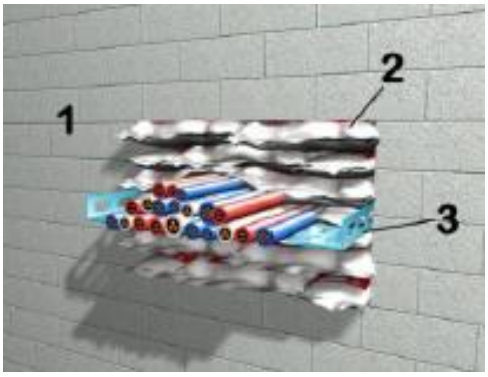

Figure 21: Cushion sealing[95]

1 – masonry 2 – fire protection cushion 3 – cable tray

Foam sealing

A foam sealing is accomplished over fire protection foam which expands and burns down very slowly. It is important to observe the assemble regulations in order to reach the required fire resistance rating over the thickness of the foam. The rest of the unburned section provides the integrity and insulation. It is a fast and easy way of a penetration sealing.

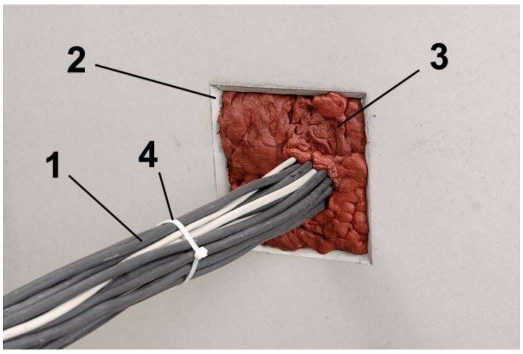

Figure 22: Foam sealing[96]

1 – cable 2 – example: metal stud wall with a reveal

3 – fire protection foam 4 – cable fixer

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[95] Ibid. p. 13

[96] Ibid. p. 14

6.5.2 Pipe sealing

Generally it is important to divide combustible pipes (plastic and aluminum) and non-combustible pipes (metal). The issue with combustible pipes is the fuse effect, which describes a quicker flame spread compared to a non-combustible pipe. In contrast, non-combustible are dangerous because of the fact of heat transmission which can lead to the ignition of other materials.

6.5.2.1 Combustible pipes

Fire protection pipe sleeve

This type of sealing uses an expanding material. Under a certain amount of temperature the material closes the section of the pipe and prevents a flame spread and a smoke expansion. It is necessary to install two sleeves, one on each side of the wall, to provide the fire resistance rating.

The sleeve should be attached to massive or load carrying elements, plus, if the usage of a soft sealing is required (non-load carrying elements) the two sleeves should be connected over threaded rods.

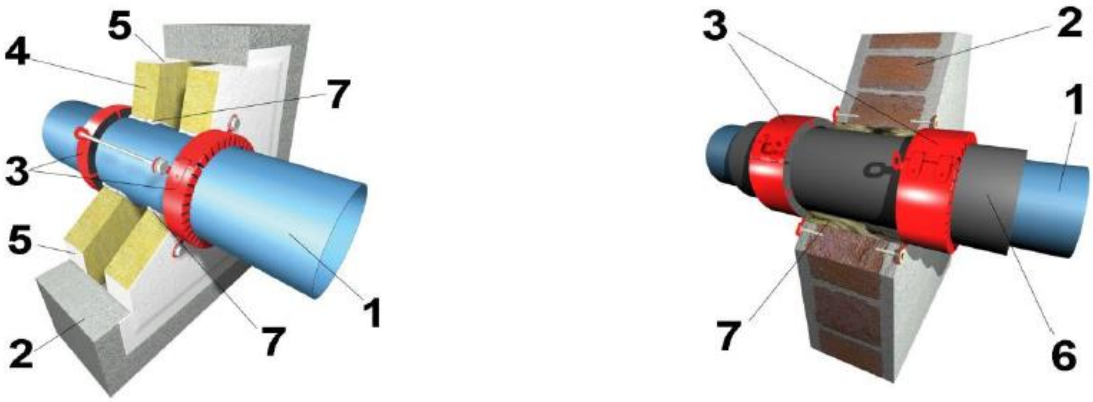

Figure 23: Fire protection pipe sleeve[97]

1 – plastic pipe	2 – wall/ceiling	3 – fire protection sleeve
4 – soft sealing	5 – reveal coating	6 – combustible insulation
7 – annular clearance seal		

[97] Ibid. p. 18

Fire protection strip

The effect of a fire protection strip is the same as mentioned by the sleeve. The strip begins to expand at about 150 °C and should close the pipe. Different to the sleeve the strip closes flush with the sealing surface; it is not allowed to coat or cover the strip on the surface. Additionally, the sealing reveal has to take the expansion pressure. The amount of strip windings depends on the diameter of the pipe, insulation thickness and material of the pipe.

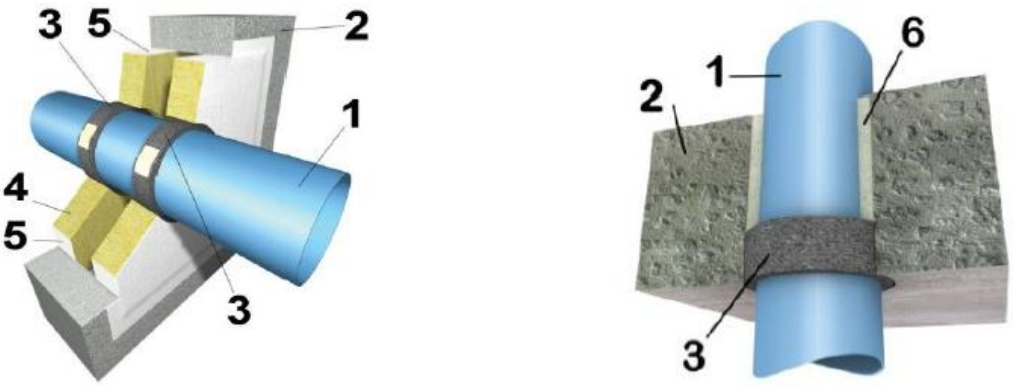

Figure 24: Fire protection strip[98]

1 – plastic pipe	2 – wall/ceiling	3 – fire protection strip
4 – soft sealing	5 – reveal coating	6 –annular clearance seal

Sealing compound

A sealing compound expands at a temperature of 190 °C; it has to fill up the annular clearance seal to take the expansion pressure and close the section of a burnt off pipe.

6.5.2.2 Non-combustible pipes

As already mentioned, the issue with non-combustible pipes is the heat transmission itself, which can lead to the self-ignition of materials on the non-flared site. Therefore additional measurements, like section insulation, have to be considered.

Note: These measurements are not admitted by gas and fluid pipes.

Non-combustible pipes with non-combustible insulation

To provide the heat transmission section insulation is used, which is typically out of rock wool that has a melting point at about 1000 °C. It has to be assembled on each side of the

[98] Ibid. p. 19

element. Generally the length of the section insulation is about 50-100 cm, 3 cm thick and has one pipe hanger at least every 25 cm. (These measurements concern the Austrian regulations)

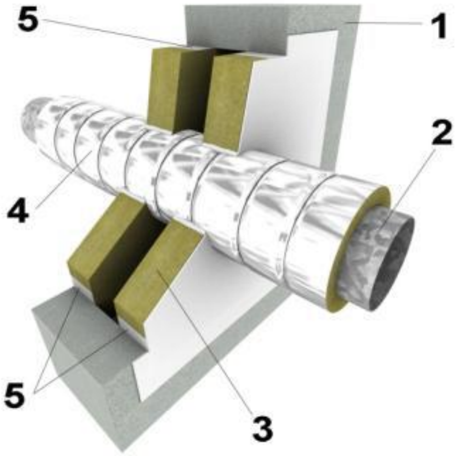

Figure 25: Non-combustible pipes with non-combustible insulation[99]

1 –wall/ceiling 2 – non-combustible pipe 3 – soft sealing

4 – section insulation 5 – reveal coating

Non-combustible pipes with combustible insulation

Combustible insulation, like EPS, XPS and glass wool should be removed or improved with fire protections sleeves, fire protection strips or a sealing compound. See above for the system definition.

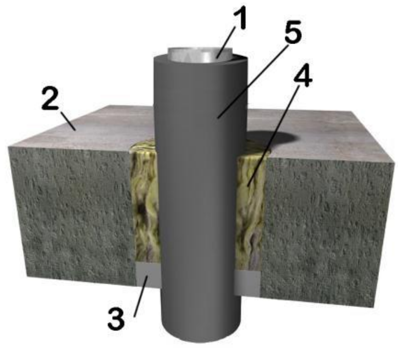

Figure 26: Non-combustible pipes with combustible insulation[100]

1 –metal pipe 2 – wall/ceiling 3 – foam up sealing compound

4 – backfill (rock wool) 5 – combustible insulation

[99] Ibid. p. 21
[100] Ibid. p. 21

Aluminum-composite pipes

Not insulated pipes can be sealed with fire protection sleeves, fire protection strips and section insulation. See above for the system definition and system figures.

6.5.3 Installation shafts and ducts

Typically there are two types:

- Installation ducts (horizontal)
- Installation shafts (vertical)

Each system is protected over a cladding, for example fire gypsum plasterboard, which protects pipes and cables from influence of heat in the event of a fire. The cladding should also guarantee that a fire of a cable or pipe in the shaft or duct can come out.

It is important that the hanger system has to withstand the fire for the required amount of time and is not allowed to penetrate the cladding. Additionally, it is not allowed to connect to a light weight construction wall.

Note: Air conductions are not allowed to contain installation ducts/shafts.

The following figure gives an overview of the system.

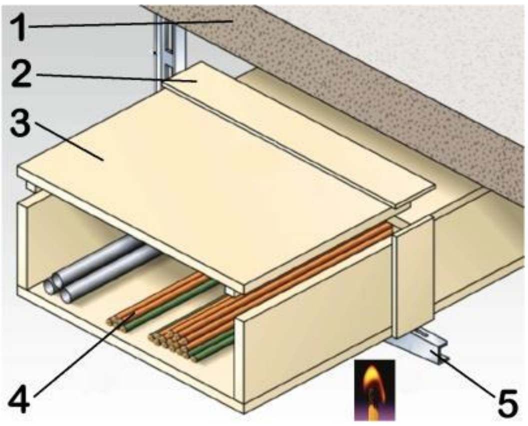

Figure 27: Fire load outside the shaft[101]

1 –wall/ceiling	2 – edge covering	3 – cable cladding
4 – conductions	5 – supporting structure	

[101] Ibid. p. 24

6.5.4 Air shafts

Air shafts are primarily used for constant air exchange to get fresh air into rooms (or, as an example, into a big hall with a crowd of people or a machine). The second type is the so called smoke extracting duct or shaft, which helps to get the smoke out of the building.

The requirements on the hangers are the same, as mentioned above in the point installation shafts and ducts.

The fire protection of air shafts can be accomplished through different systems.

The following systems are the common air shaft systems:

Cladding air shaft

The steel sheet is covered with a cladding out of fire protection plates and planks. Basically, silicate plates or rock wool plates/planks with/or without coating are used.

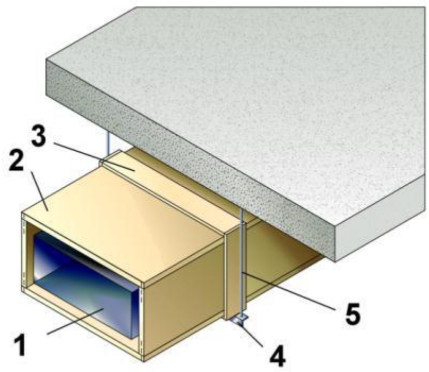

Figure 28: Cladding air shaft[102]

1 –steel sheet shaft 2 – fire protection cladding 3 – edge covering

4 – supporting structure 5 – threaded rod

[102] Ibid. p. 26

Self-sustaining air shafts

The air shafts are directly made out of the fire protection plates. A common material used is a silicate plate.

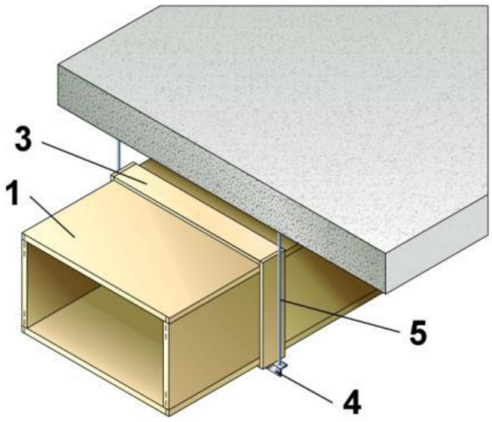

Figure 29: Self-sustaining air shafts[103]

1 –air shaft 3 – edge covering

4 – supporting structure 5 – threaded rod

Smoke extracting shafts

The system is the same as used for self-sustaining air shafts. The difference is merely in the way of usage. Smoke extracting shafts, as the name already says, are used to remove the smoke.

Fire dampers

Dampers are a common system to provide the spread of fire and smoke over a fire wall/barrier.

Generally there are three types of it:

- Fire damper
- Smoke damper
- Fire and smoke damper

Austria differentiates between fire damper and smoke damper. This is due to the fact that fire dampers are also taking care of the smoke.

[103] Ibid. p. 26

Nevertheless, the requirements are basically the same. They have to close the air shaft, in order to prevent flames from spreading throw the fire walls/barriers or/and the smoke/airflow is interrupted through the duct. Fire or smoke dampers work automatically. Fire dampers work with a thermal trigger device (fusible link), which react at 72°C and closes the damper over a spring. There are also motor-operated fire dampers, fire dampers with impulse magnets and pneumatic-operated dampers. In contrast, smoke dampers work with smoke detectors. The smoke goes through the smoke detector and inside the detector is a light diode which sends out light beams; these beams get reflected over the smoke particles and come into photo lines, which triggers the damper. The smoke damper operates in the same way as the fire damper.

Generally, it is important that fire/smoke dampers have to be installed over a soft sealing or hard sealing, which seals the open space between the damper and construction element.

Note: In Austria it is not allowed to install a damper on non-load bearing walls, except the strain compensation in accordance to thermal expansion or the developed force under the collapse of the air shafts can be minimized to make no changes at the damper or the sealing.

In the United States/California are different classifications for Fire/smoke dampers.

Fire dampers are defined over the fire damper rating in the California building code.

The leakage rate for fire and smoke dampers are defined over the standards.

Note: California uses the UL 555 Standard for Fire Dampers and the UL 555S – Standard for Smoke Dampers. Austria uses the EN 1366-1.

6.6 Protection of openings[104]

Fire door

In California, fire doors are rated in 20 minute, 30 minute, 45 minute, 1 ½ hour, 3 hour and 4 hour, which describes the duration of fire exposure. The testing is defined by the NFPA 252 – Standard Methods of Fire Tests of Door Assemblies. Optional it can also be classified by the temperature of the unexposed surface after 30 minutes. In general, fire doors are tested with the NFPA 252, where they are exposed to a standard temperature-time curve and a hose stream test. In a hose stream test the material (normally glass) gets heated up and water is delivered through a hose stream over a specific distance with specific force on the glass or door. If the glass or door is intact and does not exceed the tolerable openings, it passes the test and guarantees the integrity.

The California building code has the following definition:

"Doors in a fire barrier wall, including doors to corridors, shall be self-closing fire door assemblies having a fire protection rating of not less than 3/4 hour."[105]

In comparison to California, Austria uses the abbreviations "E", "I", "C", "S" and "M". See Chapter 6.4.1.

For fire doors and fire dampers there are two additional subtypes for the terminology "I".

- **I_1** – the temperature at the edge of the system is limited to 180 °C.
- **I_2** – the temperature at the edge of the system is limited to 360 °C.

C defines the closing cycles of the fire door and is split up in six subtypes from C0-C5.

The classification ranges from no requirements (C0 – 0 closing cycles) to very frequent operation (C5 – 200.000 closing cycles).

The terminology "S" has also two subtypes:

- **Sa** – "consider the smoke tightness under ambient temperature"[106]
- **Sm** – "consider the smoke tightness under ambient temperature and at 200 °C"[107]

Example: EI_2 90– C5 Sm

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[104] Cf. California Building Code 2013 p. 222-228

[105] Ibid. p. 147

[106] Fire classification of construction products and building elements – Part 2 p. 19

[107] Ibid. p. 19

The fire cannot spread from the flared side to the non flared side of the door over a 90 minutes period; the temperature at the edge of the system is limited to 360°C over a 90 minutes period; the fire door doesn't lose it self-closing mechanism under 200.000 cycles of opening and closing and it has to consider its smoke tightness under an ambient temperature or a temperature at 200 °C.

The requirements for doors are defined in the OIB guideline 2.

Fire rated glazing

Glazing materials are often used for vision panels as in doors or windows. It is important to know, that the glass weakens at a temperature of 799 °C and deforms badly at 871°C where it can drop out. In California it gets tested in accordance with NFPA 257,Standard on Fire Test for Window and Glass Block Assemblies.

The next figure gives an overview of the used fire standards and markings of the glazing assemblies.

TABLE 716.3
MARKING FIRE-RATED GLAZING ASSEMBLIES

FIRE TEST STANDARD	MARKING	DEFINITION OF MARKING
ASTM E 119 or UL 263	W	Meets wall assembly criteria.
NFPA 257 or UL 9	OH	Meets fire window assembly criteria including the hose stream test.
NFPA 252 or UL 10B or UL 10C	D H T	Meets fire door assembly criteria. Meets fire door assembly "Hose Stream" test. Meets 450°F temperature rise criteria for 30 minutes
	XXX	The time in minutes of the fire resistance or fire protection rating of the glazing assembly

For SI: °C = [(°F) - 32]/1.8.

Table 1: Table 716.3 – Marking fire-rated glazing assemblies[108]

Generally, the classification of a fire door and a window are the same. The criteria T describes the classification of a door under a temperature, which is not used by the classification of fire windows.

[108] California Building Code 2013 p. 222

In Austria the classifications of the doors and windows have the same abbreviations, or more specifically, the same classifications. As already mentioned, the standard EN 13501- 2 is used for the classification and it gets tested according to the EN 1634-1: Fire resistance and smoke control tests for door and shutter assemblies, opening windows and elements of building hardware - Part 1: Fire resistance test for doors and shutter assemblies and openable windows.

The difference between the two countries isn’t that remarkable. On the one hand the test gives back the abilities of each item, which are basically the smoke tightness and the fire spread or heat transmission, but on the other hand the test itself has different definitions and boundaries.

6.7 Safety goals

Safety goals are the basement for fire protection. Each country has some legal life safety goals, which have to be provided; other goals (property damage) can be agreed separately.

Generally, there are two ways to provide those goals:

- Prescriptive-based provisions
- Performance-based provisions

The difference between them is the way how the safety goals are reached. Prescriptive-based provisions are always following a code, regulation or standard. There is a prescribed design which has to be used. The problem of it is to cover every constellation of structure and design, which is not possible and would also contribute to even longer and complex documents. Advantages are definitely the verifiability of the technical requirements and a good legal compliance.

Performance-based provisions are especially good for special structures and designs, where codes, regulations and standards do not have a solution or a good solution. Basically, it is allowed to do things differently, but in fact it has to be tested whether it complies with the targeted requirements. Those tests and the proofing can take a lot of effort, but make it possible to differ from the codes, regulations and standards. In fact the performance-based is needed for complex construction projects or innovative architectural solutions. A combination of those provisions can make it possible to build every kind of building and provide its economy/efficiency.[109,110]

Austria – Styria[111]

The Guideline 2 of Austria (Styria) orients itself towards the building product regulation 305/2011 which defines that following safety goals have to be reached in case of a fire:

- the sustainability of the building is maintained during a certain period,
- the development and spread of fire and smoke is bounded inside the building,
- the spread of fire to neighbouring structure is limited,
- the occupants can leave the building unharmed or rescued by taking in other measurements,
- the safety of rescue teams is considered.

[109] Cf. Trade magazine: OIB Guideline 2 p. 4,5

[110] Cf. California Building Code 2013 p. 38

[111] Cf. OIB Guideline: Definitions p. 2

United States – California[112,113]

It is important to mention, that the United States goals are not that specific. They can be measured by qualitative basis and objectives are more specific about how the problem is being solved. They can be categorized as qualitative and quantitative.

The following sentence is part of the California Building Code and defines the purpose of the code:

"…….safety to life and property from fire and other hazards attributed to the built environment; and to provide safety to fire fighters and emergency responders during emergency operations."[114]

A more precise definition for fire safety can be found in the NFPA 101 – Life Safety Code. It is allowed to use the Life Safety Code conjunction with the California building code. The following text contains parts of the life safety code:

Required goals:

- "Protection of occupants not intimate with the initial fire development
- Improvement of the survivability of occupants intimate with the initial fire development
- An additional goal is to provide for reasonably safe emergency crowd movement and, where required, reasonably safe nonemergency crowd movement."[115]

To achieve these goals, the following objectives have to be accomplished:

- **"4.2.1 Occupant Protection.** A structure shall be designed, constructed, and maintained to protect occupants who are not intimate with the initial fire development for the time needed to evacuate, relocate, or defend in place.
- **4.2.2 Structural Integrity.** Structural integrity shall be maintained for the time needed to evacuate, relocate, or defend in place occupants who are not intimate with the initial fire development.
- **4.2.3 Systems Effectiveness.** Systems utilized to achieve the goals … shall be effective in mitigating the hazard or condition for which they are being used, shall be reliable, shall be maintained to the level at which they were designed to operate, and shall remain operational."[116]

Additional it is to say that it is important what the buildings are used for. For example a one family dwelling has different life safety requirements than a hospital.

[112] Cf. Fire Protection Handbook sec. 20-4 – 20-5

[113] Cf. NFPA 101 – Life safety code p. 37-38

[114] California Building Code 2013 p. 3

[115] NFPA 101 – Life safety code p. 37

[116] Ibid. p. 37

Other goals

Apart from the statutory protection goals, there are certain buildings or buildings with a specific use, where an individual fire protection is needed. The safety of material goods are not statutory defined, these goals have to be agreed separately. This applies for Austria and the United States.

Comparison

Austria and the United States have life safety as their main goal. The goals do not really differ from each other. The point that the spread of fire to neighbouring structure is limited is not directly defined as a safety goal in United States, but it is regulated in the California building code under the point fire separation distance. The code defines different requirements related to fire separation distance to provide the safety of neighbours and vice versa.

6.8 Fire detection/alarm system[117,118,119]

There are different kinds of fire detection/alarm system, to find out what kind of fire detection/alarm system is necessary to determine the safety goals and occupancy. It is important to define the level of life safety to provide the people with occupying the building (also in relation to the defined requirements of the code), then the level of property protection and other things like the support of the fire run, mission protection and other environmental protection have to be ensured.

Therefore, it is important to have a look on the building itself and what it should provide. In fact, safety goals lead to the right fire detection/alarm system.

Typically, there two types of fire detection system; an automatic and a non-automatic fire detection system. The term smoke detection system is a system which can be used to contribute to the life safety. This for example, is important in case of dorm rooms, lodging rooms and hotel rooms, where people often do not recognize a fire. Therefore, the system or the detector makes an audible signal so that people get out of harm’s way.

The differences between fire and smoke detection systems are that smoke detection system contributes to personal protection, whereas the fire detection, beyond the personal aspect, has a significant contribution to property and assets.

[117] Cf. TRVB S 123 03 p. 2,3
[118] Cf. Fire Protection Handbook sec. 14-3 – 14-12
[119] Cf. California Building Code 2013 p. 332-349

In fact, the fire detection system takes over the function of smoke detection and can measure the temperature over the fire detectors and send a signal, when a defined value is exceeded. Additional a signal is send to a fire alarm centre. This is an automatic fire detection/alarm systems, which works completely automatic, compared to a non-automatic fire detection/alarm system, where the signal has to be triggered over a tripping device by a person.

The system is responsible for an audible signal (alarm signal) - warning of fire danger, a supervisory signal – that indicates the action which is needed or activates the sprinkler system, smoke and heat exhaust/extraction ventilation system and smoke draft curtains. The last signal (trouble signal) indicates issues with the system itself and furthermore if there are problems with the power supply. (Those systems have to provide a second power supply)

6.9 Smoke and heat extraction/exhaust ventilation system[120]

First of all, there are different types of exhaust ventilation systems. On one hand smoke can be diluted and on the other hand smoke can be suppressed. Additional to that there are smoke and heat extraction/exhaust ventilation systems, which can be divided over the process how smoke is discharged. The first process is the natural smoke discharge over openings in ceilings; the second one uses a ventilator. Thereby, it is important to keep a low flow rate to avoid turbulences.

Generally, the aim of a smoke and heat extraction/exhaust ventilation system is to work against adverse dangerous fire behaviour. If the system is dimensioned rightly, it removes as much heat and smoke until other extinguishing measurements can be made.

In case of a fire, evacuation routes can be heated up and filled with smoke; that is one fact why it is sometimes necessary to make use of a smoke and heat extraction/exhaust ventilation system. Another common term for this system is smoke and heat removal system.

Basically, it is important that the lower floor level is free of smoke. This makes it easier for fire-fighters to fight against the fire and help people which cannot escape (unaided or injured people). As already mentioned, it also prevents a safe evacuation route and additional it can reduce the flame spread. In fact the system helps to fulfil the safety goals. See Section 6.7.

Functional principle

The functional principle behind the system is not complicated. The smoke and heat will be removed over a natural or ventilation process. The natural process uses openings and the ventilation process uses ventilators. It is important to provide an air supply over openings like doors, which help to reach a sufficient discharge of the smoke. The movement of the smoke is normally upwards, which is due to the density. See Section 6.1.2.

Smoke gets out through ceiling openings or gets sucked off by ventilators in smoke removal shafts. These shafts require a fire resistance rating. Usually these shafts should be assembled vertically to provide a quick discharge.

Additional to the smoke discharge, fresh air of the ground and doors gets sucked up and cools down the smoke layer. This causes a thermal discharge in the smoke layer, which prevents heat accumulation and in further consequences the reduction of heat transmission on combustible materials and people below.

[120] Cf. TRVB S 125 97A p. 2-6

To assure that the smoke stays in a certain area (smoke section), fire and smoke barriers and partitions are used. One type of barrier is a smoke draft curtain which can be flexible or stiff assembled. The curtain itself has to be tested for fire resistance.

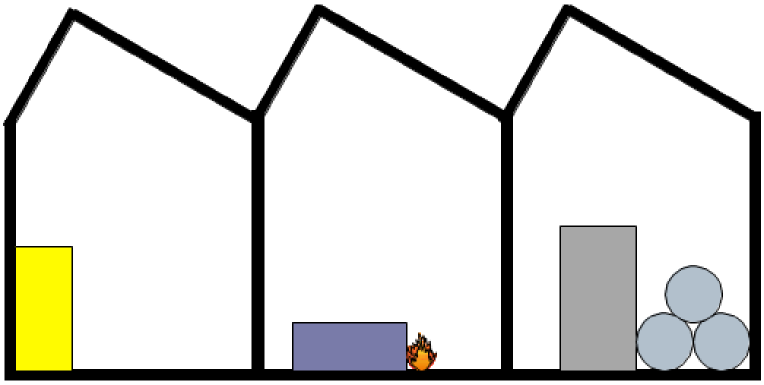

Figure 30: Exhaust/ extraction system – Initial fire[121]

Figure 31: Exhaust/ extraction system – Smoke moves upwards and accumulates under the ceiling/roof. A smoke and heat exhaust/extraction system would already open the opening elements on the roof or would suck off the smoke over the shafts with ventilators.[122]

[121] TRVB 125 S (Hasenbichler) p. 5

[122] TRVB 125 S (Hasenbichler) p. 6

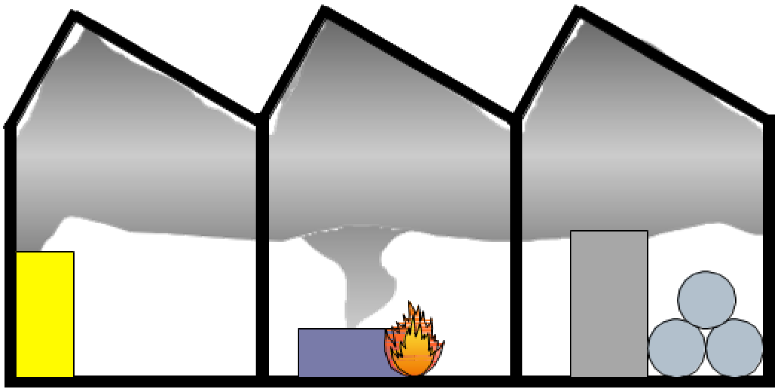

Figure 32: Exhaust/ extraction system - A big smoke layer is formed. In further consequences the hot smoke layer can lead to ignition of the combustible materials, which reach into the smoke layer.[123]

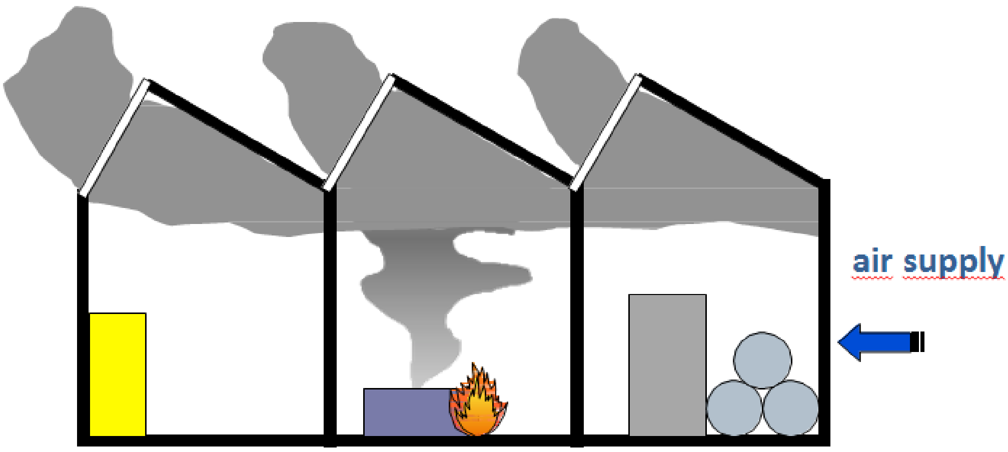

Figure 33: Exhaust/ extraction system – If a smoke and heat exhaust/extraction system is used, the smoke would be discharged to the outside. Thereby it is important to provide an air supply for a sufficient discharge of smoke.[124]

Figure 33 gives an overview of the smoke and heat exhaust/extraction system. The time when the smoke is sucked off or moves out over openings depends on the tripping device. A smoke draft curtain can prevent that the smoke can move to the left and right section. This could be necessary, if these sections are smoke section.

The arrangements of the shaft openings, the distances between them and walls, as the height of the allowed smoke layer are defined by the different standards. (Styria – TRVB S 125 97A Smoke and heat exhaust system; California – NFPA 92 Standard for smoke control system)

[123] TRVB 125 S (Hasenbichler) p. 6

[124] TRVB 125 S (Hasenbichler) p. 7

Figure 34 shows how much temperature and smoke can be reduced under the use of a smoke and heat exhaust system.

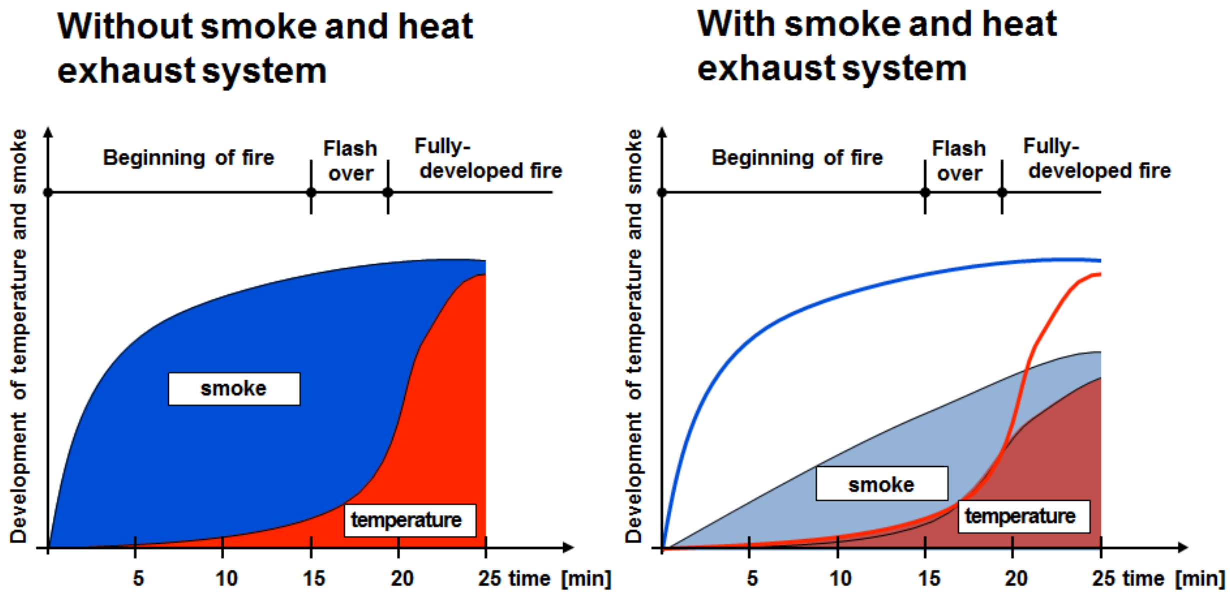

Figure 34: With/-out smoke and heat exhaust system[125]

Generally there are two opportunities to trigger a smoke and heat exhaust system. The automatic method uses a fire detection/alarm system and the manual method uses a trigger, which is installed on a wall per smoke section. Also the safety goals have influence which type of trigger has to be used or if they have to be combined.

When the system is activated, openings for air supply and smoke discharge should be opened; ventilators and smoke draft curtains should be activated.

Maintenance or assembly regulation can be found in the standards mentioned before.

Note: 20% of the height of the room draft curtain depth but ≥4, except by high pilled storage.[126]

Codes & Standards

It differs from country to country, when a smoke and heat removal system has to be used or installed and under which conditions. The California building code and the NFPA 204: "Standard for Smoke and Heat Venting" gives information about installation, requirements

[125] TRVB 125 S (Hasenbichler) p. 7

[126] Cf. California Building Code 2013 p. 360

and definitions of smoke and heat removal systems. In Austria those parts are covered with the Austrian institute of engineering construction guidelines 2, 2.1, 2.2 and 2.3 as the TRVB S 125: “Smoke and heat extraction / exhaust system”.

Additional to those codes are other codes and guidelines which can be referenced in the named codes or which can be used instead of them.

6.10 Automatic sprinkler

In general, there are three types of heat release from a fire: radiation, conduction and convection. The most important type for sprinkler systems is the convective heat, because a sprinkler system uses heat detection to response to fire. Convection always needs a medium, in this case it is the air in the room which gets heated up by the fire and rises up. After the plume reaches the ceiling, it spreads out. This triggers the heat sensing elements of the sprinklers over the conduction of the hot air.[127]

The aim of a sprinkler system is primarily to cool down by a water spray. This exactly means that the water droplets cause a significant cooling in the room. To sustain combustion, a radiative/radiant form of heat is needed. Through the cooling down process with the water droplets the radiative/radiant component is reduced and can stop the combustion process.

Additional to that there is the evaporation of water droplets: they can produce steam with a bigger volume, which deprives the needed oxygen for a sustaining fire. Tests have revealed at least a “critical rate” of water application, which is needed to make it possible to extinguish a fire. The time to control or extinguish the fire falls rapidly, if the rate of water application increases above the critical rate.[128]

[127] Cf. Fire Protection Handbook sec. 16-3 – 16-4
[128] Cf. ibid. sec. 16-6 – 16-7

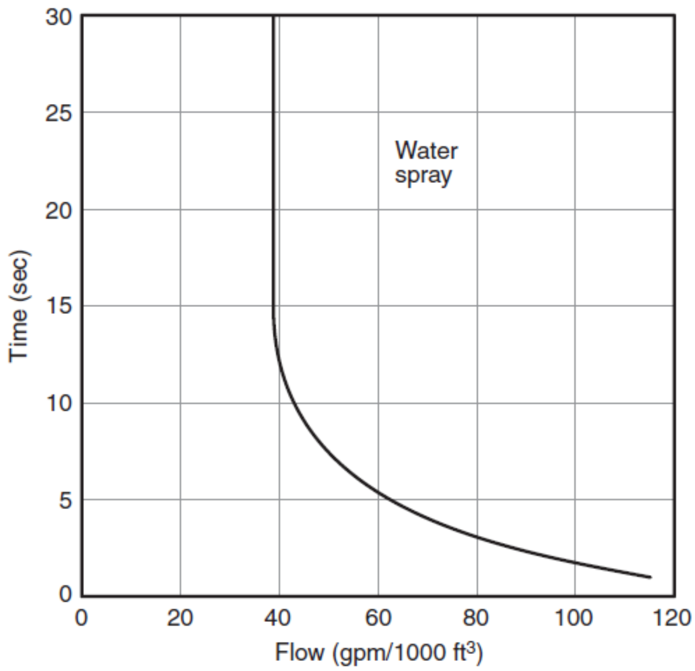

Figure 35: Time to Extinguish Fire in Model Room at Various Flows.
For S.I. units: 1 gpm = 3.785 L /min; 1 ft³ = 0.0283 m³.[129]

In fact, cooling and steam production have the best efficiency, if the environment is unventilated. Otherwise the strong fire can create updrafts, which can sweep away the droplets. Therefore, sprinkler systems are distributing a variety of droplets to cool down the air and control or extinguish the fire.

The cool down process of air is an important fact for the system as the fire gets controlled. When a fire occurs and the plume reaches the ceiling the sprinklers get activated, plus the surrounding sprinklers get activated. This part is very important, since the sprinkler may not be able to extinguish the fire, but the surrounding sprinklers help to cool down vicinity of the fire. Thereby, the materials get protected and help to prevent the spread of fire. Furthermore, the air gets cooled down, so that other sprinklers are prevented from operating.

If suppression wants to be achieved, there must be a sufficient quantity of water to stop the combustion process and minimize the heat release. This should avoid a re-growth of the fire itself. These sprinkler systems are called early suppression fast-response (ESFR) sprinkler; the idea behind it is, that the system has a fast response to a fire and is able to fight its way down through the plume to the burning fuel.

[129] Ibid. p. 16.7

6.10.1 Sprinkler types[130,131]

Sprinklers are available in many different kinds of variations, but the purpose is always the same; a stream of water is released and distributed in a variety of droplets on a specified area. The water comes from a piping system which is generally installed overhead.

Basically there are two kinds of operating elements:

- Fusible sprinklers
- Bulb sprinklers

Fusible sprinklers

Fusible sprinklers operate when the metal alloy fuses. The metal alloys have a certain melting point, which can be adjusted by different metal combinations (for example tin and lead). To reduce the force which is acting on the solder - levers, struts and links or other soldered members are used. The fusible metal has a small mass to minimize its operation time.

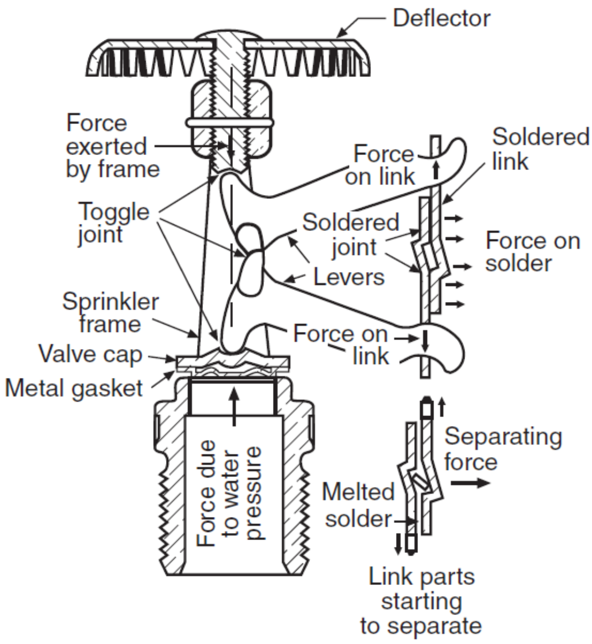

Figure 36: Solder-Type Link-and-Lever Automatic Sprinkler[132]

Figure 36 gives an overview of the mechanical parts. First of all, it is important that the system can resist the force due to water pressure, which can be accomplished over the link

[130] Cf. ibid. p. 16-15 – 16-28

[131] Cf. NFPA 13 p. 13-19 – 13-20

[132] Fire Protection Handbook sec. 16-16

and the levers. These constructions can resist a force which is many times bigger than developed by the water - that is why a possibility of leakage can be excluded. The functional principle behind a link-and-lever sprinkler is that the forces on the solder are very low, because the solder composition should be able to cold flow under high stress. This means that when the melting point is reached the solder cannot bear the forces on the links. The levers are now moveable and can be moved over the water pressure.

Bulb sprinklers

A bulb sprinkler uses a frangible bulb. This bulb is not completely filled with liquid, but on the top of it there is a small air bubble. The liquid expands under heat until the bubble gets absorbed by the liquid - then the bulb shatters and releases the cap. Therefore, it is important to know, that there are different kinds of liquid colors which give some indication of the temperature which is needed to shatter the bulb. This is important, because otherwise the sprinkler might operate when it shouldn't. For example, rooms or halls in which something is produced which naturally causes heat, need a different type of liquid color then for example a room in an office building.

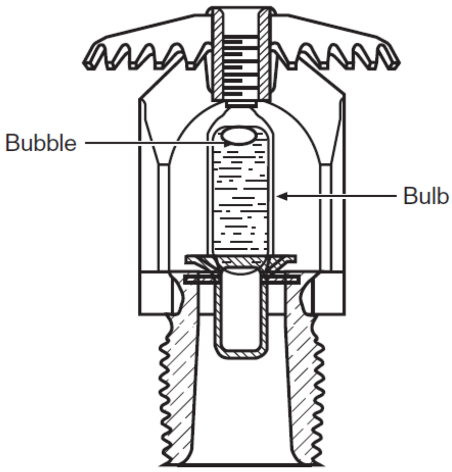

Figure 37: Bulb sprinkler[133]

Another element of the sprinkler is the deflector or distributor, through which the water stream gets directed and converted into a spray. Other parts like the water pressure and the size of orifice have influence on the amount of water which is discharged.

[133] Ibid. p. 16-16

A sprinkler can be installed upright or pendent. The installation itself doesn't have a big influence on the water distribution.

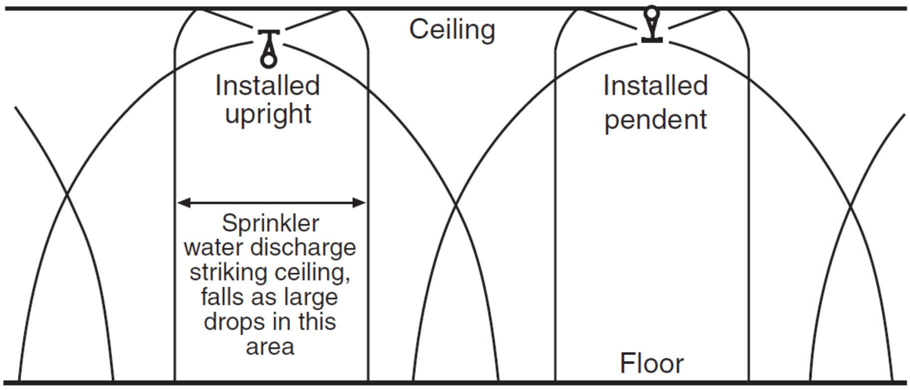

Figure 38: Principal Distribution Pattern of Water[134]

There are many different types of sprinkler systems. The following list should give a short overview of the different types:

- Recessed sprinklers
- Flush-type sprinkler
- Ornamental Sprinklers
- Dry Pendent and Dry Upright Sprinklers
- Large Drop Sprinklers
- ESFR Sprinklers
- Residential Sprinklers
- On/Off Sprinklers
- Sprinklers for Corrosive Conditions
- Sidewall Sprinklers
- Extended Coverage Sidewall Sprinklers
- Open Sprinklers
- Small- and Large-Orifice Sprinklers
- Spray Sprinklers with Different Orifice Sizes
- Picker Trunk Sprinklers
- Intermediate-Level Sprinklers
- Specific Application Control Mode Sprinklers

[134] Fire Protection Handbook sec. 16-21

All of these sprinkler types have their special areas of application. For example, a dry pendent sprinkler is a sprinkler type with no bulb or fusible. This kind of sprinkler is used for dry pipe sprinkler systems. See also Chapter 6.10.2.

The following sprinkler types give an overview of the important sprinklers in this thesis. These are generally used in lodgings, residential buildings as well as in office buildings. These occupancies are defined as light hazard. Each hazard classification has different requirements for the sprinkler system.

Sidewall sprinkler

As the name implies, it is a sprinkler which generally is installed on a wall. The differences to other sprinklers is that is has a special deflector which discharges the water in the required direction. Typically they are used where a pipe is difficult to install, on a ceiling or the ceiling is subjected to low temperatures. This applies for example to: Hotel lobbies, dining rooms and offices.

Residential Sprinklers

This type of sprinkler is a fast response sprinkler, because of the fact of life safety. It is usually used in case of a light hazard. The difference to other sprinklers is the fast response, which is accomplished over a low melting point by fusible sprinklers or over a liquid, which expands under a lower temperature by bulb sprinklers. The discharge of water is also different to spray sprinklers; thereby the requirements of the spray patterns are different. In residential buildings the furniture is up against a wall or situated in the edges of the room. Basically, the aim of sprinkler is to distribute water on the fuel or where it is actually needed. This kind of sprinkler wets up the walls higher and distributes water to the fuel sources, in contrast to office buildings, in which case the things might be rather placed in the middle of the room.

6.10.2 Sprinkler system types[135]

6.10.2.1 Sprinkler system - water supply and pumping systems[136]

Basically, the sprinkler system needs a water supply to guarantee the distribution of water in case of a fire. Theoretically, one water supply should be enough, but in this case the system is not redundant. Therefore, most buildings have two water supplies to provide a distribution of water.

There are many sources which can be used, such as municipal water supply, different kinds of tanks, rivers, lakes and ground water.

Figure 39 gives an overview of the different possibilities of a water supply sources.

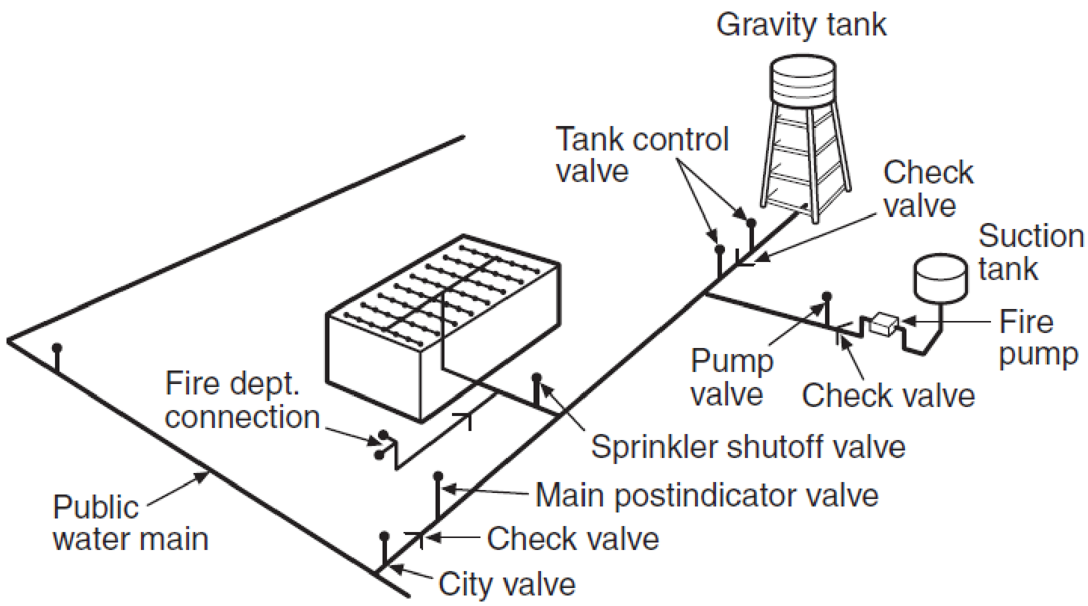

Figure 39: Sprinkler system with various water supply sources and system attachments[137]

The following kinds of water supplies are allowed to be used in California and Austria.

Public and private water supply

In general, the primary water suppliers are connections to the public waterworks. This means it is important that waterworks can provide reliable and adequate water supply with enough pressure. That is the fact why it is necessary to know the minimal pressure and flow rate at unfavorable times, such as a summer month or early in the morning, when people go to work.

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[135] Cf. NFPA 13 p. 13-18 – 13-19

[136] Cf. Fire Protection Handbook sec. 15-63 – 15-65, 16-34

[137] Ibid. sec. 16-34

Sometimes the primary source is not good enough to provide the needed pressure and flow rate or a secondary water supply is desirable. A common secondary water supply is over a private supply. Those water supplies can be connected over a cross connection to feed into a single fire protection system. Those cross connections may be prohibited in some locations, when the private water supply is potable.

Tanks

Gravity tank

Those tanks are elevated above the roof of a building. They get filled up over a pump and are controlled over tank valves. Gravity tanks can be used as a primary water supply source.

Suction tank

Suction tanks use fire pumps for the water distribution of a sprinkler system. Those pumps work with hydraulic, which provide a water supply with high pressure. Generally, the pumps work automatically which is necessary for sprinkler systems or standpipes. To prevent delays in water distribution the suction tanks have a positive pressure.

Note: Positive pressure means that the pressure in the suction tank is bigger than the atmospheric pressure outside of the tank.

Pressure tanks

Pressure tanks have different fields of application. An advantage is definitely the small volume of water which can be stored.

This can be useful, when the private or public water supply pressure is not sufficient. Thereby the pressure tanks can be used to receive a good starting pressure. It can also be used in high buildings to bridge the time which fire pumps need to supply water.

Fire department connections

When many sprinklers have to operate at the same time, public water supply, private water and tanks may not provide a sufficient water pressure for the sprinklers. A fire department connection is a connection where the fire department can pump water into sprinkler system installations to provide a sufficient water pressure. In fact a fire department connection should be used, when an insufficient water pressure occurs. The water supply itself is categorized as a secondary one.

6.10.2.2 Sprinkler systems[138]

Basically, there are four types of sprinkler system:

- Wet pipe system
- Dry pipe system
- Preaction system (single-interlock or double-interlock)
- Deluge system

There are also some other types of systems, which basically are variations of these types. In Austria, wet pipe, dry pipe and preaction systems are common.

Wet pipe system

This system is a reliable system; it is easy to install and simple to maintain.

The pipes of this system are filled with water and stand under pressure. A certain amount of heat activates the sprinklers and water discharges immediately. Therefore, an automatic water supply has to be mandated. These systems are not used in a danger of frost or in case of high temperature for example by kilns. In case of high temperature the water can evaporate, which is not useful for the cool down process. In case of frost, the water expands in the pipes and may cause big damages.

[138] Cf. ibid. sec. 16-34 – 16-37

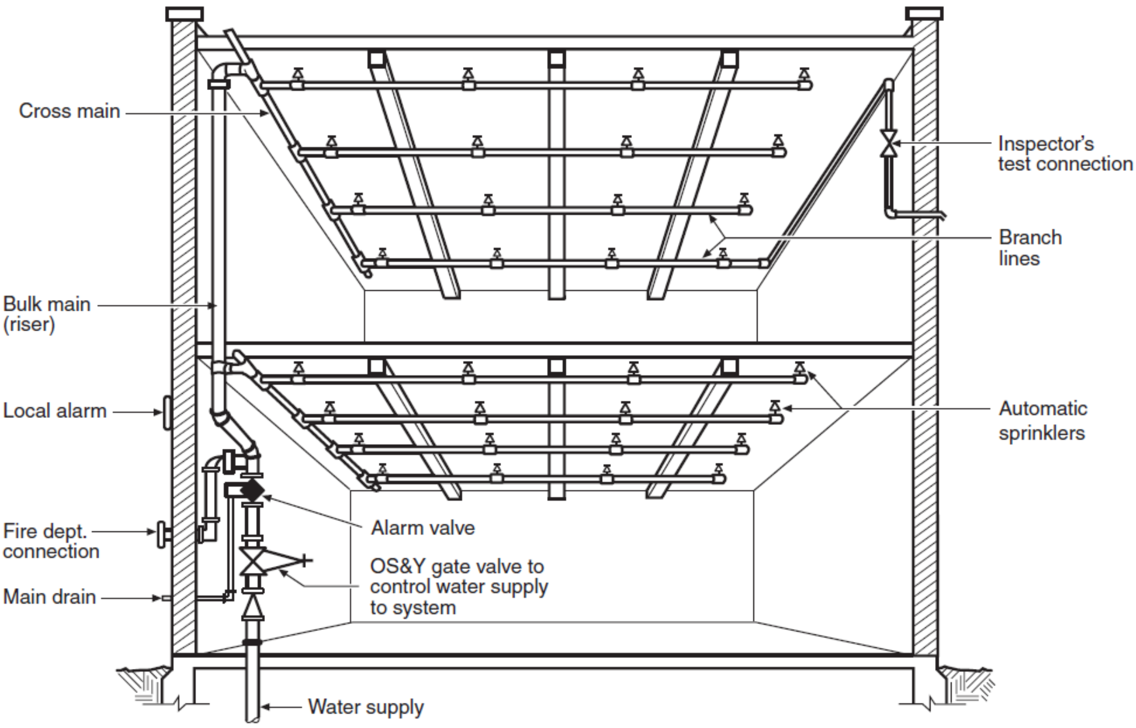

Figure 40: Basic components of a wet pipe sprinkler system[139]

Dry pipe system

Dry pipe systems are used for the aforementioned scenarios, namely frost and high temperature environments. The difference to the wet pipe system is that the pipes are not filled with water but with air or gas which is a constant replenishment to keep a constant pressure. A valve holds back the water and acts on a pressure difference. The heat of the fire activates the sprinklers to operate. As a result of it, the open sprinklers cause a dropping pressure in the piping, if the pressure falls under certain level, the valve opens and flows through the system. The system itself is more complex than a wet pipe system, because of the reliable air supply source and the delay of water delivery from valve to the open sprinkler. In addition, this system is predisposed on internal corrosion (moisture of air).

[139] Ibid. p. 16-35

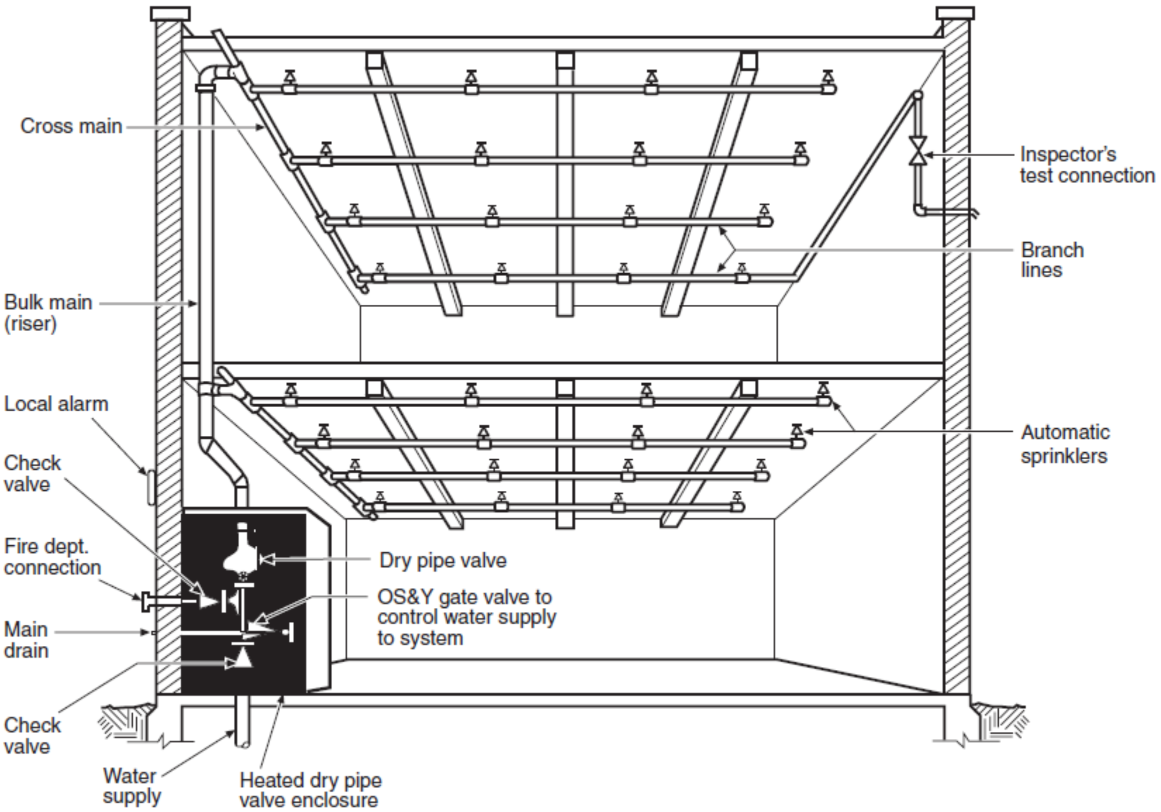

Figure 41: Basic components of a dry pipe system[140]

Preaction system

A single-interlock preaction system is basically similar to a dry pipe system, except for that it doesn't operate in case of a dropping pressure; it acts over a detection system, which operates when a sufficient amount of heat is exceeded. Then valves open and the water flows over the pipes to the open sprinkler. Similar to the dry pipe system, the pipes are filled with air to ensure that the pipes do not have any leakages. Therefore, the system always measures the pressure in the piping system and gives an alarm, if it recognizes any pressure loss.

[140] Ibid. p. 16-36

The second type is called double-interlock preaction system. This system reacts when pressure drops or when the detection system gives alarm. It is a combination of the single-interlock preaction system and the dry pipe system. The moisture of the air in the piping system can also cause rust.

In Austria these systems are defined by a different term called pilot-operated system. This system can be divided into two subtypes which are classified into Type A and Type B. Type A is generally the same as a single-interlock preaction system and Type B as a double interlock preaction system.

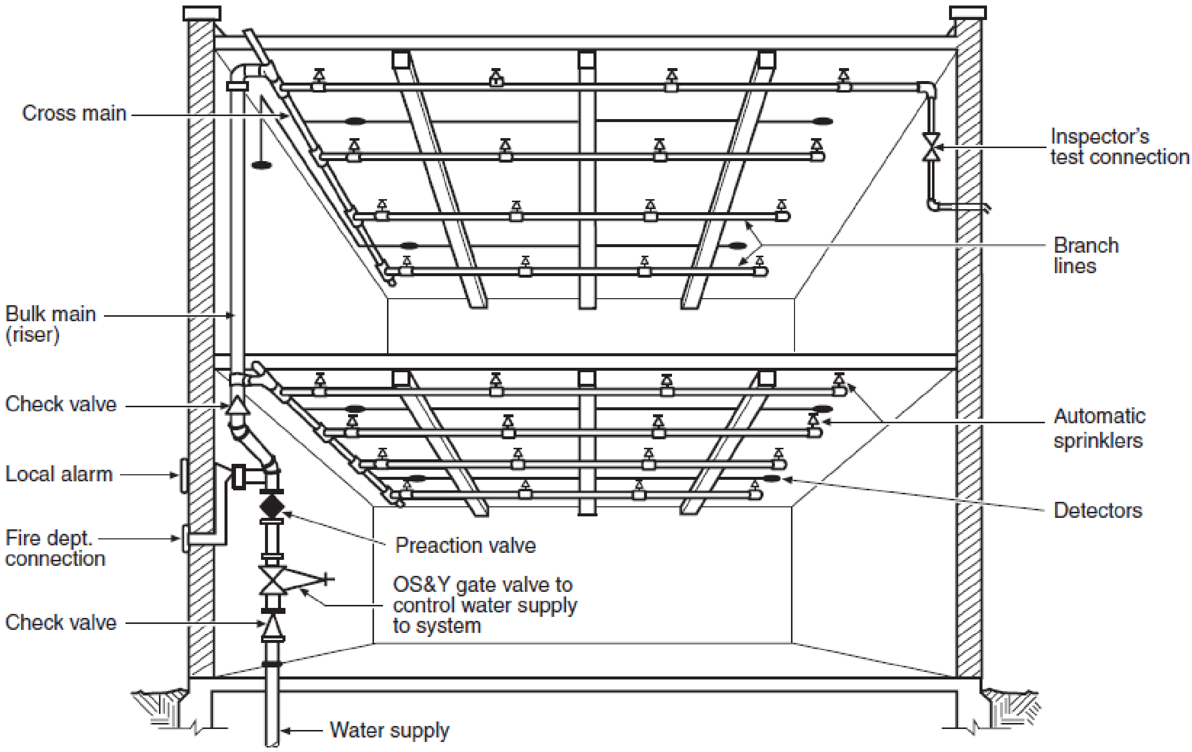

Figure 42: Basic components of a preaction sprinkler system[141]

[141] Ibid. p. 16-36

Deluge system

A deluge system is a system which delivers large amounts of water to a certain area over a short period of time. This kind of system is used, where big amounts of combustible materials are present. It is activated over a fire detection system. For example, aircraft hangars are places where such systems get installed. This kind of definition is mainly used in the United States.

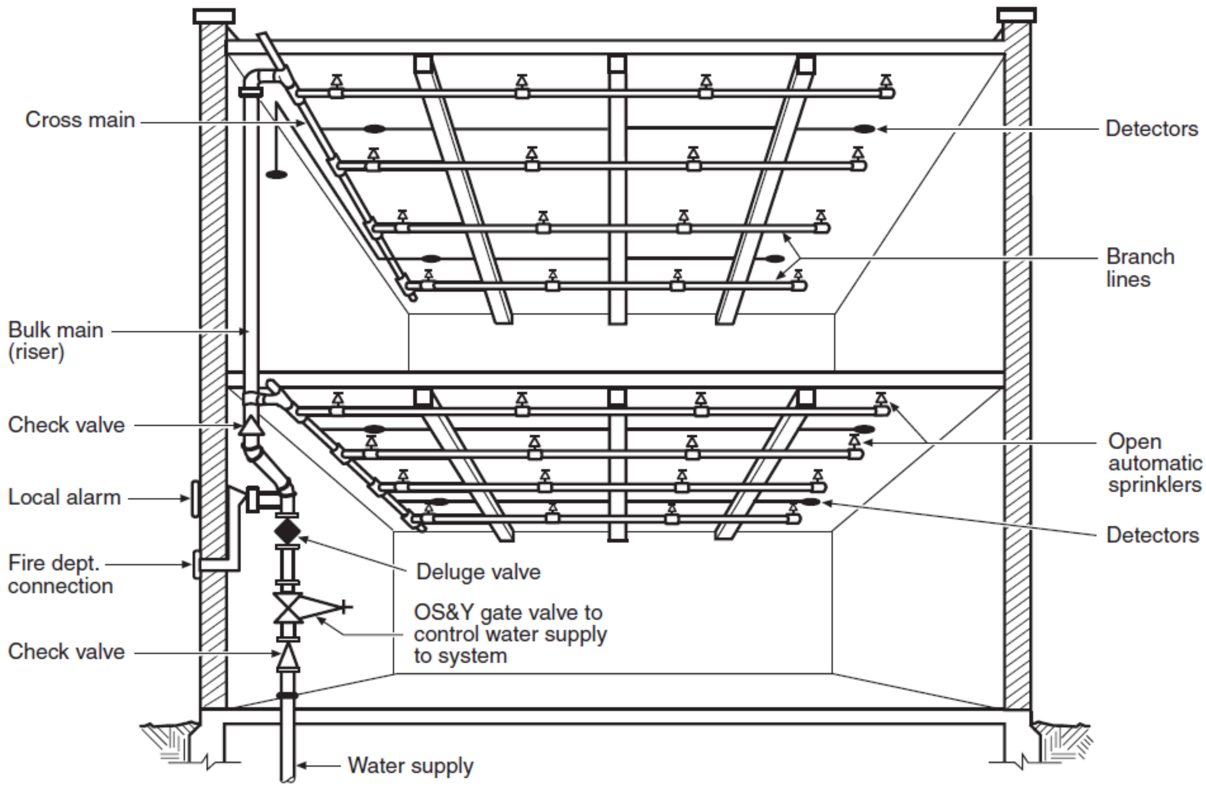

Figure 43: Basic components of a deluge system[142]

Codes & Standards

Whether a sprinkler system has to be installed and under which conditions is defined by the codes and guidelines of each state. The California building code and the NFPA 13: “Standard for the Installation of Sprinkler Systems” gives information about installation, requirements and definitions of sprinkler systems. In Austria those parts are covered by the Austrian institute of engineering construction guidelines 2, 2.1, 2.2 and 2.3 as the TRVB S 127: “Sprinkler systems”.

In addition to those codes there are also other codes and guidelines which can be referenced in the named codes or which can be used instead of those.

[142] Ibid. p. 16-37

6.11 Standpipes[143,144]

Standpipes are fixed piping systems in a building, which transport water from a water supply to a defined area in a building. This can save a lot of time for the manual fire fighting, because long cumbers can be omitted. Standpipe systems have fire hose reels at defined areas and stories, where fire fighting equipment can be connected or a hose, a nozzle and a hose rack are already connected to improve the efficiency of fire fighting. In general, those systems are needed in high and big buildings or used in areas which are difficult to access.

The classification of the United States and Austria is different.

In the United States there are three classes of systems - which type should be used depends on the intended use. Class I is for full-scale fire fighting with a 65 mm hose connection and is typically used in buildings with three or more stories. This Class is designed to be used by the fire department. Class II systems have a 40 mm hose connection and can be used by trained fire brigades before the fire department arrives. The system is used for the first-aid fire fighting and finds use in large non-sprinkler buildings or areas such as exhibit halls.

Class III is a combination of Class I and Class II. This can be accomplished over a removable adapter from 40 mm to 60 mm hose connection and is used for the fire department and fire brigade.

In addition to the classes there are also different types in the United States.

Basically there are dry and wet systems and those are subdivided over there automatically.

Automatic-wet systems

The piping is already filled up with water and has an automatically water supply which can provide the needed amount of water and pressure.

Automatic-dry systems

The difference to wet systems is that the pipes are filled with pressurized air and get filled with water when a hose valve is opened.

Semiautomatic-dry systems

Those systems are filled with pressurized or not pressurized air and are used by deluge valves to distribute the amount of water, when a remote actuation device is located. The water supply is also preconnected.

[143] Ibid. p. 16-191 – 16-204

[144] California Building Code 2013 p. 328-331

Manual-dry systems

Manual dry systems are the same as automatic dry systems, except that a fire department connection has to be used to supply water.

Manual wet systems

As an automatic-wet system, the piping is filled with water and differs from the automatic-wet system in the water supply, which has to be provided by a fire department connection.

Generally, there are the same water supplies for standpipe system as for sprinkler systems. It is in fact important, which minimum flow rate and pressure is required and which water supplies can provide it.

Compared to Austria[145]

In Austria there are technically three types of standpipe systems:

Dry standpipe

This system can be compared with a manual-dry system, which gets its water supply over a fire department connection. Important is that every dry standpipe system, whether Austria or United States, has to have a vent valve which provides that trapped air gets out of the system.

Wet standpipe without a pressure rising facility

This system is similar to the automatic-wet standpipe; it is generally directly connected to a public water supply. The piping is already filled with water and additionally equipped with a fire department connection to increase the pressure in the system in an emergency.

Wet standpipe with a pressure rising facility

Additional to a common wet standpipe system, a pressure rising facility is used to keep the pressure on a required level. Most of these systems are used for high buildings or buildings which require a higher pressure which cannot be provided over a public water supply.

Codes & Standards

If a standpipe system has to be installed and under which conditions is defined by the codes and guidelines of each state. The California building code and the NFPA 14: “Standard for the Installation of Standpipe and Hose Systems” gives information about installation, requirements and definitions of standpipes.

[145] Cf. TRVB F 128 00 p. 3-7

In Austria those parts are covered with the Austrian institute of engineering construction guidelines 2, 2.1, 2.2 and 2.3 as the TRVB F 128: “Standpipe and fire hose reel”.

Additional to those codes are other codes and guidelines which can be referenced in the named codes or which can be used instead of those.

7 Legal regulations and technical specifications

First of all, it needs to be defined what the major differences between legal regulations and technical specifications are. Basically it is to say, that legal regulations are legally fixed and technical specifications are rather an advice. In fact, anyone who wants to carry out building work has to make sure that it complies with the regulations of the legislation. Guidelines are basically technical requirements, which are proofed to fulfil the level of protection and achieve the goals of safety.

7.1 United States of America - California

In the early twentieth century, the first codes were developed. They were generally characterized by the different insurance companies, which wanted to reduce properly loss payouts. In that century three big organizations were established: BOCA (Building Officials and Code Administrators), ICBO (International Conference of Building Officials), and SBCCI (Southern Building Code Congress International), while each organization is responsible for the different regions and states of the United States. The issue with these organizations has been that many of their codes were duplications. To prevent duplications and to consolidate the development process, the International Code Council (ICC) was formed.

The biggest opponent of the International Code Council was the National Fire Protection Association (NFPA). These organizations tried to work together on several codes, but there were too many conflicts between them. Then they decided to make their own codes. The NFPA developed the NFPA 5000 to offer an alternative to the International Building Code (IBC). Over the years most of the states incorporated with the IBC and also California decided to integrate the IBC after Schwarzenegger had became governor. In fact, most of the states adopted the IBC and build their codes based on it. When the codes were adopted they automatically got legally fixed. ICC also developed other codes like the International Fire Code, International Residential Code or the International Mechanical Code, which refer to each other in some parts.

Concerning California, the California Building Code and California Fire Code are resources of the legal requirements and relevant for this thesis. Those codes have to be authorized by the California Building Standards Commission (CBSC). Nonetheless, the codes also refer to technical solutions like ASTM Standards (American Society for Testing and Materials), ANSI Standards (American National Standards Institute), NFPA Standards (National Fire Protection Association) and UL Standards (Underwriter Laboratories). These specifications and standards are advices. In fact it is allowed to deviate from the codes in some cases, if it is demonstrated that an equal level of protection is achieved. For a comparison and hierarchy of the different documents see Table 2.

Note: It is important to know the differences between the California Building Code, the California Residential Code and the California Fire Code. In fact, the California Residential Code is for one and two family dwellings and townhouses with not more than 3 stories, all other buildings are regulated by the California Building Code. Therefore, this thesis deals with California Building Code. The California Fire Code and California Building Code differ especially in the fire protection parts. Basically, the California Building Code defines the construction and design, whereby the California Fire Code deals more with design. As an example the California Fire Code provides that an adequate water supply for fire-fighting is available, also that the access exits are not allowed to be blocked and the hazards which can be housed are defined. The California Building Code defines the materials for the structural parts, areas and heights, requirements of the location of the property, occupancy et cetera. [146,147,148,149,150]

7.2 Austria - Styria

The system in Austria is nearly the same as in the United States. The civil engineering is subject to the federal state legislation. This means, each federal state has its own building code. In Austria there are nine different legislations, which accounts for nine different construction acts. In 2008 the technical regulations were harmonized by the Austrian Institute of Construction Engineering (OIB), which helped to unify the system. Each federal state declared to bind the OIB-Guidelines in their building codes. It is possible to deviate from the guidelines, if it is demonstrated that an equal level of protection is achieved. The OIB-Guidelines are separated into 6 different groups. Group 2 contains the fire protection, which is divided into 4 guidelines with one manual.

This thesis considers the OIB-Guideline 2 “Safety in case of fire”, the manual of the OIB-Guideline 2 “Deviations in fire protection and fire protection concepts” and the OIB-Guideline 2 “Explanatory remarks”, which are especially important for residential buildings, office buildings and lodgings. Beside the guidelines there is a wide range of technical standards in Austria. Table 2 gives an overview of the most important documents, which are used for fire protection.[151]

[146] Cf. California Building Code 2013 p. xii

[147] Cf. http://lagunabeachcity.net/civicax/filebank/blobdload.aspx?BlobID=6856

[148] Cf. http://www.strategicstandards.com/files/InternationalBuildingCode.pdf

[149] Cf. http://www.bizjournals.com/sacramento/stories/2005/04/25/focus5.html?page=1

[150] Cf. http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab089219.pdf

[151] Cf. http://www.oib.or.at/en/oib-guidelines

7.3 Comparison of legal regulations and technical specifications of the different countries

Basically, it is to say that the structures of the legal regulations and technical specifications are nearly the same. Each codes or guidelines are bound or adopted by the federal law. The California Building Code or the California Fire Code have specific sections and include specific requirements and solutions. In comparison, the OIB Guidelines give more general information about the requirements and are not as specific as the codes of ICC are. Therefore, Austria has a wide range of standards for technical solutions to provide corresponding safety.

Table 2 gives an overview of the comparison of these two federal states. California has a combination of legal requirements and technical requirements, which is similar to the old system of Austria. Nevertheless, Austria and the United Sates have safety goals, which are legally fixed. Those safety goals have to be achieved and the California Building Code as well as the OIB Guidelines are proofed to fulfil those goals.

	United States of America **-California**	**Austria** **-Styria**
Legal regulation (functional/legal requirements)	California Building Code* California Fire Code* (including some technical solutions)	Construction Act**
Guidelines (technical requirements)		OIB Guidelines
Standards, technical policy (Methods and solutions)	Standards (ANSI, ASTM, NFPA, UL)	Standards (EN, ÖNorm) Guidelines (TRVB)
Notice: * based on the International Codes ** Austria has 9 different federal states and each state has different laws and guidelines		

Table 2: Hierarchy of the codes and specifications of the different states

In addition, it is to say that technical requirements can be defined as performance requirements or prescriptive requirements. Performance requirements can be for example a limited value of temperature in a certain height in a room. Prescriptive requirements are for example the maximum length of an escape route from every point in the room to a safe place. To summarize, it is an advantage to follow such requirements, because they are accepted by the law and have a good legal compliance. On the other hand, it is allowed to deviate from those technical requirements, if it is demonstrated that the functional requirements and safety goals can be achieved. This possibility gives a better flexibility for the design of a building.[152,153,154]

[152] Cf. Trade magazine: OIB Guideline 2 p. 4-5
[153] Cf. Fire Protection Handbook sec. 1-56 – 1-58
[154] Cf. ibid. sec. 2-60

7.4 Classification of Building requirements

The following pages should give an overview of the different ways the countries use to define a fire protection concept. Each country has a basic concept and the most important points are going to be defined. For more detailed information, the codes and guidelines should be checked, as well as the standards and technical policy.

Often people ask themselves what a fire protection concept is or when they need it. Basically, a fire protection concept should be well-conceived. It is the basis for the planning and execution phase, because it is very difficult to make adjustments later. This costs time and money. First the building is analysed; Which occupancies are there? Where should it be build? Which type of construction should be used? What height and area should the building have? This information is the basis for the fire protection concept. The next part is to determine the requirements which are legally fixed in construction acts and codes. After that, guidelines and standards etc. are used to fulfil the legally fixed requirements. With this information the fire protection measurements can be made – which finally leads to the fire protection concept.

7.4.1 Classifying of buildings in Austria - Styria[155,156,157]

As already mentioned, Austria has guidelines which help to reach a certain level of protection. Basically, the most important documents for this thesis are:

- OIB Guideline – “Definitions”
- OIB Guideline 2 – “Safety in case of fire”
- OIB Guideline 2 – “Deviations in fire protection and fire protection concepts”
- OIB Guideline 2 – “Explanatory remarks”

These guidelines are used for buildings and not for garages, parking facilities/decks, buildings with an escape level over 22 m or buildings with a gross area of less than or equal 15 m² and which are accessible for firefighting.

These are the main parts of the fire safety concept:

- Occupancy classification
- General requirements and load capacity in case of fire
    - Fire behaviour

[155] Cf. OIB Guideline: Definitions p. 5
[156] Cf. OIB Guideline 2: Explanatory notes p. 16
[157] Cf. OIB Guideline 2: Safety in case of fire p. 2-10

    - Load carrying capacity
- Spread of fire and smoke inside a building
- Spread of fire to other buildings
- Means of egress
- Firefighting

7.4.1.1 Occupancy classification

First of all, the term occupancy has to be defined. Basically, the thesis deals with residential buildings and office buildings. The occupancy gives information about which guideline has to be chosen. In this case, the OIB Guideline 2 – "Safety in case of fire" is used.

The next step is to clarify the building class. The guidelines distinguish five building classes with different characteristics.

Building class 1

- The building is detached
- At least three sides are accessible for firefighting over the own property or traffic areas
- Not more than three stories above the ground
- The escape level is not allowed to be over 7 metres
- The gross floor area overall is not more than 400 m²
- The building does not consist of more than two residences or an operating unit

Building class 2

(a) Building

- Not more than three stories above the ground
- The escape level is not allowed to be over 7 metres
- The gross floor area overall is not more than 400 m²

(b) Terrace house

- Not more than three stories above the ground
- The escape level is not allowed to be over 7 metres
- Consists out of residences or operating units with overall gross floor area not more than 400 m²

(c) Building with exclusively residential use

- The building is detached
- At least three sides are accessible for firefighting over the own property or traffic areas
- Not more than three stories above the ground
- The escape level is not allowed to be over 7 metres
- The gross floor area overall is not more than 800 m²

Building class 3

- Not more than three stories above the ground
- The escape level is not allowed to be over 7 metres
- Not covered by building class 1 or building class 2

Building class 4

(a) Building

- Not more than four stories above the ground
- The escape level is not allowed to be over 11 metres
- Consists out of several residences or several operating units where each unit has not more than 400 m² gross floor area

(b) Building

- Not more than four stories above the ground
- The escape level is not allowed to be over 11 metres
- Consists out of one residence or one operating unit with an unlimited gross floor area

Building class 5

- The escape level is not allowed to be over 22 metres
- Not covered by building class 1 to 4

The building class is an important factor for the general requirements of load carrying capacity and fire behaviour of building elements.

Note: Operating units are generally office communities or other types like shop in shop systems and can be seen as residences in technical and functional regards. Nonetheless, operating units have nothing to do with industrial buildings. Industrial buildings are used for production processes and storages for products and goods. This means that office buildings and shops are not industrial buildings. That is why they are regulated over the OIB-Guideline 2.

7.4.1.2 General requirements and load capacity in case of fire

The general requirements are summarized in different tables which depend on the building class. After the building is classified over a building class the requirements can be declared.

7.4.1.2.1 Fire behaviour

Table 3 is depicting the general requirements for fire behaviour of materials and building elements. For detailed information on the fire behaviour classification in Austria, see Section 6.4.1.

Building class (GK)	GK 1	GK 2	GK 3	GK 4	GK 5	
					≤ 6 aboveground stories	> 6 aboveground stories
1 Cladding						
1.1 Exterior-composite heat insulation system	E	D	D	C-d1	C-d1	C-d1
1.2 Cladding system - rainscreen , ventilated or unventilated						
1.2.1 Total system or	E	D-d1	D-d1	B-d1 (1)	B-d1 (1)	B-d1
1.2.2 Single component						
- Facing	E	D	D	A2-d1 (2)	A2-d1 (2)	A2-d1 (3)
- Subconstruction - bar-shaped / dot-shaped	E / E	D / D	D / A2	D / A2	D / A2	C / A2
- Insulation layer or Insulation	E	D	D	B (2)	B (2)	B (3)
1.3 Any external wall cladding or covering	E	D-d1	D-d1	B-d1 (4)	B-d1 (4)	B-d1
1.4 Building joint material	E	E	E	A2	A2	A2
1.5 Railing filling by balconies, loggias and so on	-	-	-	B (4)	B (4)	B
2 Corridors and stairways each outside residence: claddings, coverings and suspended ceilings						
2.1 Wall covering (5)						
2.1.1 Total system or	-	D	D	C	B	B
2.1.2 Single component						
- Facing	-	D	D	C (4)	B	B
- Subconstruction	-	D	D	A2 (4)	A2 (4)	A2 (4)
- Insulation layer or Insulation	-	C	C	C	A2	A2
2.2 Suspended ceiling	-	D-d0	C-s1, d0	B-s1, d0	B-s1, d0	B-s1, d0
2.3 Wall and ceiling coverings	-	D-d0	C-s1, d0	B-s1, d0	B-s1, d0	B-s1, d0
2.4 Flooring	-	D_{fl}	D_{fl}	C_{fl}-s1 (6)	C_{fl}-s1	C_{fl}-s1
3 Stairways: claddings, coverings and suspended ceilings						
3.1 Wall covering (5)						
3.1.1 Total system or	-	D	C	B	A2	A2
3.1.2 Single component						
- Facing	-	D	C (4)	B	A2	A2
- Subconstruction	-	D	A2 (4)	A2 (4)	A2 (4)	A2 (4)
- Insulation layer or Insulation	-	C	C	A2	A2	A2
3.2 Suspended ceiling		D-s1, d0	C-s1, d0	B-s1, d0	A2-s1, d0	A2-s1, d0
3.3 Wall and ceiling coverings	-	D-s1, d0	C-s1, d0	B-s1,d0	A2-s1, d0	A2-s1, d0
3.4 Flooring						
3.4.1 in stairways according to Table 2a, 2b	-	D_{fl}-s1	C_{fl}-s1	B_{fl}-s1	$A2_{fl}$-s1	$A2_{fl}$-s1
3.4.2 in stairways according to Table 3	-	D_{fl}-s1	C_{fl}-s1 (6)	C_{fl}-s1	B_{fl}-s1	$A2_{fl}$-s1
4 Roofs with a slope ≤ 60°						
4.1 Roof covering or roofing (7)	B_{ROOF} (t1)	B_{ROOF} (t1)	B_{ROOF} (t1)	B_{ROOF} (t1)	B_{ROOF} (t1) (8)	B_{ROOF} (t1) (8)
4.1 Insulation layer or insulation in roof construction	E	E	E	B (9)	B (10)	B (10)
5 Undeveloped attic						
3.4 Cladding (floor construction)						
5.1.1 Total system or	-	E	D	D	B	B
5.1.2 Single component						
- Facing	-	C	C	B	B	B
- Insulation layer or Insulation	-	E	E	B (9)	B (10)	B (10)
5.2 Flooring	-	E_{fl}	D_{fl}	C_{fl}-s1 (11)	B_{fl}-s1 (11)	B_{fl}-s1 (11)
(1) Wood and wood-based materials are permitted in D, if the total system complies with Class D-d0;						
(2) A facing in B-d1 or a wood and wood-based material in D is allowed, in an insulation layer or insulation in A2;						
(3) A facing in B-d1 is allowed, in an insulation layer or insulation in A2;						
(4) Wood and wood-based materials are permitted in D;						
(5) Requirements for wall- and ceiling coverings in accordance with line 2.3 or 3.3 apply to missing wall and ceiling coverings in corridors and stairways;						
(6) Hardwoods (as oak, beech, ash) with a minimum thickness of 15 mm are allowed;						
(7) A uppermost layer of 5 cm of gravels or equivalent materials is sufficient by roofs with a slope <20 °;						
(8) Roofing, battens, counter battens and formwork have to correspond to Class A2 by roofs with a slope ≥ 20 °; wood and wood-based materials in D are also permitted for battens, counter battens and formwork;						
(9) EPS, XPS and PUR of Class E are permitted in the following cases: - roofs with a slope <20 ° or on the top ceiling or - roofs with a slope ≥ 20 °, which are produced in A2 and meet the required fire resistance time and terms of performance characteristics E and I according to Table 1b;						
(10) EPS, XPS and PUR of Class E are permitted for roofs with a slope <20 ° or on the top ceiling, if they are produced in A2 and meet the requirements in Table 1b, relating to the fire resistance time and terms of performance characteristics;						
(11) Floor coverings in D_{fl} are permitted, if the insulation layer or insulation is of Class B materials;						

Table 3: Table 1a - General requirements for the fire behaviour[158]

[158] OIB Guideline 2: Safety in case of fire p. 14

7.4.1.2.2 Load carrying capacity

Table 4 gives an overview of the different fire resistance requirements of each building class. Furthermore, this table is displaying certain classifications of the individual building components.

Building class (GK)	GK 1	GK 2	GK 3	GK 4	GK 5	
					≤ 6 stories aboveground	> 6 stories aboveground
1 Primary structure (except ceilings and walls, which are forming a fire section)						
1.1 in top storey	-	R 30	R 30	R 30	R 60	R 60
1.2 in other stories aboveground	R 30 (1)	R 30	R 60	R 60	R 90	R 90 and A2
1.3 in underground stories	R 60	R 60	R 90 and A2	R 90 and A2	R 90 and A2	R 90 and A2
2 Partition walls (except walls of stairways)						
2.1 in top storey	-	REI 30 EI 30	REI 30 EI 30	REI 60 EI 60	REI 60 EI 60	REI 60 EI 60
2.2 in aboveground stories	-	REI 30 EI 30	REI 60 EI 60	REI 60 EI 60	REI 90 EI 90	REI 90 and A2 EI 90 and A2
2.3 in underground stories	-	REI 60 EI 60	REI 90 and A2 EI 90 and A2	REI 90 and A2 EI 90 and A2	REI 90 and A2 EI 90 and A2	REI 90 and A2 EI 90 and A2
2.4 between residences or operating units in terrace houses	not applicable	REI 60 EI 60	not applicable	REI 60 EI 60	not applicable	not applicable
3 Walls and ceilings, which are forming a fire section						
3.1 fire walls at neighoring property- and building site boundary	REI 60 EI 60	REI 90 (2) EI 90 (2)	REI 90 and A2 EI 90 and A2	REI 90 and A2 EI 90 and A2	REI 90 and A2 EI 90 and A2	REI 90 and A2 EI 90 and A2
3.2 other walls and ceilings, which are forming a fire section	-	REI 90 EI 90	REI 90 EI 90	REI 90 EI 90	REI 90 EI 90	REI 90 and A2 EI 90 and A2
4 Ceiling and roof slopes with a slope ≤ 60°						
4.1 Ceiling above the top floor	-	R 30	R 30	R 30	R 60	R 60
4.2 Partition ceiling over the top floor	-	REI 30	REI 30	REI 60	REI 60	REI 60
4.3 Partition ceiling in other aboveground stories	-	REI 30	REI 60	REI 60	REI 90	REI 90 and A2
4.4 Ceilings of residences and operatings units in aboveground stories	R 30 (1)	R 30	R 30	R 30	R 60	R 90 and A2
4.5 Ceilings over underground stories	R 30 (1)	R 30	R 30	R 30	R 60	R 90 and A2
5 Balcony plate	-	-	-	R 30 or A2	R 30 or A2	R 30 or A2 (4)
(1) Not required for buildings with a residential purpose or used as an office or other similar office buildings;						
(2) In terrace houses, walls in REI 60 or EI 60 are sufficient between residences or operating units as on neighouring property- and building site boundary ;						
(3) The requirement R 60 is sufficient for terraced houses and buildings with no more than two operating units with office use or similar office use;						
(4) A classification of R 30 or A2 is sufficient for single balconies, if the area is not over 10 m², the cantilever arm of the balconie is not more than 2.50 metres and the distance between the balconies is at least 2.0 metres.						

Table 4: Table 1b - General requirements for the fire resistance of building components[159]

7.4.1.3 Spread of fire and smoke within the structure

To prevent fire and smoke to spread within the structure, fire sections have to be used. It is important to subdivide the building into different fire sections. On one hand, it prevents the fire and smoke to spread from one section to the other and on the other hand, it is necessary to decimate the loss of property. The OIB-Guideline 2 includes a table, which limits stories, areas and lengths of a building. Table 5 is a reflection of this table and gives information on the limitation of the different occupancies.

[159] Ibid. p. 15

Use	Maximum net floor area	Maximum length expansion	Maximum number of stories aboveground per fire section
Residential building	-	60 m	-
Office building or buildings with a similiar office use	1.600 m²	60 m	4
Other use	1.200 m²	60 m	4

Table 5: Fire section limitations[160]

The limitation for the underground net floor areas are 800 m². Basically, a building is separated in fire sections over fire walls. Stairways, partition walls and doors deviate from the general requirements, which were mentioned in Section 7.4.1.2. The following tables give some information about the requirements for these building elements.

[160] Ibid. p. 3

Object	GK 2 (1)	GK 3	GK 4
1 Walls of stairways			
1.1 in aboveground stories (2)	REI 30 EI 30	REI 60 EI 60	REI 60 (3) EI 60 (3)
1.2 in underground stories	REI 60 EI 60	REI 90 and A2 EI 90 and A2	REI 90 and A2 EI 90 and A2
2 Ceiling over stairway (4)	REI 30 EI 30	REI 60 EI 60	REI 60 (3) EI 60 (3)
3 Doors in walls of stairways			
3.1 to residences, operating units and other rooms	EI_2 30	EI_2 30-C	EI_2 30-C-S_m
3.2 to corridors in aboveground stories (5)	-	E 30-C	E 30-C
3.3 to corridors in underground stories	EI_2 30	EI_2 30-C	EI_2 30-C
4 Flight of stairs and landings in stairways	R 30	R 60	R 60 and A2
5 Railing fillings in stairways	-	-	B (6)
6 Smoke extraction system			
6.1 Location	at the top of the stairway (7)	at the top of the stairway	at the top of the stairway
6.2 Size	geometrically free cross-section of 1.00 m² (7)	geometrically free cross-section of 1.00 m²	geometrically free cross-section of 1.00 m²
6.3 Triggering device	in the level of access of the fire brigade and the top landing of the stairway with access to lounges; independent of the public mains (7)	in the level of access of the fire brigade and the top landing of the stairway with access to lounges; independent of the public mains and a highly sensitive element on the ceiling	in the level of access of the fire brigade and the top landing of the stairway with access to lounges; independent of the public mains and a highly sensitive element on the ceiling
7 Outdoor stairs	A2 and no interference in case of fire by flames and dangerous radiant heat	A2 and no interference in case of fire by flames and dangerous radiant heat	A2 and no interference in case of fire by flames and dangerous radiant heat
(1) Does not apply to terrace houses and buildings with not more than two residences;			
(2) Exterior walls of stairways have no requirements in fire resistance, if the walls are out of A2 materials and walls cannot be jeopardized by other adjaent building parts in case of a fire;			
(3) The building parts on the stairway side have to be out of A2 materials;			
(4) It is allowed to deviate from the requirements, if a fire spreading from the adjacent building parts to the stairwell is prevented over appropriate measures;			
(5) For the doors surrounding glass surfaces with a surface area of not more than three times of the door leaf area, a E 30 is sufficient;			
(6) Hardwoods (as oak, beech, ash) with a minimum thickness of 15 mm are allowed;			
(7) The smoke extraction system can be omitted, if there are directly disposed windows at each floor leading to the outside with a free cross-section of at least 0.50 m² and can be opened with unassisted aids.			

Table 6: Table 2a - Requirements for stairways or exterior stairs for the only escape route in buildings with building class 2, 3 and 4[161]

[161] Ibid. p. 16

Object	GK 5 with mechanical ventilation	GK 5 with automatic fire alarm system and smoke extraction system	GK 5 with lock and smoke extraction system
1 Walls of stairways			
1.1 in aboveground stories (1)	REI 90 and A2	REI 90 and A2	REI 90 and A2
1.2 in underground stories	REI 90 and A2	REI 90 and A2	REI 90 and A2
2 Ceiling over stairway (2)	REI 90 and A2	REI 90 and A2	REI 90 and A2
3 Doors in walls of stairways			
3.1 to corridors in aboveground stories (5)	E 30-C	E 30-C-S_m	not applicable
3.2 to residences, operating units and other rooms	EI_2 30-C	EI_2 30-C-S_m	inadmissible
3.3 to corridors in underground stories	EI_2 30-C	EI_2 30-C-S_m	not applicable
4 Doors in walls of locks			
4.1 to corridors and stairways (3)	not applicable	not applicable	E 30-C
4.2 to residences, operating units and other rooms	not applicable	not applicable	EI_2 30-C
5 Flight of stairs and landings in stairways	R 90 and A2	R 90 and A2	R 60 and A2
6 Railing fillings in stairways	B	B	B
7 Mechanical ventilation system	Suitability for own rescuing of people from the fire room, preventing the penetration of smoke into the stairway with closed doors to the fire room and dilution and removal by momentary opening of the door to the fire room to the stairway invading smoke	not applicable	not applicable
8 Automatic fire alarm system	not applicable	in the stairwell, including common areas, such as corridors and cellar areas within the scope of "equipment protection" with internal alarm	not applicable
9 Smoke extraction system			
9.1 Location	not applicable	at the top of the stairway	at the top of the stairway
9.2 Size	not applicable	geometrically free cross-section of 1.00 m²	geometrically free cross-section of 1.00 m²
9.3 Triggering device	not applicable	in the level of access of the fire brigade and the top landing of the stairway with access to lounges; independent of the public mains and over the auotmatic fire alarm system and in addition to the level of access of the fire brigade, the possibility of manual operation with a position indicator	in the level of access of the fire brigade and the top landing of the stairway with access to lounges; independent of the public mains and a highly sensitive element on the ceiling of the stairway and in addition to the level of access of the fire brigade, the possibility of manual operation with a position indicator
10 Outdoor stairs	A2 and no interference in case of fire by flames, dangerous radiant heat and/or and smoke		
(1) Exterior walls of stairways have no requirements in fire resistance, if the walls are out of A2 materials and walls cannot be jeopardized by other adjaent building parts in case of a fire;			
(2) It is allowed to deviate from the requirements, if a fire spreading from the adjacent building parts to the stairwell is prevented over appropriate measures;			
(3) For the doors surrounding glass surfaces with a surface area of not more than three times of the door leaf area, a E 30 is sufficient;			

Table 7: Table 2b - Requirements for stairways or exterior stairs for the only escape route in buildings with building class 5[162]

[162] Ibid. p. 17

Object	GK 2 (1)	GK 3	GK 4	GK 5
1 Walls of stairways				
1.1 in aboveground stories (2)	REI 30 EI 30	REI 60 EI 60	REI 60 EI 60	REI 90 and A2 EI 90 and A2
1.2 in underground stories	REI 60 EI 60	REI 90 and A2 EI 90 and A2	REI 90 and A2 EI 90 and A2	REI 90 and A2 EI 90 and A2
2 Ceiling over stairway (3)	REI 30	REI 60	REI 60	REI 90 and A2
3 Doors in walls of stairways				
3.1 to residences	-	EI_2 30	EI_2 30	EI_2 30
3.2 to operating units	EI_2 30	EI_2 30-C	EI_2 30-C	EI_2 30-C
3.3 to corridors in aboveground stories (4)	-	E 30-C	E 30-C	E 30-C
3.4 to corridors in underground stories	EI_2 30	EI_2 30-C	EI_2 30-C	EI_2 30-C
4 Flight of stairs and landings in stairways				
4.1 to residences, operating units and other rooms	R 30	R 60	R 60	R 90 and A2
4.2 to residences, operating units and other rooms	-	R 30 or A2	A2	R 30 and A2
5 Smoke extraction system				
5.1 Location	-	at the top of the stairway (5)	at the top of the stairway	at the top of the stairway
5.2 Size	-	geometrically free cross-section of 1.00 m² (5)	geometrically free cross-section of 1.00 m²	geometrically free cross-section of 1.00 m²
5.3 Triggering device	-	in the level of access of the fire brigade and the top landing of the stairway with access to lounges; independent of the public mains (5)	in the level of access of the fire brigade and the top landing of the stairway with access to lounges; independent of the public mains	in the level of access of the fire brigade and the top landing of the stairway with access to lounges; independent of the public mains and a highly sensitive element on the ceiling
6 Outdoor stairs	-	R 30 or A2 and no interference in case of fire by flames and dangerous radiant heat	A2 and no interference in case of fire by flames and dangerous radiant heat	A2 and no interference in case of fire by flames and dangerous radiant heat
(1) Does not apply to terrace houses and buildings with not more than two residences;				
(2) Exterior walls of stairways have no requirements in fire resistance, if the walls are out of A2 materials and walls cannot be jeopardized by other adjaent building parts in case of a fire;				
(3) It is allowed to deviate from the requirements, if a fire spreading from the adjacent building parts to the stairwell is prevented over appropriate measures;				
(4) For the doors surrounding glass surfaces with a surface area of not more than three times of the door leaf area, a E 30 is sufficient;				
(5) The smoke extraction system can be omitted, if there are directly disposed windows at each floor leading to the outside with a free cross-section of at least 0.50 m² and can be opened with unassisted aids;				

Table 8: Table 3 - Requirements for stairways or exterior stairs in the course of escape routes[163]

The guideline regulates specific distances between the different fire resistance walls, openings and building elements. Furthermore, the fire behaviour for certain building elements is defined. The upcoming figures give a better understanding of the requirements.

[163] Ibid. p. 18

The guideline stipulates that fire walls have to exceed the roof by at least 15 cm, if no other measures are taken.

Openings in fire section walls must have the same classification like the wall itself. The classification EI_2 30–C or EI 30 is allowed, if the openings are not more than 5 m² of a wall with 50 m² or less or for walls with an opening space of not more than 10 m² for walls with 50 m².

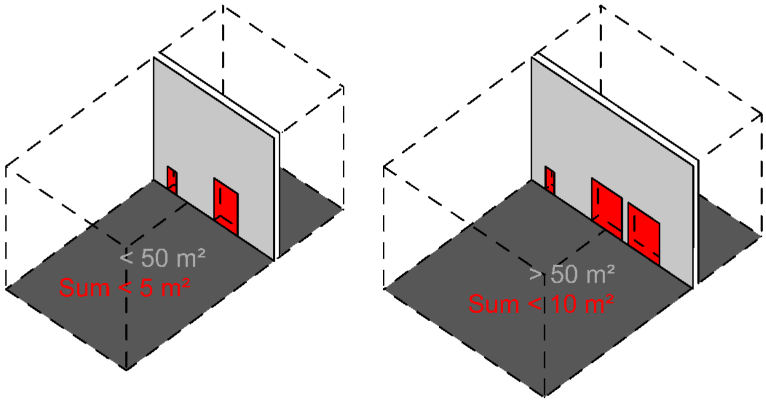

Figure 44: Openings in fire walls

Fire sections also have limitations in stories. It is important to provide a fire spread over an opening in an exterior wall. Therefore, a 1.2 metres strip of the exterior wall with a fire resistance of EI 90 has to be integrated. The position of this strip has to be located at the height of the ceiling between the stories of the different fire section. It is also allowed to prevent the fire spread with a projection of 0.80 metres of the ceiling. In addition, buildings of building class 5 have to use materials with an A2 classification for their structural measures, except an appropriate technical fire protection system like an extinguishing system is available. If the building has more than 6 stories, each story has to provide a fire spread over a strip or projection. In this case the classification of the strip is EI 30-ef and A2 or EW 30-ef and A2 and for the projection REI 30 or EI 30 is allowed.

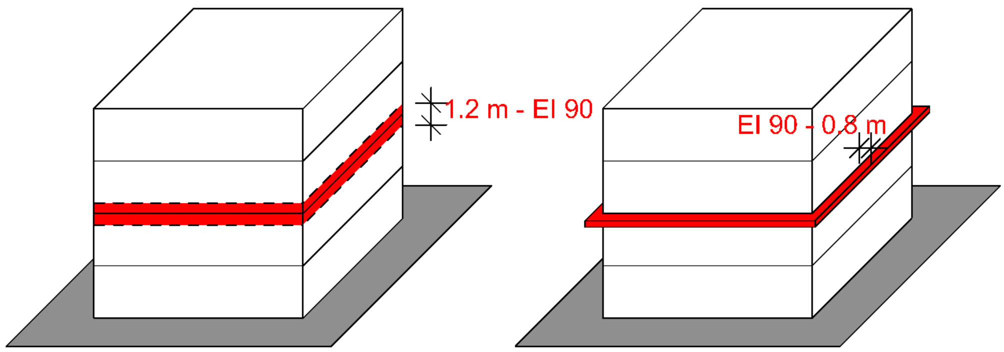

Figure 45: Horizontal separation of fire sections

Note: EI 30-ef – ef means that the outside fire curve is used instead of the standard time temperature curve.[164]

Openings in exterior walls, which are connected to a fire wall, must have a clearance length of 0.50 metres, measured between the opening and the middle of the fire wall. The distance between such openings has to be at least 3 metres, if the angle degree between the exterior wall and fire section wall is under or equal 135°. These specifications are not applicable for arcades, entrances, passages, garage doors and loggias.

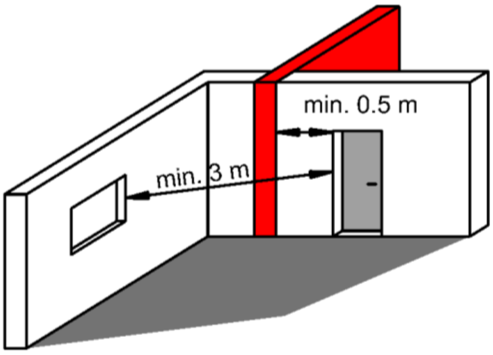

Figure 46: Distances between openings of fire sections and exterior walls

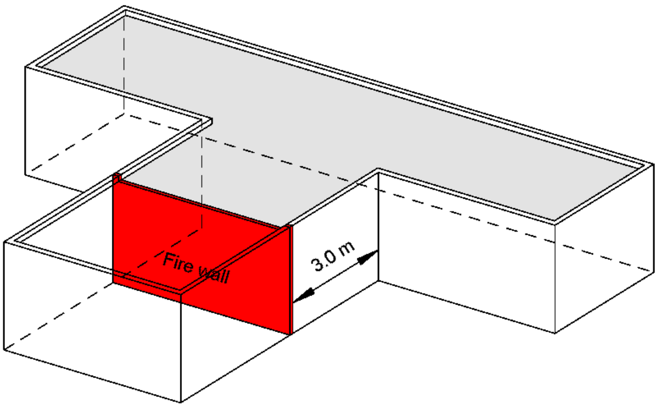

Figure 47: Distances between fire section walls and exterior walls

At least a minimum distance of 1 metre is required between a roof opening or a dormer and the middle of the fire wall. Same distances have to be adhered to a gable wall, as shown in Figure 49.

[164] Fire classification of construction products and building elements – Part 2 p. 23

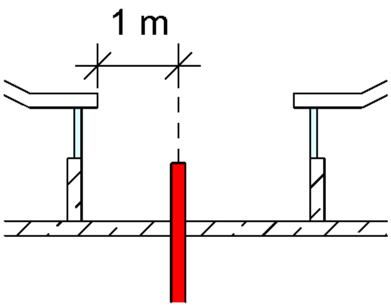

Figure 48: Distance between roof opening and fire wall

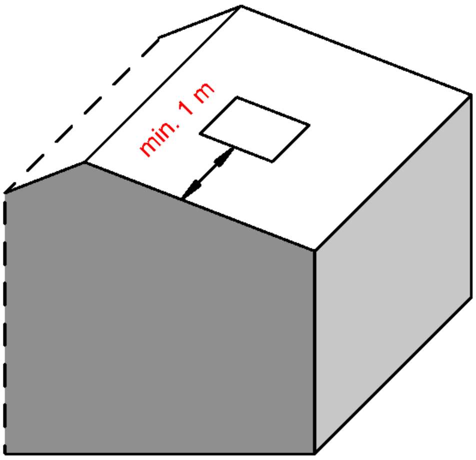

Figure 49: Distance between a roof opening and a gable wall

Fire spreading over openings of a higher level to a different fire section has to be prevented over a separation distance with more than 4 m. See Figure 50.

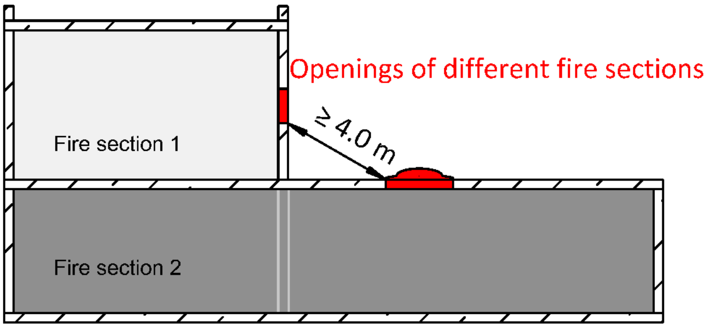

Figure 50: Separation distance between openings of a different height

Partition walls and ceilings

Residences or operating units have to be separated among themselves and from other building parts, like Corridors. The requirements for partition walls and ceilings can be found in Table 4. Separations are not required for buildings with building class 1.

In contrast, several operating units with office use or similar use and places of sale do not have this separation. There the maximum allowable fire section area can be seen as one operating unit or place of sale.

The guidelines have special requirements for walls of a stairway. These requirements are specified in Table 6, Table 7 and Table 8. These tables contain requirements for doors in partition walls too.

An EI_2 30 classification is required for doors which connect corridors and residences or operating units with office, or similar use. Surrounding glass surfaces of a door must provide a classification of EI 30. The glass surface area is not allowed to be bigger than the door leaf area itself, except for buildings of building class 2.

Other types of doors must have an EI_2 30-C classification. Doors or closings in ceilings to undeveloped attic spaces are classified with EI_2 30.

In case of other openings in partition walls, a self closing element with the same fire resistance as the partition wall has to be installed.

Shafts, ducts, pipes and other installations

Shafts, ducts, pipes and other installations shall be designed in order to not affect the fire resistance of the penetrated element and the spread of fire and smoke is effectively limited over the fire resistance duration.

Facade

Facades of buildings in building class 4 and 5 have to limit the fire spreading over the surface of the facade to the upper story, as this might evoke the falling of large parts of the facade.

Exterior walls with a composite heat insulation system and an insulation out of polystyrene or insulations which are classified with A2, do not have any additional requirements, if the insulation thickness is below 10 cm.

Each floor has to provide a fire protection bulkhead out of mineral wool with a height of 20 cm in the ceiling, if the insulation thickness is over 10 cm. The mineral wool has to be glued and pegged. Another possibility is a fire protection bolt of mineral wool in the lintel area of windows and balcony doors with a lateral encroachment of 30 cm and a height of 20 cm, which is glued and pegged.

Ceiling soffits of projection or understudying building elements with more than 2 m are permitted with A2 materials, by buildings with building class 5 and an exterior wall with a composite heat insulation system. Such building elements can be alcoves, balconies and outdoor loggias.

Buildings of building class 4 and 5, where exterior walls have a composite heat insulation system, require an A2 insulation for passages, which are single escape routes and single fire fighting routes. These walls are allowed to have an insulation thickness over 10 cm if it is classified with A2 and the means of escape is only possible in one direction.

To prevent fire from spreading over the surface of the facade and the falling of large parts, some requirements for building class 4 have to be considered, if the fire brigade has a minimum of 3 sides to the property open for fire fighting.

The insulation has to be classified as an A2 material and has to be fixed with materials like steel. Additionally, it is allowed to use materials with classification A2, B and D for the outer layer of the facade. The maximum ventilation gap of a ventilated facade is defined with 6 cm.

Double facades and curtain facades at buildings with building class 4 and 5 have specific requirements. Double facades are facades with a big space between the layers, which can be up to several metres. Therefore, it is important to prevent the fire or smoke from spreading over this spacing. This should be accomplished over partition ceilings and fire section forming ceilings.

The other facade type is a curtain wall facade, which does not have a ventilation layer and is used to separate the inner space of the building element from the outside. The inner space, or more specific the joints and voids in the inner space have to be build to prevent a spreading of fire and smoke.

In addition, the guideline allows to perform the dado of a building with building materials of class E.

Elevators

In general, elevators interconnect the stories of a building. This leads to a fire protection problem, because it allows the spreading of fire and smoke over the shaft itself. Therefore, the walls and ceiling of an elevator shaft have to be constructed out of fire section forming walls and ceilings, if the shaft interconnects fire sections. The access areas of the elevator should also prevent a spreading of fire and smoke. Therefore, a fire protected pass-through should be constructed to prevent this danger.

Basically, buildings in building class 3 and 4 have to be covered in the inner surface of the shaft, with an A2 material. In comparison to building class 5, an own shaft fencing in A2 materials is necessary to prevent a fire and smoke spread.

The requirements of the following points of the OIB-Guideline are not completely considered:

- **Heating appliances and connection pieces**

  This point gives information about arrangement of these appliances, so that no danger for people arises.

- **Exhaust system**

  The requirements for exhaust systems are a soot fire resistance, a sealing and sheathing for penetrated walls and ceilings and a sufficient distance to combustible materials to prevent the ignition of them.

- **Rooms with increased fire hazard**

  These rooms are boiler rooms, fuel storage and waste storage facilities, which have special fire resistance requirements to walls, ceilings and openings. Basically, a fire spreading to other building elements have to be prevented. The guideline also defines the arrangement of such rooms and their storage size.

First and extended extinguishing aid

A first extinguishing aid is generally a fire extinguisher, which has to be provided in residences and operating units to extinguish the fire or contain it.

Fire extinguisher shall be positioned in all parts of a building, if it is seen as necessary.

Buildings with buildings class 5 and more than six stories aboveground have to provide a fire hose reel with a D-pipe at every story of building. In addition, it has to be possible for the fire fighters to connect to the hose reel in order to provide a better and faster extinguishing operation.

Note: A dry extinguishing pipe with access at each floor is enough for residential buildings with the same classification.

Smoke detector

Smoke detectors are warning systems, which help to identify an early smoke and fire development. Therefore, it is necessary to install smoke detectors in all lounges of a residential building. Generally, each lounge should have at least one smoke detector. The smoke detectors do not have to be networked.

The guideline defines that it is not necessary to install a smoke detector in kitchens and corridors with an escape route through a lounge.

The point “smoke exhaust of underground stories” is regulated in the guideline too. Nevertheless, this point is not discussed in detail, because it is not necessary for the main message and fictitious buildings of this thesis.

7.4.1.4 Spread of fire to other buildings

The Styria Construction Act regulates the distances between buildings and between buildings and plot boundaries.

It is defined that buildings must either be built directly adjacent or at a sufficient distance.

The distance between the building and the plot boundary is calculated as followed:

Distance [m] = stories of the building * 1 m + 2 m

Generally, it is to say that the distances between two buildings should not fall below 2 metres, unless it is built directly adjacent. Nevertheless, it is allowed to reduce the distance under certain circumstances. For example, it is permitted to build outbuildings on the plot boundary with an approval of the neighbour.[165]

Furthermore, the guideline contains additional requirements for distances between buildings and plot boundaries. It is defined that exterior walls with a distance below 2 metres to the plot boundary have to be built as fire section forming walls, except if the development of the neighbouring plot is impossible (circulation area, public parking areas or waters).

Eaves, porches, alcoves and balconies have to be built with fire protection measurements.

It also permitted to build shelters or garden shelters without a fire section forming wall, if a fire spreading to buildings on the neighbouring plot is impossible and the built over area is not more than 50 m². The wall, which is parallel to the plot boundary, has to be built according to REI 30 or EI 30.

Fire walls have to consider self-closing windows with the same fire resistance as the wall itself. Wall coverings and claddings have to be built out of A2 materials, except for buildings with building class 1, 2 and 3 or in case it is not allowed to connect directly to the wall.

Note: Connection openings between buildings are permitted, if the opening has not a bad influence relating to the fire protection.

In addition, fire protection measurements have to be made, if the distances between buildings on the same plot are not more than 4 m, except for buildings like shelters or garden shelters, buildings with building class 1 or terraces houses with building class 2.

[165] https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrStmk&Gesetzesnummer=20000070

7.4.1.5 Escape and rescue routes

7.4.1.5.1 Escape route

An escape route is one of the most important points to save lives in case of a fire.

The exit access travel distance is defined as the distance from any point in any room in the building to a safe place. The distance is not allowed to exceed 40 metres.

An exit to a safe place on an adjacent outdoor area must be reachable within a length of not more than 40 metres, from any point in the building, by the following exits:

(a) a direct exit
(b) a stairway or an exterior stair according to Table 6 and Table 7
(c) a stairway or an exterior stair according to Table 8. The exit access travel distance of residences (do not connect more than two stories) is not measured from a point in the residence itself. It is measured from the entrance of the residences to an exit mentioned in (b) and (c).

The requirements of walls, doors and other building parts of a stairway, is regulated in Table 6, Table 7 and Table 8.

In case of (c) it has to be guaranteed that

- a rescue route according to 0 is available, or
- an independent escape route to another stairway or exterior stair is available for each story with at least one lounge, or
- an independent escape route to a neighbouring fire section, which leads to a safe place over a stairway or an exterior stair

Note: The travel distance to the fire section is not limited

Escape routes as defined in (b) and (c) have a limitation for distance in which they are allowed to proceed in common with residences and operating units. For residences the limitation of the distance is 15 metres and for the operating unit 25 metres.

7.4.1.5.2 Rescue route

A rescue route with rescue devices of the fire department has specific requirements and is only permitted, if the distance between the fire brigade and the building is not more than 10 kilometres. Accordingly, all entrances driveways and parking spaces must be suitable for the devices of the fire brigade. An advantage of the fixed installed rescue route system is that there is no need for special entrances, driveways and parking spaces.

Furthermore, rescue routes and fixed installed rescue route system are only useful if all residences and operating units are accessible over appropriate openings.

7.4.1.5.3 Corridors, stairways and doors along the escape routes

Ceilings between corridors have a fire resistance rating as regulated in Table 4 - Point 4.4, if the corridors are used as an escape route to the stairways.

Generally, all corridors have to be separated every 40 metres of the corridor to counteract the spreading of fire and smoke. These separations must have doors with an E 30-C classification.

The flight of stairs and stair landings have the same classifications as regulated in Table 6, Table 7 and Table 8, except for buildings of building class 2, where A2 materials are allowed too.

Buildings of building class 5 with six stories above ground require an additional A2 classification, whereby other buildings of building class 5 require only a R90 classification without A2.

Closed arcades are seen as corridors and have the same requirements as corridors, relating to fire resistance and fire behaviour.

The requirements of Table 1b Point 2 are the same as for walls and ceilings of opened arcades. A2 classification for walls and ceilings are sufficient, if the building has a building class of 2, 3 or 4 and two exit accesses can be reached in case of a fire.

It has to be guaranteed that the stability during the fire is sufficient and it can be used as an escape route.

There are different fire resistance requirements for openings to opened arcades.

Windows need a classification of at least EI 30 and can be fixed installed or function with self-closing. Doors need a classification of EI_2 30.

“Exceptions for these requirements are:

(a) an exit access travel distance not more than 40 metres to an exit to a safe place on an adjacent outdoor area or
(b) escape routes to two different stairways and exterior stairs or
(c) escape routes to one stairway and exterior stair and a fixed installed rescue route system or
(d) the glazing in the outer wall has a parapet height of 1.5 m and the parapet height of the arcades too. The parapet has to be closed, except for 3 cm in dado, which is design related or

(e) *for buildings of building class 2 and 4 with an rescue route for all residences and operating units which is provided by the equipment of the fire brigade at an another side of the building."*[166] *(not the same side as the arcade)*

Escape route orientation lighting

An escape route orientation lighting is necessary for buildings of building class 4 and 5. The lightings should be installed in direction to the exit on the exterior walls of the buildings.

These lightings should be installed in corridors, stairways and exterior stairs.

7.4.1.6 Firefighting

It is to ensure that buildings are accessible for fire fighters. Therefore, access roads and areas for fire engine have to be built correspondingly.

The distance between the most remote points of a necessary fire fighting area to the nearest point of access to the building, is not allowed to be more than 80 metres. In addition, the accessibility must be considered in buildings of building classes 4 and 5 and if it is not infringed, other fire protection measurements have to be made.

Another important point for firefighting is a sufficient amount of extinguishing water. Basically, the amount of water is regulated by the municipal based on a federal state provision. Nonetheless, the guideline defines that at least an extinguishing water rate of 1 l/ (m² min) is sufficient for the biggest fire sections in office buildings and buildings with a similar use. For residential buildings 800 l/min is seen as sufficient.

7.4.1.7 Fire protection concept

Each point of the guideline helps to fulfil the safety goals of the construction act. Additional, it is to mention that this is the basic concept. For more detailed information of technical fire protection, Austrian Standards and the TRVBs should be used.

[166] OIB Guideline 2: Safety in case of fire p. 10

7.4.2 Classification of buildings in the United States of America - California[167]

California and Styria have basically the same way to develop a fire protection concept.

As mentioned in the Section 7.1, California has the California Building Code, which is based on the International Building Code of the United States. For this thesis the California Building Code 2013 is important.

The code distinguishes between the following occupancies:

- Occupancy classification
- Fire Protection System
- Type of construction
- Allowable floor area
- Height and number of stories
- Location on property
- Means of egress

After the buildings are classified by these points, a review for each point has to be made, because the requirements can change during the classification.

7.4.2.1 Occupancy classification

The first step to classify a building is to define its occupancy group. The occupancy group should reflect the use of the building or portion. The code also provides mixed occupancies.

The code differs between the following occupancies:

1. Assembly: Groups A-1, A-2, A-3,A-4 and A-5
2. **Business: Group B**
3. Educational: Group E
4. Factory and Industrial: Groups F-1 and F-2
5. High Hazard: Groups H-1, H-2, H-3, H-4 and H-5
6. Institutional: Groups I-1, I-2, I-3 and I-4
7. Laboratory: Group B, unless classified as Group L or Group H
8. Mercantile: Group M

[167] Cf. Building Codes Illustrated: A Guide to Understanding the 2012 International Building Code p. 14-206

9. [SFM] Organized Camps: Group C10.

10. [SFM] Research Laboratories: Group L

11. **Residential: Group**s R-1, **R-2**, R-3 and R-4

12. Storage: Groups S-1 and S-2

13. Utility and Miscellaneous: Group U

Note: SFM is for existing buildings housing existing protective social care homes or facilities.[168]

The following points provide an overview of the different occupancies.

Group B: mainly used for office, professional or service-type transactions

Examples: Offices, ambulatory care facilities, banks, laundries[169]

Group R-1: for occupants less than 30 days there or transient occupancies

Examples: Hotels and Motels

Group R-2: for occupants who are permanently there; the building contains more than two dwelling units

Examples: apartments, boarding houses

Group R-3: for occupants who are permanently there; These are primarily houses with one or dwellings, or day cares for only a few people.

Examples: Family houses, Boarding houses for a few people and day cares for a few people

Note: One or two family residences are generally regulated in the California Residential Code.

Group R-4: for occupants for residential care or occupants who need an assisted-living; not more than 16 occupants.

Examples: assisted living facilities, residential care[170]

[168] Cf. California Building Code 2013 p. 91

[169] Cf. ibid. p. 92

[170] Cf. ibid. p. 99-101

For this thesis occupancies of Groups B and R-2 are relevant. Therefore, only sections are considered, which are dealing with these groups. High-rise buildings are not considered.

After the occupancy is defined, the special detailed requirements based on the use and occupancy should be checked.

In case of Group B, no special detailed requirements are defined, whereby special detailed requirements for Group R occupancies are made.

It is defined, that dwelling and sleeping units have to provide a separation. The walls are classified as fire partitions and the floor assemblies shall be constructed as horizontal assemblies.

Automatic sprinkler systems are required for all units in Group R occupancies. Smoke detection and fire alarm systems have to be provided in R-2 occupancies.[171]

7.4.2.1.1 Floor Area

After the occupancy is defined, the desired floor area can be checked by taking into account Table 9. It shows the possible height and area, as the type of construction, which may be needed. See also Section 7.4.2.3.

GROUP		TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
	Height	Unlimited	160 ft (48.8 m)	65 ft (19.8 m)	55 ft (16.8 m)	65 ft (19.8 m)	55 ft (16.8 m)	65 ft (19.8 m)	50 ft (15.2 m)	40 ft (12.2m)
B	Story	Unlimited	11	5	3	5	3	5	3	2
	Area	Unlimited	Unlimited	37,500 sf (3484 m²)	23,000 sf (2137 m²)	28,500 sf (2648 m²)	19,000 sf (1765 m²)	36,000 sf (3344 m²)	18,000 sf (1672 m²)	9,000 sf (836 m²)
R-2	Story	Unlimited	11	4	4	4	4	4	3	2
	Area	Unlimited	Unlimited	24,000 sf (2230 m²)	16,000 sf (1486 m²)	24,000 sf (2230 m²)	16,000 sf (1486 m²)	20,500 sf (1904 m²)	12,000 sf (1115 m²)	7,000 sf (650 m²)

Table 9: Excerpt from CBC Table 503 – Allowable building heights and areas[172]

Under special circumstances the area, height and story number can be increased. See 0

7.4.2.1.2 Occupant load

The occupant load is a number, which is basically needed for the means of egress. It is important for the exit access travel distance, for the widths of the exits and also for many other purposes of fire protection. In fact, it refers to the number of people, who have to get out of a building in an emergency.

Generally, the code provides a formula to calculate the occupant load in dependence of the occupancy group. The occupant load for a fixed seated area can be counted over the seats.

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[171] Cf. ibid. p. 152

[172] Ibid. p. 180-181

In case of Group B or Group R-2, the formula has to be used. This formula divides the space of the room or area with the occupant load factor.[173]

The occupant load factor is the maximum allowable floor area per occupant.

Group B: 100 gross (9,29 m²)

Group R-2: 200 gross (18,58 m²)

Note: Gross means gross square feet.

After the occupant factor is defined, the design occupant load can be calculated. Restrooms do not have an occupant factor, because it is assumed that the people are already associated with an area in the building.

7.4.2.2 Fire protection system

7.4.2.2.1 Sprinkler system[174]

As already mentioned before, buildings of Group R require an automatic fire sprinkler system, whereby office buildings of Group B have no requirements, except ambulatory care facilities.

Section 903.2.11 of the CBC defines that all occupancies except for Group U have to install an automatic sprinkler system, if they have stories without openings and the floor area exceeds 1,500 square feet (139.4 m²) and if one of the following points are not provided:

1. Openings in exterior walls below the grade have to lead to the ground level over an exterior stair or ramp. At least one opening at one side has to be located in every 50 feet (15.24 m)
2. Openings in exterior walls, which are entirely above the adjoining ground level must have opening area of at least 20 sf (1.86 m²) every 50 feet (15.24 m)

Openings must have at least a minimum dimension of 30 in. (76,2 cm) and must be accessible to the fire brigade from the exterior wall. This is necessary for firefighting or rescuing people.

Figure 51 helps to understand the subject and gives an overview of the positions.

[173] Cf. ibid. p. 371,372

[174] Cf. ibid. p. 319-322, 324,325

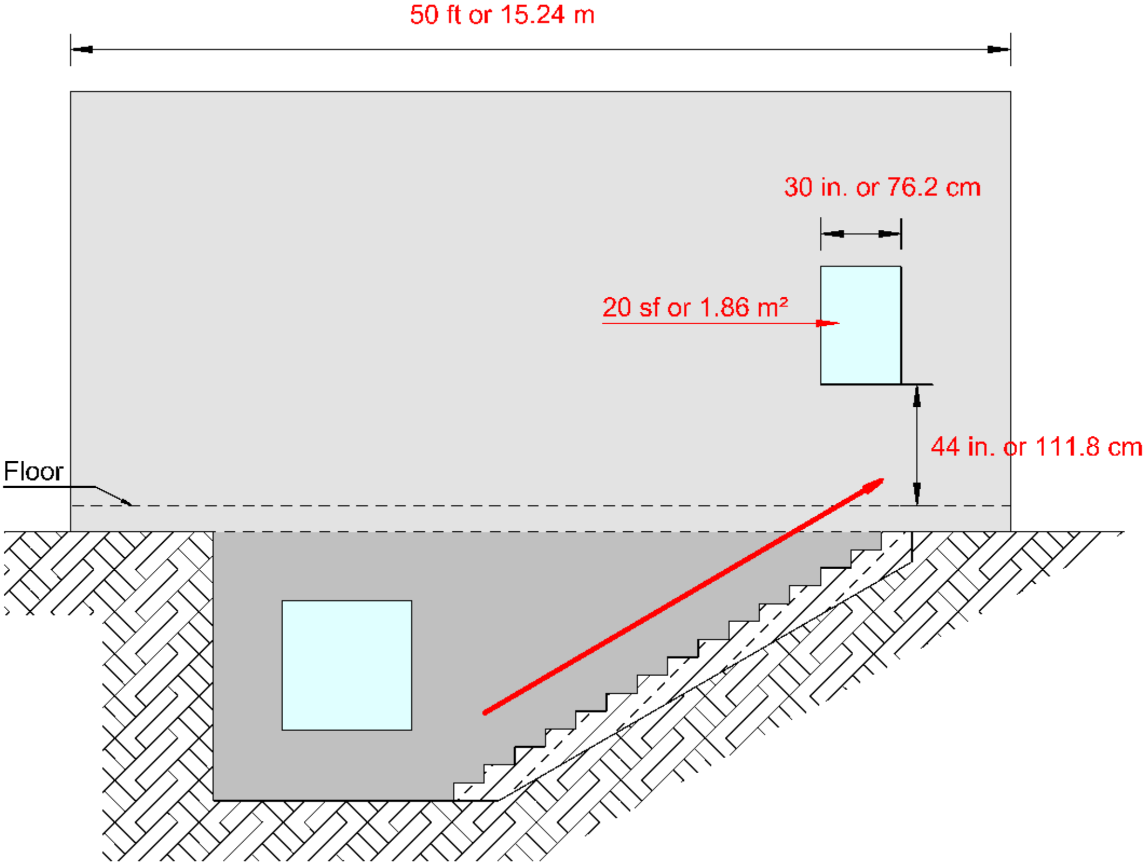

Figure 51: Sprinkler requirements relating to openings in exterior walls

The code regulates that, if there are openings on only one side of a story and the distance between the opening and the opposite wall is more than 75 ft (22.86 m), the story has to install an automatic sprinkler system, except there are openings in the adjacent walls.

Figure 52 gives an overview of the distances and lengths. As shown there, the distance between opening and opposite wall is more than 75 ft ((22.86 m). In fact, there are two possibilities:

1. installation of an automatic sprinkler system or
2. two openings on the adjacent exterior walls are added (two openings are required, because the length of the wall is more than 50 feet (15.24 m).)

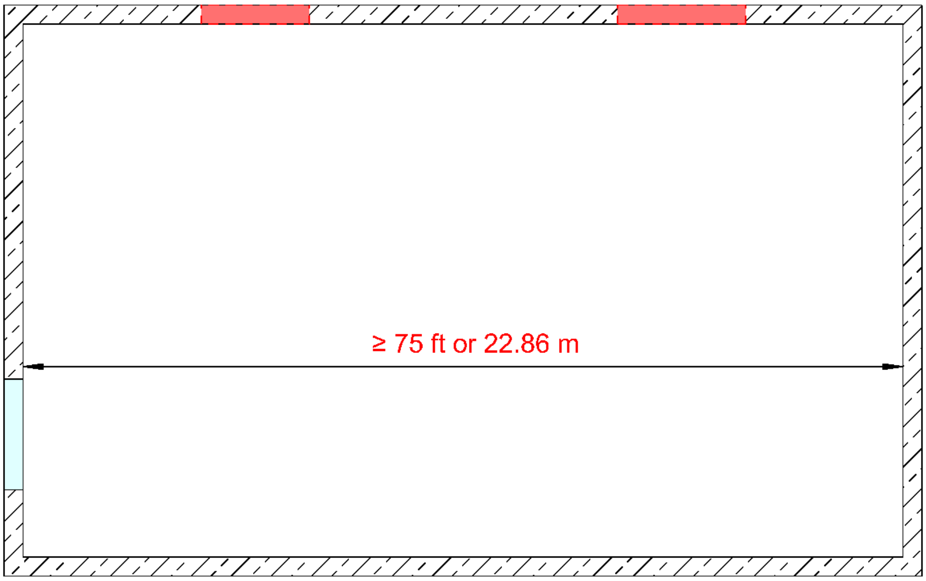

Figure 52: Maximum distance between the opposite walls with an opening only on one side

If any point of the basement is more than 75 ft (22.86 m) away from an opening (defined by the points mentioned before) or the hose stream is restricted by anything, than an automatic sprinkler system is necessary. In case of Figure 53 the wall of room 1 restricts the hose stream and the distance to the opening is more than 75 ft (22.86 m). This means that room 1 and 2 require an automatic sprinkler system.

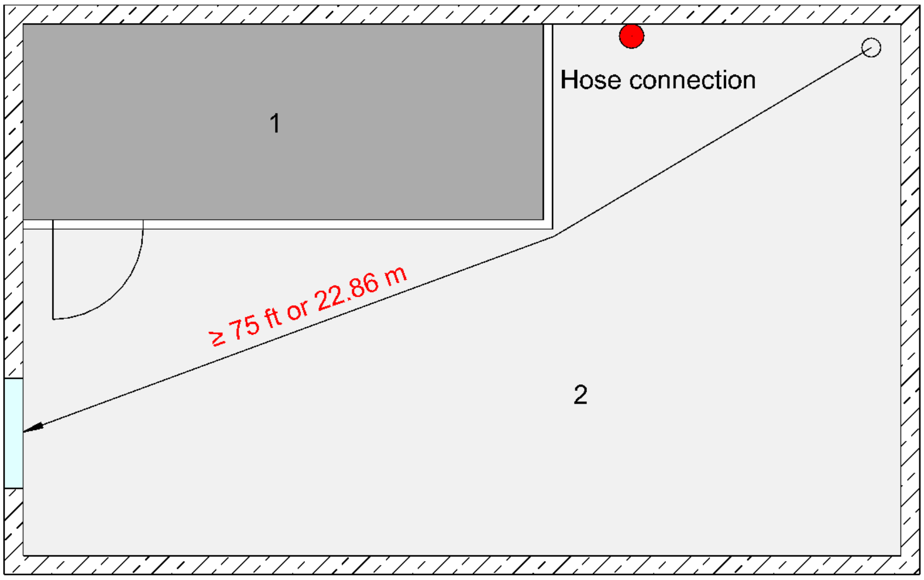

Figure 53: Restrict hose stream and distance to an opening of the basement

An automatic sprinkler system has to be installed in buildings with floors higher than 55 ft (16,754 m) and with an occupant load of 30 or more.

Note: The fire department vehicle has only access to a height of 55 ft (16.754 m).

Which type of sprinkler system is allowed, is regulated by the code. First of all, there is the NFPA 13 sprinkler system, the NFPA 13R sprinkler system and the NFPA 13D.

NFPA 13 sprinkler systems are used for life safety and property protection, whereas the NFPA 13R and NFPA 13D sprinkler systems provide only life safety. NFPA 13 R sprinkler are only allowed for buildings with not more than 4 stories and buildings of Group R. NFPA 13 D are buildings of Group R-3 (one or two family residences), which are regulated in the California Residential Code.

In addition, Group R occupancies must have a quick-response or residential automatic sprinklers in dwelling and sleeping units.

Another point of the California Building Code, gives the possibility to use an alternative automatic fire-extinguishing system, if it is approved by the California Fire Code. An issue may be that all exceptions or reductions which are allowed by other requirements of the code are not allowed to be considered.

For information about the water supply see Section 6.10.2.1.

7.4.2.2.2 Standpipe system[175]

Standpipe systems are allowed to be combined with an automatic sprinkler system. They are divided in 3 types - Class I, Class II and Class II. See Section 6.11.

Standpipe systems should be installed in all occupancies, except for Group R-3. All other occupancies should have a Class III Standpipe system at each floor where one of the following points occurs:

1. Buildings with a floor level higher than 30 ft (9.144m) or 30 ft (9.144m) below of the lowest level of fire department engine access.
2. Buildings with 4 or more stories in height
3. Buildings with 2 or more stories below the highest level of fire department engine access.

However, if an automatic sprinkler system is installed, then a Class I Standpipe system is permitted.

The location of the hose connections is not considered in this thesis.

[175] Cf. ibid. p. 328-331

7.4.2.2.3 Portable fire extinguisher[176]

Portable fire extinguishers are important as a first extinguishing aid. Those are definitely required in Group B and Group R occupancies. Nevertheless, occupancies of Group R-3 with cooking equipment or flammable or combustible liquids and special hazard areas need them. Dwellings units should have at least one portable fire extinguisher with a rating of 1-A:10-B:C

Class A is for ordinary combustibles, Class B for flammable liquids and Class C for electrical equipment.

Basically, Group B and Group R-2 buildings have a light or low hazard level.

	Class A	**Class B**
Minimum rated single extinguisher	2-A 2x 1-A water extinguisher	5-B 10-B
Maximum floor area per unit	3,000 sf (278,7 m²)	-
Maximum floor area for extinguisher	11,250 sf (1045,16m²)	-
Travel distance to extinguisher [feet]	75	30 (for 5-B) 50 (for 5-B)

Table 10: Excerpt of Table 906.3 - Portable fire extinguisher[177]

7.4.2.2.4 Fire alarm and detection systems

1. Manual fire system

Group B

Group B buildings have to install a manual fire system, if

- the occupant load is more than 500 or
- the occupant load is more than 100 above or below the lowest exit discharge or
- the building contains an ambulatory health facility

...except for buildings which have an automatic sprinkler system with a water flow alarm.

[176] Cf. ibid. p. 331-332

[177] Cf. ibid. p. 331-332

Group R-2[178]

Group R-2 buildings have to install a manual fire system if

- the building has three or more stories
- one dwelling unit is more than one story below a discharge exit.
- the building has more than 16 dwelling units

...except the building has not more than 2 stories and all units are separated with at least one hour fire-resistance and each unit has a direct exit. A manual fire alarm system is also not needed, if the building has an automatic sprinkler system with a water flow alarm.

2. Smoke alarms[179]

Group B – no requirements.

Group R-2

Single- or multiple-station smoke alarms should be installed for buildings classified as Group R-2:

- in the vicinity of sleeping areas and bedrooms
- in every sleeping room
- in every story of a dwelling unit

Dwellings with more than one smoke detector, need an interconnection for the smoke detectors.

3. Smoke control system

Group B – no requirements

Group R-2 – no requirements

4. Smoke and heat vents

Group B – no requirements

Group R-2 – no requirements

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[178] Cf. ibid. p. 337,338

[179] Cf. ibid. p. 339-340

7.4.2.3 Type of construction[180]

The type of construction depends on many factors, like occupancy, fire protection systems and height and area of the building.

Section 7.4.2.1 already defines the type of construction, which will be used. This decision is based on the intended occupancy as on the desired building height and area.

In fact, the type of construction is already defined and now the requirements of each type will be determined.

Basically, the code differs between 5 types of construction:

- Type I (A,B)
- Type II (A,B)
- Type III (A,B)
- Type IV (HT)
- Type V (A,B)

Type I and Type II allows only non-combustible materials for the principal elements of the construction itself. The California building codes definition:

"*A material shall not be classified as a non-combustible building construction material if it is subject to an increase in combustibility or flame spread beyond the limitations herein established through the effects of age, moisture or other atmospheric conditions.*" [181]

Example: Masonry, concrete and steel (with coating or covers)

Type III, Type IV and Type V allow combustible materials in varying degrees. Mixed construction types of non-combustible and combustible construction elements are categorized with Type III, Type IV and Type V.

The letters in the brackets stand for the protection of the construction elements, except in Type IV, where a material is defined. (HT stands for HeavyTimber)

Examples: Wood and plastics; Basically everything, which can ignite and burn)

> **A stands for protected**, which means that all structural elements have an additional coating or cover, which extends the fire resistance of the elements at least by 1 hour.
>
> **B stands for unprotected**, which means that the elements do not have any additional coating or coverings to improve the fire resistance rating.

[180] Cf. ibid. p. 195-198
[181] Ibid. p. 202

Buildings have to be classified with one type of construction and it is allowed to use elements of a higher construction type with a higher fire resistance rating, but in fact the building has to reach the requirements of the lowest type.

A fire wall separates the building, which makes it possible to use different construction types for the separated parts of a building.

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[f, g] Interior	 3 3[a]	 2 2[a]	 1 1	 0 0	 2 1	 2 0	 2 1/HT	 1 1	 0 0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and associated secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and associated secondary members (see Section 202)	1 1/2[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	HT	1[b,c]	0

For SI: 1 foot = 304.8 mm.

a. Roof supports: Fire-resistance ratings of primary structural frame and bearing walls are permitted to be reduced by 1 hour where supporting a roof only.

b.*1.*Except in Group *A, E*, F-1, H, *I, L*, M, *R-1, R-2, R-2.1* and S-1 *occupancies, high-rise buildings, and other applications listed in Section 1.11 regulated by the Office of the State Fire Marshal,* fire protection of structural members shall not be required, including protection of roof framing and decking where every part of the roof construction is 20 feet or more above any floor immediately below. Fire-retardant-treated wood members shall be allowed to be used for such unprotected members.

b.2.For Group A, E, I, L, R-1, R-2 and R-2.1 occupancies, high-rise buildings, and other applications listed in Section 1.11 regulated by the Office of the State Fire Marshal, fire protection of members other than the structural frame shall not be required, including protection of roof framing and decking where every part of the roof construction is 20 feet or more above any floor immediately below. Fire-retardant-treated wood members shall be allowed to be used for such unprotected members.

b.3. For one-story portions of Group A and E assembly occupancies the roof-framing system of Type II A or Type III A construction may be of unprotected construction when such roof-framing system is open to the assembly area and does not contain concealed spaces.

c. In all occupancies, heavy timber shall be allowed where a 1-hour or less fire-resistance rating is required.

d. An approved automatic sprinkler system in accordance with Section 903.3.1.1 shall be allowed to be substituted for 1-hour fire-resistance-rated construction, provided such system is not otherwise required by other provisions of the code or used for an allowable area increase in accordance with Section 506.3 or an allowable height increase in accordance with Section 504.2. The 1-hour substitution for the fire resistance of exterior walls shall not be permitted.

e. Not less than the fire-resistance rating required by other sections of this code.

f. Not less than the fire-resistance rating based on fire separation distance (see Table 602).

g. Not less than the fire-resistance rating as referenced in Section 704.10

Table 11: Table 601 - Fire-resistance rating requirements for building elements (hours)[182]

Note: Section 202 consists of definitions. All other tables and sections, which are mentioned in the footnotes of Table 11, are treated throughout the thesis.

Section 602.4.6 of the California building defines that partitions have to be constructed with solid wood construction (2-layer each 1 in.(25 mm)) or laminated construction (1- layer 4 in. (102 mm)) or a construction with a fire resistance construction of at least one hour.

Table 12 requires the definition of the fire separation distance, whereby the distance directly influences the fire resistance rating of the walls.

[182] Ibid. p. 195

The fire separation distance depends on the occupancy, the type of construction and the location of the building on the property.

It is the distance between a building and one of the following:

"1. The closest interior lot line;

2. To the centerline of a street, an alley or public way; or

3. To an imaginary line between two buildings on the property.

The distance shall be measured at right angles from the face of the wall."[183]

Note: It is allowed to measure to the centreline of a street, an alley or public way, instead of measuring to the closest interior lot line. Otherwise, buildings with open glazing facing the streets or public ways wouldn't be allowed. (Example: shops)

The fire resistance of non-bearing exterior walls depends on the fire separation distance, as seen in Table 12. Openings in those walls are regulated in Table 18,Table 19 and Table 20.

FIRE SEPARATION DISTANCE = X (feet)	TYPE OF CONSTRUCTION	OCCUPANCY GROUP H[f], L	OCCUPANCY GROUP F-1, M, S-1[g]	OCCUPANCY GROUP A, B, E, F-2, I, R[h, i], S-2[g], U[b, h, i]
$X < 5^c$	All	3	2	1
$5 \le X < 10$	IA Others	3 2	2 1	1 1
$10 \le X < 30$	IA, IB IIB, VB Others	2 1 1	1 0 1	1^d 0 1^d
$X \ge 30$	All	0	0	0

For SI: 1 foot = 304.8 mm.
a. Load-bearing exterior walls shall also comply with the fire-resistance rating requirements of Table 601.
b. For special requirements for Group U occupancies, see Section 406.3.
c. See Section 706.1.1 for party walls.
d. Open parking garages complying with Section 406 shall not be required to have a fire-resistance rating.
e. The fire-resistance rating of an exterior wall is determined based upon the fire separation distance of the exterior wall and the story in which the wall is located.
f. For special requirements for Group H occupancies, see Section 415.5.
g. For special requirements for Group S aircraft hangars, see Section 412.4.1.
h. Where Table 705.8 permits nonbearing exterior walls with unlimited area of unprotected openings, the required fire-resistance rating for the exterior walls is 0 hours.
i. Group R-3 and Group U occupancies when used as accessory to Group R-3 occupancies, shall not be required to have a fire-resistance rating where the fire separation distance is 5 feet or more; or when equipped throughout with an automatic residential fire sprinkler system installed in accordance with Section 903.3 the fire-resistance rating shall not be required where the fire separation distance is 3 feet or more.

Table 12: Table 602 – Fire resistance rating requirements for exterior walls based on fire separation distance [a,e]

Ratings for corridors and stairways are defined in Section 7.4.2.7.

[183] Ibid. p. 60

Type I and II construction[184]

There are different ways to use all kind of materials, even combustible materials but only in a limited quantity.

Type I-A has the highest level of protection. It requires a passive fire protection for all elements. Type II-A allows an active or passive fire protection for the elements. Type I-B and Type II-B are similar to the Type I-A and II-A, except that B-Types have reduced fire resistance.

Fire retardant treated wood is also permitted to be used in Type I and Type II construction, if:

- non-bearing partitions with a maximum fire resistance rating of 2 hours.
- non-bearing exterior walls with non fire resistance
- roofs as mentioned in Table 11

Except for roofs in buildings of Type I-A construction with a height of more than 20 feet (6.096 m) to the roof or more than two stories.

The flame spread index of thermal and acoustical insulation materials is limited to 25.

There are a lot of exceptions, when it is possible to use insulations with a higher fire spread index.

Examples:

- Insulation between two layers of non-combustible materials without air space– fire spread index < 100.
- Insulation between two layers of non-combustible materials at floors without air space– fire spread index < 200.
- Roof coverings of Class A,B and C.

Only a handful of the exceptions are considered.

Type III construction

The difference to Type I and Type II is that, interior constructions are allowed to be accomplished with combustible materials, whereby exterior walls have to be out of non-combustible materials. Fire retardant treated wood can be used for exterior walls, if a fire resistance rating of not more than 2 hours is required and the requirements of Table 12 are fulfilled.

[184] Cf. Building Codes Illustrated: A Guide to Understanding the 2012 International Building Code p. 76

Type IV construction

Exterior walls are constructed out of non-combustible materials and interior elements out of combustible wood elements, like solid or laminated wood. An important factor of this construction type is, that those wood elements do not have concealed spaces, which prevents an inside smouldering of the building elements. Another advantage is that the structure does not collapse suddenly.

As mentioned before, solid and laminated wood are permitted. The point is that the code gives a nominal solid sawn size, which is not the actual size. Therefore, the code provides an equivalencies table for wood member sizes between a minimum solid sawn size and the minimum glued laminated net size.

MINIMUM NOMINAL SOLID SAWN SIZE		MINIMUM GLUED-LAMINATED NET SIZE	
Width, inch	Depth, inch	Width, inch	Depth, inch
8	8	$6^3/_4$	$8^1/_4$
6	10	5	$10^1/_2$
6	8	5	$8^1/_4$
6	6	5	6
4	6	3	$6^7/_8$

For SI: 1 inch = 25.4 mm.

Table 13: Table 602.4 – Wood member size equivalencies[185]

The code regulates the minimum size of wood members in different building elements, which are not mentioned in the thesis.

Nevertheless, floors are not allowed to directly contact the exterior wall and should provide a fire blocking systems.

Type V construction

In this type of construction all materials can be used, which are allowed by the code.

Typically, types of this construction are platform framing and balloon framing. See Section 4.3.

Type V-A has generally a fire resistance rating of one hour for all buildings element, except non bearing interior walls and partitions. See Table 11. This fire resistance can be complied over the use of gypsum boards.

Type V-B has no fire resistance rating, except it is stipulated in Table 12.

[185] California Building Code 2013 p. 196

7.4.2.3.1 Interior finishes[186]

Wall and ceiling finishes

Finishes are classified over Class A, Class B and Class C. Each class has specific limitations for flame spread and smoke development. For detailed information see Section 6.4.2.

Wall and ceiling finishes have to be tested with different standards like NFPA 286, NFPA 265, and ASTM E84 or UL 723 for the different materials. Basically a Class A classification is used, except one of the tests permits the use of another classification as Class A.

Table 14 gives an overview of the required finish classification based on the occupancy.

GROUP	Sprinklered			Non-sprinklered		
	Interior exit stairways, interior exit ramps and exit passageways [a, b]	Corridors and enclosure for exit access stairways and exit access ramps	Rooms and enclosed spaces [c]	Interior exit stairways, interior exit ramps and exit passageways [a, b]	Corridors and enclosure for exit access stairways and exit access ramps	Rooms and enclosed spaces [c]
B	B	C	C	A	B	C
R-2	C	C	C	B	B	C

Table 14: Excerpt of Table 803.9 – Interior wall and ceiling finish requirements per occupancy[187]

Application of interior finishes by elements with fire resistance rating or have to be out of non-combustible materials

The interior finish material has to be classified with Class A, except the interior finish materials are protected on both sides through an automatic sprinkler system.

Materials with a thickness of not more than 0.25 in. (6.4 mm) have to be applied directly, except the material is classified with Class A or the material is non-combustible.

Interior floor finish

Floor finishes are classified with Class II materials in buildings of Group B and Group R-2.

Interior floor finishes are tested by the NFPA 253 and are defined over the minimum resistance of a radiant flux, Class I 0.45 watts/cm² or greater and Class II 0.22 watts/cm² or greater.

Note: Radiant flux or radiant heat flux is the energy, which can affect a material relating to flaming or ignition.

[186] Cf. California Building Code 2013 p.

[187] Cf. ibid. p. 303-306

7.4.2.3.2 *Exterior covering*

One of the following requirements has to be made:

- the covering has to be made out of materials which are non-combustible or ignition-resistant or
- the wall assemblies meet the performance criteria in SFM Standard 12-7A-1 or
- a 1.59 cm fire resistance gypsum sheathing behind the exterior covering or cladding has to be applied

Combustible materials on the exterior side of exterior walls[188]

Combustible materials in Type I, II, III and IV construction are allowed, if:

- the covering does not exceed 10 percentage of the wall, if the fire separation distance is 5 ft (1.524 m) or less and
- the combustible material is limited to 40 ft (12.192m) in height.

For a fire separation distance of 5 ft or less the NFP 268 test must be passed. Otherwise the radiant heat flux is binding, which is based on the fire separation distance. See Table 15.

FIRE SEPARATION DISTANCE (feet)	TOLERABLE LEVEL INCIDENT RADIANT HEAT ENERGY(kW/m^2)	FIRE SEPARATION DISTANCE (feet)	TOLERABLE LEVEL INCIDENT RADIANT HEAT ENERGY(kW/m^2)
5	12.5	16	5.9
6	11.8	17	5.5
7	11.0	18	5.2
8	10.3	19	4.9
9	9.6	20	4.6
10	8.9	21	4.4
11	8.3	22	4.1
12	7.7	23	3.9
13	7.2	24	3.7
14	6.7	25	3.5
15	6.3		

For SI: 1 foot = 304.8 mm, 1 $Btu/H^2 \times °F = 0.0057\ kW/m^2 \times K$.

Table 15: Table 1406.2.1.1.2 – Minimum fire separation for combustible exterior wall coverings.[189]

The level of incident radiant heat energy shows the maximum energy that does not cause a flaming.

[188] Cf. ibid. p. 716,717
[189] Ibid. p. 716

7.4.2.4 Allowable floor area[190]

It is allowed to increase the floor area in Section 7.4.2.1.1, if certain factors are fulfilled.

The first factor is the frontage to a public way (I_f) and the second one is an installation of a sprinkler system (I_S).

Note: Unlimited area buildings and mixed occupancies are not considered.

7.4.2.4.1 Frontage increase

To increase the area of the building, more than 25 percentage of the building's perimeter has to be on public way, or the distance between the perimeter of the building and the open space is at least 20 ft (6.096 m).

The Equation for the frontage factor is:

"$I_f = [F/P - 0.25]\ W/30$ (Equation 5-2)

where:

I_f = Area increase due to frontage.

F = Building perimeter that fronts on a public way or open space having 20 feet (6096 mm) open minimum width (feet).

P = Perimeter of entire building (feet).

W = Width of public way or open space (feet)"[191]

If W varies, the average width should be calculated as followed:

"Weighted average $W = (L_1 \times w_1 + L_2 \times w_2 + L_3 \times w_3 \ldots)/F$ (Equation 5-3)

where:

L_n = Length of a portion of the exterior perimeter wall.

w_n = Width of open space associated with that portion of the exterior perimeter wall.

F = Building perimeter that fronts on a public way or open space having a width of 20 ft (6096 mm) or more."[192]

W is always measured from the building to the closest interior lot line (by lengths which have to be measured to the property line). If W is more than 30 ft (9.144m), then the value 30 ft should be used in calculations. Otherwise the measured distance should be used, if the

[190] Cf. ibid. p. 183,184

[191] Ibid. p. 183

[192] Ibid. p. 183

length is between 20ft and 30 ft. The weighted average W can not exceed 1.0, except in the case of an unlimited area building under certain conditions.

7.4.2.4.2 Automatic sprinkler system increase

Buildings with more than one story and an automatic sprinkler system can increase the area by 200% ($I_s = 2$). Buildings with not more than one story have an area increase factor of 3.

Note: Buildings of Group R-2 and Type V-A construction are allowed to be increased with a NFPA R13 sprinkler system.

7.4.2.4.3 Single occupancy buildings with more than one story

The total allowable floor areas for buildings with at least 3 stories have a total area limitation for the whole building of three times the maximum floor area. For buildings with 2 stories, the total allowable floor area is two times the maximum floor area.

The code contains an exception for buildings of Group R occupancies, in which case the total allowable floor area is defined over the maximum floor area multiplied by the number of stories, which allows a higher total floor area of the building.

Note: Basement area is not included by the total allowable floor area of the building. The story numbers are the number of stories above grade plane.

7.4.2.4.4 Calculation of the maximum allowable floor area

The formula for the allowable building area per story is calculated as followed:

“$A_a = \{A_t + [A_t \times I_f] + [A_t \times I_s]\}$ (Equation 5-1)”[193]

where:

A_f = floor area per story in accordance to Table 9

I_f = frontage increase factor

I_s = automatic sprinkler increase factor

7.4.2.5 Height and number of stories

The building height can be increased, if the building is equipped with an automatic sprinkler system. In fact, each building with an automatic sprinkler is allowed to increase 20 ft (6.096m) and one story in height. Buildings of Group R-2 and Type V-A construction are limited to 4 stories and are not allowed to exceed 60 ft (18.288 m) in height.

Note: Some occupancy groups do not allow an increase in height.

[193] Ibid. p. 183

7.4.2.6 Location on property[194]

The location of a building on a property is important to define the fire resistance of exterior walls and their openings. The fire separation distance is one factor, which defines the ratings. See Section 7.4.2.3.

7.4.2.6.1 Exterior walls – Projections

Projections of exterior walls can be balconies, eave overhangs and similar projections.

Basically it is to say that projections in Type I and II constructions are only allowed to be build of non-combustible materials, whereby the other types of constructions allow combustible materials. The code regulates the fire separation distance for the projections in Table 16.

FIRE SEPARATION DISTANCE (FSD)	MINIMUM DISTANCE FROM LINE USED TO DETERMINE FSD
0 feet to less than 2 feet	Projections not permitted
2 feet to less than 5 feet	24 inches
5 feet or greater	40 inches

For SI: 1 foot = 304.8 mm; 1 inch = 25.4 mm.

Table 16: Table 705.2 – Minimum distance of projection[195]

These distances do not apply for buildings on the same lot, which are actually defined as one building or buildings which do not exceed the allowed limitations of total allowable building areas and heights in Section 7.4.2.1 and 7.4.2.4.

If there are more buildings on the same lot, an imaginary line defines the fire separation distance and the protected openings. It is allowed to choose the location of the line between the buildings, as long as the requirements of the code are fulfilled and a fire spread is prevented.

The fire resistance ratings and fire separation distance define the exposure from inside and outside. In short, a wall with a distance to the lot line of 10 ft (3.048 m) or smaller must be rated for fire exposure from inside and outside. For a distance of more than 10 ft (3.048 m), a fire exposure is assumed to be only from inside.

[194] Cf. ibid. p. 204-208
[195] Ibid. p. 204

7.4.2.6.2 Openings

The code gives the possibility to calculate the fire resistance rating of protective openings or to use the requirements of Table 17.

FIRE SEPARATION DISTANCE (feet)	DEGREE OF OPENING PROTECTION	ALLOWABLE AREA[a]
0 to less than 3[b, c]	Unprotected, Nonsprinklered (UP, NS)	Not Permitted
	Unprotected, Sprinklered (UP, S)[i]	Not Permitted
	Protected (P)	Not Permitted
3 to less than 5[d, e]	Unprotected, Nonsprinklered (UP, NS)	Not Permitted
	Unprotected, Sprinklered (UP, S)[i]	15%
	Protected (P)	15%
5 to less than 10[e, f, j]	Unprotected, Nonsprinklered (UP, NS)	10%[h]
	Unprotected, Sprinklered (UP, S)[i]	25%
	Protected (P)	25%
10 to less than 15[e, f, g]	Unprotected, Nonsprinklered (UP, NS)	15%[h]
	Unprotected, Sprinklered (UP, S)[i]	45%
	Protected (P)	45%
15 to less than 20[f, g]	Unprotected, Nonsprinklered (UP, NS)	25%
	Unprotected, Sprinklered (UP, S)[i]	75%
	Protected (P)	75%
20 to less than 25[f, g]	Unprotected, Nonsprinklered (UP, NS)	45%
	Unprotected, Sprinklered (UP, S)[i]	No Limit
	Protected (P)	No Limit
25 to less than 30[f, g]	Unprotected, Nonsprinklered (UP, NS)	70%
	Unprotected, Sprinklered (UP, S)[i]	No Limit
	Protected (P)	No Limit
30 or greater	Unprotected, Nonsprinklered (UP, NS)	No Limit
	Unprotected, Sprinklered (UP, S)[i]	Not Required
	Protected (P)	Not Required

For SI: 1 foot = 304.8 mm.
UP, NS = Unprotected openings in buildings not equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1.
UP, S = Unprotected openings in buildings equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1.
P = Openings protected with an opening protective assembly in accordance with Section 705.8.2.
a. Values indicated are the percentage of the area of the exterior wall, per story.
b. For the requirements for fire walls of buildings with differing heights, see Section 706.6.1.
c. For openings in a fire wall for buildings on the same lot, see Section 706.8.
d. The maximum percentage of unprotected and protected openings shall be 25 percent for Group R-3 occupancies.
e. Unprotected openings shall not be permitted for openings with a fire separation distance of less than 15 feet for Group H-2 and H-3 occupancies.
f. The area of unprotected and protected openings shall not be limited for Group R-3 occupancies, with a fire separation distance of 5 feet or greater.
g. The area of openings in an open parking structure with a fire separation distance of 10 feet or greater shall not be limited.
h. Includes buildings accessory to Group R-3.
i. Not applicable to Group H-1, H-2 and H-3 occupancies.
j. For special requirements for Group U occupancies, see Section 406.3.2.

Table 17: Table 705.8 – Maximum area of exterior wall openings based on fire separation distance and degree of opening protection[196]

Table 17 gives an overview of the permitted area of openings in exterior walls based on the fire separation distance and protection. Fire doors, fire shutters and fire window assemblies have to fulfil the requirements of Table 18,Table 19 and Table 20.

Protected openings are openings which accomplish the requirements by a passive fire protection or to be more exact a fire rating, whereby unprotected openings do not have a fire rating. Nevertheless, the area of unprotected openings can be increased over the installation

[196] Ibid. p. 206

of a fire sprinkler system. Unprotected openings can be constructed of any approved material.

It is allowed to have unlimited unprotected openings, if:

- the distance between wall and centreline of the street is more than 15 ft (4.572 m) or
- the distance between lot line and wall is 30 ft (9.144 m) or more.

If an exterior wall consists of unprotected and protected openings, the following equation must be fulfilled:

„$(A_p / a_p) + (A_u / a_u) \leq 1$ (Equation 7-2)

where:

A_p = Actual area of protected openings, or the equivalent area of protected openings..

a_p = Allowable area of protected openings.

A_u = Actual area of unprotected openings.

a_u = Allowable area of unprotected openings."[197]

7.4.2.6.3 Vertical separation of openings and vertical exposure

If there are openings in adjacent stories within a horizontal distance of 5 ft (1.524 m) and the opening in the lower story is an unprotected window, then it has to be separated.

- the vertically separation distance between them has to be at least 3 ft (0.914 m) and requires a 1 hour fire resistance rating or
- at least a 30 in (0.762 m) horizontal flame barrier with 1 hour fire resistance rating

Openings must have a minimum fire resistance rating of ¾ hour, if the vertical distance from the adjacent roof of one building to a window of the other building is less than 15 ft (4.572 m) and the horizontal distance to the adjacent building is less than 15 ft (4.572 m).

Except the roof assembly of the lower building has a fire resistance rating of at least 1 hour over a minimum distance of 10 ft (3.048 m), or the buildings are considered as one building.

7.4.2.6.4 Parapets

Parapets can prevent a fire spreading above the roof and typically 30 in. (0.762 m), which should be provided by exterior walls.

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[197] Ibid. p. 207

There are also some exceptions, where a parapet is not needed:

- no fire resistance rating, because of fire separation distance
- building area is not more than 1,000 sf (93 m²)
- roof construction is not less than 2 hours or the roof is made out of non-combustible materials
- requirements for roof/ceiling framing with exterior walls with 1 hour fire resistance rating. The dark red parts in Figure 54 show the parts which should have at least a fire resistance rating of one hour. This includes the framing parallel to the wall too.
  If the framing is not parallel to the exterior wall, the complete spans must have a 1 hour fire resistance rating.

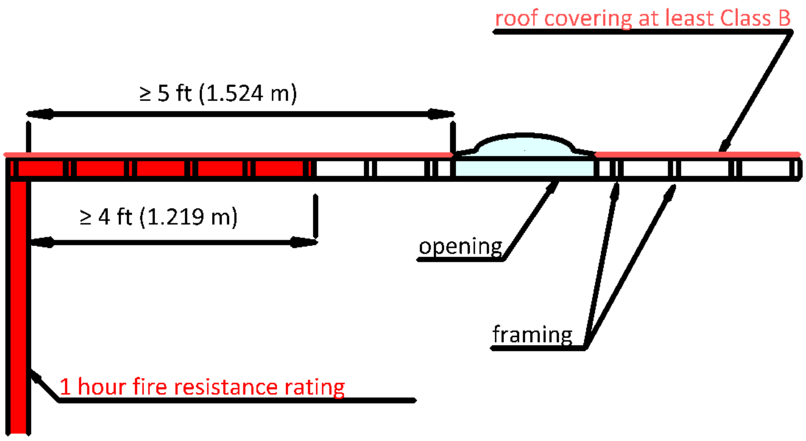

Figure 54: Group-R roof/ceiling parallel to wall

- Group R-2 buildings have at least a Class C covering and the roof sheathing or deck is built with fire retardant wood on a length of 4 ft (1.220 m)
- or the fire separation distance allows, that 25 percentages of the wall can contain unprotected openings

7.4.2.6.5 Fire walls[198]

For a definition see Section 5.10. The fire wall fire resistance rating in buildings of Group B and Group R-2 is defined with 3 hours. Except in Buildings of construction Type II or V where a fire resistance of not less than 2 hours is allowed.

There are a lot of restrictions for a fire wall. Basically it is to say, that those walls restrict the spread of fire and separate buildings.

[198] Cf. ibid. p. 208-210

Fire walls have to be continuous from the basement to at least 30 in. (0.762 m) above the roof, except 4 ft (1.220 m) of the roof on both sides of the fire wall have a fire resistance rating of at least 1 hour.

The walls as well have to extend beyond surface of exterior walls at least 18 in. (0.457 m), except:

- the finish of the adjacent exterior walls must extend at least 4 ft (1.220 m) on both sides and have to provide a fire resistance rating of at least 1 hour.
- each side of the fire wall is protected over an automatic fire sprinkler system
- exterior wall intersections at fire walls, which are forming an angle of more than 180° do not need a fire protection, if the angle is less than 180°

In case of horizontal projections the fire wall has to extend to the edge of horizontal projections within 4 ft. (1.220 m) of the fire wall.

Exceptions can be made if a certain distance to the projections has a fire resistance rating. It also depends on the concealed spaces and non concealed space. Those points are not described in detail.

Openings in a fire wall are allowed by the code, if the area of the opening is not more than 156 sf (15 m²) and the length of the horizontal dimension of all openings in the wall is not more than 25 percentage of the length of the fire wall itself.

For opening ratings in fire walls see Section 7.4.2.6.11.

7.4.2.6.6 Fire barriers[199]

For a definition see Section 5.11. Fire barriers are similar to fire walls. Those types of walls are used for the separation of occupancies and interior exit stairways. The fire resistance rating of a fire barrier or horizontal assemblies between fire areas have to be at least 2 hours in buildings of Group B and Group R-2 occupancies.

Fire barriers must be continuous from the top of the floor to the underside of the ceiling and should go through hollowed vertical spaces. These walls can also be located on the outside of a building as an exterior wall, which can change the requirements of fire resistance rating, openings and exits.

A single protected opening is not allowed to have an area of more than 15 sf (15 m²) and the sum of the horizontal length of the openings is not allowed to exceed a length of 25 percentages of the fire barrier.

[199] Cf. ibid. p. 210-212

Openings do not have to meet the requirements, if:

- an automatic sprinkler system is installed
- the opening is a fire door for exit access stairways, interior exit stairways or for the same type of ramps.
- the opening protectives have the same fire resistance rating as the wall
- the opening is a fire door in a fire barrier and separating an enclosure for exit accesses.

For opening ratings in fire barriers see Section 7.4.2.6.11.

7.4.2.6.7 Fire partitions[200]

For a definition see Section 5.11. This type of wall normally has an 1 hour fire resistance rating, except for Type II-B, Type III-B and V-B where a fire resistance rating of not less than half an hour is required. Typically, they are used to separate dwellings and sleeping units in the same building. Fire partitions have similar requirements as fire walls and fire barriers. Fire partitions do not have to extent in the crawl space, if the floor has at least a fire resistance rating of 1 hour.

Walls of corridors are defined as fire partitions. For fire resistance rating of corridors see Section 7.4.2.7.

Enclosed elevator lobbies have to be separated by fire partitions. Buildings of Group R have to ensure that each floor has an enclosed elevator lobby, if the shaft enclosure connects more than two stories. In case of buildings of Group B, enclosed elevator lobbies have to be ensured, if the shaft connects more than three stories.

Buildings of Group R-2 with not more than four stories do not require an extension of the fire partition, if the attic is draft stopped every 3000 sf (279 m^2) or every two dwelling or sleeping units (depending on which of them is smaller).

Attic draft stopping is not required for buildings which have an automatic sprinkler system.

For protective openings in fire partition see Section 7.4.2.6.11.

7.4.2.6.8 Smoke barriers and smoke partitions[201]

The purpose of smoke barriers and partitions is to prevent smoke migration. The walls need to reach from one outside of an exterior wall to the opposite outside of the exterior wall. Smoke barriers are used for elevator lobbies. The difference between barriers and partitions

[200] Cf. ibid. p. 212,213

[201] Cf. ibid. p. 213,214

is that barriers have a fire resistance rating of 1 hour, whereby partitions do not have a fire resistance rating unless it is specifically mentioned.

For protective openings in smoke barriers and smoke partitions see Section 7.4.2.6.11.

7.4.2.6.9 Horizontal assemblies[202]

Horizontal assemblies include floor, ceiling and roof assemblies. The fire resistance rating is regulated in Table 11. For horizontal assemblies which are separating sleeping units must have at least a fire resistance rating of 1 hour, except for Type II-B, Type III-B and V-B, where a fire resistance rating of not less than half an hour is required. Requirements of horizontal assemblies are also defined by ratings for fire barriers. Therefore, it is important to compare the tables and requirements to define the fire resistance rating.

Supporting members of horizontal assemblies like walls, columns and so on are not allowed to have a lower fire resistance rating than the horizontal assembly itself. Skylight openings are permitted, if they meet the requirements of Section 7.4.2.6.3.

7.4.2.6.10 Shaft enclosures[203]

Shaft enclosures should be made out of the same materials as fire barriers or horizontal assemblies. For buildings with four and more stories the fire resistance rating should be 2 hours and for less than 4 stories 1 hour. Openings are allowed in accordance to Section 7.4.2.6.11.

If the shaft enclosure does not extend to the bottom or top, a construction is required to be enclosed with elements of the same fire resistance rating as the shaft enclosure. For enclosed elevator lobbies see Section 7.4.2.6.7.

7.4.2.6.11 Opening protectives

The requirements of opening protectives are basically defined in Table 18, Table 19 and Table 20. For detailed information about the classification and abbreviations see Section 6.6.

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[202] Cf. ibid. p. 214,215

[203] Cf. ibid. p. 216-218

TYPE OF ASSEMBLY	REQUIRED WALL ASSEMBLY RATING (hours)	MINIMUM FIRE DOOR AND FIRE SHUTTER ASSEMBLY RATING (hours)	DOOR VISION PANEL SIZE	FIRE RATED GLAZING MARKING DOOR VISION PANEL[e]	MINIMUM SIDELIGHT/ TRANSOM ASSEMBLY RATING (hours)		FIRE-RATED GLAZING MARKING SIDELITE/TRANSOM PANEL	
					Fire protection	Fire resistance	Fire protection	Fire resistance
Fire walls and fire barriers having a required fire-resistance rating greater than 1 hour	4	3	Not Permitted	Not Permitted	Not Permitted	4	Not Permitted	W-240
	3	3[a]	Not Permitted	Not Permitted	Not Permitted	3	Not Permitted	W-180
	2	$1\frac{1}{2}$	100 sq. in.[c]	≤100 sq.in. = D-H-90 >100 sq.in.= D-H-W-90	Not Permitted	2	Not Permitted	W-120
	$1\frac{1}{2}$	$1\frac{1}{2}$	100 sq. in.[c]	≤100 sq.in. = D-H-90 >100 sq.in.= D-H-W-90	Not Permitted	$1\frac{1}{2}$	Not Permitted	W-90
Shaft, exit enclosures and exit passageway walls	2	$1\frac{1}{2}$	100 sq. in.[c, d]	≤100 sq.in. = D-H-90 > 100 sq.in.= D-H-T-or D-H-T-W-90	Not Permitted	2	Not Permitted	W-120
Fire barriers having a required fire-resistance rating of 1 hour: Enclosures for shafts, exit access stairways, exit access ramps, interior exit stairways, interior exit ramps and exit passageway walls	1	1	100 sq. in.[c, d]	≤100 sq.in. = D-H-60 >100 sq.in.= D-H-T-60 or D-H-T-W-60	Not Permitted	1	Not Permitted	W-60
					Fire protection			
Other fire barriers	1	$\frac{3}{4}$	Maximum size tested	D-H-NT-45	$\frac{3}{4}$		D-H-NT-45	
Fire partitions: Corridor walls	1	$\frac{1}{3}$[b]	Maximum size tested	D-20	$\frac{3}{4}$[b]		D-H-OH-45	
	0.5	$\frac{1}{3}$[b]	Maximum size tested	D-20	$\frac{1}{3}$		D-H-OH-20	
Other fire partitions	1	$\frac{3}{4}$	Maximum size tested	D-H-45	$\frac{3}{4}$		D-H-45	
	0.5	$\frac{1}{3}$	Maximum size tested	D-H-20	$\frac{1}{3}$		D-H-20	

Table 18: Table 716.5 - Part 1 - Opening fire protection assemblies, ratings and markings[204]

[204] Ibid. p. 224

TYPE OF ASSEMBLY	REQUIRED WALL ASSEMBLY RATING (hours)	MINIMUM FIRE DOOR AND FIRE SHUTTER ASSEMBLY RATING (hours)	DOOR VISION PANEL SIZE	FIRE RATED GLAZING MARKING DOOR VISION PANEL [e]	MINIMUM SIDELIGHT/ TRANSOM ASSEMBLY RATING (hours)		FIRE-RATED GLAZING MARKING SIDELITE/TRANSOM PANEL	
					Fire protection	Fire resistance	Fire protection	Fire resistance
Exterior walls	3	$1^1/_2$	100 sq. in.[c]	≤100 sq.in. = D-H-90 >100 sq.in = D-H-W-90	Not Permitted	3	Not Permitted	W-180
	2	$1^1/_2$	100 sq. in.[c]	≤100 sq.in. = D-H-90 >100 sq.in.= D-H-W-90	Not Permitted	2	Not Permitted	W-120
					Fire Protection			
	1	$^3/_4$	Maximum size tested	D-H-45	$^3/_4$		D-H-45	
Smoke barriers					Fire protection			
	1	$^1/_3$[b]	Maximum size tested	D-20	$^3/_4$		D-H-OH-45	

For SI: 1 square inch = 645.2 mm.
a. Two doors, each with a fire protection rating of $1^1/_2$ hours, installed on opposite sides of the same opening in a fire wall, shall be deemed equivalent in fire protection rating to one 3-hour fire door.
b. For testing requirements, see Section 716.6.3.
c. Fire-resistance-rated glazing tested to ASTM E 119 in accordance with Section 716.2 shall be permitted, in the maximum size tested.
d. Except where the building is equipped throughout with an automatic sprinkler and the fire-rated glazing meets the criteria established in Section 716.5.5.
e. Under the column heading "Fire-rated glazing marking door vision panel," W refers to the fire-resistance rating of the glazing, not the frame.

Table 19: Table 716.5 - Part 2 - Opening fire protection assemblies, ratings and markings[205]

TYPE OF WALL ASSEMBLY	REQUIRED WALL ASSEMBLY RATING (hours)	MINIMUM FIRE WINDOW ASSEMBLY RATING (hours)	FIRE-RATED GLAZING MARKING
Interior walls			
Fire walls	All	NP[a]	W-XXX[b]
Fire barriers	>1	NP[a]	W-XXX[b]
	1	NP[a]	W-XXX[b]
Incidental use areas (707.3.6), Mixed occupancy separations (707.3.8)	1	$^3/_4$	OH-45 or W-60
Fire partitions	1	$^3/_4$	OH-45 or W-60
	0.5	$^1/_3$	OH-20 or W-30
Smoke barriers	1	$^3/_4$	OH-45 or W-60
Exterior walls	>1	$1^1/_2$	OH-90 or W-XXX[b]
	1	$^3/_4$	OH-45 or W-60
	0.5	$^1/_3$	OH-20 or W-30
Party wall	All	NP	Not Applicable

NP = Not Permitted.
a. Not permitted except fire-resistance-rated glazing assemblies tested to ASTM E 119 or UL 263, as specified in Section 716.2.
b. XXX = The fire rating duration period in minutes, which shall be equal to the fire-resistance rating required for the wall assembly.

Table 20: Table 716.6 – Fire window assembly fire protection ratings[206]

The code regulates that not more than 25 percentage of the wall area is allowed to be covered over fire windows. Basically, it is permitted to use fire windows in fire barriers and walls.

[205] Ibid. p. 225
[206] Ibid. p. 227

7.4.2.7 Means of egress

The means of egress regulates the requirements for an escape in case of a fire.

Escape routes are divided into three parts:

1. **Exit access**
   The exit access is defined as the length which has to be walked from the most remote point in a building to the door of an exit. This distance is limited by the code.
2. **Exit**
   The exit is a protected enclosure, where people can escape the building. The structure has a fire resistance rating to provide an exit in case of a fire. The exit travel distance is not limited by the code.
3. **Exit discharge**
   The last part of the means of egress is the exit discharge. It is defined as the distance from an exit to an outside area of safety.

An important factor of means of egress is the occupant load. This number defines the amount of people per room, story and building, which have to escape in case of a fire. The occupant load has influence on the number of exits and the width of exits. For the calculation of the design occupant load see Section 7.4.2.1.2.

7.4.2.7.1 Stairways[207,208]

Generally, stairways are divided in exit stairways and exit access stairways. The difference is that exit stairways are used for an exit, where the travel distance is not limited, whereas exit access stairs have limitations in the travel distance.

Exit access stairways between stories have to be enclosed, except the stairway is for a single dwelling unit in buildings of Group R-2.

In buildings of Group B, where an automatic sprinkler system is installed, the exit access stairway does not have to be enclosed, if the floor opening area is not twice as much as the horizontal projection area of the exit stairway and the opening is equipped with a draft curtain and a closely spaced sprinkler.

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207 Cf. ibid. p. 94

208 Cf. Building Codes Illustrated: A Guide to Understanding the 2012 International Building Code p. 171

The fire resistance rating for buildings with four or more stories is 2 hours and for buildings with less than four stories, 1 hour. Basically, the enclosure should have at least the fire resistance rating of the penetrated floor, but does not have to exceed 2 hours.

Stairways should be built with the same materials, which are permitted for the type of construction.

7.4.2.7.2 Exit Access[209]

As mentioned before, the exit access leads from the most remote point of the building to the door of an exit.

The California building code defines a lot of design requirements, for example that it is not permitted for the exit access parts to lead through kitchens, storerooms, bathrooms or sleeping areas of dwellings. An exception is, however, if a tenant of a dwelling unit has to go through the own kitchen of the dwelling unit to reach a public corridor. The requirements of openings in exit access have to meet the criteria of Section 7.4.2.6.11.

A part of an exit access is the common path of egress travel. A common path of egress travel is the distance between the most remote point in the building and the point where the occupant has to choose between two or more exits. In fact, it is the travel distance the occupant has to walk until more paths to different exits are available.

This distance is limited for the different occupancies.

GROUP	Without sprinkler system		With sprinkler system
	Occupant load		
	≤ 30	> 30	
B	100 ft (30.5 m)	75 ft (22.9 m)	100 ft (30.5 m)
R-2	75 ft (22.9 m)	75 ft (22.9 m)	125 ft (38.1 m)

Table 21: Excerpt of Table 1014.3 – Common path of egress travel[210]

Number of exits and exit access doorways

Table 22 gives an overview of the number of exits based on the occupant load. For buildings of Group R-2 an exception is made, which allows an occupant load of 20, where an automatic sprinkler system is installed.

[209] Cf. California Building Code 2013 p. 394-401
[210] Ibid. p. 394

GROUP	Occupant load			
	1 Exit	2 Exits	3 Exits	4 Exits
B	≤ 49 ≤ 29 (2nd story)	50-500	501-1,000	> 1000
R-2	10	11-500	501-1,000	> 1000

Table 22: Excerpt of Table 1015.1, 1021.1 and 1021.2 – Number of exits based on occupant load[211]

Arrangement of exits and exit access doorway

Two exits should be placed to fulfil the following requirement:

- The diagonal distance from one exit to the other exit should be half of the diagonal distance from the most remote edge points of the building itself.

Except a corridor interconnect the stairways: then the length has to be measured over the corridor travel distance, whereby the corridor has a 1 hour fire resistance rating. The code contains another exception for buildings with an automatic sprinkler system.

Note: the diagonal distance between the edges of the building can go outside too; the distance does not have to proceed inside the building.

Three exits have the same requirements as mentioned for two exits. In addition to the requirements of two exits, the third exit has to be placed in a reasonable distance, so if one exit access is blocked two others will be available.

Exit access travel distance

Basically, it is the distance which has to be walked from the most remote point to an exit door. The measurement has to include unenclosed stairs and ramps.

Table 23 defines the maximum allowable exit access travel distance.

GROUP	Without sprinkler system	With sprinkler system
B	200 ft (61.0 m)	300 ft (91.4 m)
R-2	200 ft (61.0 m)	250 ft (76.2 m)

Table 23: Excerpt Table 1016.2 – Exit access travel distance[212]

[211] Ibid. p. 395,400,401

Corridors[213]

Corridors must have a fire resistance rating in accordance with Table 24.

GROUP	Corridor required for occupant load	Fire resistance rating	
		not sprinklered	sprinklered
B	> 30	1 h	0 h
	≤ 49	0 h	0 h
R-2	> 10	not permitted	0,5 h

Table 24: Excerpt of Table 1015.1 and 1018.1 – Corridor fire resistance rating

Additional, corridors inside dwelling units do not have a fire resistance rating.

The distance for dead ends in buildings of Group B and Group R-2 are limited to

50 ft (15.24 m).

Rooms which interrupt corridors must have at least the same fire resistance as the corridor.

Egress balconies must have a minimum of 50 percentage of the side open to minimize the accumulation of smoke.

7.4.2.7.3 Exit[214]

Table 25 shows additional requirements to Table 2 and Table 22 Table 23 for buildings with one exit.

Story	Occupancy	Sprinkler system required	Maximum number of occupancies or dwelling units	Maximum exit access travel distance
First story or basement	B	no	49 occupants	75 ft (22.9 m)
	B	yes	49 occupants	100 ft (30.5 m)
	R-2 with dwelling units	yes	4 dwelling units	125 ft (38.1 m)
	R-2 with sleeping units	yes	10 occupants	75 ft (22.9 m)
Second story	B		29 occupants	100 ft (30.5 m)
	R-2 with dwelling units	yes	4 dwelling units	125 ft (38.1 m)
Third story	B - not permitted	-	-	-
	R-2 with dwelling units	yes	4 dwelling units	125 ft (38.1 m)

Table 25: Excerpt of Table 1021.2 – Stories with one exit[215]

[212] Ibid. p. 396

[213] Cf. ibid. p. 395,397, 398

[214] Cf. ibid. p. 399-402

[215] Ibid. p. 401

For the basic requirements of stairways, see Section 7.4.2.7.1. Ramps have the same requirements as stairways. For the minimum required number of exits see Section 7.4.2.7.2.

Exterior exit stairways[216]

Exterior exit stairways must have an open side at each level with an area of at least 35 sf (3.3 m²) and have to be located at a height 42 in. (1.067 m) measured from the walking surface.

Exterior stairways should be separated from the interior of the building, except:

- buildings of Group R-2 with not more than 2 stories in height and where the exit discharge is located on the first story or
- where an egress balcony connects two exterior stairways or ramps and meeting the requirements of Section 7.4.2.7.2 for corridors or
- the stairways or ramps are unenclosed or
- the stairways or ramps are connected to an open-ended corridor, where stairways and ramps should be located at each edge of the open-ended corridor and are equipped with an automatic sprinkler system.

7.4.2.7.4 Exit discharge[217]

The last part of the means of egress is the exit discharge. It is basically at the grade or leads to the grade and provides access to a safe zone, which are generally streets or other public ways. If this is not possible an area of 5 sf (0.46 m²) per person with a separation distance of 50 ft (15.24 m) to the building has to be provided. The exit discharge is not allowed to run back into the building and can lead over an egress court.

[216] Cf. ibid. p. 405,406

[217] Cf. ibid. p. 406,407

7.4.2.8 Fire fighting water[218]

The minimum fire-flow for fire-fighting is defined in Table 26.

FIRE-FLOW CALCULATION AREA (square feet)					FIRE-FLOW (gallons per minute)[c]	FLOW DURATION (hours)
Type IA and IB[b]	Type IIA and IIIA[b]	Type IV and V-A[b]	Type IIB and IIIB[b]	Type V-B[b]		
0-22,700	0-12,700	0-8,200	0-5,900	0-3,600	1,500	2
22,701-30,200	12,701-17,000	8,201-10,900	5,901-7,900	3,601-4,800	1,750	
30,201-38,700	17,001-21,800	10,901-12,900	7,901-9,800	4,801-6,200	2,000	
38,701-48,300	21,801-24,200	12,901-17,400	9,801-12,600	6,201-7,700	2,250	
48,301-59,000	24,201-33,200	17,401-21,300	12,601-15,400	7,701-9,400	2,500	
59,001-70,900	33,201-39,700	21,301-25,500	15,401-18,400	9,401-11,300	2,750	
70,901-83,700	39,701-47,100	25,501-30,100	18,401-21,800	11,301-13,400	3,000	3
83,701-97,700	47,101-54,900	30,101-35,200	21,801-25,900	13,401-15,600	3,250	
97,701-112,700	54,901-63,400	35,201-40,600	25,901-29,300	15,601-18,000	3,500	
112,701-128,700	63,401-72,400	40,601-46,400	29,301-33,500	18,001-20,600	3,750	
128,701-145,900	72,401-82,100	46,401-52,500	33,501-37,900	20,601-23,300	4,000	4
145,901-164,200	82,101-92,400	52,501-59,100	37,901-42,700	23,301-26,300	4,250	
164,201-183,400	92,401-103,100	59,101-66,000	42,701-47,700	26,301-29,300	4,500	
183,401-203,700	103,101-114,600	66,001-73,300	47,701-53,000	29,301-32,600	4,750	
203,701-225,200	114,601-126,700	73,301-81,100	53,001-58,600	32,601-36,000	5,000	
225,201-247,700	126,701-139,400	81,101-89,200	58,601-65,400	36,001-39,600	5,250	
247,701-271,200	139,401-152,600	89,201-97,700	65,401-70,600	39,601-43,400	5,500	
271,201-295,900	152,601-166,500	97,701-106,500	70,601-77,000	43,401-47,400	5,750	
295,901-Greater	166,501-Greater	106,501-115,800	77,001-83,700	47,401-51,500	6,000	
—	—	115,801-125,500	83,701-90,600	51,501-55,700	6,250	
—	—	125,501-135,500	90,601-97,900	55,701-60,200	6,500	
—	—	135,501-145,800	97,901-106,800	60,201-64,800	6,750	
—	—	145,801-156,700	106,801-113,200	64,801-69,600	7,000	
—	—	156,701-167,900	113,201-121,300	69,601-74,600	7,250	
—	—	167,901-179,400	121,301-129,600	74,601-79,800	7,500	
—	—	179,401-191,400	129,601-138,300	79,801-85,100	7,750	
—	—	191,401-Greater	138,301-Greater	85,101-Greater	8,000	

For SI: 1 square foot = 0.0929 m^2, 1 gallon per minute = 3.785 L/m, 1 pound per square inch = 6.895 kPa.
a. The minimum required fire flow shall be allowed to be reduced by 25 percent for Group R.
b. Types of construction are based on the *California Building Code*.
c. Measured at 20 psi.

Table 26: Table B105.1 – Minimum required fire-flow and flow duration for buildings[219]

The fire flow demand can be reduced up to 75 percent, if an automatic sprinkler system is installed.

[218] Cf. California Fire Code 2013 p. 537
[219] Ibid. p. 538

7.4.2.9 Fire department access[220]

Fire apparatus access roads should be provided at a maximum distance of 150 ft (45.72 m) of portions of the buildings and exteriors walls of the first story.

The distance can be increased, if the building has an automatic sprinkler system installed or roads cannot be made, because of the location, topography and similar conditions.

7.4.2.10 Fire protection concept

Each point should be reviewed to provide a correct fire protection concept, because some requirements may have been changed by different points which are determined later. For more detailed information of technical fire protection, the California Building Code, California Fire Code and referenced standards should be used.

[220] Cf. ibid. p. 88

8 Case-study buildings

The case study should give an overview of the different fire protection concepts of each country. The first case study is made with a fictitious residential building and the second one with a fictitious office building. The comparison is not planned in detail, but involves the basic requirements of fire protection for each building.

8.1 Residential building

8.1.1 Description

Type: Residential building with flat roof

Primary structure: Concrete/ reinforced concrete

Partition wall type: plasterboard stud wall

Height: 4 stories, each 3.40 m = 13.6 m + attic 0.80 m = 14.4 m

Area per story: 1250 m² gross area per floor

Exits: 1 Stairways and one elevator

Specific requirements: composite heat insulation system for exterior walls (20 cm)

Location:

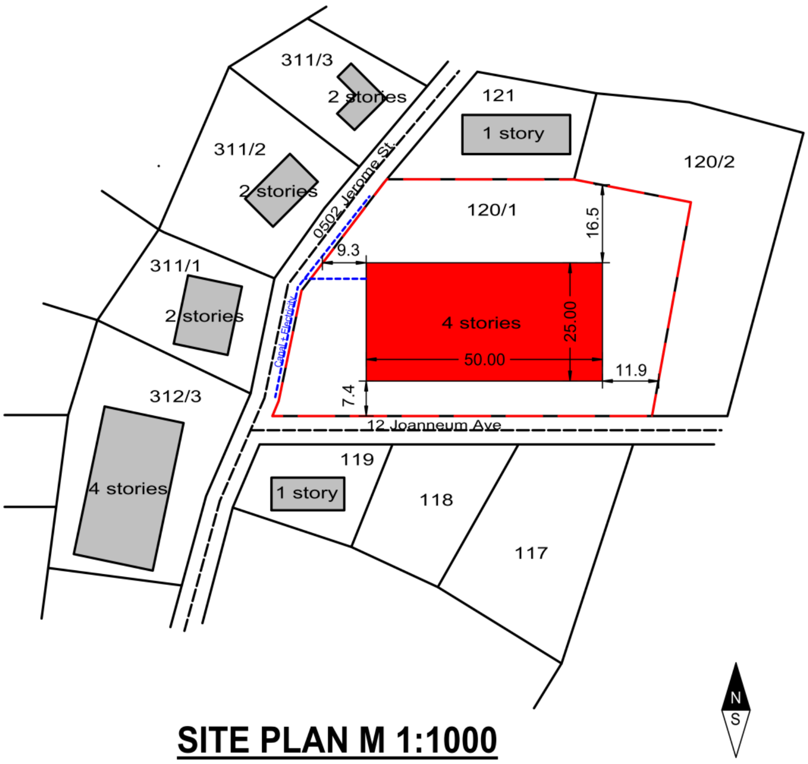

Figure 55: Site plan of the residential building

Note: The building does not have underground stories. Parking spaces are not considered.

8.1.2 Austria – Styria requirements

8.1.2.1 Occupancy classification

The occupancy is a residential building: this definition clarifies the necessary OIB-Guideline, which is basically the OIB-Guideline 2 – “Safety in case of fire”.

The building has 4 stories and the height is 14.4 m. The highest escape level is at a height of 10.2 m.

No dwelling unit or residence exceeds a gross floor area of 400 m².

This means, that the building is classified with building class 4.

8.1.2.2 General requirements and load capacity in case of fire

8.1.2.2.1 Fire behaviour

See column with building class 4 in Table 3.

8.1.2.2.2 Load carrying capacity

See column with building class 4 in Table 4 and Table 6 (only one exit).

8.1.2.3 Spread of fire and smoke inside a building

The limitations for fire sections are:

Maximum net floor are	**unlimited**
Maximum length expansion	**60 m**
Maximum stories aboveground	**unlimited**

Residences have to be separated among themselves with partition walls and partition ceilings with the same fire resistance, as used for corridors. Doors between corridors and residences have to install doors which are classified with EI_2 30. Doors between corridors and stairways must have a door which is classified with E 30-C.

Facades of buildings with building class 4 have to limit the fire spread over the surface. If the composite heat insulation system is thicker than 10 cm, each floor has to provide a fire protection bulkhead out of mineral wool with a height of 20 cm in the ceiling. The mineral wool has to be glued and pegged.

Elevators which interconnect stories must have an inner surface out of A2 materials. The walls and ceilings of the shaft have to build out fire section forming walls or to be more specific, as fire barriers.

Smoke detectors have to be installed in all lounges of a residential building.

8.1.2.4 Spread of fire to other buildings

The Styria construction act, defines that the distance to the plot boundary has to be at least:

d = 4 stories * 1 m + 2 m = 6 metres

As shown in the description the building provides a separation distance of more than 6 metres on all sides. In fact, exterior walls do not have to be built as fire section forming walls. If the fire separation distance between the exterior wall and plot boundary is less than 2 m, a fire section forming wall has to be installed. For exceptions see Section 8.1.2.4.

8.1.2.5 Means of egress

The exit access travel distance is not allowed to be more than 40 m. The number of exits which have to be provided depends on the exit travel distance from the most remote point of the building. The OIB Guideline measures from the entrance of a residence or dwelling unit to the door of an exit. The building provides an exit access travel distance of 40 metres, which means the building must have at least one exit.

Corridor ceilings have to meet the requirements of Table 4, Point 4.4, if they are used for an exit access. Generally, those corridors have to be separated all 40 m and must have doors with E 30-C. A smoke exhaust system has to be installed on top of the stairway with an area of 1 m². The trigger device has to be installed at the following points:

- at the fire brigade level of access
- at the top landing of the stairway with access to the restrooms
- independent of the public mains and a highly sensitive element on the ceiling

8.1.2.6 Firefighting

It is ensured that the most remote point of a fire fighting area to the nearest point of an access to a building is not more than 80 m. Access roads for the fire brigade are provided on the property. The amount of 800 l/min of extinguishing water is sufficient for residential buildings.

8.1.2.7 Layout plan with fire resistance rating

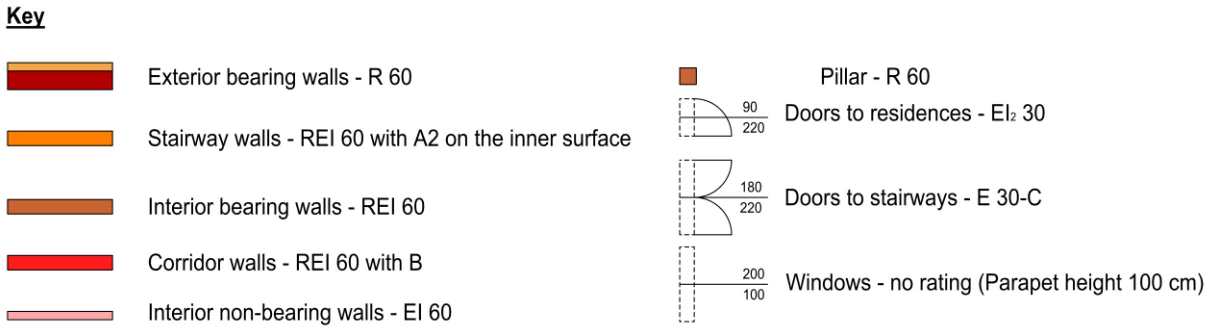

Figure 56: Key for the layout plan of the residential building based on Styrian requirements

Note: Joists are not delineated, but are necessary for the stability of the building. For information about the classification see Section 8.1.2.3. The layout plan is the same for all stories and the room numbers can be changed in every story.

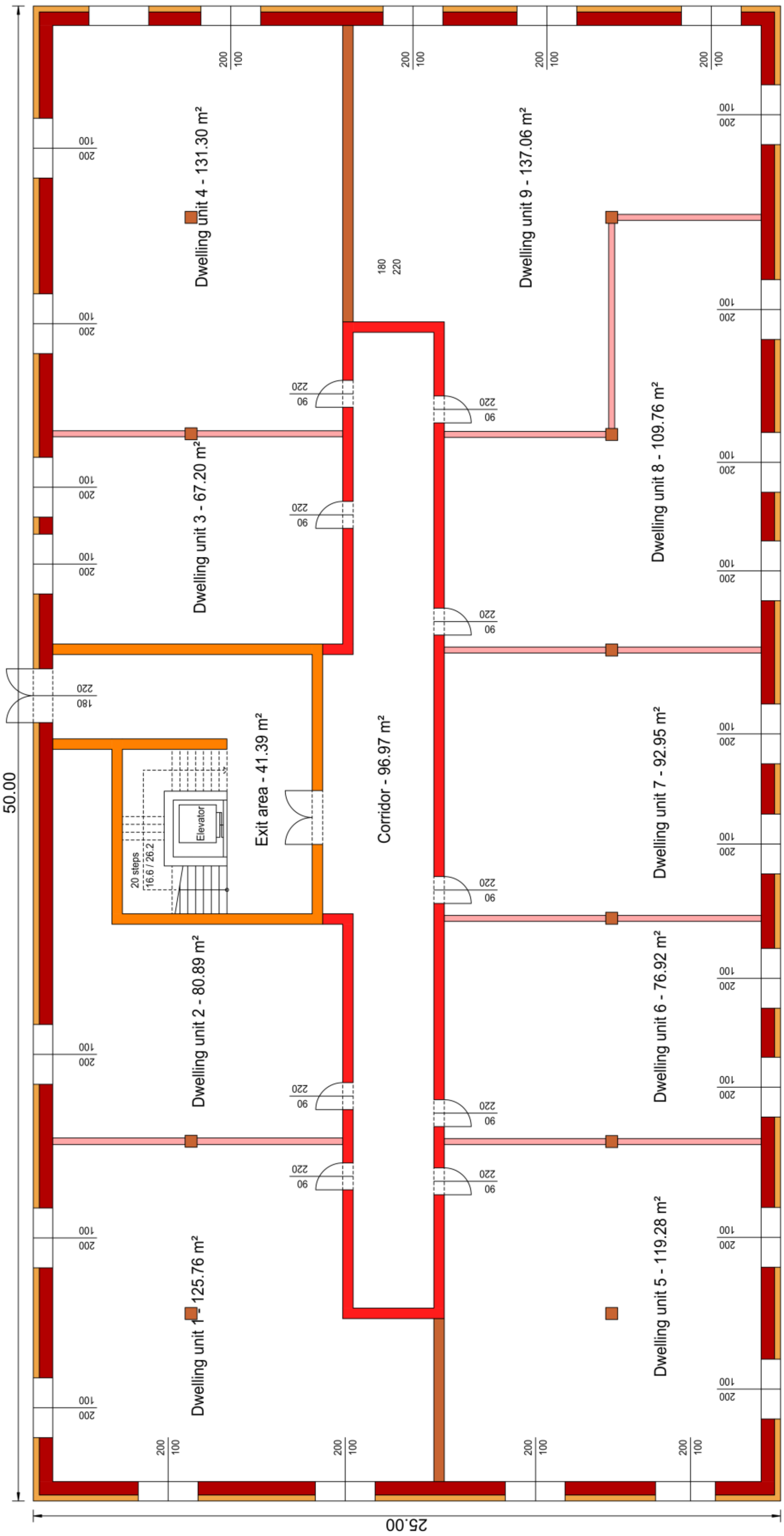

Figure 57: Layout plan – residential building in Styria

8.1.3 United States – California requirements

8.1.3.1 Occupancy classification

It is a residential building with more than two dwellings. The building is classified as an apartment, which means that the **Occupancy** is classified as **Group R-2**.

Floor area

The floor area is 1250 m², which means that all types of constructions are allowed, except Type V constructions. In this case the construction Type III-B is necessary. This type allows a maximal area of 1486 m² and a height of 4 stories with a maximum height of 16.8 m. Nevertheless, Type V-A construction allows an area of 1115 m² and 15.2 m height over a maximum of 3 stories. In fact, one more story and a bigger floor area is needed. This may be allowed over the Section 8.1.3.4, which allows an area modification under certain conditions.

Occupant load

In residential buildings the occupant load factor is 18.58 m² per person. The total area of all dwelling units of the Figure 55 is 942.74 m². This means 75 percentages of 1250 m² are used for dwellings. This divided with the occupant load factor gives 51 occupants per floor.

8.1.3.2 Fire Protection System

Automatic sprinkler system

An automatic NFPA R13 sprinkler system is required for all residential buildings.

Standpipe system

In addition a standpipe system Class III is required, because the building has 4 stories. Nonetheless, a standpipe system class I is allowed, because an automatic sprinkler system is installed.

Fire alarm and detection systems

A manual fire system does not have to be installed, because an automatic sprinkler with water flow alarm is installed.

A smoke alarm should be installed in every sleeping room and in the vicinity of sleeping areas.

8.1.3.3 Type of construction

Basically a Type III construction would be a good choice so far, but with area modifications in Section 8.1.3.4, the Type V-A construction might be admissible.

The fire resistance of each building element is defined in Table 11 and Table 12.

Fire resistance rating of Type V-A:

Primary structural frame	1 h
Bearing walls	
Exterior	1 h
Interior	1 h
Non-bearing exterior walls and partitions	0 h
Non-bearing interior walls and partitions	0 h
Floor construction and associated secondary members	1 h
Roof construction and associated secondary members	1 h

Note: The fire resistance rating can be reduced by one hour if an automatic sprinkler system is used, except the allowable area is modified.

Interior walls and ceiling finishes have to be built with materials, which are classified with Class C. The floor finishes have to be built with materials of Class II.

The roof covering is allowed to be built with Class C materials.

8.1.3.4 Allowable floor area

The fire separation distance is needed to calculate the weighted average W for the frontage increase factor. The value of the width is limited with 9.144 m. All widths with a fire separation distance of more than 9.144 m, count as a width with 9.144 m.

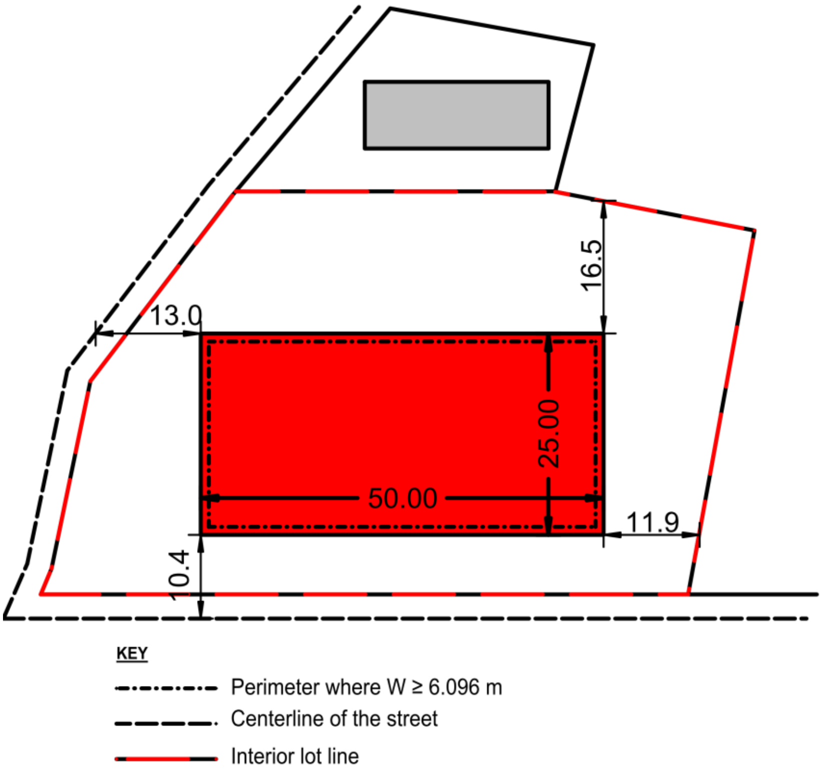

Figure 58: Location on property - site plan residential building

A_f = actual floor area per story →1115 m²

$$W = \frac{(50\ m * 9.144\ m) + (25\ m * 9.144\ m) + (50\ m * 9.144\ m) + (25\ m * 9.144\ m)}{(9.144\ m + 9.144\ m + 9.144\ m + 9.144\ m)}$$

W = 37.5 m

F = 50 m + 25 m +50 m + 25 m = 150 m

P = 50 m + 25 m +50 m + 25 m = 150 m

Note: W/30 cannot exceed 1.0 →37,5 /30 = 1,25 > 1.0 → 1.0

I_f = (150 m / 150 m -0.25) * 1.0 = 0.75

I_s = 2 (because the building has more than one story and an automatic sprinkler system)

A_a = (1115 m² + (1115 m² * 0.75) + (1115 m² * 2)) = <u>4181.3 m²</u> → Allowable Area

8.1.3.5 Height and number of stories

Buildings with an automatic sprinkler system are allowed to increase by 6.096 m and one story in height. Type V-A in Group R-2 have restrictions, whereby a maximum of 4 stories and a height of 18.288 m is allowed.

In this case, the building is allowed to be built in construction Type V-A.

8.1.3.6 Location on property

The exterior walls do not have any projections and Table 17 allows unlimited windows in all exterior walls.

The fire resistance rating of the different wall types:

Fire walls 2 hours

Fire doors 1 ½ hours

Fire walls do not have to extend beyond the surface, because an automatic sprinkler system is installed. Basically, this type of wall is used to separate buildings.

Fire barriers 2 hours

Fire doors 1 ½ hours

Horizontal assemblies 2 hours

Fire barriers and horizontal assemblies are necessary for occupancy separation and for interior exit stairways.

Fire partitions 1 hour

Fire doors $^1/_3$ hour by corridor walls otherwise ¾ hour

Fire partitions are used for separating dwelling and sleeping units and enclosed elevator lobbies. Normally, buildings of Group-2 require a draft stopping, but if an automatic sprinkler system is installed, the draft stops are not necessary.

Smoke barriers 1 hour

Fire doors $^1/_3$ hour

Generally this type of wall is not used in residential buildings.

Smoke partitions 0 hour

Smoke partitions are used for enclosed elevator lobbies in sprinklered buildings.

Horizontal assemblies 1 hour

Horizontal assemblies are necessary to separate dwelling and sleeping units.

Shaft enclosures 2 hours

Fire doors 1 ½ hours

Buildings with 4 or more stories need a fire resistance rating of 2 hours.

The vertical separation of openings in buildings with more than 3 stories has to provide a 0.914 m assembly with a fire resistance rating of 1 hour.

8.1.3.7 Means of egress

The occupant load per floor or story is 54.

Residential buildings with an automatic sprinkler system allow a common path of egress travel of 38.1 m.

If the occupant load per floor or story is between 11 and 500, two exits are necessary. For one exit the occupant load can be increased to 20, if an automatic sprinkler system is installed. Nevertheless, the occupant load is 54 and requires two exits.

The exit access travel distance in residential buildings with a sprinkler system is 76.2 m.

Corridors must have a fire resistance rating of at least ½ hour. In fact the fire resistance of corridors remains at 1 hour.

8.1.3.8 Firefighting water & fire department access

1250 m² (13,454.89 sf) requires a minimum fire flow of 2,250 gallons per minute (gpm) for buildings with a Type V-A construction.

2,250 * 3.785 = 8516.25 litres per minutes (L/min)

This value can be reduced by 75 percents because of the installation of an automatic sprinkler system – 2129.06 L/min.

The fire department access is provided over sufficient roads around the building.

8.1.4 Comparison of the requirements for residential buildings in each country

	Austria - Styria		United States - California	
	Requirements	Notes	Requirements	Notes
1 General information				
1.1 Occupancy	Residential building		Residential building Group R-2	
1.2 Building area	1250 m²		1250 m²	
1.3 Building height	13.6 m 4 stories		13.6 m 4 stories	
2 Load bearing capacity - fire resistance rating				
2.1 Exterior bearing walls, pillars and joists	R 60	concrete allowed	1 h	concrete allowed
2.2 Stairway walls	R 60 and A2	concrete with a classified covering allowed	2 h	concrete with a classified covering allowed
2.2.1 Doors between corridors and stairways	EI_2 - 30		1 1/2 h	
2.3 Interior bearing walls	REI 60	concrete allowed	1 h	concrete allowed
2.4 Corridor walls	REI 60 and B	concrete with a classified covering allowed	1 h	concrete with a classified covering allowed
2.4.1 Doors between corridors and dwelling/sleeping units	E - 30		1/3 h	
2.5 Interior non-bearing walls (separation of dwellings)	EI 60	plasterboard stud wall allowed	1 h	plasterboard stud wall allowed
2.6 Horizontal assemblies (ceiling, floors)	REI 60		1 h	
3 Fire behaviour				
3.1 Cladding/facade	C-d1		combustible	
3.2 Floors, walls and ceilings in corridors and stairways	ND	there are special requirements.	ND	there are special requirements.
3.3 Roof	BROOF (t1)		Class C	
3.4 Composite heat insulation system allowed?	yes		yes	
4 Fire area or fire section - spread of fire and smoke to other buildings				
4.1 Maximum allowable area	unlimited		4181.3 m²	because of an automatic sprinkler system
4.2 Maximum length expansion	60 m		no restriction	
4.3 Maximum number of stories	unlimited	with a fire protection bulkhead out of mineral wool with a height of 20 cm in each ceiling	4	horizontal assembly with a height of 0.914 m and a fire resistance rating of an 1 h
4.4 Maximum number height of building /escape level	ND / 11 m		18.29 m / ND	because of an automatic sprinkler system
4.5 Building classification	Building class 4		Type V-A	only over the area modification
5 Fire protection system				
5.1 Fire sprinkler system required?	no		yes - NFPA 13R Sprinkler with a water flow alarm	required in all types of residential buildings
5.2 Standpipe system required?	no		yes - Class I Standpipe	required, when an automatic sprinkler system is installed
5.3 Smoke detectors required?	yes		yes	
5.4 Smoke exhaust system required?	yes	at the top of the stairway	no	
5.5 Smoke and heat extraction/exhaust system required?	no		no	
5.6 Fire separation distance to lot line (minimum without a party wall)	0 m	under 2 m a fire section forming wall has to be used. The normal distance is managed by other codes	0 m	under a certain distance fire barrier has to be used. The normal distance is managed by other codes
5.7 Manual fire system	ND		no	
6 Means of egress				
6.1 Exit access travel distance	40 m		76.2 m	because of an automatic sprinkler system
6.2 Number of exits (stairways)	1		2	depending on the occupant load
7 Firefighting				
7.1 Extinguishing water	800 l/min		2129.06 l/min	75 % reduction because of an automatic sprinkler system

Table 27: Comparison of the residential building

Note: ND stands for not defined and for the classifications see Section 6.3 and 6.4.

Table 27 gives an overview of the different requirements of each country or federal state. There are big differences at the maximum area and story, which is a result of the new OIB guideline 2. The guideline gives more clearances in case of design, which is accomplished over the unlimited area and stories.

Furthermore, residential buildings in California require an automatic sprinkler system and a standpipe system, which will certainly reflect in the cost of the building. An automatic sprinkler system also allows a longer exit access travel distance. The number of exits is different, because they are based on different factors. In Austria the factor is the exit access travel distance which is limited to 40 m and if it exceeds the 40 metres another exit has to be provided, that the 40 m can be adhered. In the United States, the number of exits depends on the occupant load.

Relating to the materials which can be used, it depends on the restrictions in fire behaviour, but it is important to say that the residential building can be built with all kinds of combustible materials, which are defined in the California building code.

8.2 Office building

8.2.1 Description

Type: Residential building with flat roof

Primary structure: Concrete/ reinforced concrete

Partition wall type: plasterboard stud wall

Height: 4 stories, each 3.40 m = 13.6 m + attic 0.80 m = 14.4 m

Area per story: 1250 m² gross area per floor

Exits: 1 Stairways and one elevator

Specific requirements: composite heat insulation system for exterior walls (20 cm)

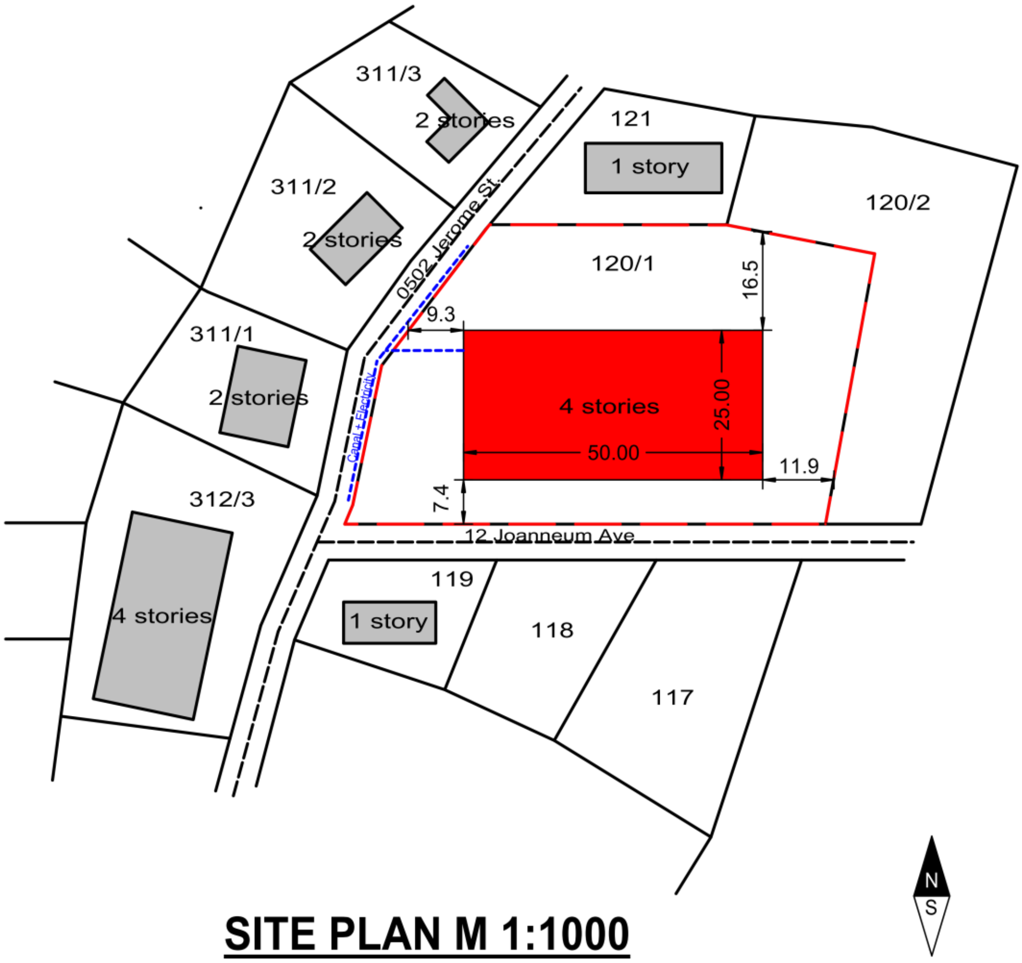

Figure 59: Site plan of the office building

Note: The building does not have underground stories. Parking spaces are not considered.

8.2.2 Austria – Styria requirements

8.2.2.1 Occupancy classification

The occupancy is an office building. This definition clarifies the necessary OIB-Guideline, which is basically the OIB-Guideline 2 – “Safety in case of fire”.

The building has 4 stories and the height is 14.4 m. The escape level is at a height of 10.2 m.

No operating unit exceeds a gross floor area of 400 m².

This means, that the building is classified with building class 4.

8.2.2.2 General requirements and load capacity in case of fire

8.2.2.2.1 Fire behaviour

See column with building class 4 in Table 3

8.2.2.2.2 Load carrying capacity

See column with building class 4 in Table 4 and Table 6 (only one exit).

8.2.2.3 Spread of fire and smoke inside a building

The limitations for fire sections are:

Maximum net floor are	**1600 m²**
Maximum length expansion	**60 m**
Maximum stories aboveground	**4**

Operating units with office use do not have to be separated among themselves with partition walls and partition ceilings. The maximum allowable fire unit can be seen as one operating unit. This means doors and non bearing interior walls must not have a fire resistance rating. Doors between corridors and stairways have at least a door classified with E 30-C. Facades of buildings of building class 4 have to limit the fire spread over the surface. If the composite heat insulation system is thicker than 10 cm, each floor has to provide a fire protection bulkhead out of mineral wool with a height of 20 cm in the ceiling. The mineral wool has to be glued and pegged. Elevators, which interconnect stories, must have an inner surface out of A2 materials. The walls and ceilings of the shaft have to be built out of fire section forming walls or to be more specific, fire barriers.

8.2.2.4 Spread of fire to other buildings

The Styria construction act, defines that the distance to the plot boundary has to be at least:

d = 4 stories * 1 m + 2 m = 6 metres

As shown in the description the building provides a separation distance of more than 6 metres on all sides. In fact, the exterior walls do not have to be built as a fire section forming wall. If the fire separation distance between the exterior wall and plot boundary is below 2 m, a fire section forming wall has to be installed. For exceptions see Section 8.1.2.4.

8.2.2.5 Means of egress

The exit access travel distance is not allowed to be more than 40 m. The number of exits, which have to be provided, depends on the exit travel distance from the most remote point of the building. The OIB Guideline measures from the entrance of a residence or dwelling unit to the door of an exit. The building provides an exit access travel distance of 40 metres- this means the buildings must have at least one exit.

Corridor ceilings have to meet the requirements of Table 4, Point 4.4, if they are used for an exit access. Generally, those corridors have to be separated every 40 m and have doors with E 30-C. A smoke exhaust system has to be installed at the top of the stairway with an area of 1 m². The trigger device has to be installed at the following points:

- at the fire brigade level of access
- at the top landing of the stairway with access to the restrooms
- independent of the public mains and a highly sensitive element on the ceiling

8.2.2.6 Firefighting

It is ensured that the most remote point of a fire fighting area to the nearest point of an access to a building is not more than 80 m. Access roads for the fire brigade are provided on the property. The amount of 800 l/min of extinguishing water is sufficient for residential buildings.

8.2.2.7 Layout plan with fire resistance rating

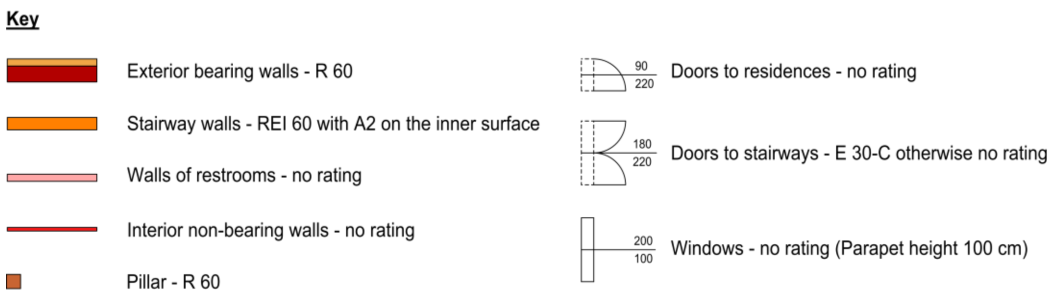

Figure 60: Key for the layout plan of the office building based on Styrian requirements

Note: Joists are not delineated, but are necessary for the stability of the building. The walls and doors between the offices are plasterboard stud walls with no fire resistance rating. See Section 8.1.2.3. The layout plan is the same for all stories and the room numbers can be changed in every story.

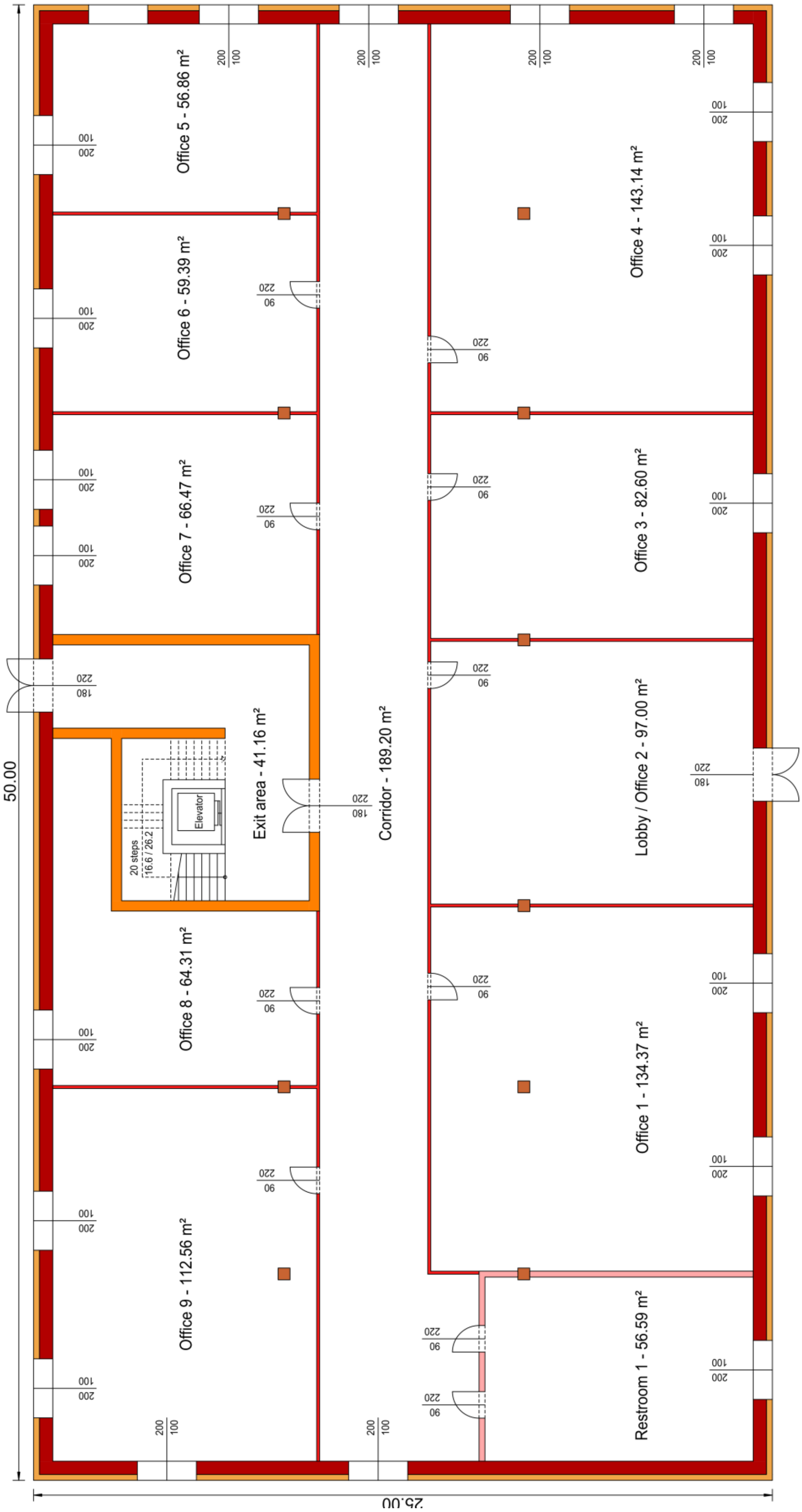

Figure 61: Layout plan – office building in Styria

8.2.3 United States – California requirements

8.2.3.1 Occupancy classification

Office buildings are classified as business buildings. Therefore, the **Occupancy** is classified as **Group B**.

Floor area

The floor area is 1250 m², which means that all types of constructions are allowed except for Type V constructions. In this case the construction Type III-A is necessary. This type allows a maximal area of 1765 m² and a height of 5 stories with a maximum height of 19.8 m. Nevertheless, Type V-A construction allows an area of 1672 m² and 15.2 m height over a maximum of 3 stories. In fact, one more story is needed. This may be allowed by the Section 8.2.3.4, which allows an area modification under certain conditions. In this case an automatic sprinkler system can be installed, but this might not be economical and because of that the Type V-A construction is used for this building.

Occupant load

In residential buildings the occupant load factor is 9.29 m² per person. The total area of all dwelling units of the Figure 61 is 816.7 m². This means 65 percents of 1250 m² are used for offices - divided with the occupant load factor equals 88 occupants per floor.

8.2.3.2 Fire Protection System

Automatic sprinkler system

Not required, except bigger gross area and a story is needed.

Standpipe system

The building has more than 3 stories, which is why a stand pipe of Class III is required.

Fire alarm and detection systems

A manual fire system is not required.

8.2.3.3 Type of construction

The fire resistance of each building element is defined in Table 11 and Table 12.

Fire resistance rating of Type III-A:

Primary structural frame	1 h
Bearing walls	
Exterior	2 h
Interior	1 h
Non-bearing exterior walls and partitions	0 h
Non-bearing interior walls and partitions	0 h
Floor construction and associated secondary members	1 h
Roof construction and associated secondary members	1 h

Note: The fire resistance rating can be reduced by one hour if an automatic sprinkler system is used, except the allowable area is modified.

Interior exit stairways finishes have to be out of materials, which are classified with Class A. Corridors need a finish material with Class B and rooms and other spaces need Class C materials.

The floor finishes have to be built with materials of Class II.

The roof covering is allowed to be built with Class C

8.2.3.4 Allowable floor area

The fire separation distance is needed to calculate the weighted average W for the frontage increase factor. The value of the width is limited with 9.144 m. All widths with a fire separation distance of more than 9.144 m, count as a width with 9.144 m.

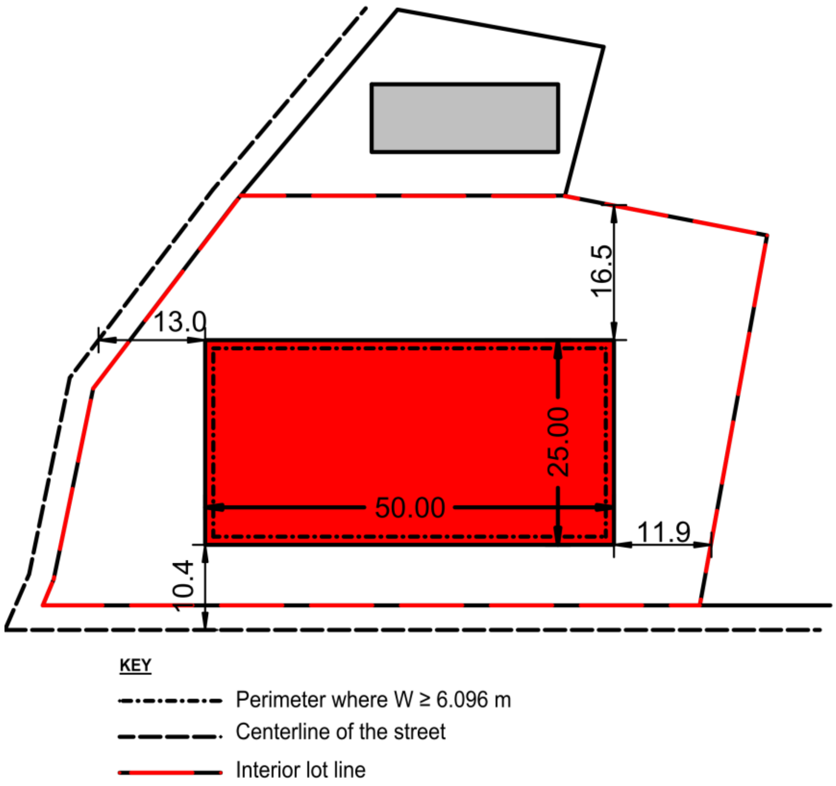

Figure 62: Location on property - site plan office building

A_f = actual floor area per story → 1765 m²

$$W = \frac{(50\,m * 9.144\,m) + (25\,m * 9.144\,m) + (50\,m * 9.144\,m) + (25\,m * 9.144\,m)}{(9.144\,m + 9.144\,m + 9.144\,m + 9.144\,m)}$$

W = 37.5 m

F = 50 m + 25 m +50 m + 25 m = 150 m

P = 50 m + 25 m +50 m + 25 m = 150 m

Note: W/30 cannot exceed 1.0 → 37,5 /30 = 1,25 > 1.0 → 1.0

I_f = (150 m / 150 m -0.25) * 1.0 = 0.75

I_s = 0 (because an automatic sprinkler system is not installed)

A_a = (1765 m² + (1765 m² * 0.75) + (1765 m² * 0)) = <u>3088.75 m²</u> → Allowable Area

8.2.3.5 Height and number of stories

The building has not installed an automatic sprinkler system, which is why a rise in building height or number of stories is not permitted.

8.2.3.6 Location on property

The exterior walls do not have any projections and Table 17 allows unlimited windows in all exterior walls.

The fire resistance rating of the different wall types:

Fire walls	3 hours
Fire doors	3 hours

Fire walls do not have to extend beyond the surface, because an automatic sprinkler system is installed. Basically, this type of wall is used to separate buildings.

Fire barriers	2 hours
Fire doors	1 ½ hours
Horizontal assemblies	2 hours

Fire barriers and horizontal assemblies are necessary for occupancy separation and for interior exit stairways.

Fire partitions	1 hour
Fire doors	$^{1}/_{3}$ hour by corridor walls otherwise ¾ hour

Fire partitions are used for enclosed elevator lobbies.

Smoke barriers	1 hour
Fire doors	$^{1}/_{3}$ hour

Generally this type of wall is not used in residential buildings.

Smoke partitions	0 hour

Smoke partitions are used for elevator lobbies in sprinkled buildings.

Horizontal assemblies	1 hour

Horizontal assemblies are necessary to separate dwelling and sleeping units.

Shaft enclosures	2 hours
Fire doors	1 ½ hours

Buildings with 4 or more stories need a fire resistance rating of 2 hours.

The vertical separation of openings in buildings with more than 3 stories has to provide a 0.914 m assembly with a fire resistance rating of 1 hour.

8.2.3.7 Means of egress

The occupant load per floor or story is 88.

Office buildings without an automatic sprinkler system allow a common path of egress travel of 22.9 m.

If the occupant load per floor or story is between 49 and 500, two exits are necessary.

The exit access travel distance in office buildings without a sprinkler system is 61.0 m.

Corridors must have a fire resistance rating of at least 1 hour. In fact the fire resistance of corridors remains by 1 hour.

8.2.3.8 Firefighting water & fire department access

1250 m² (13,454.89 sf) requires a minimum fire flow of 2,250 gallons per minute (gpm) for buildings with a Type III-A construction.

1,750 * 3.785 = 6623.75 litres per minutes (L/min) divided by the area 1250 m² =

= 5.3 L/(m²*min)

The fire department access is provided over sufficient roads around the building.

8.2.4 Comparison of the requirements for office buildings in each country

	Austria - Styria		United States - California	
	Requirements	Notes	Requirements	Notes
1 General information				
1.1 Occupancy	Office building		Office building Group B	
1.2 Building area	1250 m²		1250 m²	
1.3 Building height	14.4 m 4 stories		14.4 m 4 stories	
2 Load bearing capacity - fire resistance rating				
2.1 Exterior bearing walls, pillars and joists	R 60	concrete allowed	1 h	concrete allowed
2.2 Stairway walls	R 60 and A2	concrete with a classified covering allowed	2 h	concrete with a classified covering allowed
2.2.1 Doors between corridors and stairways	EI_2 - 30		1 1/2 h	
2.3 Interior bearing walls	REI 60	concrete allowed	1 h	concrete allowed
2.4 Corridor walls	no restriction	plasterboard stud wall allowed; no restriction because of office use - seen as one operating unit	1 h	concrete with a classified covering allowed
2.4.1 Doors between corridors and operating units	no restriction		1/3 h	
2.5 Interior non-bearing walls (separation of operating units)	no restriction	plasterboard stud wall allowed; no restriction because of office use - seen as one operating unit	0 h	plasterboard stud wall allowed
2.6 Horizontal assemblies (ceiling, floors)	REI 60		1 h	
3 Fire behaviour				
3.1 Cladding/facade	C-d1		non-combustible or ignition resistant	with a fire resistance gypsum sheathing is behind the exterior covering
3.2 Floors, walls and ceilings in corridors and stairways	ND	There are special requirements.	ND	There are special requirements.
3.3 Roof	BROOF (t1)		Class C	
3.4 Composite heat insulation system allowed?	yes		yes	if a fire resistance gypsum sheathing is behind the exterior covering and horizontal assembly
4 Fire area or fire section - spread of fire and smoke to other buildings				
4.1 Maximum allowable area	1600 m²		3088.8 m²	
4.2 Maximum length expansion	60 m		no restriction	
4.3 Maximum number of stories	4	with a fire protection bulkhead out of mineral wool with a height of 20 cm in each ceiling	5	horizontal assembly with a height of 0.914 m and a fire resistance rating of an 1 h
4.4 Maximum number height of building /escape level	ND / 11 m		19.8 m / ND	
4.5 Building classification	Building class 4		Type III-A	
5 Fire protection system				
5.1 Fire sprinkler system required?	no		no	
5.2 Standpipe system required?	no		yes - Class III Standpipe	
5.3 Smoke detectors required?	no		no	
5.4 Smoke exhaust system required?	yes		no	
5.5 Smoke and heat extraction/exhaust system required?	no		no	
5.6 Fire separation distance to lot line (minimum without a party wall)	0 m	under 2 m a fire section forming wall has to be used. The normal distance is managed by other codes	0 m	under a certain distance fire barrier has to be used. The normal distance is managed by other codes
5.7 Manual fire system	ND		no	
6 Means of egress				
6.1 Exit access travel distance	40 m		61.0 m	because of an automatic sprinkler system
6.2 Number of exits (stairways)	1		2	depending on the occupant load
7 Firefighting				
7.1 Extinguishing water	1 l/(m²*min)		5.3 l/(m²*min)	75 % reduction because of an automatic sprinkler system

Table 28: Comparison of the office building

Note: ND stands for not defined and for the classifications see Section 6.3 and 6.4.

Table 28 shows that there are not that many differences. Nonetheless, the requirements in California are stricter, but also allow bigger buildings. As shown, a standpipe system is necessary. This is typical for buildings with a certain height in California, whereas in Austria standpipes are necessary for buildings with six or more stories.

The OIB guideline permits that operating units with an office use can be seen as one operating unit with the maximum allowable area of a fire section. This is a big advantage for the fire resistance of the non-bearing interior walls. A point, where the countries diverge is the extinguishing water, which might be a result of the influence of historical differences in the countries.

9 Conclusion

The aim of the thesis was to compare the different fire protection concepts of each country or federal state and to find points where the countries might be able to improve their concepts.

It is to say, that the countries have different histories concerning the development of fire protection. This might be the cause of conceptual differences in many cases.

During the 20^{th} century the Austrian development in fire protection progressed slowly because of the Second World War, whereas in the United States more and more insurance companies emerged. The insurances companies realized that big losses in case of fire were made. That is why they wanted to improve the fire prevention codes and guidelines. In fact an extensive amount of the Austrian knowledge regarding fire protection comes from the United States.

Nevertheless, each country has established its own codes, guidelines and standards.

To begin with the structural types, the differences are big: In the United States there are a lot of buildings which are built over balloon and platforming framing, whereas in Austria solid constructions are more common. A crucial factor in Austria is definitely the durability of buildings, in contrast to the fact that most of the Americans appreciate the flexibility. Austria has the mentality that houses should be built for more generations. Another point is that the costs of a wood framing building in the United States are much lower than a solid construction. Tornados are also very common in the United States and it is not guaranteed that a solid construction can resist such natural phenomena.

In fact, each country has different conditions and a different mentality, which also defines different requirements relating to the construction of a building.

However, the fire protection concepts and the classifications do not always differ. The classification of fire behaviour in the United States is very similar compared to Austria. In Austria there are classifications from A to E, while the United States differentiate between non-combustible and combustible and split combustible in three classes.

The fire resistance rating is very similar, except that the United States do not use the abbreviations REI. In the United States the fire resistance rating is defined by a time within the structural integrity and/or heat-transfer resistance has to be maintained. In addition, load bearing building elements have to be stable in case of a fire.

In short, the fire resistance rating is the same but is not as precisely defined, as in Austria.

The next notable difference is the structure of legal regulations and technical specifications of the countries. The system of the United States resembles the old system of Austria, when the legal regulations and the guidelines were in one document.

Nonetheless, a major difference cannot be recognized. The California Building Code and the Construction Act of Styria define the level of protection over life safety. Austria ensures this through the level of protection by the Construction Act and the OIB Guidelines, whereas California provides this through the different codes. To sum up, the countries do not establish the requirements of the documents by law, which gives the flexibility to build things differently, if the level of protection is obtained.

Before comparing the documents, it is to say that the codes differ relating to the degree of how detailed information is provided.

The OIB Guidelines are being kept more general, whereas the California Codes define everything in detail and often reference standards. That is one point why it is complex to define a fire protection concept in the United States. Furthermore, the classifications and requirements of walls, ceilings, openings and other building elements are often not that clearly defined and refer to different sections in the codes or to different documents.

Additional, the concept has to be defined and reviewed to be taken into consideration for changes. On the contrary, the Austrian OIB Guidelines make it possible to define the most important parts for building with consideration of a view pages.

In my opinion the California Building Code is very detailed and the complexity makes it hard to understand and compare it. I have noticed that there are a lot of exceptions, especially if an automatic sprinkler system is installed. Thereby, the area and height of a building can be extremely increased. Another point is that every kind of residential building has to install an automatic sprinkler system.

To summarize, it is difficult to define which requirements should be taken over from one code to the other. Nevertheless, the different fire protection concepts have their advantages and disadvantages. In my opinion, a sprinkler system should not be required in all kinds of residential buildings, because the Austrian fire protection concept also provides a sufficient level of protection without an automatic sprinkler system. Nonetheless, the main point is that all of these fire protection concepts provide a sufficient level of life safety. This can be accomplished through the California Building Code, as well as through the OIB Guidelines.

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List of figures

List of tables