Developing the Structure of a Fire Risk Index Method for Timber-frame Multi-storey Apartment Buildings

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Abstract
The Fire Risk Index Method is a tool for assessing fire safety in multi-storey apartment buildings. This report contains a description of how Version 1.2 of the Fire Risk Index Method was developed. The terminology frequently used in the development process of the method is also explained.

The use of the Fire Risk Index Method is described and illustrated by an example. The method is applied to an existing timber-frame building and the results are compared to a corresponding concrete building.

Other existing risk assessment methods are briefly described and evaluated in the report.

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1 Introduction

1.1 General background

During the last years the trend in a great part of the world has been to introduce performance-based building regulations instead of the detailed regulations used earlier. The new regulations, based on functional requirements, have also been accepted in the Nordic countries. The new possibilities have opened the way for new design solutions, e.g. new applications for timber-structures. (Like many other researchers König has given his thoughts of this new situation [1].)

From a fire safety point of view a wider use of timber-structures is of course of considerable interest. It is, however, necessary to verify that the fire safety, with respect to both life safety and property protection, is as high in timber-frame buildings as in other types of buildings. To allow a comparison it has been observed that there is a need of developing new fire risk assessment techniques. Such a technique has to answer questions from the society on the fire safety in a building. It has to be possible to compare the level of safety in a specific building to other buildings and to an acceptable risk. The level of fire safety in a building depends on a great number of factors and there is a need of systemizing the way of identifying, analyzing and evaluating these.

As a result of these needs a fire risk index method has been developed for multi-storey apartment buildings. The purpose of this report is to present the method and to describe how it was developed.

1.2 Background on the Nordic Wood project

For short, Nordic Wood is a research- and development program initiated by the Nordic Industrial Fund and financed by the Nordic wood industry. The main aim of the program, since it started in 1993, has been to consolidate the position of wood as a construction material, especially in multi-storey buildings.

The second phase of a project named “Fire-safe Wooden Houses” has been running since 1997. (The first phase was finished in 1996 [2]). The project was originally planned to be finished in June 2000. “Fire-safe Wooden Houses” runs parallel with another Nordic Wood project named “Multi-storey Wooden Houses” (coordinated by Lund University in Sweden).

“Fire-safe Wooden Houses” focuses on the fire safety problems, which always have been connected to timber-frame buildings. For a long period of time wood-structures and wood-facades have not been used in multi-storey buildings, at least not in the Nordic countries. The main reason has of course been the bad experiences from fires in these types of buildings over the years. Today the knowledge is, however, much better about wood as a construction material. The weak parts of a timber-frame building are rather well known and the experts now know how to compensate for these deficiencies. Birgit Östman, Trätek, who also coordinates the project and leads the steering group, has summarized the present knowledge in the field of fire safety design of timber-frame buildings [3]. The knowledge of today should make it possible to build timber-constructions at least as safe as non-combustible buildings.

The purpose of the project (according to Östman [4]) has been to develop wood as a construction material. For achieving this, the behavior of timber-constructions (i.e. different combinations of timber-frames, insulation and linings), when exposed to a fire, have to be made more predictable.

The project "Fire-safe Wooden Houses" is divided into three main areas [4]:
1. "Strategic Knowledge"
2. "Technical Knowledge and Methods"
3. "Development of Products and Systems"

"Risk Evaluation" is a sub-project to "Strategic Knowledge". As mentioned above, the need for new and better fire risk assessment methods has been evident for quite a long time. The development of new methods will in the end hopefully make it possible to verify that the fire safety generally may be as high in timber-frame buildings as in non-combustible buildings.

As a result of these obvious needs Lund University in Sweden and VTT in Finland have been applying modern methods for fire risk evaluation of multi-storey apartment buildings. The aim was to be able to compare the level of safety/risk in different types of buildings, both to each other and to an acceptable level. The Swedish and the Finnish projects have been interdependent and they both have been paying regard to received results and drawn conclusions in other projects included in the Nordic Wood project. VTT had the objective of calculating life safety using quantitative risk simulation methods. Lund University had the objective of producing a practical semi-quantitative index method. This report will describe the development and the design of the latter method.

1.3 Background on MADM and Delphi

When following the development process of the Fire Risk Index Method in this report it is important to be familiar with some of the terminology frequently used. In the following chapters terms like "MADM" and especially "Delphi" will be used. They are both examples of techniques developed in order to help decision makers to structure, to quantify and to evaluate a problem. It is therefore appropriate to give a brief explanation to these two terms here in the introduction-chapter.

As mentioned above the level of fire safety/risk for an object depends on many different factors, sometimes called components, but in this report they will be referred to as attributes. It is not difficult to find situations when there is a problem of trying to find the best alternative, i.e. to find the best combination of different attributes. Over the years a great number of techniques have been developed in order to help the decision maker to make the best choice among different alternatives. Often the term "Multi Attribute Decision Making (MADM) methods" is used as a uniting name for these techniques. Yoon and Hwang [5] define MADM as "making preference decisions (e.g., evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes". The fields of application for MADM-methods are very wide thanks to the varying grade of accuracy needed. When applying MADM to fire safety just a few of the methods are of practical use.

The use of multiattribute evaluation in fire safety has been described by Watts [6]. He suggests a general five-step process when constructing a multiattribute model.

Step 1: Identify the set of attributes that characterize fire safety in the group of buildings to be evaluated.
First of all the attributes have to be identified. We have to ask ourselves what factors influence the fire safety in the specific type of object.
Step 2: Develop an importance weight for each attribute.
Step 3: Develop methods for assigning values to each attribute for each building.
In step 2 and 3 an importance weight for each attribute and methods for assigning values to the attributes are developed. The weights are always the same for a specific group of buildings (hospitals, apartment buildings etc.) while the values are unique for each building.
There exist a lot of different techniques designed for producing weights and values to the attributes. Some of these techniques are explained in the following chapters (Delphi, AHP, decision tables etc.).
Step 4: Select an evaluation model.
How do we combine weights and values for each attribute and how do we combine the different attributes?
Step 5: Validate and calibrate the evaluation procedure.
According to Watts a sufficient amount of data has to be collected to support the validity. (Validity indicates the procedure measures what it was designed to measure.) If the evaluation includes a norm or acceptable level, then the procedure must also be calibrated.

Different fire risk assessment models have been developed over the years more or less based on Watts' five-step process. The most commonly used models are discussed in the next chapter.

The best way of getting reliable results in a constructing process is, among many experts, considered to be to use the so-called "Delphi technique", especially when there are little data or statistics available. The technique, very well described and evaluated by Shields [7], has been successfully used in many different fields of application. For short, a panel, consisting of a great number of varying kinds of experts, is chosen to give its opinion on different questions and problems. The project manager, who collects the answers, has to repeat the question rounds until consensus has been reached in every single question. The Delphi technique is considered to be especially efficient in the weighting process described above (Step 2 in Watts' five-step process). To develop attribute weights is maybe the most difficult step of the construction procedure because it is characterized by subjective estimates, which often differ depending on who is asked. To involve only a few decision makers in this step is therefore not a desirable solution. The many different expert opinions to which the technique pays regard and the consensus, which hopefully will be reached between them in the end, have made the Delphi technique widely used and accepted. Further description of the Delphi technique is to be found in Chapter 4.

1.4 Overview of this thesis

This report summarizes some of the work carried out in the project “Risk Evaluation”, a sub-project to the Nordic Wood project “Fire-safe Wooden Houses” (see Section 1.2). The project, led by Lund University in Sweden, had the objective of producing a simple risk index method possible to apply to both combustible and non-combustible buildings.

In the second chapter different types of existing fire risk assessment methods are described. The most appropriate approach has then been applied to multi-storey apartment buildings. The development of such a risk index method is described in Chapter 3 (the first part of the process) and in Chapter 4 (the later part of the process). In the project a decision method called the Delphi technique has been used. The Delphi technique and the decision procedure are extensively described in the fourth chapter.

The last version of the Fire Risk Index Method, applicable to multi-storey apartment buildings, is presented extensively in Chapter 5 and in Appendix A. The use of the method is described and also illustrated by an example in Chapter 6. The method is there applied to an existing timber-frame building and the results are compared to a corresponding, non-existing concrete building.

The final chapter, Chapter 7, contains a short summary of the results, conclusions and proposed work for the future.

2 General on fire risk assessment methods

2.1 Background

In the first chapter the need for a fire risk assessment method applicable to multi-storey buildings was established. At this attempt of producing a method an early decision was made to confine ourselves to apartment buildings. However, the desire was to choose a method or technique that may be applicable to other types of multi-storey buildings as well.

Earlier attempts of producing a fire risk assessment method tell us that the first phase often may be characterized as a phase dominated by confusion. The goals are usually indistinct at this early stage. To remedy this, it is necessary for the producers of the method to early face themselves with a number of questions. In this specific approach Sven Erik Magnusson (Lund University, Sweden) and Tomas Rantatalo (Boverket, Sweden) carried out the first steps. In the pilot study [8] they started by asking a number of questions. The following questions were asked in order to make it easier to lay down the general outlines for the development process and to put the efforts on the relevant problems:

- Is there a need to put efforts in a risk analysis when constructing a multi-storey wood-framed dwelling building? (cost benefits, safety benefits)
- What level and type of risk analysis is needed? (quantitative, qualitative, checklist, Delphi analysis)
- What information do we get from different kinds of risk analysis?
- What information do we need as an engineer?
- Is there enough information and statistics about fires in buildings so that the risk analysis can properly identify and quantify the risk? (judgement, statistics, experience)
- Can we identify the level of safety? (individual, social)

Some of the questions could rather easily be answered once the goals had been clearly formulated. In this approach the objectives of the method are rather well defined. Most of all the method has to be simple and applicable to different types of multi-storey apartment buildings. It has to be possible to compare the level of fire safety in a specific building, both to other buildings and to an acceptable risk. Since the level of fire safety in a building depends on a great number of attributes one objective is also to systemize the way of identifying, analyzing and evaluating these.

Magnusson and a Rantatalo [8] express the goal of the approach in the form of two main requirements which both must be fulfilled by the method:

1. The method has to be comprehensive in the sense that all important fire safety attributes are included and/or covered.
2. The method should also provide a numerical ranking so that alternative design configurations can be reliably compared.

Also the development process should fulfil some major demands. Watts [9] has compiled a list of criteria as a guideline when developing new risk assessment methods. The criterions are based on a review of existing risk ranking systems. The aim is of course to produce a risk assessment method that is going to be very well accepted among the users. To achieve this the users must not have any doubt about the method. In order to give the method credibility and thereby hopefully make it widely used, the development process should fulfil Watts' criterions.

Watts' list of criteria is given below. With the following comments (extracts from [9]) Watts gives the background to why a risk assessment method should fulfil each criterion.

Criterion 1: Development and implementation of the method should be thoroughly documented according to standard procedures.
One of the hallmarks of professionalism is that as a study proceeds, a record is made of assumptions, data, parameter estimates and why they were chosen, model structure and details, steps in the analysis, relevant constraints, results, sensitivity tests, validation, and so on. Little of this information is available for most risk ranking methods.

Criterion 2: Partition the universe rather than select from it.
One of the least well-established procedures in fire risk ranking is the choice of parameters. In following a systematic approach e.g. it is best to be comprehensive. In the Edinburgh Model [9], [10], this is achieved by using NFPA Fire Safety Concepts Tree. A cut set of the Tree will then identify a group of parameters which encompasses all possible fire safety features.

Criterion 3: Parameters should represent the most frequent fire scenarios.
In determining the level of detail of the parameters, it is necessary to look at those factors which are most significant, statistically or by experienced judgement. This criterion may also be used as an alternative to Criterion 2, providing the need for systemic comprehensiveness is satisfied.

Criterion 4: Provide operational definitions of parameters.
If the methodology is to be used by more than a single individual, it is necessary to ensure precise communication of the intent of key items. Many fire risk parameters are esoteric concepts which have a wide variety of interpretations even within the fire community.

Criterion 5: Elicit subjective values systematically.
Most fire risk ranking systems rely heavily on experienced judgement. The use of formalized, documented procedures, such as the previously mentioned multiattribute utility theory, Analytical Hierarchy Process, and Delphi, significantly increases credibility of the system. Similarly, use of recognizable scaling techniques will enhance credibility.

Criterion 6: Parameter values should be maintainable.
One variable that is not explicitly included in fire risk ranking is time. Yet the influence of time is ubiquitous. It influences the fire risk both internally (e.g. deterioration) and externally (e.g. technological development). In order for a method to have a reasonably useful lifetime, it must be amenable to updating. This implies that the procedure for generating parameter values must be repeatable. Changes over time and new information dictate that the system facilitates revisions.

Criterion 7: Treat parameter interaction consistently.
In the majority of the cases this will consist of an explicitly stated assumption of no interactive effect among parameters. Where interactions are considered, it is important that they will be dealt with systematically to avoid bias. The Edinburgh interaction matrix is one approach to this assessment.

Criterion 8: State the linearity assumption.
While this assumption is universal in fire risk ranking, it is also well known that fire risk variables do not necessarily behave in a linear fashion. It is important to the acceptance of ranking methods and their limitations that such assumptions are understood.

Criterion 9: Describe fire risk by a single indicator.
The objective of most fire risk ranking methods is to sacrifice details and individual features for the sake of making the assessment easier. Information should be reduced to a single score even in the most complex applications.

Criterion 10: Validate results.
Some attempt should be made to verify that the method does in fact differentiate between lesser and greater fire risks with sufficient precision. The level of accuracy demanded here is not the same as for other engineering purposes, establishing an order of magnitude will generally suffice.

2.2 Fire risk assessment methods

Some of the information needed to answer the questions given in Section 2.1 is possible to get through studying the design and the development of different existing risk assessment methods. Over the years a great number of methods have been produced for almost all kinds of activities, buildings etc. It was thought that maybe some of those methods may be applicable to multi-storey apartment buildings. Magnusson and Rantatalo made a considerable effort to evaluate available risk assessment methods. Their conclusion was that there exists no method that fulfils the two main requirements above (see Section 2.1). In many cases very few of Watts' ten criterions had been satisfactorily fulfilled (see Section 2.1).

The most widely accepted and used risk assessment methods will be described in this chapter. Some of Magnusson's and Rantatalo's objections to these methods are included in the text. As a result of the observed deficiencies of the existing methods it was obvious that a new risk assessment method had to be developed. The development process and the latest suggestion of a risk assessment method are described in the following chapters.

2.2.1 Regulations and checklists

A simple and safe way of achieving a satisfactory level of fire safety in a building is to simply follow the existing building codes. This has very little in common with regular risk assessment methods, but it has to be mentioned here to illustrate the easiest way of solving the fire safety problems. An engineer (or in this case even a layman) just has to follow a number of detailed regulations and no "real" risk analysis is therefore necessary. Different types of checklists are often used as tools to make sure the building fulfils the building code. Checklists are (if they are adapted to a specific process, activity or building) often the fastest (and therefore often the best) way of identifying risk features. The main problem is that it is not possible to quantify the importance of such a feature. Another problem is that a checklist usually has to be very specific to be useful. Therefore different lists have to be developed and used for almost similar types of buildings.

Since building codes have a long tradition they were often introduced not based on traditional engineering estimates but on observations and experiences. The situation of today is not that different, i.e. the codes are often still based on a small number of major accidents. The greatest disadvantage of just slavishly following detailed recommendations is the fact that every hazard situation shows a great variety in detail. In this approach it is desirable to choose a much more flexible method.

2.2.2 Quantitative methods

In an increasing number of countries the situation for building engineers and fire protection engineers has gone through a rather radical change. By the introduction of performance-based criteria for fire safety it is now up to the engineer to verify that the level of fire safety in the building is equivalent to a building built according to current building codes. The engineer has to rely more on his own knowledge, which means that considerable responsibility has moved over to him/her personally. At the same time the freedom has increased, the engineer is free to use the tools he/she thinks are necessary. In many cases the engineer chooses to only evaluate a small number of the most likely scenarios. Computer models have then become a valuable tool for simulation of fire and smoke spread, evacuation etc.

When calculating the total risk or the risk for a single scenario in more complex situations, an event-tree analysis is often the best tool. (Event-trees and other risk assessment methods are described in Mathews and Karydas [11].) Fault-tree analysis is another example of a similar risk assessment method. The term “deterministic methods” is often used when referring to this type of methods.

Perhaps the most time-consuming and complex way of evaluating the level of fire risk is to use a probabilistic method. One of the disadvantages is that the methods require a large base of input data. The engineer also has to be familiar with different mathematical techniques as for example stochastic modeling and linear regression. The advantage is the precision in the results.

It is important to remember that no method or technique is the perfect choice in every situation, the most appropriate method has to be chosen from case to case. A probabilistic or deterministic method is very often the choice when the risk has to be known as accurately as possible. On the other hand, in many cases these methods are too complex, time-consuming and costly. In this specific approach the objective has been to find an assessment method which is rapid and easy to use, i.e. one should not have to be a fire safety expert to be able to use it in a satisfactory way. With this in mind it is easy to understand that a quantitative method is not the best choice in this case. Instead Magnusson and Rantatalo decided to focus on semi-quantitative methods, which most likely better fulfil the demands formulated in Section 2.1.

Semi-quantitative methods or ranking methods are described in Section 2.2.3. Below follows a brief description of some of the existing and most widely used quantitative methods. This as examples of alternative methods that also are applicable to multi-storey buildings.

The Building Fire Safety Engineering Method

An extensive guide to the Building Fire Safety Engineering Method (BFSEM) is given by Fitzgerald [12]. The method is often simply called “The Engineering Method” or “The L-curve method”.

The fire safety in a building is expressed graphically by means of a curve. The inclination of the curve corresponds to the estimated risk in the building. The flame spread is represented on the x-axis and the probability of flame stop is represented on the y-axis. The L-curve is composed of the T, A and M-curves, representing the probability of self-termination, successful automatic extinguishment and successful fire department extinguishment respectively. Effects of certain actions with comparisons between cost and safety are presented graphically.

The analysis process is closely described in the handbook [12]. Terms like barriers, established fire, full room involvement etc. are explained in the text. Network diagrams (also described in the text) are useful tools in facilitating the calculation work. The reliability of the results depends on the input values and therefore it is desirable if these are based on a combination of knowledge, experience and statistics.

As a part of the Nordic Wood project a Norwegian evaluation of the L-curve method has been made [13], [14]. The evaluation group seems to have a positive attitude to the L-curve method. However, some sections still have to be improved (and therefore the development work is continuing). Above all there is a need for detailed documentation of life safety and external fire spread, which are two parameters the L-curve method pays little regard to.

The graphic presentation makes it very easy to understand the results and to compare these with regulations, other buildings etc. It is possible to use the L-curve method even when the input values are based on rather coarse estimates. To increase the validity it is, however, desirable to use computer models and other engineering methods.

Magnusson and Rantatalo [8] found that the L-curve method gives good information about the fire spread in a building, but also that it is not that suitable for evaluation of life safety. Another disadvantage is the amount of engineering judgements required to get all the input data. Finally, the background for the reliability and variations of the different parameters is, according to Magnusson and Rantatalo, presented in a very sketchy way.

CRISP II

The Fire Research Station (FRS) in Borehamwood, UK is developing a zone model of the complete fire system called Crisp II [15], [16]. It is written in object-oriented fashion, which means that the system is treated as a collection of objects. The objects, which usually correspond to physical components, interact in a number of ways. Object classes that are used in Crisp II are: burning items, hot gas and cold air layers, vents, walls, rooms, smoke detectors, fire brigade and occupants. The behavior of the occupants is the most complex detail to model since the decision process is influenced by a number of factors such as physiological reactions, sensory perceptions etc.

Crisp II may be used for Monte-Carlo estimates of risk in domestic houses. The input conditions are determined randomly and the simulations are repeated a great number of times. The mean number of casualties then gives the relative risk.

VTT in Finland has been using Crisp II for risk calculations in their part of the project "Risk Evaluation" (see Section 1.2).

FireCAM

In order to support the introduction of performance-based building regulations in Canada, the National Research Council of Canada (NRC) is developing a computer fire risk assessment model called FireCAM [17].

FireCAM assesses the expected risk to life to the occupants as a result of all probable fire scenarios over the design life of the building. By comparison to the performance required in the performance-based code, the computer model can assess whether a building meets the performance requirements, or is equivalent to the reference design. The structural frame of the building may be both combustible and non-combustible.

FireCAM also assesses the expected cost of fire losses and fire protection in an object. The model makes it possible to find out whether a proposed design has the lowest fire costs of all acceptable designs.

In the pilot study Magnusson and Rantatalo [8] found that the major objection to the model is that it, in its present form, does not treat fire spread in a satisfactory way. They state that FireCAM treats the fire spread process too summarily to be used as a verification tool for the overall fire safety requirement (the so-called "Fire Safety Policy", see Chapter 3). The model is, however, a candidate model for the evaluation of the life safety objective (see Chapter 3).

2.2.3 Ranking methods

Ranking methods or semi-quantitative methods are today used in a wide variety of applications. Usually fire risk ranking is defined as a process of modeling and scoring hazard and exposure parameters to produce a rapid and simple estimate of relative risk. In short, fire risk ranking methods are, according to Watts [10], heuristic models which use professional knowledge and past experience to assign values to selected variables.

Fire risk ranking methods have most often been developed with the purpose of simplifying the risk assessment process for a specific type of building, process etc. Quantitative methods often have been found to be too expensive and too time-consuming, which has led to a need to find, or develop, a new risk ranking method which may be applied to the specific type of building, process etc.

Ranking methods remove most of the responsibility from the user to the producer of the method. Usually a group of experts first has to identify every single factor (in this report called attribute) that affects the level of safety/risk. The attributes represent both positive features (increase the level of safety) and negative features (decrease the level of safety). The experts then usually decide the importance of each attribute, i.e. a value is assigned to each one. The values are usually based on the knowledge and the experience of a panel of numerous experts. The different knowledge and experience of the members of the panel is in a way a step towards reliable results. The assigned values are then operated on by some combination of arithmetic functions to arrive at a single value. The value, often called "risk index", is a measure of the level of safety/risk in the object and it is possible to compare this to other similar objects and/or to a stipulated minimum value.

To simplify the ranking procedure for the user, who often is unfamiliar with ranking methods, some sort of rating schedules, grading schemes etc. are usually incorporated into the method. Examples of grading schemes will be found in Appendix A (where the Fire Risk Index Method will be presented).

The greatest advantage of fire risk ranking methods is probably their simplicity. Thanks to the rapid risk assessment, fire risk ranking methods are considered to be very cost-effective tools. However, a demand on a ranking method should always be that the received results should not suffer too much from the simplicity of the method. Another advantage of fire risk ranking is the structured way in which the decision making is treated. This facilitates understanding of the system for persons not involved in the development process and makes it easier to implement new knowledge and technology into the system.

The remaining part of this chapter describes some of the mostly used risk ranking methods. The purpose is to present different alternatives, with its advantages and disadvantages. In the pilot study Magnusson and Rantatalo [8] have chosen the most appropriate of these methodologies. In the next two chapters the application of this method to multi-storey apartment buildings will be described.

Risk ranking methods that are not described below, but should nevertheless be mentioned are the ISO Specific Commercial Property Evaluation Schedule [10] and Dow's Fire and Explosion Index [10]. These methods do not, however, fulfil the wishes formulated for this project.

The Fire Safety Evaluation System

The Fire Safety Evaluation System (FSES) was developed in the 1970's at the Center for Fire Research, National Bureau of Standards in cooperation with the U.S. Department of Health and Human Services. FSES is a schedule approach for determining equivalencies to the NFPA 101 Life Safety Code for certain institutions and other occupancies. It was developed to provide a uniform method for evaluating health care facilities.

The method treats risk and safety separately. The methodology for treating risk was developed using characteristics of a health care occupancy. The five risk factors are: patient mobility, patient density, fire zone location, ratio of patients to attendants and average patient age. Thirteen safety factors were also derived. Each risk factor and safety factor has been assigned a relative weight from a panel of fire safety experts.

The relative risk is calculated as the products of the assigned values for the five risk factors.

The expert panel also identified three different fire safety strategies: containment, extinguishment and people movement. The panel then determined which safety parameter applies to each safety strategy. The level of safety for each strategy is then calculated as the sum of its parameter values. These levels are then compared to predetermined minimum levels.

The total level of safety is calculated as the sum of all the thirteen parameter values. This level is then finally compared to the level of risk described above.

The FSES is not developed for multi-storey apartment buildings, but apart from that the structure of the method fulfils many of the demands that have to be put on a risk ranking method. For further information about the Fire Safety Evaluation System see Watts [10].

SIA 81

This method was originally developed in Switzerland in the early 1960's and published for the first time in 1965, but it has since then been revised a number of times. In 1984 the version "the Fire Risk Evaluation Method SIA DOC 81" was published [18]. The method is probably better known as the Gretener method, named after Max Gretener, Head of the Swiss Fire Prevention Service (today SI – Safety Institute in Zurich), who started the work in the 1960's. Gretener thought that determining fire risk by statistical methods based on loss experience had to be complemented by a more rapid alternative.

Fontana [18] states that the method is well accepted in Switzerland, as well as in several other countries. It has there been recommended as a rapid assessment to evaluate the fire risk of alternative concepts for large buildings. The method is one of the most important fire risk ranking methods because of its acceptance for insurance rating and code enforcement.

The Gretener method is used to evaluate and compare the level of fire risk of alternative concepts by grading the elements of a building and their performance. The grading factors are claimed to be based on expert knowledge, a large statistical survey and tested by a wide practical application.

The calculated risk is compared to the accepted risk, where the latter is a function of the number and the mobility of the persons involved and of the location of the relevant fire compartments within the building.

The calculated risk is given as follows:

$R_{calculated} = A \times B$ (Formula 2.1)

A stands for the probability of fire occurrence.
B stands for fire hazard, degree of danger or probably severity, and is given as follows:

$B = P_{danger} / M_{applied}$ (Formula 2.2)

P_{danger} stands for "potential danger", which is a function of the building and its contents that influence fire ignition and spread of fire.

$P_{danger} = q \times c \times f \times k \times i \times e \times g$ (Formula 2.3)

<u>Content:</u>
q = fire load
c = burning behavior
f = smoke production
k = content of corrosive agents in the smoke

Building:
i = fire load in building construction
e = storey, basements, storage height
g = size of the fire compartmentation, ratio between length and width

$M_{applied}$ stands for "applied fire protection measures", which is given as follows:

$M_{applied} = n \times s \times f$ (Formula 2.4)

n stands for "normal measures" meaning fire extinguishers, fire hydrants, trained personnel.
s stands for "active measures" meaning sprinkler, alarm, type of fire department, sprinkler, smoke and heat detectors.
f stands for "passive measures" meaning supporting structures, surrounding walls and ceilings, sizes of fire compartments.

When Magnusson and Rantatalo evaluated the Gretener method in the pilot study [8] they compared it to Watts' ten criterions (see Section 2.1). They found that criterion 5 was not fulfilled in the best way. According to Magnusson and Rantatalo the suggested method (the Fire Risk Index Method, which is extensively described in Chapters 4 and 5 and in Appendix A) fulfils this criterion better. The methodology, which the Fire Risk Index Method is based on, is claimed to be logic and transparent. The entire work will be documented and assumptions made will be clearly stated. The Delphi process, which will be used at many stages of the development process, has been used in many different fields of engineering and is a well-developed methodology.

Magnusson and Rantatalo also found another problem with the Gretener method. A number of important fire spread routes have not been described to the level of detail that is desirable. The knowledge of today about which factors influence the risk of fire spread in a building is relatively good and well-documented. Reports, among many others, which describes important fire spread routes and the behavior of building assemblies when exposed to fires, have been presented by Stenstad [19] (general description of fire spread routes) and [20] (fire spread in roofs), Hakkarinen and Mikkola [21] and Karjalainn [22] (fire spread along facades), Mehaffey, Cuerrier and Carisse [23], Richardson and McPhee [24] and Richardson and Batista [25] (fire spread through walls). It should be possible to implement this new knowledge into a fire risk index method.

The hierarchical approach

Many attempts have been made to define fire safety in words. However, it has of course been found very difficult. Depending on the level of accuracy, fire safety may be expressed very generally in terms of aims/tactics or more detailed in terms of specific hardware items. Examples of the first might be to prevent fire ignition, to provide safe egress etc. and examples of the latter might be lining materials, alarm system etc.

A way of taking every level of accuracy and their attributes into consideration when defining the fire safety is to construct a matrix of fire safety objectives versus more specific fire safety features. This exercise was initially undertaken at the University of Edinburgh (and therefore the methodology sometimes is referred to as "the Edinburgh Model"), where the development of an index method was an attempt to create a systematic model for the evaluation of fire safety in hospitals [10], [26]. The concept has later been used for other objects as well. The University of Ulster developed the method further for application to dwelling occupancies.

During the last years the method has been improved and, for example, been applied to telecommunications facilities [27], [28] and historic buildings [29].

Usually there is a need for more than two levels in the hierarchy of fire safety. In the applications mentioned above, five different “decision making levels” have been used. The levels of the hierarchy may sometimes have other names, but usually the names presented in Table 2.1 are used [10].

Table 2.1 Decision making levels

Level	**Name**	**Description**
1	POLICY	Course or general plan of action adopted by an organization to achieve security against fire and its effects
2	OBJECTIVES	Specific fire safety goals to be achieved
3	STRATEGIES	Independent fire safety alternatives, each of which contributes wholly or partly to the fulfillment of fire safety objectives
4	PARAMETERS	Components of fire risk that are determinable by direct or indirect measure or estimate
5	SURVEY ITEMS	Measurable feature that serves as a constituent part of a fire safety parameter

Examples of attributes that might be found on each level of the hierarchy are:
- The Objective “Life safety”
- The Strategy “To provide safe egress”
- The Parameter “Detector system”
- The Survey Item “Type of detectors”

Sometimes it is impossible, or at least difficult, to connect the Parameters directly with the Survey Items. The solution is Sub-Parameters (or in some cases even “Sub-Sub-Parameters”), i.e. an extra level between the levels 4 and 5. However, the many levels of the fire safety hierarchy result in a series of matrices, which makes the mathematical operations more complex and time-consuming.

The greatest advantage of this method is perhaps the logical way of numerically expressing the fire safety in terms of measurable features. As other risk ranking methods, the hierarchical approach is also usually easy to understand and to use.

Once the levels of the hierarchy have been identified the attributes comprising each level have to be specified. These attributes, especially the ones in the lower levels, have to be specific for every type of building. The attributes are for instance not the same for hospitals as for museums. Therefore, if the hierarchical model is going to be applied to multi-storey apartment buildings, new attributes have to be specified. Some of the work already carried out in other applications and the conclusions drawn there may, however, be used in the new approach.

In the next step each attribute in a level has to be expressed numerically in terms of the attributes in the immediate lower level. For example the importance of a specific Strategy for a specific Objective has to be expressed by a weight. Often the Likert scale is used, which means the weights are expressed on a scale from 0 to 5. In most applications the Delphi technique (see Chapter 4) is used for these rather subjective judgements. The Analytical Hierarchy Process (AHP) is another suitable technique, developed by Saaty [30] and used in some earlier works (see e.g. Parks, Kushler and others [27]). AHP is, however, according to Watts [10] and Shields and Silcock [31], unstable when more than five/six attributes are to be ranked.

The subsequent matrix manipulation is illustrated in Figure 2.1. The Objectives×Policy vector is multiplied by the Strategies×Objectives matrix to give the Strategies×Policy vector. This is then multiplied by the Parameters×Strategies matrix to finally give the Parameters×Policy vector. This vector gives the weights of each Parameter with respect to the overall Policy.

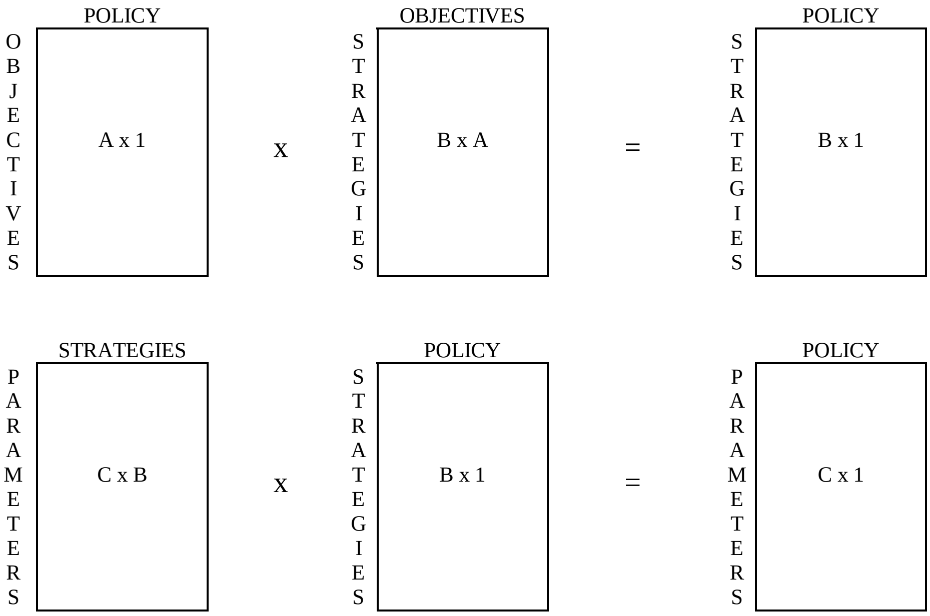

Figure 2.1 Matrix manipulation

Matrices cannot, however, describe the influence Survey Items and Sub-Parameters have on the Parameters. The relationships between the Parameters and their Survey Items have to be formulated separately for each Parameter.

As mentioned above the final result of the matrix manipulation is a vector, describing the overall Fire Safety Policy in terms of all the Parameters. The received risk index may be calculated according to a simple formula like for instance:

$$S = \sum_{i=1}^{n} w_i \, x_i \qquad \text{(Formula 2.5)}$$

where

S = risk index expressing the fire safety
n = number of Parameters
w_i = weight for Parameter i
x_i = grade for Parameter i

The weights are usually normalized so:

$$\sum_{i=1}^{n} w_i = 1 \qquad \text{(Formula 2.6)}$$

When the Parameter grade is described in the Likert scale, the risk index receives a value between 0 and 5.

The risk index is then compared either to other buildings or to a predetermined minimum value.

Unlike the Parameter weights the Parameter grades are individual for every specific building. The grade represents the extent to which each Parameter is present. Since the Parameters are often not directly measurable they have to be derived from various functions of a lower level of attributes that includes specific hardware items. As mentioned above, these attributes are referred to as Survey Items. The Survey Items are always measurable or somehow observable. A Survey Item could for example be number of detectors in the building, maximum travel distance to an escape route or type of lining material.

The Parameter grades are often assigned using specially designed tables, including Survey Items and Sub-Parameters. These tables are referred to as grading schemes and will be described in Chapters 4 and 5 and in Appendix A.

Magnusson and Rantatalo found that the hierarchical approach was the most interesting risk assessment method compared to other existing methods. The following advantages were mentioned in the pilot study [8]:

- The method is comprehensive, covering important aspects from structures to frequency of inspections.
- The basic methodology is transparent and logical and lends itself easily to documentation.
- New information is easily introduced.
- Weak parts of the total fire protection system are easily identified.

It was decided in the pilot study that the methodology should be applied to multi-storey apartment buildings. Completed with a Delphi exercise this should result in the reliable and simple risk index method as was desired.

3 The pilot study

As it was established in the second chapter, the hierarchical approach was found to be the most appropriate risk assessment methodology for application to multi-storey buildings. In the pilot study Magnusson and Rantatalo [8] suggested a generalized five-step process for ranking the attributes. The suggestion was based on the five-step process originally developed by Watts [6] and briefly described in Section 1.3.

The procedure that Magnusson and Rantatalo used in the pilot study had the following steps:

Step 1: Identify hierarchical levels of fire safety specification.
Step 2: Specify attributes comprising each level.
Step 3: Assign weights to the attributes listed above. These weights are always the same for a specific group of buildings, i.e. in this approach multi-storey apartment buildings.
Step 4: Develop a numerical scale on which the attributes can be assigned values or measures. The values are individual for each building.
Step 5: Select an evaluation model. Select a mathematical model that combines weights and values for each attribute and combines the different attributes to receive a single value.

The two first steps were carried out in the pilot study, while the rest of the procedure was carried out in the next phase of the project (see Chapter 4).

3.1 Identification of hierarchical levels

Magnusson and Rantatalo [8] suggested the same decision making levels as shown in Table 2.1. These levels were suggested by Watts [10] and have been used earlier in many different applications. For the project described in this report, his division of levels was later accepted by both the project group and the Delphi panel (see Chapter 4).

3.2 Specification of attributes comprising each level

This is perhaps the most important and difficult part of the development process. It now has to be specified which attributes really influence the fire safety of the specific object. Over the years a considerable research work has been carried out in this field. However, the conclusions drawn in the different surveys do not always correspond. (Authors who, into a varying level of detail, discuss what influences the behavior of a fire and the fire resistance of a building are for example Stenstad [32], Dowling and Caird [33], Lin and Mehaffey [34] and Law [35].)

The construction of the hierarchy has to result in a list of very distinct attributes. Every person involved in the decision process has to understand the definition of every single attribute. The list has to be complete, which means that no major features are allowed to be left out, but at the same time the list has to be easy to grasp and possible to mathematically quantify. Usually some sort of matrix operation is used and therefore the wish is to restrict the number of attributes if possible.

Another demand is that different attributes on the same level have to be independent of each other. Double counting of elements is to be avoided for best results. In other words, this is a very sensitive phase, worthy of considerable effort.

Magnusson and Rantatalo [8] suggested the attributes, listed in Table 3.1, comprising the different levels in the hierarchy. The suggestion gives the first outline of the Fire Risk Index Method and was the base for the further study, described in the next chapter.

Table 3.1 Hierarchy suggested by Magnusson and Rantatalo [8] (O = Objective, S = Strategy, P = Parameter)

Policy:	Fire safety performance for a wood-frame building should be at least equivalent to that of corresponding building with a non-combustible frame
$\mathbf{O_1}$:	Provide life safety
$\mathbf{O_2}$:	Prevent fire spread from room of origin
$\mathbf{O_3}$:	Prevent fire spread to the adjacent building
$\mathbf{S_1}$:	Establish safe egress
$\mathbf{S_2}$:	Establish safe rescue operation
$\mathbf{S_3}$:	Control fire growth
Prevent fire spread through:	
$\mathbf{S_4}$:	room boundaries
$\mathbf{S_5}$:	joints and intersection
$\mathbf{S_6}$:	concealed spaces
$\mathbf{S_7}$:	window openings, facades
$\mathbf{S_8}$:	attic
$\mathbf{S_9}$:	Prevent ignition of structure
$\mathbf{S_{10}}$:	Limit size of radiation from burning building
Building:	
$\mathbf{P_1}$:	Load-bearing capacity
$\mathbf{P_2}$:	Integrity E / insulation I
$\mathbf{P_3}$:	Firestop at joints/intersections
$\mathbf{P_4}$:	Firestop in concealed spaces
$\mathbf{P_5}$:	Facade construction
$\mathbf{P_6}$:	Firestop in eaves
$\mathbf{P_7}$:	Doors (self closing)
Fire protection system:	
$\mathbf{P_8}$:	Alarm system
$\mathbf{P_9}$:	Detection system
$\mathbf{P_{10}}$:	Suppression system
$\mathbf{P_{11}}$:	Fire department capability and effectiveness
$\mathbf{P_{12}}$:	Management, surveillance and education
$\mathbf{P_{13}}$:	Safe separating distance

In the pilot study Magnusson and Rantatalo [8] explain how the proposal was derived.

In some projects a Delphi panel is used to define the Fire Safety Policy in terms of a specified list of Objectives. Magnusson and Rantatalo establish the fact that no significant work has been carried out to identify what it is that fire safety is trying to achieve, and thereby the Objectives will be a rather subjective list. It may include statements about life safety, property protection, continuity of operations, environmental protection, and heritage preservation.

Magnusson and Rantatalo preliminary formulated the Policy as; "Fire safety performance for a wood-frame building should be at least equivalent to that of corresponding building with a non-combustible frame." The Policy could be expressed in terms of the following Objectives:

1. Provide life safety
2a. Prevent fire spread through compartment boundaries (Contain fire)
2b. Prevent fire spread through building structure
3. Prevent fire spread to adjacent building

Objectives 2a and 2b were, however, found not to be independent of each other, which they must be. The more general Objective "Prevent fire spread from room of origin" was instead used to cover for the significance of both 2a and 2b. As a consequence, the number of Objectives had been decreased to three, which of course simplified the evaluation procedure.

The NFPA Fire Concepts Tree was used when defining the list of Strategies. The Objectives above were found to depend on the following Strategies:

"Provide life safety":
- Prevent ignition
- Control fire growth (S_3)
- Control fire spread
- Establish safe egress (S_1)
- Establish safe/effective rescue operation (S_2)

"Prevent fire spread through compartment boundaries":
- Control fire growth (S_3)
- Prevent fire spread through room boundaries (S_4)
- Prevent fire spread through joints and intersections (S_5)

"Prevent spread through building structure":
- Prevent fire spread through/in concealed spaces (S_6)
- Prevent ignition of structure (S_9)
- Prevent fire spread through window openings, facades (S_7)
- Prevent fire spread to/through attic (S_8)

"Prevent fire spread to adjacent building":
- Limit size of exposing fire (burning building) (S_{10})
- Safe separating distance

As mentioned above Objectives 2a and 2b were combined to form a more general Objective. It is also important to observe that two of the Strategies above were eliminated in the final suggestion. “Prevent ignition” was left out because there should be no difference in frequency of ignition of interiors between apartment buildings made of timber-frame and those made of non-combustible frame. “Control fire spread” was believed to be of minor importance for the Life Safety Objective, although it is deemed to be of considerable importance for Objective 2.

The next level, referred to as the Parameter-level, consists of individual features that are measurable, directly or indirectly. The Parameters contribute to the achievement of the Strategies and thereby also to the achievements of the Objectives and the Policy. In the pilot study 13 main Parameters were identified that significantly influence the fire risk in a multi-storey timber-frame apartment building. However, the authors realized that the list of Parameters should be amended in the main study.

Survey Items were not identified at this stage due to the detailed analysis needed. Identification of Survey Items is found in the in the main study (see Chapters 4 and 5 and Appendix A).

4 The Delphi exercise

4.1 General on the organization of the project

The manager of the current project has been Björn Karlsson, Senior Lecturer at Lund University, Sweden. Karlsson has been running the project with some assistance of Daniel Larsson, student at Lund University and the author of this report.

A project group was formed with one member from each of the Nordic countries, but it also included the project manager Björn Karlsson, Professor Sven Erik Magnusson (Lund University), Daniel Larsson and Birgit Östman (coordinator of the project "Fire-safe Wooden Houses", Trätek, Sweden). The national members were Tomas Rantatalo (Boverket, Sweden), Vidar Stenstad (Norges Byggforskningsinstitutt, Norway), Charlotte Mikkelsen (Bygg og boligministeriet, Denmark) and Matti Kokkala (VTT, Finland).

The project manager has been using two external advisors, Dr. John Watts (Fire Safety Institute, USA) and Professor Jim Shields (University of Ulster, Great Britain). These two both have great experience in the methods used in the project. Other external experts have contributed with comments as well.

The general procedure was that Karlsson and Larsson initially developed suggestions to the structure of the method. Karlsson regularly presented the work for the project group whereupon its members contributed with comments. This resulted in a proposal presented to the Delphi panel (see Sections 4.2 - 4.4). The Delphi panel gave their personal opinions on the structure of the method. The aim was to reach consensus on every single point. When the structure had been accepted (i.e. consensus had been reached) the weighting process could start. In order to express the importance of each attribute for the overall Fire Safety Policy each member of the Delphi panel was asked to put grades from 1 to 5 on every single attribute in the system. A number of question rounds had to be used until consensus was reached. A further description of the procedure will be found in the following pages.

4.2 Description of the Delphi technique

4.2.1 General description

For over a century the common opinion in the Western world has been that democracy is the best way of making decisions. The meaning is that a decision has to be based on a majority and that the credibility of the decision increases with a larger majority. The traditional "one-man leadership" has today in many areas often been replaced by some sort of committee or panel. The knowledge of a panel is greater and, depending on the composition of the group, much wider than for the single decision maker. If persons representing different parts of the society are allowed to participate in the discussion, the risk that some interest may be disregarded is minimized.

These very basic thoughts have been developed into a decision making method called the Delphi technique, named after the famous oracle of Delphi. In "A Fire Safety Evaluation Points Scheme for Dwellings" [7] Shields describes the technique and its advantages. The reason why there was a need for developing a decision technique like Delphi was that the regular face-to-face discussion was found to have several weaknesses. Dominant individuals and group pressure most often led to distorted results. The Delphi technique was originally developed for the American army in the 1950's. At this time it was used as a tool for utilizing and organizing different expert opinions of atomic warfare. Details on the methodology were then secret, but in the early 1960's the information was de-classified and it became possible to use it for applications in other areas as well. However, it was not until in the late 1970's that the methodology was applied to fire safety engineering. At first the Delphi technique was used to develop a fire safety evaluation scheme for hospitals, but soon the methodology spread to other areas where similar systems were created.

Linstone and Turoff give the following definition of the Delphi technique in their book "The Delphi Method – Techniques and Applications" [36]: "Delphi may be characterized as a method for structuring a group of individuals, as a whole, to deal with a complex problem." For short the Delphi technique is a methodology of working for reaching consensus on different issues. A panel of experts in a specific field is asked to give its opinion on several different questions concerning the field. A small project group usually designs the questionnaires and evaluates the results. After every question round the panel members get feedback from the project group, usually a summary of the results and sometimes also common arguments among the members. The panel members are then asked if this information has made them change opinion in some way and if they want to adjust their respond to some question. After every question round the project group develops new questionnaires. Hopefully in the end, after a number of rounds, the panel has reached consensus in every single question. The mathematical definition of consensus may be discussed (see Section 4.2.3) and usually depends of the accuracy needed. Since the final results are based on a great number of expert opinions the results may be used with considerable credibility.

Questions to and answers from the panel are usually sent in written form, so that time consuming face-to-face discussions will not be necessary. Interactions between members of the Delphi panel are avoided since the composition of the group is unknown to each member. This reduces the influence dominant personalities usually have on the decision procedure. Since the results are based on the statistical responds of the entire group, every members opinion is of equal importance. The objective is that only arguments founded on facts will convince a person to revise his/her respond. The loss of prestige when changing opinion as an expert will be very small compared to a face-to-face situation.

It is important to be aware that the Delphi technique is not normally thought of as a technique to obtain results in a technical study. Such a technique definitely would not be used if good data were available or if results could be calculated or analyzed in the traditional scientific or engineering approach.

Earlier attempts of using the Delphi technique have proven that the process is especially useful when:

1. the issues to be addressed are highly judgmental or subjective and ideas may not be fully developed.
2. the level of knowledge, influence and communication skills vary within the group.
3. there is a strong possibility that one or more group members may dominate the outcome.

With this in mind it was thought that the Delphi technique would be suitable when considering fire risks in timber-frame multi-storey buildings.

4.2.2 Panel composition

As mentioned in Section 4.1 the project manager Björn Karlsson formed a project group at an early stage of the project. The assignment of the project group was to comment on the suggestions for actions that the project manager formulated. Together with the project group the project manager prepared proposals for the Delphi panel. The communication within the project group was mainly by e-mail, but the project group also met three to four times per year.

The selection of experts for a Delphi panel can be problematic, since only a few individuals have to represent the entire field of fire safety. Different categories of fire safety occupations have to be represented to give the method the credibility and the utility that is wanted. In an early pilot study, described by Shields [7], the following categories of experts were represented:

- researchers
- legislators
- designers
- fire control personnel
- housing managers

The size of the Delphi group also has to be decided by the project group. As Shields establishes, the size of group varies considerably in earlier works. The reliability of the results increases with the size of the group. However, it is never practical to use a group that is too large. Figure 4.1 below illustrates the dependence between the size of the group and the error in the final results according to Shields [7]. The group error is in the figure represented on a logarithmic scale as:

$E = \ln (M/T)$ (Formula 4.1)

where

E = average group error
M = group median
T = true answer

Figure 4.1 The dependence between size of the group and error in the results

The size of the group usually varies with the nature of the study. In this project a suitable number of individuals in the Delphi panel was found to be around 20. The project group together decided which fire safety experts should be included in the Delphi panel. Five persons with different background in the field of fire safety (research, consultation, insurance, testing and fire service) from Sweden, Norway, Denmark and Finland respectively were finally selected.

A document, called D01, giving an introduction to the Delphi panel exercise was formulated by Björn Karlsson and sent to the panel members. The document (further described in Section 4.4) briefly described the organization of the project, the general structure of “the Index Method” (which was the preliminary name of the method at the time) and general on Delphi panels. The panel members were also informed about the working procedure and which values and guidelines he/she had to follow. Among other things the members were asked not to confer with each other in any question concerning the exercise and instead give quick subjective judgements based on his/her experience or intuition. It was, however, found that there in some questions probably would be a need for further information and therefore Karlsson emphasized that background material and references would be provided if necessary.

Karlsson and Larsson had developed a preliminary structure for the Index Method at an early stage of the project (see Section 4.3.2). The suggestion was based on the work carried out by Magnusson and Rantatalo in the pilot study [8] (see Chapter 3). Consultation in the project group resulted in some changes before the group could agree on the structure of the Index Method (see Section 4.3.4). The proposal was then sent to the Delphi panel for the first question round (see Section 4.4).

4.2.3 Consensus

The Delphi panel had to agree upon the entire design of the Index Method. This was to be done in 4 steps.

The first step was to achieve consensus on the general structure of the method (Policy, Objectives, Strategies and Parameters). Secondly the members had to agree upon the Sub-Parameters, the Survey Items and the grading schemes. Steps 3 and 4 were the most time-consuming parts of the Delphi exercise. The members were then asked to assign weights to the Objectives, Strategies and Parameters and then finally to give their opinions on the Parameter grades. Step 3, when weights were assigned, required two question rounds since the panel had to reach consensus on the weights.

We now have to ask ourselves how consensus may be defined. In reality it is almost impossible to achieve total agreement in every question. We have to accept a minor disagreement. (Shields discusses how consensus may be defined in “A Fire Safety Evaluation Points Scheme for Dwellings” [7].)

In this project the average value was accepted as the final grade if the first quartile was not lower then one grading step and the third quartile was not higher then one grading step, compared to the median value.

For example, the 20 panel members were asked to give grades to a specific Sub-Parameter. Suppose that the answers divided like this:

Grade 0: -
Grade 1: 3 answers
Grade 2: 4 answers
Grade 3: 7 answers
Grade 4: 5 answers
Grade 5: 1 answers

In this example the average is 2,85, the first quartile is 2, the median value is 3 and the third quartile is 4. The value 2,85 is accordingly accepted as the final grade.

4.3 Work done by the project group

4.3.1 Version 1

The structure presented in the pilot study, derived by Magnusson and Rantatalo, is referred to as Version 1 of the Index Method (see Chapter 3). With this as a base, further development of the structure has been done. The project group derived three more versions before all four were presented for the Delphi panel for comments (see Section 4.4).

4.3.2 Version 2

At an early stage, Version 1 of the Index Method was presented to the two external advisors of this project. Both external advisors remarked on the complicated mathematical operations needed, due to the size of the matrices. $3 \times 10 \times 13 = 390$ cells should have to be evaluated, which would be much more than in earlier works. They also remarked that the number of Strategies should be decreased and more concentrated. It was suggested that Strategies 4 and 5 were combined as well as Strategies 6 and 8. Strategy 9 "Prevent ignition of structure" represents only a very small part of the earlier suggested Strategy "Prevent ignition". The Strategy "Prevent ignition" was eliminated because it is out of control of the building regulations. "Prevent ignition of structure" might instead be included in Strategy 4, i.e. "Prevent fire spread through room boundaries". A part of this Strategy would be to protect the structure. Some Strategy names were also changed in the new version.

Many index methods for assessing fire safety are derived by taking a cut set of the NFPA Fire Concepts Tree [37]. The tree illustrates the relationship between the Fire Safety Policy, Objectives, Strategies, Parameters, Sub-Parameters and Survey Items. The systematical arrangement of the tree will decrease the risk for neglecting any significant attributes when deriving a risk index method. For this project Karlsson and Larsson developed a specific Fire Safety Concepts Tree, based on the NFPA Fire Safety Concepts Tree. Some of the attributes found in the NFPA Fire Safety Concepts Tree did not, however, apply in this specific case. For example, it was found impossible to control different combustibles in apartment buildings. The building regulations do not we have control over combustibles, except for lining materials.

The tree developed by Karlsson and Larsson was later revised. The version connected to "The project group structure of the Index Method" is published in Section 4.3.4.

The tree was used to identify Sub-Parameters, Survey Items and a number of new Parameters. "Escape routes", "Internal linings", "Windows", "Compartmentation" and "Smoke control system" became new Parameters in this version. Some names were also changed. The size of the matrices were now down to $3 \times 7 \times 18 = 378$ cells, which still was found fairly large. The feeling was, however, that the structure had been sharpened at the same time that more Parameters had been taken into account.

In the final version of the Index Method the risk index is calculated as a combination of the Parameter weights and the Parameter grades. The weights were derived in the Delphi exercise. The project group derived the grades, but they also had to be accepted by the Delphi panel.

The purpose of identifying Sub-Parameters and Survey Items is to find a connection between measurable items and Parameters. In almost every earlier developed version of a hierarchical method, so-called "decision tables" have been used to give grades to the Parameters. Watts, Budnick and Kushler give a brief introduction to the technique in "Using Decision Tables to Quantify Fire Risk Parameters" [38].

A decision table, sometimes referred to as a "point scheme", is used to transform combinations of measurable, observable Survey Items into a grade for a Sub-Parameter or directly to a grade for a Parameter (if the Sub-Parameter level is not used). A decision table may also be used to transform different combinations of Sub-Parameter grades into a

Parameter grade. A possible combination of Survey Items / Sub-Parameters, which produces a conclusion, is called a “decision rule”.

In this approach the project group gave grades to every decision rule. In the “Sub-Parameter tables” a four-grade scale was used (N = no grade, L = low grade, M = medium grade and H = high grade). In the “Parameter tables” the Likert scale (a scale from 0 to 5) was used. (The Likert scale was not used in the “Sub-Parameter tables” since this would result in too many decision rules in the “Parameter tables”.)

Every possible decision rule has to be included in a decision table. With a lot of Survey Items or Sub-Parameters a decision table may, however, become too complex. In these cases a weighting procedure can be used instead, in the same way as for the higher levels.

The Parameter grades is then calculated as:

$$G = \sum_{i=1}^{n} w_i \; x_i \qquad \text{(Formula 4.2)}$$

where

G = Parameter grade
n = number of Sub-Parameters
w_i = weight for Sub-Parameter i
x_i = grade for Sub-Parameter i

The advantage of using decision tables, compared to the weighting model, is that a decision table is very easy to use, no mathematical operations have to be made by the user, one only has to read from the table. Since every decision rule is analyzed individually a higher accuracy is also reached.

For each Parameter the project group identified Survey Items and in most cases also Sub-Parameters. Grading models were developed individually for each Parameter including decision tables and/or weighting models. The grading model for a Parameter is in this report called a “grading scheme”. An example of a grading scheme is presented in Figure 4.2 concerning “Suppression system” (P_2). In total 18 grading schemes were developed by Karlsson and Larsson in co-operation with the project group. The grading schemes were included in Version 2 of the Index Method.

P_2. SUPPRESSION SYSTEM

DEFINITION: equipment and systems for suppression of fires

SUB-PARAMETERS:

Automatic sprinkler system
Type of sprinkler (N = no sprinkler, A = apartment sprinkler, O = ordinary sprinkler) and Location of sprinkler (A = in apartment, E = in escape route, B = both in apartment and escape route)

SURVEY ITEMS	DECISION RULES						
Type of sprinkler	N	A	A	A	O	O	O
Location of sprinkler	-	A	E	B	A	E	B
GRADE	N	M	L	H	M	L	H

(N = no grade, L = low grade, M = medium grade and H = high grade)

Portable equipment

N	None
F	Extinguishing equipment on every floor
A	Extinguishing equipment in every apartment

PARAMETER GRADE:

SUB-PARAMETERS	DECISION RULES											
Automatic sprinkler system	N	N	N	L	L	L	M	M	M	H	H	H
Portable equipment	N	F	A	N	F	A	N	F	A	N	F	A
GRADE	**0**	**1**	**1**	**2**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**

(Minimum grade = 0 and maximum grade = 5)

Figure 4.2 An example of how Parameters are graded using Survey Items, Sub-Parameters and decision tables. Please observe that the grades are arbitrarily chosen and given here as an example.

Table 4.1 below presents an outline of Version 2 of the Index Method. The grading schemes are, however, not presented here due to the size of these documents and because this was not the final version of the Index Method. The last version of the Index Method including the grading schemes is to be found in Appendix A.

Table 4.1 An outline of Version 2 of the Index Method.

Policy:

What level of fire safety do we need in our building?

Objectives:

O_1	Provide life safety
O_2	Prevent fire spread from room of origin
O_3	Prevent fire spread to adjacent building

Strategies:

S_1	Establish safe rescue operation
S_2	Establish safe egress
S_3	Suppress fire
S_4	Prevent fire spread through room boundaries
S_5	Prevent fire spread through concealed spaces and attic
S_6	Prevent external fire spread
S_7	Limit size of radiation from burning building

Parameters:

P_1	Load-bearing capacity
P_2	Detection system
P_3	Alarm system
P_4	Integrity and insulation
P_5	Escape routes
P_6	Suppression system
P_7	Fire brigade
P_8	Internal linings
P_9	Doors
P_{10}	Firestops at joints and intersections
P_{11}	Firestops in concealed spaces
P_{12}	Firestops in attic
P_{13}	Facades
P_{14}	Windows
P_{15}	Safe separating distance
P_{16}	Compartmentation
P_{17}	Smoke control system
P_{18}	Maintenance and education

4.3.3 Version 3

Version 2 of the Index Method was sent to the two external advisors for comments. Both Shields and Watts indicated that Objectives 2 and 3 were not independent of each other. The natural choice would be to simply divide the Objectives into two parts only; “Life safety” and “Property protection”. The importance of having attributes on the same level as independent of each other as possible was emphasized. Another remark was that Strategies should have a greater reflection on the text in the building regulations.

As a result of these observations, the project group had a meeting where considerable changes to the Strategies were discussed. An International Standards Organization (ISO TR 13387 Part 1 “Framework document”) document was consulted as a check. Matti Kokkala, at VTT in Finland and a member of the project group, summarized the discussion and suggested a different structure of the Index Method, here referred to as Version 3 of the Index Method. This suggestion included a rather radical change of the structure, a new decision level. In order to define the Objectives better, seven Sub-Objectives had been added.

Apart from the extra level the Strategies were also somewhat changed as a result of the discussion above. The Parameters were, however, not changed that much in this version.

The third version of the Index Method is presented in Table 4.2.

Table 4.2 An outline of Version 3 of the Index Method

Objectives:

O_1 Life safety
O_2 Property protection

Sub-Objectives:

L_1 Safety of occupants in the compartment of origin
L_2 Safety of occupants in the rest of the building
L_3 Safety of people outside and in adjacent buildings
L_4 Safety of fire fighters
E_1 Protection of property in the compartment of origin
E_2 Protection of property in the rest of the building
E_2 Protection of property outside and in adjacent buildings

Strategies:

S_1 Prevent ignition
S_2 Control fire growth
S_3 Control yield of hazardous fire effluent (smoke & gaseous species)
S_4 Control the movement of fire effluent
S_5 Confine the fire (one room, one compartment, one building)
S_6 Provide safe egress
S_7 Provide safe rescue (defend in place first - provide safe egress when needed)

Parameters:

P_1 Number & type of occupants
P_2 Fire safety management (maintenance & education)
P_3 Contents
P_4 Linings (& materials inside the structural elements possibly contributing to fire?)
P_5 Compartmentation - size, number & complexity of building layout…
P_6 Structure - load-bearing
P_7 Structure - separating (joints, cavities, penetrations, …)
P_8 Doors (between apartment and corridor/staircase)
P_9 Windows
P_{10} Facades
P_{11} Attics
P_{12} Escape routes (number, dimensions, how easy to use, materials, smoke control)
P_{13} Detection system
P_{14} Alarm system
P_{15} Smoke control (from the compartment of origin)
P_{16} Suppression system
P_{17} Fire brigade
P_{18} Surroundings (neighboring buildings, landscape around the building)

4.3.4 The project group structure of the Index Method

Version 3 of the Index Method was discussed with one of the external advisors. It was also distributed to the rest of the project group for comments. The remarks and observations made led to some changes of the basic structure and of single attributes.

The matrix was above all found far too large ($2 \times 7 \times 7 \times 18 = 1764$ cells should have to be evaluated). The Sub-Objective level therefore had to be removed. The best way of paying regard to the Sub-Objectives also in future versions of the method was simply to include them in the definitions of the Objectives.

Strategy 1 “Prevent ignition” had to be deleted since the building regulations have little or no control of sources of ignition in apartment buildings. Strategy 3 had to be deleted for the same reason; the building regulations have little or no control of the yield of hazardous fire effluent.

It was observed that Strategy 4 “Control the movement of fire effluent” was dependent of some of the other Strategies, especially Strategies 5 and 6, “Confine the fire” and “Provide safe egress” respectively. The better you confine a fire the better you control the movement of fire effluent. As a result of this Strategy 4 had to be deleted and instead included in the definitions of some of the other Strategies.

Some comments were also made to the Parameters. Parameter 1 “Number and type of occupants” and Parameter 3 “Contents” were eliminated since they cannot be controlled by the building regulations. The rest of the Parameters were left unchanged or they just changed names.

With these changes the new version of the Index Method, consisted of 2 Objectives, 4 Strategies and 16 Parameters. The size of the matrices has been decreased to $2 \times 4 \times 16 = 128$ cells, which was found acceptable. In order to help the Delphi panel in their weighting work the Policy, the Objectives, the Strategies and the Parameters were also completed with short definition texts.

This new document was circulated to the project group and also discussed in a project group meeting. After a few amendments the project group agreed to send a new version to the Delphi panel, referred to as “The project group structure of the Index Method”. This version is outlined in Table 4.3. The Fire Safety Concepts Tree constructed and revised during this work (see Section 4.3.2) is also published below as an illustration of how the structure of the hierarchy was developed.

Table 4.3 An outline of “The project group structure of the Index Method”

Policy:

Provide acceptable fire safety level in multi-storey apartment buildings

Def: Apartment buildings shall be designed in a way that ensures sufficient safety in case of fire for persons being present in or on the buildings and for material values. This includes acceptable possibilities of rescuing people, and of performing extinguishing work. Apartment buildings shall be so located as to ensure that the risk of fire spreading to other buildings becomes acceptably low.

Objectives:

O_1 Provide life safety

Def: life safety of occupants in the compartment of origin, the rest of the building, outside and in adjacent buildings and life safety of fire fighters

O_2 Provide property protection

Def: protection of property in the compartment of origin, in the rest of the building, outside and in adjacent buildings

Strategies:

S_1 Control fire growth

Def: Controlling the fire growth by using active systems (suppression systems and smoke control systems) and the fire service.

S_2 Confine fire by construction

Def: Provide structural stability, control the movement of fire through containment, use fire safe materials (linings). This has to do with passive systems or materials that are constantly in place.

S_3 Establish safe egress

Def: Cause movement of occupants and provide movement means for occupants. This is done by designing detection systems, signal systems, by designing escape routes and by educating or training the occupants. In some cases the design of the escape route may involve action by the fire brigade (escape by ladder through window).

S_4 Establish safe rescue

Def: Protect the lives and ensure safety of fire brigades officers during rescue. This is done by providing structural stability.

Parameters:

P_1 Linings in apartment
Def: Possibility of internal linings in an apartment to delay the ignition of the structure and to reduce fire growth

P_2 Suppression system
Def: Equipment and systems for suppression of fires

P_3 Fire service
Def: Possibility of external agencies to save lives and to prevent further fire spread

P_4 Compartmentation
Def: Extent to which floor areas are divided into fire compartments

P_5 Structure - separating
Def: Heat, smoke and fire resistance of building assemblies separating fire compartments

P_6 Doors
Def: Fire and smoke separating function of doors between fire compartments

P_7 Windows
Def: Windows and protection of windows, i.e. factors affecting the possibility of fire spread through the openings

P_8 Facade
Def: Facade material, suppression system etc., i.e. factors affecting the possibility of fire spread along the facade

P_9 Attic
Def: Prevention of fire spread to and in attic

P_{10} Surroundings
Def: Minimum separation distance from other building

P_{11} Smoke control system
Def: Equipment and systems for limiting spread of toxic and corrosive fire products

P_{12} Detection system
Def: Equipment and systems for detecting fires

P_{13} Signal system
Def: Equipment and systems for transmitting an alarm of fire

P_{14} Escape routes
Def: Adequacy and reliability of escape routes

P_{15} Structure - load-bearing
Def: Structural stability of the building when exposed to a fire

P_{16} Fire safety management
Def: Inspection and maintenance of fire safety equipment, escape routes etc. and education of occupants in suppression and evacuation

The Fire Safety Concepts Tree depicted in Figures 4.3 – 4.10 was developed using the Strategies given in the pilot study as a basis. This version of the tree corresponds to "The project group structure of the Index Method".

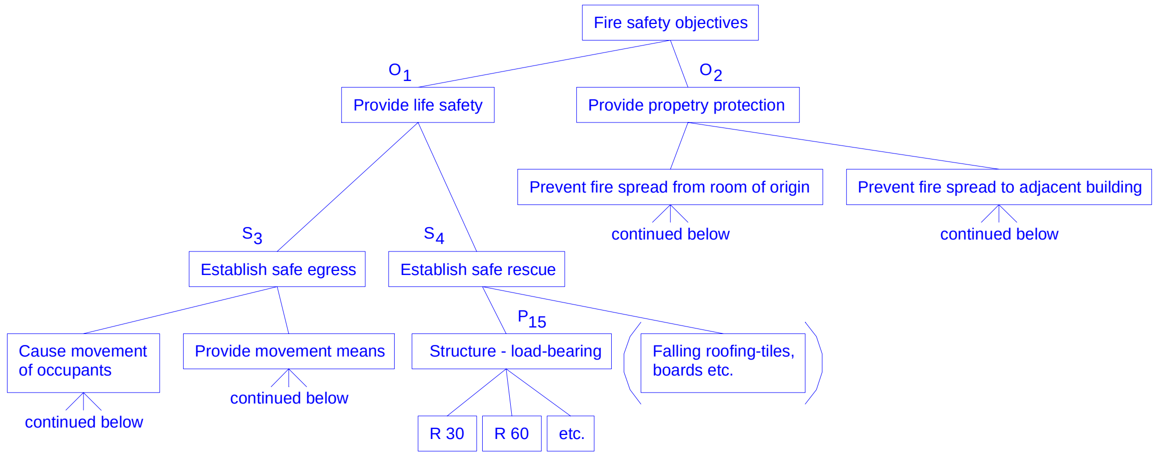

Figure 4.3 Fire Safety Objectives

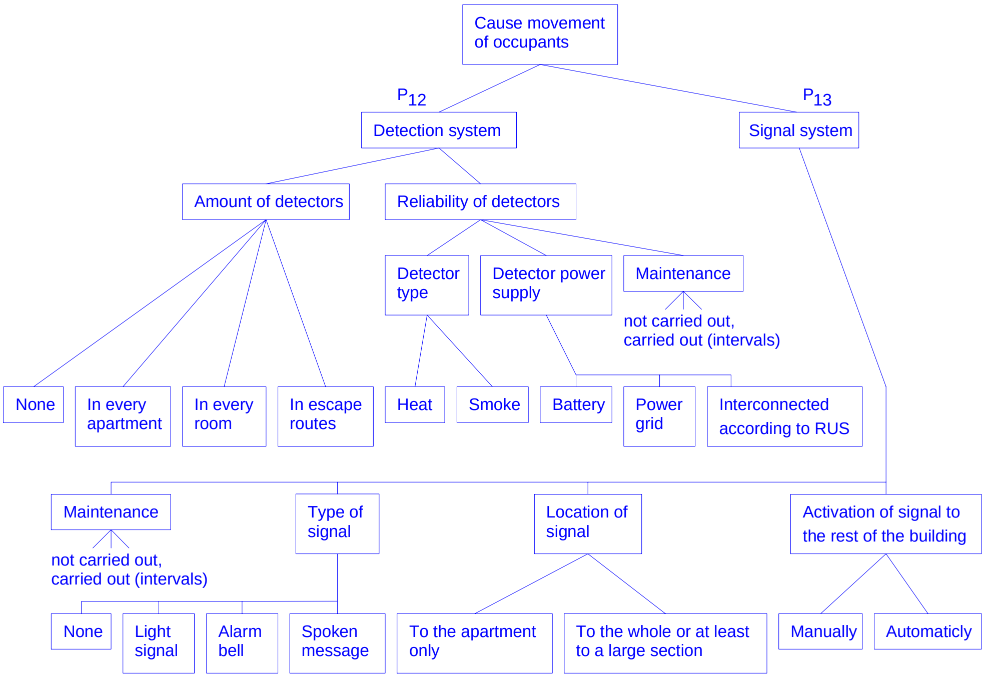

Figure 4.4 Cause movement of occupants

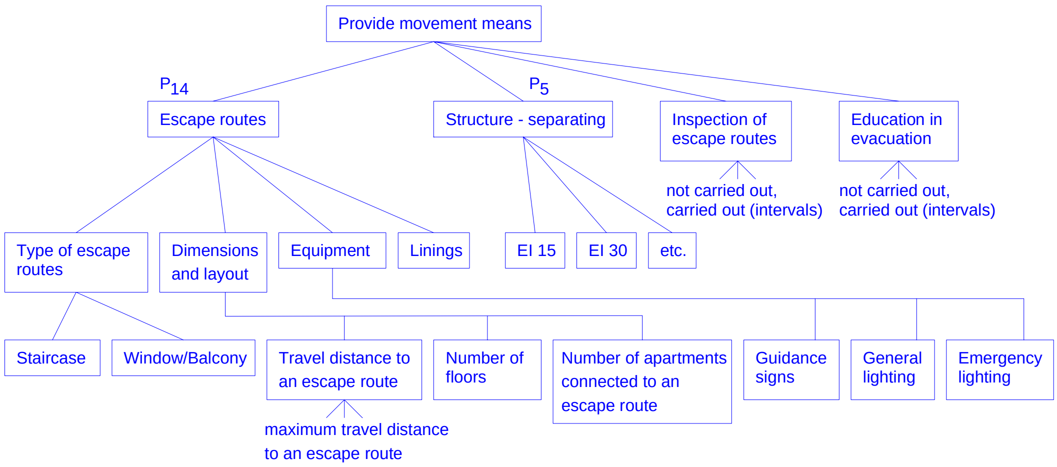

Figure 4.5 Provide movement means

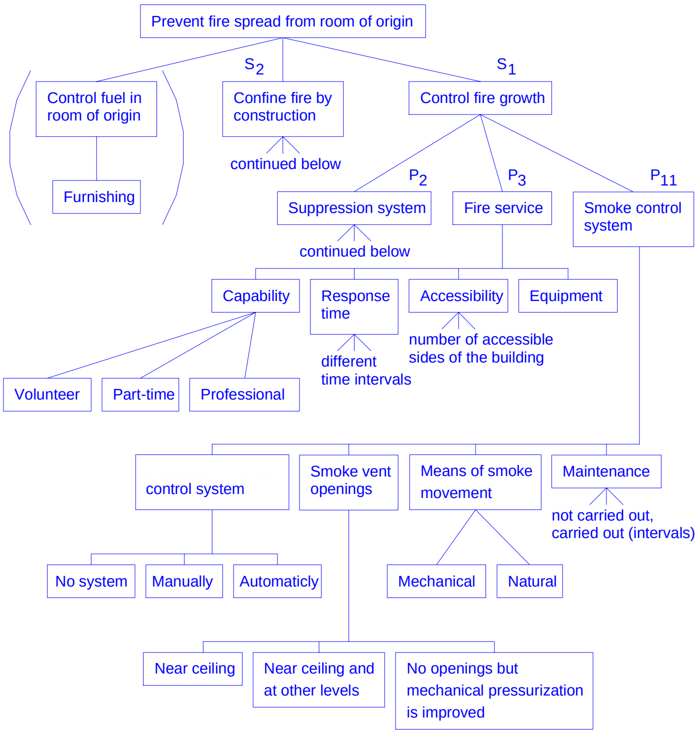

Figure 4.6 Prevent fire spread from room of origin

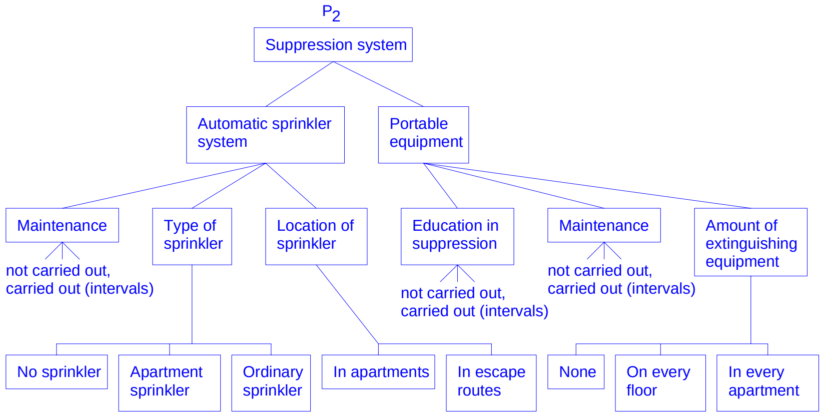

Figure 4.7 Suppression system

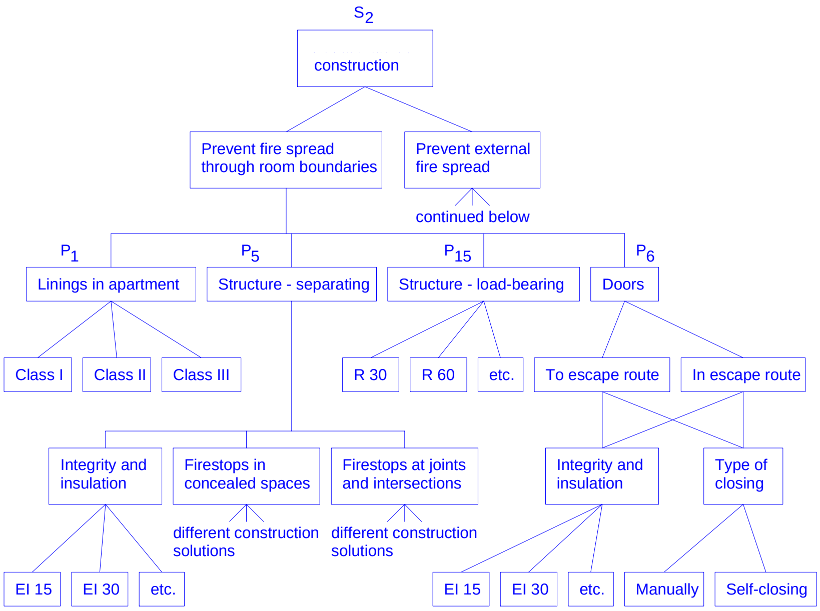

Figure 4.8 Confine fire by construction

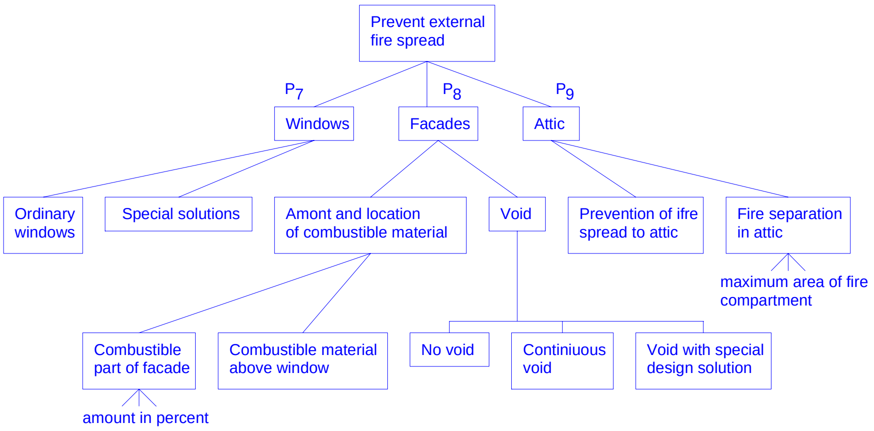

Figure 4.9 Prevent external fire spread

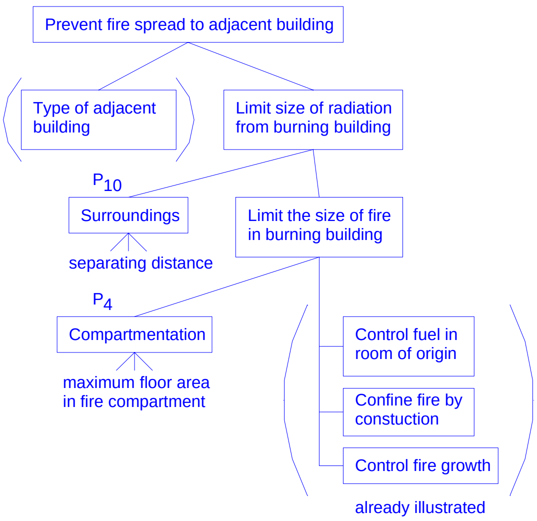

Figure 4.10 Prevent fire spread to adjacent building

4.4 Question rounds

The members of the Delphi panel were introduced to the Delphi exercise in a document, D01, sent out by the project manager, Björn Karlsson. All the documents sent out are presented in a separate report by Karlsson and Larsson [39]. During the Delphi exercise all documents, questionnaires and answer forms were distributed by e-mail.

Document D01 was sent out a few weeks before the first questionnaire was presented to the members of the Delphi panel. The purpose of the document was to give a brief introduction to the work planned for the Delphi panel and to present expected actions from the members. The pilot study, by Magnusson and Rantatalo, was enclosed in case some members would be asking for further information about some parts of the Index Method or the Delphi exercise.

The introduction presented in document D01 was divided into four parts:
1. General on the organization of the project
2. General on the structure of the Index Method
3. General on Delphi panels
4. Planned work for the Delphi panel

The first part of the document briefly described the organization of the project. The purpose of the steering group, project group, external advisors, Delphi panel etc. was also discussed.

The hierarchical levels and their attributes were described in "General on the structure of the Index Method". The ranking procedure, including weights, grades, decision tables etc. were introduced to the panel members.

"General on Delphi panels" introduced the members of the panel to the guidelines presented in "A Fire Safety Evaluation Points Scheme for Dwellings" [7] by Shields and in "The Delphi Method – Techniques and Applications" [36] by Linstone and Turoff.

Finally the planned work for the Delphi panel was presented. Four basic steps had been identified. Some of them would most likely have to be repeated several times until consensus has been reached:

1. The project group will concern themselves with the preliminary structure of the Index Method described in the next document, D02. The panel members will be asked a number of questions on the list of suggested Policy, Objectives, Strategies and Parameters.
2. Once the general structure of the method has been agreed upon, the members will be asked to give their opinions on the structure of the Sub-Parameters, the Survey Items and the decision tables.
3. When the complete structure of the method has been agreed upon, the members will be asked to assign weights to the Objectives, Strategies and Parameters.
4. Finally, the panel members will be asked to give their opinion on the Parameter grades. When consensus has been reached on this issue, the Delphi exercise is over.

In an appendix to document D01, an example of how grading of Parameters may be done in the Index Method was presented. Parameter 2, "Suppression system", with its Sub-Parameters and decision tables illustrated the basic idea.

4.4.1 Round 1

The next document sent out, D02, principally reflected the procedure described in Section 4.3, i.e. the work carried out by the project group. The purpose of the document was to introduce the preliminary structure of the Index Method, i.e. the levels of the hierarchy with their attributes, but without Sub-Parameters and Survey Items. In document D02 the suggested version was called "The project group structure of the Index Method" (see Section 4.3.4). The three earlier versions of the Index Method were also distributed as appendixes in order to give the panel the opportunity to follow the procedure and to express opinions about those versions as well. Comments to each version made by the project group and by the external advisors explained the development process.

The members of the Delphi panel were asked to build an opinion on whether the project group structure could be accepted or if additions or deletions should be made.

Seventeen answers were received to document D02. The detailed answers are given in Karlsson and Larsson [39]. Only one person did not agree with the project group proposal and instead suggested Version 3. The main explanation was that this version, with its Sub-Objectives, was much clearer. Even though the rest of the panel agreed to the preliminary structure developed by the project group, many members had some comments to the suggested attributes. Some of the comments to the attributes were taken into account and led to changes of the structure.

Some members emphasized the importance of preventing ignition and of controlling the contents of the building. This had not been taken into account in the project group proposal, but should be done according to some opinions. The project group agreed that these details, of course, are of great importance and therefore this was taken into reconsideration. The opinion was, however, still found to be the same in the project group. The building regulations cannot control the major part of those things and they should not differ that much between different types of apartment buildings. Interiors may also change at any time and there are no inspection routines for this.

As mentioned above one member suggested Version 3 instead of the project group proposal. Version 3 was, however, not possible to realize since the Delphi panel then must consider 1764 weight factors instead of 144. The definitions of both the Policy and the Objectives were, however, revised to make the attributes clearer. The Policy definition was shortened very much and instead included in the definitions given in the Objectives. These had to be formulated differently in order to have the same meaning.

Some members suggested that a new Parameter should be included in the structure, the ventilation system. This was found to be a very interesting suggestion, which had to be considered in the project group.

"Control the movement of smoke" should, according to one panel member, be included in the Strategy-level, since this is a very important way of providing life safety. This discussion had been carried out earlier in the project group and the opinion was found to still be the same; i.e. the prevention of smoke spread could only be implemented by either using active systems (S_1) or passive measures (S_2). The project group found that it would be very difficult to assign weights to a specific Strategy for smoke transport that uses and combines other Strategies.

The opinion of the project group was that the system becomes much clearer without a specific Strategy on smoke spread.

Some minor changes were also made regarding attribute names and attribute definitions as a consequence of reported deficiencies by some members of the panel.

4.4.2 Round 2

In the next round the Delphi panel was introduced more extensively to each Parameter. The full Index Method with Sub-Parameters, Survey Items and grading schemes (still without any grades) was presented. The document distributed was referred to as document “D03 Structure of the full Index Method”. A report on the results of the voting and comments to document “D02 Structure of the Index Method” was also enclosed.

The members of the Delphi panel were asked to consider the full Index Method in detail and to comment on the structure of Parameters, Sub-Parameters, decision tables and grading schemes. However, they were not asked to give grades or weights at this stage of the procedure.

Fifteen answers were received on document D03. These comments led to many changes of the Index Method and a new version called Version 1.0 was developed. However, some changes had to wait until the method had been tried in practice. The rest of the comments were considered in the project group, but no changes were made. In Version 1.0 the project group additionally gave suggested grades to all Sub-Parameters. Version 1.0 is not published in this paper due to the size of the document and because this was not the final version of the Index Method. (The version is presented in Karlsson and Larsson [39].) A summary of the changes made is, however, presented below. All changes were results of observed deficiencies by members of the Delphi panel.

A general observation made by a member of the Delphi panel was that there were several Sub-Parameters and Survey Items, which do not meet the building codes. The member supposed this was the way it was meant to be, because one purpose of the project is to search for different approaches to problems. However, the member thought that there should not exist a possibility to use solutions below certain minimum level. Remarks were made on the possibility of using plastics in P_1 and P_{14}, penetrations without any seals and voids without firestops in P_5 and leaving smoke control system out in P_{11}.

The issue was discussed in detail in the project group. The Index Method is mainly intended for use in the Nordic countries, but it is also to be used internationally. Since building codes are very different, it is sometimes difficult to decide what to include. There are also some inconsistencies between the Parameters, as to what is included.

Listed below are some of the changes which were made and resulted in Version 1.0 of the Index Method.

P_1 Linings in apartment
Small changes in the Finnish lining classes were made.

P_2 Suppression system
Small editorial changes were made.

P_3 Fire service

The Parameter was more or less completely redone.

Some members thought that the suggested Sub-Parameter “Capability of fire service” indicated a difference in quality between a part-time and a volunteer fire brigade and that there is no reason for such a difference. Some countries have part-timers and some have volunteers because the legislation and tradition for organization of fire services are different from country to country. As a fire fighting group the part-timers and volunteers are very similar. A more important Sub-Parameter would be if the fire fighters are capable of operating inside a building in fire or not. That means if they are competent breathing apparatus users or not. This would be of importance both for saving lives and prevention of fire spread. The Sub-Parameter should rather be; a) Fire fighting capability only outside the building, b) Fire fighting capability but no smoke diving capability c) Fire fighting and smoke diving capabilities d) Simultaneous fire fighting, smoke diving and external rescue by ladders.

Another comment was that ladder-trucks (which was a factor included in one of the Survey Items) of course are helpful in the rescue and extinguishing work, but it is not good to put too much emphasis on the accessibility of a ladder-truck. Parked cars, snow and other objects are often a hinder for ladder-trucks, even though there is unrestricted access in theory. “Accessibility” should instead be called “Accessibility and equipment” and should be divided into; a) All windows accessible by fire service ladder b) One window in each apartment is accessible by fire service ladders c) Less than one window in each apartment accessible by fire service ladders.

The project group found these comments very relevant and correct and therefore the “Fire service”-Parameter was changed considerably, based on these comments.

Access to water was discussed as a new Sub-Parameter. The project group assumed water supply not to vary very much within the Nordic countries, but the comments indicated that this should be considered.

P_4 Compartmentation

The area range (with respect to maximum area in fire compartment) was enlarged.

P_5 Structure – separating

Slight change in definition and a number of editorial changes were made.

Some members thought that division into only non-combustible or combustible building materials (with respect to separating structure and insulation) was not enough. They had the same opinion about “Facade” (P_8) and “Structure – load-bearing” (P_{15}) (with respect to load-bearing structure and insulation) and suggested the same classes as for “Linings in apartment” (P_1). The project group found this being an interesting proposal. However, the complexity would increase and it was decided to keep the existing, simple version of these Sub-Parameters for the moment. A definition of combustibility should be made in the User’s Guide.

P_6 Doors

Slight change in definition was made. The Survey Item “Doors in escape route” had to be explained better. In the User’s Guide escape routes have to be very clearly defined.

P_7 Windows

Slight change in definition and a number of editorial changes were made.

Some members thought that the Sub-Parameter “Relative vertical distance” (i.e. the relative relationship between the vertical distance between windows and the window height) is simple but is not the whole truth. For example the width have an influence, especially when both windows have different widths. The project agreed that there are very many geometrical configurations possible here. When trying to isolate the greatest importance, the project group decided on window height and distance to the above window.

There was also a proposal to take sprinklers into account in this Parameter. If the building has a sprinkler system there is little need of setting demands on heights or fire classes where the sprinkler operates. This was found to be a very valid point and was therefore discussed in the project group. The project group thought it might be clearer to bring the sprinkler into this Parameter, but instead the influence of sprinkler could be enhanced when giving weights to the Parameters, i.e. by giving sprinkler a high weight for controlling fire growth.

Firestops above or below windows (small sills that stick out from the facade), balconies etc. had to be considered in the next phase of the project.

P_8 Facade

No changes were made.

P_9 Attic

No changes were made.

P_{10} Adjacent buildings

Change in definition and small editorial changes were made.

A valid comment was that an alternative to separating distance between buildings is to build a separating wall to hinder fire spread, e.g. a fire wall. The definition was therefore changed and a fire wall was said to be equivalent to an 8 m distance.

P_{11} Smoke control system

One Sub-Parameter was deleted. The following proposal, formulated by a panel member; was instead adopted:

“Type of smoke control system” (Sub-Parameter):
N - Natural ventilation trough openings near ceiling
M - Mechanical ventilation
NP - Natural ventilation with pressurization
MP - Mechanical venting + pressurization

P_{12} Detection system

Slight change in Sub-Parameter definition and some editorial changes were made.

P_{13} Signal system

The Sub-Parameter "Activation of signal to the rest of building" was deleted since some members claimed that this would not work in practice.

P_{14} Escape routes

Several corrections were made, like for example:

Escape route, travel distance etc. had to be better defined. A clear definition will be found in the User's Guide.

The importance of floorings was emphasized by some members and was therefore included in the new definition of the existing Sub-Parameter "Linings".

P_{15} Structure - load-bearing

Small editorial changes were made.

P_{16} Maintenance and information

The Parameter name was changed.

P_{17} Ventilation system

This was a new Parameter included in the new version of the Index Method (Version 1.0). The Parameter was a result of comments from members of the Delphi panel.

4.4.3 Round 3

Version 1.0 of the Index Method was distributed to the panel members in the introduction to the third round of the Delphi exercise. The purpose of the document sent out, "D04: Assigning weights to Version 1.0 of the Index Method" was to introduce the panel members to the weighting work. A report on the responses of the Delphi panel to document "D03: Structure of the full Index Method" was also enclosed to the letter.

The project group had already given grades to all the Sub-Parameters and to most of the Parameters. The panel members were now asked to give their opinions on these grades, to assign weights to the Objectives, Strategies and Parameters and finally to assign weights to some of the Sub-Parameters (see below).

Assigning weights to Objectives, Strategies and Parameters

The project group asked for weights to the Objectives, Strategies and Parameters. Here the Delphi panel had to use a scale from 0 to 5. The sum of the weights was not important. The scale was the following:

0 = No influence at all
1 = Only of very slight importance
2 = Not important
3 = Important
4 = Very important
5 = Extremely important

Three levels in the hierarchy had to considered:

- Objectives/Policy (2 weights had to be assigned)
- Strategies/Objectives (8 weights had to be assigned)
- Parameters/Strategies (68 weights had to be assigned)

For example when assigning weights to Objectives the panel members had to face themselves with questions like "How important is "Provide life safety" (O_1) for achieving the Policy ("Provide acceptable fire safety level…")?". The following table had to be filled in:

	Policy
O_1	
O_2	

When consider Strategies/Objectives following questions had to be answered:

- How important is it to control fire growth by active means if we wish to provide life safety? (S_1/O_1)
- How important is it to control fire growth by active means if we wish to provide property protection? (S_1/O_2)
- How important is it to confine fire by construction if we wish to provide life safety? (S_2/O_1)
- How important is it to confine fire by construction if we wish to provide property protection? (S_2/O_2)
- How important is it to establish safe egress if we wish to provide life safety? (S_3/O_1)
- How important is it to establish safe egress if we wish to provide property protection? (S_3/O_2)
- How important is it to establish safe rescue if we wish to provide life safety? (S_4/O_1)
- How important is it to establish safe rescue if we wish to provide property protection? (S_4/O_2)

Each member was asked to fill in the following table:

	O_1	O_2
S_1		
S_2		
S_3		
S_4		

When considering Parameters/Strategies 68 questions had to be answered in the same way as above.

	S_1	S_2	S_3	S_4
P_1				
P_2				
P_3				
P_4				

etc.

Assigning weights to Sub-Parameters

Some of the Parameters were found to be too complex to be described with just simple grading schemes. A better way of describing them is by using the same mathematical equation as has been done for the higher levels of the hierarchy. The Parameter grade is accordingly calculated from the Sub-Parameter weights and the Sub-Parameter grades, as described in Formula 4.2.

The scale for each Sub-Parameter was 0% - 100%, and the sum of the weights for each Parameter had to be 100%. Seven tables like this one for Parameter 3, "Fire service", had to be filled in by each member of the Delphi panel. The panel members had to ask themselves: How important is "Capability" in relation to the other two Sub-Parameters? etc.

P_3. Fire service

	Sub-Parameter	% importance
a	Capability	
b	Response time	
c	Accessibility and equipment	

Sum = 100%

Answers

The following answers were received from the Delphi panel. The full results are given in Karlsson and Larsson [39].

First the weighting of Objectives, Strategies and Parameters is presented. According to the project manager assigning weights to the Objectives and the Strategies went reasonably well, but there was a problem with the weighting of the Parameters. The results are summarized in the tables below. Tables for the Parameter weights are, however, too comprehensive to be published here (altogether 17 tables).

The average values, specially marked in the tables (extra bold types), were chosen to represent the weights of the attributes in the Index Method.

Objective Weights		
	O_1/Policy	O_2/Policy
Average	**4.8**	**3.2**
1st Quartile	5	3
Median	5	3
3rd Quartile	5	4

Strategy Weights				
	S_1/O_1	S_2/O_1	S_3/O_1	S_4/O_1
Average	**4.05**	**3.5**	**4.6**	**3.7**
1st Quartile	3	3	4	3
Median	4	3	5	4
3rd Quartile	5	4	5	5

Strategy Weights				
	S_1/O_2	S_2/O_2	S_3/O_2	S_4/O_2
Average	**3.85**	**4.25**	**1.25**	**2.25**
1st Quartile	3	4	0	0
Median	4	4	1	3
3rd Quartile	4.25	5	2	3.25

In the first table weights were assigned to the two Objectives versus the Policy. The consensus was found very good and the working resulted in the grades: O_1 = 4.8 and O_2 = 3.2. Normalizing this it was found that "Provide life safety" (O_1) stands for 4.8 / (4.8 + 3.2) = 60 % and "Provide property protection"(O_2) stands for 3.2 / (4.8 + 3.2) = 40 % of the importance for reaching the Policy.

The consensus was also quite good for Strategies versus "Provide life safety" (O_1) and Strategies versus "Provide property protection" (O_2). The worst consensus is for S_4/O_2, but the result was still deemed acceptable.

The average results were the following:

For "Provide life safety" (O_1)

Control fire by active means (S_1)	25 %
Control fire by construction (S_2)	22 %
Establish safe egress (S_3)	29 %
Establish safe rescue (S_4)	23 %

For "Provide property protection" (O_2)

Control fire by active means (S_1)	33 %
Control fire by construction (S_2)	37 %
Establish safe egress (S_3)	11 %
Establish safe rescue (S_4)	19 %

When looking at the grades given for the Parameters versus the Strategies the project group felt that the results were too "flat". Two main reasons were found for this:

1. The directions on how to give weights, provided in document D04, may not have been clear enough. The directions should have been clearer and weights should have been given in a slightly different order.
2. The whole scale of weights from 0 to 5 was not used much, Delphi members tended to use the weights 3 to 5.

In the next round these things had to be changed. This is further discussed in Section 4.4.4.

The weights for the Parameters versus the Policy, which will be used in the calculation of the risk index (according to Formula 2.5), were, however, preliminary calculated, based on the given grades.

Figure 2.1 illustrates the matrix manipulation used to calculate the weights. By multiplying the Objectives×Policy vector (a 2×1 vector) by the Strategies×Objectives matrix (a 4×2 matrix) a Strategies×Policy vector (a 4×1 vector) is received. Multiplying this by the Parameters×Strategies matrix (a 17×4 matrix) the Parameters×Policy vector (a 17×1 vector) is received. When normalizing this vector (so the sum of all the values is 1.0) it shows how important each Parameter is for the overall Fire Safety Policy.

The averaged Parameter weights, results of the third question round, were the following:

Linings (P_1)	4.97 %
Suppression system (P_2)	6.66 %
Fire service (P_3)	6.71 %
Compartmentation (P_4)	6.24 %
Structure-separating (P_5)	6.79 %
Doors (P_6)	6.94 %
Windows (P_7)	4.87 %
Facade (P_8)	5.17 %
Attic) (P_9)	5.41 %
Adjacent buildings (P_{10})	4.49 %
Smoke control system (P_{11})	6.26 %
Detection system (P_{12})	6.07 %
Signal system (P_{13})	5.06 %
Escape routes (P_{14})	6.02 %
Structure-load-bearing (P_{15})	6.53 %
Maintenance and info (P_{16})	6.28 %
Ventilation system (P_{17})	5.54 %
Sum	100 %

Weighting of some of the Sub-Parameters (for the Parameters P_3, P_5, P_6, P_8, P_{14}, P_{15} and P_{16}) were the second part of the work carried out in this round of the Delphi exercise. According to the project manager, the weighting went very well and there was good consensus. However, the spread of the answers of course varied between the different Sub-Parameters. P_6 and P_{15} were found to have the largest spread of answers. However, the members of the Delphi panel would get a chance to change their weights in the next question round.

The average values, specially marked in the tables, were chosen to represent the weights of the Sub-Parameters in the Index Method.

Sub-Parameter Weights			
	P3a	P3b	P3c
Average	**30.75**	**46.75**	**22.5**
1st Quartile	20	40	20
Median	30	50	20
3rd Quartile	40	60	30

Sub-Parameter Weights				
	P5a	P5b	P5c	P5d
Average	**34.5**	**28**	**24.5**	**13**
1st Quartile	28.75	20	20	10
Median	40	25	25	10
3rd Quartile	40	30	30	20

Sub-Parameter Weights		
	P6a	P6b
Average	**67.25**	**32.75**
1st Quartile	57.5	20
Median	70	30
3rd Quartile	80	42.5

Sub-Parameter Weights			
	P8a	P8b	P8c
Average	**40.9**	**29.95**	**29.15**
1st Quartile	30	20	20
Median	40	30	30
3rd Quartile	50	34.25	40

Sub-Parameter Weights				
	P14a	P14b	P14c	P14d
Average	**33.5**	**27.25**	**16**	**23.25**
1st Quartile	25	20	10	17.5
Median	30	27.5	15	22.5
3rd Quartile	40	30	20	30

Sub-Parameter Weights		
	P15a	P15b
Average	**73.75**	**26.25**
1st Quartile	67.5	10
Median	70	30
3rd Quartile	90	32.5

Sub-Parameter Weights			
	P16a	P16b	P16c
Average	**39.5**	**27.25**	**33.25**
1st Quartile	30	20	20
Median	40	27.5	30
3rd Quartile	46.25	40	41.25

To summarize the results the average values are shown below (0.31 stands for 31% of the importance etc.):

- **Fire service (P_3):** (0.31 × Capability + 0.47 × Response time + 0.22 × Accessibility and equipment)
- **Structure-separating (P_5):** (0.35 × Integrity and insulation + 0.28 × Firestops at joints, intersections and concealed spaces + 0.24 × Penetrations + 0.13 × Combustibility)
- **Doors (P_6):** (0.67 × Doors leading to escape route + 0.33 × Doors in escape route)
- **Facade (P_8):** (0.41 × Combustible part of facade + 0.30 × Combustible material above windows + 0.29 × Void)
- **Escape routes (P_{14}):** (0.34 × Type of escape routes + 0.27 × Dimensions and layout + 0.16 × Equipment + 0.23 × Linings and floorings)
- **Structure - load-bearing (P_{15}):** (0.74 × Load-bearing capacity + 0.26 × Combustibility)
- **Maintenance and information (P_{16}):** (0.40 × Maintenance of fire safety systems + 0.27 × Inspection of escape routes + 0.33 × Information)

The question round resulted in Version 1.1 of the Index Method.

However, as stated above, the project group felt that some of the results were somewhat “flat”. Another question round was therefore carried out to give the panel members the opportunity to change their results if they wished to.

4.4.4 Round 4

The main purpose of this question round was to give the members of the Delphi panel a second opportunity to give weights to Parameters versus Strategies. In the Delphi process, it is, however, customary to circulate the results from the questionnaires to allow the members of the panel to revise all their inputs. A second chance was therefore given to change the Sub-Parameters weights for P_3, P_5, P_6, P_8, P_{14}, P_{15} and P_{16} and to change the weights for Parameters versus Strategies, Strategies versus Objectives and Objectives versus the Policy.

The document sent out to the Delphi panel was called “D05: Round 2 - Assigning weights to Version 1.1 of the Index Method”. In the document guidelines for the round and results from the last round were given. In the appendixes two new forms for new weights were enclosed.

As stated above the consensus for the Sub-Parameter weights was generally good, but the panel members were although asked to take a look at the results and maybe change their weights. Especially, new weights for P_6 and P_{15} were asked for.

Even though the weighting of Objectives versus Policy and Strategies versus Objectives went quite well the consensus was weak in some parts. Especially the consensus for S_4/O_2 was questionable and therefore the members of the Delphi panel were asked to have a special look at this value.

The project group felt that the weights for Parameters versus Strategies were somewhat “flat” and the panel members were therefore asked again to fill in the Parameters/Strategies table. However, this time the panel members, instead of considering Parameter P_1 first and consider the weight it has for Strategies S_1, S_2, S_3 and S_4, were asked to do this in a different order. The panel members were now asked to look at Strategy S_1 and consider the weights it has for all

Parameters, P_1 to P_{17}. Instead of filling in the table horizontally, this time the table was filled in vertically:

	S_1
Linings (P_1)	
Suppression system (P_2)	
Fire service (P_3)	
Compartmentation (P_4)	
Structure-separating (P_5)	
Doors (P_6)	
Windows (P_7)	
Facade (P_8)	
Attic (P_9)	
Adjacent buildings (P_{10})	
Smoke control system (P_{11})	
Detection system (P_{12})	
Signal system (P_{13})	
Escape routes (P_{14})	
Structure-load-bearing (P_{15})	
Maintenance and info (P_{16})	
Ventilation system (P_{17})	

Questions like these now had to be answered by each member of the Delphi panel:

- If we wish to control fire growth by active means (S_1), which Parameters are extremely important? These Parameters should get the weight 5.
- If we wish to control fire growth by active means (S_1), which Parameters are very important? These Parameters should get the weight 4.
- If we wish to control fire growth by active means (S_1), which Parameters are of medium importance? These Parameters should get the weight 3.
- If we wish to control fire growth by active means (S_1), which Parameters are of little importance? These Parameters should get the weight 2.
- If we wish to control fire growth by active means (S_1), which Parameters are of very slight importance? These Parameters should get the weight 1.
- If we wish to control fire growth by active means (S_1), which Parameters are of no importance? These Parameters should get the weight 0.

Corresponding questions then had to be asked for the rest of the Strategies. The consensus in the first round was particularly bad for P_{10}/S_3, P_{12}/S_4 and P_{13}/S_1. The panel members were asked to look at these three combinations more closely when assigning the weights to these. Also P_8/S_1, P_8/S_4, P_{13}/S_4, P_{14}/S_1, P_{14}/S_2, P_{15}/S_1 and P_{17}/S_1 were mentioned in the document since the consensus was not very good for these either.

Answers

The answers received in this round were quite similar to the answers received in the previous round. The full results from round 4 are given in Karlsson and Larsson [39].

The question round resulted in some minor adjustments and a new version of the method, referred to as Version 1.2 of the Index Method. This latest version of the Index Method is presented in the next chapter and in Appendix A.

5 The Fire Risk Index Method

5.1 Summary of the development process

This chapter will discuss the latest version of the Index Method. This version called ”Version 1.2 of the Index Method” is a result of the work carried out in the Nordic Wood project ”Fire-safe Wooden Houses” (see Chapter 1). The first part of the project was carried out by Magnusson and Rantatalo in a pilot study [8] (see Chapter 3) and the further work was carried out by a project group, with Björn Karlsson as project manager, in co-operation with a Delphi panel. The Delphi panel consisted of fire safety experts from the Nordic countries (see Chapter 4).

The hierarchical structure used in this method has been used in many earlier approaches and is very well accepted. The project group, through the construction of a Fire Safety Concept Tree, derived the attributes comprising each level of the structure. The attributes reflect all the factors which influence the fire safety (or at least all the factors which account for an acceptably large portion of the fire safety) and which are possible to measure or to observe. The Delphi panel accepted the structure of the method and the attributes. Also Parameter grades were derived by the project group and accepted by the Delphi panel. Weights to attributes were derived through a Delphi exercise. The values in Version 1.2 were received after a number of question rounds. (The Delphi procedure had to be repeated until reasonable consensus was reached in every single question.)

During this procedure two external experts were consulted in some parts of the work. Dr John Watts (Fire Safety Institute, USA) and Professor Jim Shields (University of Ulster, Great Britain) both have great experience in the methods which were used in this project.

5.2 How to use the method

From now on the method is referred to as “The Fire Risk Index Method”.

The Fire Risk Index Method can be applied to all types of ordinary apartment buildings, i.e. not home for aged, hospitals etc. The calculated risk of a building can thus be compared to other apartment buildings. A high risk index for a building represents a high level of fire safety and a low risk index a low level of fire safety. The theoretical maximum value is 5.0 and 0.0 is the theoretical minimum value.

The Fire Risk Index Method is aimed to be easy to use also for persons without deeper knowledge about fire safety. However, the user has to be familiar with the specific building, regarding e.g. construction solutions, materials and the design of the ventilation system. Access to drawings is necessary when using the method. Since the level of fire safety also depends on the possibility to an effective rescue operation, one has to know a bit about the capacity of the responding fire service.

When applying the Fire Risk Index Method to an apartment building all the 17 grading schemes have to be used. Grades for Survey Items and Sub-Parameters will be found in simple tables. The Parameter grades will then be given in decision tables or through an equation. The final risk index is then calculated in an equation that includes all 17 Parameter weights and grades.

The Fire Risk Index Method will be available in two different formats. In one format the user assigns grades by pencil and uses a hand-calculator to calculate the risk index. A second format is visually nearly identical, but here the user can give grades using pull down menus and the risk index is calculated manually.

To illustrate how the Fire Risk Index Method may be used, it has been applied to a reference object. The application to an existing timber-frame building in Linköping and an corresponding, non-existing concrete building is described in Chapter 6.

A User's Guide to the Fire Risk Index Method is currently being developed. This document gives a more detailed description of its use.

5.3 The latest version

The latest version of the Fire Risk Index Method (Version 1.2), without any additions or reductions, is presented in Appendix A.

The risk index is calculated from the formula:

$$S = \sum_{i=1}^{n} w_i \, x_i \qquad \text{(Formula 5.1)}$$

where

S = the risk index expressing the fire safety in the building
n = number of Parameters (= 17)
w_i = weight for Parameter i (found on the last page in Appendix A)
x_i = grade for Parameter i (found in the grading schemes in Appendix A)

The last page in Appendix A shows how the risk index is calculated and the importance of each Parameter.

6 Application of the Fire Risk Index Method to a reference object

As a part of the project "Risk Evaluation" the Fire Risk Index Method has been applied to a reference object. The purpose has been to visualize general differences between the combustible and the non-combustible building. Apart from the construction material, the conditions have to be the same for the buildings in the comparison. This will make the weak parts of the timber-frame building appear. It will, however, be possible to find different ways to compensate for the "deficiencies" of a timber-frame building and thereby to reach the same, or an even higher, level of fire safety as for a non-combustible building.

6.1 Description of the reference object

As reference object a building project in Linköping, Sweden, named Orgelbänken, was chosen. This apartment building was built in 1995/1996 as a pilot project in the resumed Nordic timber-frame construction. In this chapter, Parameter grades for the existing timber-frame building and a corresponding, non-existing concrete building are presented. The estimates made in this chapter are based on information found in drawings and in the report "Flervånings Trähus" [40]. Ulf Persson, Skanska Teknik in Malmö, Sweden, has also contributed with valuable information.

Before going through each Parameter maybe a brief description of the building is suitable. Orgelbänken consists of a single building with four floors and 36 apartments. The building has got an attic but no basement. The apartments are connected to two separate stairwells by access balconies. The load-bearing construction is carried out of wood, indoors covered by gypsum boards. Wood-panel is the facade material in access balconies and in stairwells and plaster in the rest of the building. Further details about Orgelbänken are found in the above-mentioned report, "Flervånings Trähus" [40], and in the drawings in Appendix C.

6.2 Parameters

The two buildings were found to receive grades as below. Motivations are given where they have been found necessary. Identified problems when giving grades are also commentated.

P_1 Linings in apartment

Timber-frame building: 5

Concrete building: 5

<u>Motivation:</u>

Gypsum boards / concrete

P_2 Suppression system

Timber-frame building: 0

Concrete building: 0

Motivation:

- Automatic sprinkler system: N
  - Type of sprinkler: N
  - Location of sprinkler: -
- Portable equipment: N

There is no suppression equipment in the building.

P_3 Fire service

Timber-frame building: 3.62

Concrete building: 3.62

Motivation:

- Capability: 5
- Response time: 3
- Accessibility and equipment: 3

Parameter grade: $0.31 \times 5 + 0.47 \times 3 + 0.22 \times 3 = 3.62$

Comment:

A problem appears when giving a grade to Sub-Parameter "Accessibility and equipment". It is possible that every window in the two long sides are accessible. However, if the building also got inaccessible gable windows it immediately gets a lower grade then a similar building without those windows.

P_4 Compartmentation

Timber-frame building: 2

Concrete building: 2

Comment:

Are fire compartments like stairwells also included in this Parameter?
If they are, do we sum the building space on every floor?

P_5 Structure - separating

Timber-frame building: 3.44

Concrete building: 4.28

<u>Motivation:</u>

- Integrity and insulation: 5 (?)
- Firestops at joints, intersections and concealed spaces: 2 (timber-frame) / 5 (concrete)
- Penetrations: 2
- Combustibility: 5

In both cases the <u>separating</u> structures and the insulation are non-combustible.

Parameter grade: $0.35 \times 5 + 0.28 \times 2 + 0.24 \times 2 + 0.13 \times 5 = 3.44$ (timber-frame)
Parameter grade: $0.35 \times 5 + 0.28 \times 5 + 0.24 \times 2 + 0.13 \times 5 = 4.28$ (concrete)

<u>Comment:</u>

In Orgelbänken, EI 60 has been used in separating constructions, except for the separating walls in the attic (EI 30). Do we receive the grade 5 or just 3 for “Integrity and insulation”?

P_6 Doors

Timber-frame building: 2.66

Concrete building: 2.66

<u>Motivation:</u>

- Doors leading to escape route: 2
  - Integrity and insulation: C
  - Type of closing: M
- Doors in escape route: 4
  - Integrity and insulation: C
  - Type of closing: S

Parameter grade: $0.67 \times 2 + 0.33 \times 4 = 2.66$

<u>Comment:</u>

Just the doors in the stairwells are self-closing. The grades above depend on how escape routes will be defined in the User’s Guide to the Fire Risk Index Method.

P_7 Windows

Timber-frame building: 2

Concrete building: 2

Motivation:

- Relative vertical distance: B
- Class of window: C
  - R > 1

Comment:

A problem here is the apartment doors and the balcony doors, which are placed with a smaller vertical distance than the windows. The doors are, however, separated with access balconies and balconies respectively. (The apartment doors also have EI 30 classification.)

P_8 Facades

Timber-frame building: 1.69

Concrete building: 5

Motivation:

- Combustible part of facade: 2 (?) (timber-frame) / 5 (concrete)
- Combustible material above windows: 0 (?) (timber-frame) / 5 (concrete)
- Void: 3 (timber-frame) / 5 (concrete)

Parameter grade: $0.41 \times 2 + 0.30 \times 0 + 0.29 \times 3 = 1.69$ (timber-frame)
Parameter grade: $0.41 \times 5 + 0.30 \times 5 + 0.29 \times 5 = 5$ (concrete)

Comment:

In Orgelbänken the combustible part of the facade is about 20 %. However, the combustible material is located in access balconies and in stairwells. The rest of the building has got non-combustible facade. Is the grade given too low?

P_9 Attic

Timber-frame building: 1

Concrete building: 1

Motivation:

- Prevention of fire spread to attic: N
- Fire separation in attic: L

Ventilation is provided at the eave.

Comment:

Is it impossible to receive the Parameter grade 0? (> 600 m^2 has to result in no grade, N). If it is impossible to receive the Parameter grade 0 the theoretical minimum risk index is higher than 0.

P_{10} Adjacent buildings

Timber-frame building: 2

Concrete building: 2

P_{11} Smoke control system

Timber-frame building: 2

Concrete building: 2

Motivation:

- Activation of smoke control system: M
- Type of smoke control system: N

Smoke ventilation is provided manually through windows (or through doors leading to access balconies) at the top of the stairwells.

P_{12} Detection system

Timber-frame building: 2

Concrete building: 2

Motivation:

- Amount of detectors: L
  - Detectors in apartment: A
  - Detectors in escape route: N
- Reliability of detectors: M
  - Detector type: S
  - Detector power supply: B

There are smoke detectors (battery) in every apartment.

P_{13} Signal system

Timber-frame building: 3

Concrete building: 3

Motivation:

- Type of signal: M
  - Light signal: N
  - Sound signal: A
- Location of signal: A

P_{14} Escape routes

Timber-frame building: 2.83

Concrete building: 3.52

Motivation:

- Type of escape routes: 3
  - Staircase: A
  - Window/Balcony: H
- Dimensions and layout: 5
  - Maximum travel distance to an escape route: A
  - Number of floors: D
  - Maximum number of apartments per floor connected to an escape route: G
- Equipment: 0
  - Guidance signs: A
  - General lighting: D
  - Emergency lighting: F
- Linings and floorings: 2 (timber-frame) / 5 (concrete)

Floors in access balconies are carried out of wood.

Parameter grade: $0.34 \times 3 + 0.27 \times 5 + 0.16 \times 0 + 0.23 \times 2 = 2.83$ (timber-frame)
Parameter grade: $0.34 \times 3 + 0.27 \times 5 + 0.16 \times 0 + 0.23 \times 5 = 3.52$ (concrete)

Comment:

Usually some part of the travel distance to an escape route is the same for the different alternative escape routes from an apartment. (For example very often the occupants have to leave the bedroom before they can choose between the apartment door and the balcony door.) According to Swedish recommendations in this field [41] that part of the travel distance should be multiplied by 1.5 or 2.0. In the User's Guide a guideline for this situation should be presented.

The attic is not considered to be a floor according to Swedish recommendations [41], but what is the situation in other countries?

P_{15} Structure load-bearing

Timber-frame building: 3.74

Concrete building: 4.26

Motivation:

- Load-bearing capacity: 4 (?)
- Combustibility: 3 (timber-frame) / 5 (concrete)

The load-bearing structures are carried out of wood and concrete respectively.

Parameter grade: $0.74 \times 4 + 0.26 \times 3 = 3.74$ (timber-frame)
Parameter grade: $0.74 \times 4 + 0.26 \times 5 = 4.26$ (concrete)

Comment:

R 60 is used for almost the whole building, but with exception of staircases (R 30). Do we receive the grade 4 or just 2 for "Load-bearing capacity"?

P_{16} Maintenance and information

Timber-frame building: 0

Concrete building: 0

Motivation:

- Maintenance of fire safety systems: 0
- Inspection of escape routes: 0
- Information: 0
  - Written information: A
  - Drills: D

P_{17} Ventilation system

Timber-frame building: 2

Concrete building: 2

6.3 Index calculation

The risk index will now be calculated according to Formula A.1 given in Appendix A.

$S = 0.0576 \times x_1 + 0.0668 \times x_2 + 0.0681 \times x_3 + 0.0666 \times x_4 + 0.0675 \times x_5 + 0.0698 \times x_6 + 0.0473 \times x_7 + 0.0492 \times x_8 + 0.0515 \times x_9 + 0.0396 \times x_{10} + 0.0609 \times x_{11} + 0.0630 \times x_{12} + 0.0512 \times x_{13} + 0.0620 \times x_{14} + 0.0630 \times x_{15} + 0.0601 \times x_{16} + 0.0558 \times x_{17}$

The existing timber-frame building has got the following grades:

Parameter	Weight	Grade	WEIGHTED GRADE
P1	0.0576	**5**	0.2880
P2	0.0668	**0**	0.0000
P3	0.0681	**3.62**	0.2465
P4	0.0666	**2**	0.1332
P5	0.0675	**3.44**	0.2322
P6	0.0698	**2.66**	0.1857
P7	0.0473	**2**	0.0946
P8	0.0492	**1.69**	0.0831
P9	0.0515	**1**	0.0515
P10	0.0396	**2**	0.0792
P11	0.0609	**2**	0.1218
P12	0.0630	**2**	0.1260
P13	0.0512	**3**	0.1536
P14	0.0620	**2.83**	0.1755
P15	0.0630	**3.74**	0.2356
P16	0.0601	**0**	0.0000
P17	0.0558	**2**	0.1116
Sum	1.0000		
		SCORE ⇒	**2.3181**

This results in a **risk index = 2.32**.

The corresponding concrete building has got the following grades:

Parameter	Weight	Grade	WEIGHTED GRADE
P1	0.0576	**5**	0.2880
P2	0.0668	**0**	0.0000
P3	0.0681	**3.62**	0.2465
P4	0.0666	**2**	0.1332
P5	0.0675	**4.28**	0.2889
P6	0.0698	**2.66**	0.1857
P7	0.0473	**2**	0.0946
P8	0.0492	**5**	0.2460
P9	0.0515	**1**	0.0515
P10	0.0396	**2**	0.0792
P11	0.0609	**2**	0.1218
P12	0.0630	**2**	0.1260
P13	0.0512	**3**	0.1536
P14	0.0620	**3.52**	0.2182
P15	0.0630	**4.26**	0.2684
P16	0.0601	**0**	0.0000
P17	0.0558	**2**	0.1116
Sum	1.0000		
		SCORE ⇒	**2.6132**

This results in a **risk index = 2.61**.

The grade of the concrete building is about 0.3 higher than for the timber-frame building. It is, however, possible to “compensate” for the lower grade in many different ways. By for example installing a residential sprinkler system in the apartments and in the escape routes the risk index for the timber-frame building increases to 2.65. Inspections of escape routes, information to occupants, installation of smoke control system are other examples of ways to increase the risk index.

7 Conclusions

In this report some of the work carried out in the Nordic Wood project “Fire-safe Wooden Houses” has been summarized. The Swedish part of the sub-project “Risk Evaluation”, led by Lund University in Sweden, had the objective of producing a simple fire risk assessment method, possible to apply to both combustible and non-combustible multi-storey apartment buildings. The method is named “The Fire Risk Index Method”.

As a part of the project existing risk assessment methods have been studied (see Chapter 2). The most appropriate methodology, “the hierarchical approach”, has then been applied to multi-storey apartment buildings.

A major demand has been that the reliability of the method could not suffer because of its simplicity. In order to get reliable results, the so-called “Delphi technique” has been used. In the Delphi exercise a panel, consisting of a great number of varying kinds of fire safety experts, a Delphi panel, was asked by the project group to give their opinions on several questions. This procedure has been the most time-consuming part of the project (see Chapter 4).

As mentioned above the main objective has been to develop a new, simple risk assessment method. The basic demand was that the method had to make it possible to compare combustible and non-combustible buildings from a fire safety point of view. Besides that a lot of other requirements was also introduced (see e.g. Section 2.1). In order to fulfil those requirements a strategy for the work was outlined by Magnusson and Rantatalo in the pilot study (see Chapter 3), based on Watts’ five-step process (see Section 1.3). The project group adopted the strategy, with some adjustments and additions, for the Delphi exercise.

At the end of Phase 1 of the project “Risk Evaluation” two steps remained. These steps will be concluded in Phase 2. Some of the work outlined in the steps below has already been started.

The first of the two remaining steps corresponds to Step 5 in Watts’ five-step process “Validate and calibrate the evaluation procedure” (see Section 1.3). The Fire Risk Index Method is planned to be validated over a range of timber-frame building designs and calibrated by applying it to building constructions approved by existing prescriptive regulations (building frames with non-combustible material).

This first step includes [39]:

a) Four engineers will be appointed, one in each Nordic country. The engineers will apply the method to four different types of reference objects, chosen by the project group, preferably existing timber-frame structures. Each engineer will write a short report on the difficulties encountered when applying the method and comment on the applicability.

b) The four different types of timber-frame multi-storey apartment buildings (see point a above) will be analyzed according to current regulation with respect to the Life Safety Objective. The calculation tools HAZARD and SIMULEX are planned to be used to calculate time to hazardous conditions and time to escape for a number of scenarios. It has also been found necessary to use event-tree analysis when estimating the consequences of each scenario. The results from the calculation procedure will provide a ranking of the four types of buildings. The ranking will then be compared to the ranking from the Fire Risk Index Method.

c) The buildings that have been analyzed in the Finnish part of the project “Risk Evaluation” (currently the Viikki apartment building and a virtual building) will also be analyzed as outlined in point b above.) The results from CRISP, HAZARD, SIMULEX and the event-tree assessments will be compared. The Fire Risk Index Method will also be applied to these buildings and rankings for the Life Safety Objective will be compared.

d) The Property Protection Objective will be discussed. A number of ways in which this Objective can be verified will be described.

e) Finally the results will be summarized and proposals for changes in the Fire Risk Index Method will be formulated. A final Delphi round may be carried out, if the changes are deemed to be considerable.

In the last step of the project the Fire Risk Index Method will be made practically available to engineers, researchers etc. and marketed internationally.

This last step includes [39]:

a) A technical guidance document will be produced, containing background information on the development and the applicability of the method.

b) A User’s Guide will also be produced in order to ease the practical use of the method.

c) A web site will be set up specifically for the Fire Risk Index Method. The web site will contain all background documents, the technical guidance document, the User’s Guide and also a downloadable version of the method. The user can print out these documents and use them on-site.

d) A digital version of the method will be developed and made available on the web site. The digital version will allow the user to input grades digitally so that the risk index will be calculated automatically. This version will be made available on the internet as a digital document.

At the end of Phase 2 the Fire Risk Index Method will be presented at international meetings and papers will be published in international journals. The international marketing will be facilitated by the web site on which the method, all documentation and example applications will be freely available.

At this stage the project is concluded. The goals have been achieved and the requirements have been fulfilled. The example in Chapter 6 demonstrates that the method is possible to apply to an object. The example also demonstrates that even though the risk index normally is lower for a timber-frame building than for a corresponding concrete building it is possible to “compensate” for that in many different ways (see Section 6.3).

However, even when the second phase of the project is finished some improvements may still be found necessary.

The grading schemes may for example be clearer. The method has not yet been tested on persons not regularly working with fire safety issues. May there still be any confusion?

A future step is to make the method more general, i.e. make it possible to apply it to other types of multi-storey buildings as well. This, however, requires a new development process, which has proved to be a time-consuming work.

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Appendix A –
The Fire Risk Index Method (Version 1.2)

This is Version 1.2 of the Fire Risk Index Method for timber-frame multi-storey apartment buildings. The list below presents different decision levels; Objectives, Strategies and Parameters. The Parameter grades are calculated by using the grading schemes presented in the following pages. In the grading schemes the two lowest decision levels are used; Sub-Parameters and Survey Items. Currently, we shall only consider ordinary occupancies, later we may expand to include occupancies such as homes for the elderly.

Policy:

Provide acceptable fire safety level in multi-storey apartment buildings
Def: Multi-storey apartment buildings shall be designed in a way that ensures sufficient life safety and property protection in accordance with the Objectives listed below.

Objectives:

O_1 Provide life safety
Def: Life safety of occupants in the compartment of origin, the rest of the building, outside and in adjacent buildings and life safety of fire fighters

O_2 Provide property protection
Def: Protection of property in the compartment of origin, in the rest of the building, outside and in adjacent buildings

Strategies:

S_1 Control fire growth by active means
Def: Controlling the fire growth by using active systems (suppression systems and smoke control systems) and the fire service.

S_2 Confine fire by construction
Def: Provide structural stability, control the movement of fire through containment, use fire safe materials (linings and facade material). This has to do with passive systems or materials that are constantly in place.

S_3 Establish safe egress
Def: Cause movement of occupants and provide movement means for occupants. This is done by designing detection systems, signal systems, by designing escape routes and by educating or training the occupants. In some cases the design of the escape route may involve action by the fire brigade (escape by ladder through window).

S_4 Establish safe rescue
Def: Protect the lives and ensure safety of fire brigades personnel during rescue. This is done by providing structural stability and preventing rapid unexpected fire spread and collapse of building parts.

Parameters:

P_1 Linings in apartment
Def: Possibility of internal linings in an apartment to delay the ignition of the structure and to reduce fire growth

P_2 Suppression system
Def: Equipment and systems for suppression of fires

P_3 Fire service
Def: Possibility of fire services to save lives and to prevent further fire spread

P_4 Compartmentation
Def: Extent to which building space is divided into fire compartments

P_5 Structure - separating
Def: Fire resistance of building assemblies separating fire compartments

P_6 Doors
Def: Fire and smoke separating function of doors between fire compartments

P_7 Windows
Def: Windows (and other facade openings) and protection of these, i.e. factors affecting the possibility of fire spread through the openings

P_8 Facade
Def: Facade material and factors affecting the possibility of fire spread along the facade

P_9 Attic
Def: Prevention of fire spread to and in attic

P_{10} Adjacent buildings
Def: Minimum separation distance from other buildings

P_{11} Smoke control system
Def: Equipment and systems in escape routes for limiting spread of toxic fire products

P_{12} Detection system
Def: Equipment and systems for detecting fires

P_{13} Signal system
Def: Equipment and systems for transmitting an alarm of fire

P_{14} Escape routes
Def: Adequacy and reliability of escape routes

P_{15} Structure - load-bearing
Def: Structural stability of the building when exposed to a fire

P_{16} Maintenance and information
Def: Inspection and maintenance of fire safety equipment, escape routes etc. and information to occupants in suppression and evacuation

P_{17} Ventilation system
Def: Extent to which the spread of smoke through the ventilation system is prevented

Grading schemes:

P_1. LININGS IN APARTMENT

DEFINITION: Possibility of internal linings in an apartment to delay the ignition of the structure and to reduce fire growth

PARAMETER GRADE:

This refers to the worst lining class (wall or ceiling) that is to be found in an apartment.

LINING CLASS						**GRADE**
Suggestions to Euroclasses	Typical products	DK	FIN	NO	SWE	
A1	Stone, concrete	A	1/I	In1	I	**5**
A2	Gypsum boards	A	1/I	In1	I	**5**
B	Best FR woods (impregnated)	A	1/I	In1	I	**4**
C	Textile wall cover on gypsum board		1/II 2/-	In2	II	**3**
D	Wood (untreated)	B	1/-	In2	III	**2**
E	Low density wood fibreboard	U	U	U	U	**1**
F	Some plastics	U	U	U	U	**0**

(Minimum grade = 0 and maximum grade = 5)

Resulting grade:

P_2. SUPPRESSION SYSTEM

DEFINITION: Equipment and systems for suppression of fires

SUB-PARAMETERS:

Automatic sprinkler system
Type of sprinkler (N = no sprinkler, R = residential sprinkler, O = ordinary sprinkler) and Location of sprinkler (A = in apartment, E = in escape route, B = both in apartment and escape route)

SURVEY ITEMS	DECISION RULES						
Type of sprinkler	N	R	R	R	O	O	O
Location of sprinkler	-	A	E	B	A	E	B
GRADE	N	M	L	H	M	L	H

(N = no grade, L = low grade, M = medium grade and H = high grade)

Portable equipment

N	None
F	Extinguishing equipment on every floor
A	Extinguishing equipment in every apartment

PARAMETER GRADE:

SUB-PARAMETERS	DECISION RULES											
Automatic sprinkler system	N	N	N	L	L	L	M	M	M	H	H	H
Portable equipment	N	F	A	N	F	A	N	F	A	N	F	A
GRADE	**0**	**0**	**1**	**1**	**1**	**2**	**4**	**4**	**4**	**5**	**5**	**5**

(Minimum grade = 0 and maximum grade = 5)

Resulting grade:

P_3. FIRE SERVICE

DEFINITION: Possibility of fire services to save lives and to prevent further fire spread

SUB-PARAMETERS:

Capability of responding fire service

CAPABILITY OF RESPONDING FIRE SERVICE	GRADE
No brigade available	0
Fire fighting capability only outside the building	1
Fire fighting capability but no smoke diving capability	2
Fire fighting and smoke diving capability	4
Simultaneous fire fighting, smoke diving and external rescue by ladders	5

(Minimum grade = 0 and maximum grade = 5)

Response time of fire service to the site

RESPONSE TIME (min)	GRADE
> 20	0
15 - 20	1
10 - 15	2
5 - 10	3
0 - 5	5

(Minimum grade = 0 and maximum grade = 5)

Accessibility and equipment (i.e. number of windows (or balconies) that are accessible by the fire service ladder trucks)

ACCESSIBILITY AND EQUIPMENT	GRADE
Less than one window in each apartment accessible by fire service ladders	0
At least one window in each apartment accessible by fire service ladders	3
All windows accessible by fire service ladder	5

(Minimum grade = 0 and maximum grade = 5)

PARAMETER GRADE:

(0.31 × Capability + 0.47 × Response time + 0.22 × Accessibility and equipment)

Resulting grade:

P_4. COMPARTMENTATION

DEFINITION: Extent to which building space is divided into fire compartments

PARAMETER GRADE:

MAXIMUM AREA IN FIRE COMPARTMENT	**GRADE**
> 400 m^2	**0**
200 - 400 m^2	**1**
100 – 200 m^2	**2**
50 – 100 m^2	**3**
< 50 m^2	**5**

(Minimum grade = 0 and maximum grade = 5)

Resulting grade:

P_5. STRUCTURE - SEPARATING

DEFINITION: Fire resistance of building assemblies separating fire compartments

SUB-PARAMETERS:

Integrity and insulation

INTEGRITY AND INSULATION (EI)	GRADE
EI < EI 15	0
EI 15 ≤ EI < EI 30	1
EI 30 ≤ EI < EI 45	3
EI 45 ≤ EI < EI 60	4
EI 60 ≤ EI	5

(Minimum grade = 0 and maximum grade = 5)

Firestops at joints, intersections and concealed spaces

STRUCTURE AND FIRESTOP DESIGN	GRADE
Timber-frame structure with voids and no firestops	0
Ordinary design of joints, intersections and concealed spaces, without special consideration for fire safety.	1
Joints, intersections and concealed spaces have been tested and shown to have endurance in accordance with the EI of other parts of the construction.	2
Joints, intersections and concealed spaces are specially designed for preventing fire spread and deemed by engineers to have adequate performance.	3
Homogenous construction with no voids	5

(Minimum grade = 0 and maximum grade = 5)

Penetrations
Penetrations between separating fire compartments

PENETRATIONS	GRADE
Penetrations with no seals between fire compartments	0
Non-certified sealing systems between fire compartments	1
Certified sealing systems between fire compartments	2
Special installation shafts or ducts in an own fire compartment with certified sealing systems to other fire compartments	3
No penetrations between fire compartments	5

(Minimum grade = 0 and maximum grade = 5)

Combustibility
Combustible part of the separating construction

COMBUSTIBLE PART	GRADE
Both separating structure and insulation are combustible	0
Only the insulation is combustible	2
Only the separating structure is combustible	3
Both separating structure and insulation are non- combustible	5

(Minimum grade = 0 and maximum grade = 5)

PARAMETER GRADE:

(0.35 × Integrity and insulation + 0.28 × Firestops at joints, intersections and concealed spaces + 0.24 × Penetrations + 0.13 × Combustibility)

Note: If grade for penetrations = 0, then the parameter grade = 0

Resulting grade:

P_6. DOORS

DEFINITION: Fire and smoke separating function of doors between fire compartments

SUB-PARAMETERS:

Doors leading to escape route
Integrity and insulation (= EI)
(A = EI < EI 15, B = EI 15 ≤ EI < EI 30, C = EI 30 ≤ EI < EI 60, D = EI ≥ EI 60)
and Type of closing (M = manually, S = self-closing)

SURVEY ITEMS	DECISION RULES							
Integrity and insulation	A	A	B	B	C	C	D	D
Type of closing	M	S	M	S	M	S	M	S
GRADE	0	1	1	3	2	4	3	5

(Minimum grade = 0 and maximum grade = 5)

Doors in escape route
Integrity and insulation (= EI)
(A = EI < EI 15, B = EI 15 ≤ EI < EI 30, C = EI 30 ≤ EI < EI 60, D = EI ≥ EI 60)
and Type of closing (M = manually, S = self-closing)
If no doors are needed in the escape routes the highest grade is received.

SURVEY ITEMS	DECISION RULES								
Integrity and insulation	A	A	B	B	C	C	D	D	-
Type of closing	M	S	M	S	M	S	M	S	-
GRADE	0	1	1	3	2	4	3	5	5

(Minimum grade = 0 and maximum grade = 5)

PARAMETER GRADE:

(0.67 × Doors leading to escape route + 0.33 × Doors in escape route)

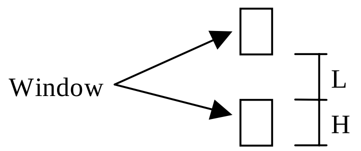
Resulting grade:

P_7. WINDOWS

DEFINITION: Windows (and other facade openings) and protection of these, i.e. factors affecting the possibility of fire spread through the openings

SUB-PARAMETERS:

Relative vertical distance
This is defined as the height of the window divided by the vertical distance between windows



Relative vertical distance, R = L/H
(A = R < 1, B = R ≥ 1)

Class of window
(C = window class < E 15, D = window class ≥ E 15, E = tested special design solution or window class ≥ E 30)

PARAMETER GRADE:

SUB-PARAMETERS	DECISION RULES					
Relative vertical distance	A	A	A	B	B	B
Class of window	C	D	E	C	D	E
GRADE	**0**	**3**	**5**	**2**	**5**	**5**

(Minimum grade = 0 and maximum grade = 5)

Resulting grade:

P_8. FACADES

DEFINITION: Facade material and factors affecting the possibility of fire spread along the facade

SUB-PARAMETERS:

Combustible part of facade

COMBUSTIBLE PART	GRADE
> 40 %	0
20 – 40 %	2
< 20 %	3
0 %	5

(Minimum grade = 0 and maximum grade = 5)

Combustible material above windows

COMBUSTIBLE MATERIAL ABOVE WINDOWS?	GRADE
Yes	0
No	5

(Minimum grade = 0 and maximum grade = 5)

Void
Does there exist a continuous void between the facade material and the supporting wall?

TYPE OF VOID	GRADE
Continuous void in combustible facade	0
Void with special design solution for preventing fire spread	3
No void	5

PARAMETER GRADE:

(0.41× Combustible part of facade + 0.30 × Combustible material above windows + 0.29 × Void)

Resulting grade:

P_9. ATTIC

DEFINITION: Prevention of fire spread to and in attic

SUB-PARAMETERS:

Prevention of fire spread to attic (e.g. is the design such that ventilation of the attic is not provided at the eave? The most common mode of exterior fire spread to the attic is through the eave. Special ventilation solutions avoid this.)

N	No
Y	Yes

Fire separation in attic (i.e. extent to which the attic area is separated into fire compartments)

MAXIMUM AREA OF FIRE COMPARTMENT IN ATTIC	GRADE
No attic	H
< 100 m^2	M
100 – 300 m^2	L
300 – 600 m^2	L
> 600 m^2	L

(N = no grade, L = low grade, M = medium grade and H = high grade)

PARAMETER GRADE:

SUB-PARAMETERS	DECISION RULES							
Prevention of fire spread to attic	N	N	N	N	Y	Y	Y	Y
Fire separation in attic	N	L	M	H	N	L	M	H
GRADE	**0**	**1**	**2**	**5**	**2**	**3**	**4**	**5**

(Minimum grade = 0 and maximum grade = 5)

Resulting grade:

P_{10}. ADJACENT BUILDINGS

DEFINITION: Minimum separation distance from other buildings. If the buildings are separated by a fire wall this is deemed to be equivalent to 8 m distance.

PARAMETER GRADE:

DISTANCE TO ADJACENT BUILDING, D	**GRADE**
D < 6 m	**0**
6 ≤ D < 8 m	**1**
8 ≤ D < 12 m	**2**
12 ≤ D < 20 m	**3**
D ≥ 20 m	**5**

(Minimum grade = 0 and maximum grade = 5)

Resulting grade:

P_{11}. SMOKE CONTROL SYSTEM

DEFINITION: Equipment and systems in escape routes for limiting spread of toxic fire products

SUB-PARAMETERS:

Activation of smoke control system

N	No smoke control system
M	Manually
A	Automatically

Type of smoke control system

N	Natural ventilation through openings near ceiling
M	Mechanical ventilation
PN	Pressurization and natural ventilation for exiting smoke
PM	Pressurization and mechanical ventilation for exiting smoke

PARAMETER GRADE:

SUB-PARAMETERS	DECISION RULES								
Activation of smoke control system	N	M	M	M	M	A	A	A	A
Smoke vent openings	-	N	M	PN	PM	N	M	PN	PM
GRADE	**0**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**

(Minimum grade = 0 and maximum grade = 5)

Resulting grade:

P_{12}. DETECTION SYSTEM

DEFINITION: Equipment and systems for detecting fires

SUB-PARAMETERS:

Amount of detectors
Detectors in apartment (N = none, A = at least one in every apartment, R = more than one in every apartment) and Detectors in escape route (N = no, Y = yes)

SURVEY ITEMS	DECISION RULES					
Detectors in apartment	N	N	A	R	A	R
Detectors in escape route	N	Y	N	N	Y	Y
GRADE	N	L	L	M	H	H

(N = no grade, L = low grade, M = medium grade and H = high grade)

Reliability of detectors
Detector type (H = heat detectors, S = smoke detectors) and Detector power supply (B = battery, P = power grid, BP = power grid and battery backup)

SURVEY ITEMS	DECISION RULES					
Detector type	H	H	H	S	S	S
Detector power supply	B	P	BP	B	P	BP
GRADE	L	M	M	M	H	H

(N = no grade, L = low grade, M = medium grade and H = high grade)

PARAMETER GRADE:

SUB-PARAMETERS	DECISION RULES									
Amount of detectors	N	L	L	L	M	M	M	H	H	H
Reliability of detectors	-	L	M	H	L	M	H	L	M	H
GRADE	**0**	**1**	**2**	**2**	**2**	**3**	**3**	**3**	**4**	**5**

(Minimum grade = 0 and maximum grade = 5)

Resulting grade:

P_{13}. SIGNAL SYSTEM

DEFINITION: Equipment and systems for transmitting an alarm of fire

SUB-PARAMETERS:

Type of signal
Light signal (N = no, Y = yes) and Sound signal (N = no, A = alarm bell, S = spoken message)

SURVEY ITEMS	DECISION RULES					
Light signal	N	Y	N	N	Y	Y
Sound signal	N	N	A	S	A	S
GRADE	N	L	M	H	M	H

(N = no grade, L = low grade, M = medium grade and H = high grade)

Location of signal
Do you just receive a signal within the fire compartmentation or is it also possible to warn other occupants?

A	The signal is sent to the compartment only.
B	It is possible to send a signal manually to the whole building or at least to a large section of the building.

PARAMETER GRADE:

SUB-PARAMETERS	DECISION RULES						
Type of signal	N	L	L	M	M	H	H
Location of signal	-	A	B	A	B	A	B
GRADE	**0**	**1**	**2**	**3**	**4**	**4**	**5**

(Minimum grade = 0 and maximum grade = 5)

Resulting grade:

P_{14}. ESCAPE ROUTES

DEFINITION: Adequacy and reliability of escape routes

SUB-PARAMETERS:

Type of escape routes
Staircase (A = one staircase may be used as an escape route, B = escape route leading to two independent staircases, C = direct escape to two independent staircases) and Window/Balcony (D = windows and balconies can not be used as escape routes, E = one window may be used as an escape route, F = at least two independent windows may be used as escape routes, G = the balcony may be used as an escape route, H = at least one window and the balcony may be used as escape routes)

SURVEY ITEMS	DECISION RULES												
Staircase	A	A	A	A	B	B	B	B	C	C	C	C	C
Window/Balcony	E	F	G	H	E	F	G	H	D	E	F	G	H
GRADE	0	1	1	3	2	3	3	4	4	5	5	5	5

(Minimum grade = 0 and maximum grade = 5)

Dimensions and layout
Maximum travel distance to an escape route (A < 10 m, B = 10 – 20 m, C > 20 m), Number of floors (D ≤ 4, E = 5 – 8) and Maximum number of apartments per floor connected to an escape route (F ≤ 4, G ≥ 5)

SURVEY ITEMS	DECISION RULES											
Travel distance to...	C	C	C	C	B	B	B	B	A	A	A	A
Number of floors	E	E	D	D	E	E	D	D	E	E	D	D
Number of apartments...	G	F	G	F	G	F	G	F	G	F	G	F
GRADE	0	1	2	2	3	3	4	4	4	4	5	5

(Minimum grade = 0 and maximum grade = 5)

Equipment
Guidance signs (A = none, B = normal, C = illuminating light), General lighting (D = manually switched on, E = always on) and Emergency lighting (F = not provided, G = provided)

SURVEY ITEMS	DECISION RULES											
Guidance signs	A	A	A	A	B	B	B	B	C	C	C	C
General lighting	D	D	E	E	D	D	E	E	D	D	E	E
Emergency lighting	F	G	F	G	F	G	F	G	F	G	F	G
GRADE	0	3	3	4	2	4	3	4	2	4	3	5

(Minimum grade = 0 and maximum grade = 5)

Linings and floorings
This refers to the worst lining or flooring class that is to be found in an escape route (excluding the small amounts allowed by building law). For Euroclasses A1, A2 and B, the flooring must have at least class D_f, if not the linings and floorings grade is according to Euroclass C.

LINING CLASS						GRADE
Suggestions to Euroclasses	Typical products	DK	FIN	NO	SWE	
A1	Stone, concrete	A	1/I	In1	I	5
A2	Gypsum boards	A	1/I	In1	I	5
B	Best FR woods (impregnated)	A	1/I	In1	I	4
C	Textile wall cover on gypsum board		1/II 2/-	In2	II	3
D	Wood (untreated)	B	1/-	In2	III	2
E	Low density wood fibreboard	U	U	U	U	1
F	Some plastics	U	U	U	U	0

(Minimum grade = 0 and maximum grade = 5)

PARAMETER GRADE:

(0.34 × Type of escape routes + 0.27 × Dimensions and layout + 0.16 × Equipment + 0.23 × Linings and floorings)

Resulting grade:

P_{15}. STRUCTURE - LOAD-BEARING

DEFINITION: Structural stability of the building when exposed to a fire

SUB-PARAMETERS:

Load-bearing capacity

LOAD-BEARING CAPACITY (LBC)	GRADE
LBC < R 30	0
R 30 ≤ LBC < R 60	2
R 60 ≤ LBC < R 90	4
R 90 ≤ LBC	5

(Minimum grade = 0 and maximum grade = 5)

Combustibility
Combustible part of the load-bearing construction

COMBUSTIBLE PART	GRADE
Both load-bearing structure and insulation are combustible	0
Only the insulation is combustible	2
Only the load-bearing structure is combustible	3
Both load-bearing structure and insulation are non- combustible	5

(Minimum grade = 0 and maximum grade = 5)

PARAMETER GRADE:

(0.74 × Load-bearing capacity + 0.26 × Combustibility)

Resulting grade:

P_{16}. MAINTENANCE AND INFORMATION

DEFINITION: Inspection and maintenance of fire safety equipment, escape routes etc. and information to occupants on suppression and evacuation

SUB-PARAMETERS:

Maintenance of fire safety systems i.e. detection, alarm, suppression and smoke control system

MAINTENANCE OF FIRE SAFETY SYSTEMS	GRADE
Carried out less than every three years	0
Carried out at least once every three years	2
Carried out at least once a year	4
Carried out at least twice a year	5

(Minimum grade = 0 and maximum grade = 5)

Inspection of escape routes

INSPECTION OF ESCAPE ROUTES	GRADE
Carried out less than every three years	0
Carried out at least once a year	1
Carried out at least once every three months	3
Carried out at least once per month	5

(Minimum grade = 0 and maximum grade = 5)

Information to occupants on suppression and evacuation

Written information (A = no information, B = written information on evacuation and suppression available in a prominent place in the building, C = written information available in a prominent place and distributed to new inhabitants) and
Drills (D = no drills, E = suppression drill carried out regularly, F = evacuation drill carried out regularly, G = suppression and evacuation drills carried out regularly)

SURVEY ITEMS	DECISION RULES											
Written information	A	A	A	A	B	B	B	B	C	C	C	C
Drills	D	E	F	G	D	E	F	G	D	E	F	G
GRADE	0	1	1	2	1	3	3	4	2	4	4	5

(Minimum grade = 0 and maximum grade = 5)

PARAMETER GRADE:

(0.40 × Maintenance of fire safety systems + 0.27 × Inspection of escape routes + 0.33 × Information)

Resulting grade:

P_{17}. VENTILATION SYSTEM

DEFINITION: Extent to which the spread of smoke through the ventilation system is prevented

PARAMETER GRADE:

TYPE OF VENTILATION SYSTEM	GRADE
No specific smoke spread prevention through the ventilation system	**0**
Central ventilation system, designed to let smoke more easily into the external air duct than ducts leading to other fire compartments. The ratio between pressure drops in these ducts is in the order of 5:1	**2**
Ventilation system specially designed to be in operation under fire conditions with sufficient capacity to hinder smoke spread to other fire compartments	**3**
Ventilation system with a non-return damper, or a smoke detector controlled fire gas damper, in ducts serving each fire compartment.	**4**
Individual ventilation system for each fire compartment	**5**

(Minimum grade = 0 and maximum grade = 5)

Resulting grade:

Results:

The risk index is calculated from the formula:

$$S = \sum_{i=1}^{n} w_i \, x_i \qquad \text{(Formula A.1)}$$

where

S = risk index expressing the fire safety
w_i = weight for Parameter i
x_i = grade for Parameter i

$S = 0.0576 \times x_1 + 0.0668 \times x_2 + 0.0681 \times x_3 + 0.0666 \times x_4 + 0.0675 \times x_5 + 0.0698 \times x_6 + 0.0473 \times x_7 + 0.0492 \times x_8 + 0.0515 \times x_9 + 0.0396 \times x_{10} + 0.0609 \times x_{11} + 0.0630 \times x_{12} + 0.0512 \times x_{13} + 0.0620 \times x_{14} + 0.0630 \times x_{15} + 0.0601 \times x_{16} + 0.0558 \times x_{17}$

Parameter Summary Table

Parameter	Weight	Grade	WEIGHTED GRADE
P1	0.0576		
P2	0.0668		
P3	0.0681		
P4	0.0666		
P5	0.0675		
P6	0.0698		
P7	0.0473		
P8	0.0492		
P9	0.0515		
P10	0.0396		
P11	0.0609		
P12	0.0630		
P13	0.0512		
P14	0.0620		
P15	0.0630		
P16	0.0601		
P17	0.0558		
Sum	1.0000		
		SCORE ⇒	

Maximum individual grade is 5.00. Maximum Score is 5.0000.

Appendix B – Literature survey

Literature survey - risk

[5] **Multiple Attribute Decision Making - an Introduction**

Yoon K. P., Hwang C.

Sage Publications, 1995

In this text the authors very closely describes a branch of the field of Multiple Criteria Decision Making (MCDM) called Multiple Attribute Decision Making (MADM). The definition, made by the authors, of MADM is ”making preference decisions over the available alternatives that are characterized by multiple, usually conflicting, attributes”. There are numerous MADM-methods and 13 of these are presented in Chapters 3 - 7. Each method is described with at least one detailed example. The methods are divided into different groups such as for example non-compensatory methods (Chapter 3), scoring methods (Chapter 4) and methods for qualitative data (Chapter 7). Chapters 1 and 2 give an introduction to the MADM-methodology and Chapter 8 describes its extensions. In this last chapter the authors also try to answer the question which MADM-method should be used to solve a particular problem.

[6] **Fire Risk Assessment using Multiattribute Evaluation**

Watts J. M. Jr.

Fire Safety Science – Proceedings of the fifth international symposium, pp 679 - 690, 1997

This report presents the use of multiattribute evaluation in fire safety. Watts means that the purpose of the report is to define explicitly a structure for Fire Risk Assessment using Multiattribute Evaluation (FRAME) system. The text begins with an introduction to this group of techniques. A definition of multiattribute evaluation is also made.
The most important components of multiattribute evaluation are the attributes, their weights, their values and the evaluation model for integration of the weights and values. In the following chapters Watts describes these four components extensively.
The first step, when developing a multiattribute system for application to fire safety, is to identify a list of attributes. Approaches to the selection of attributes are divided into three main categories. An example from a US Fire Administration study is given.
In the second step each attribute is compared with the others, which are the most important ones and how much more important? The two most common methods of assigning weights to the attributes are mentioned; the Edinburgh Model and the Analytic Hierarchy Process (AHP). The size of a single attribute value depends on to which degree this attribute exists in the specific building.
The next chapter describes scaling techniques and normalization of data, i. e. methods to make different types of attributes commensurable. Decision tables and the AHP are two different methods, which can be used to simplify attribute evaluation.

The attribute values and weights are then combined to formulate an index. Different combination models are presented in the ”evaluation model”-chapter.
In the summary Watts identifies five basic steps which together represent the fire evaluation procedure.

[7] **(A Fire Safety Evaluation Points Scheme for Dwellings)**

Shields J.

Chapters 5 - 10

These chapters consist of an extract from a version not yet published. Chapter 5 describes the Delphi exercise including selection of experts, size of the panel and a discussion about the conception of consensus. A pilot study from 1983 is commentated round by round and results from these question rounds along with conclusions are presented. Chapter 6 describes the development of the hierarchical model used in the pilot study. Interactions between and within the levels of the hierarchy are discussed and taken into consideration. Results of the Delphi process are presented in Chapter 7. Depending on if interactions between the element in each level of the hierarchy are taken into account or not, two different results are received (perturbed and unperturbed). A method, which makes it possible to increase the spread of the received weightings of values, is also described. This method can be used without re-ordering the entries in the vectors. Chapter 8 deals with problems and limitations. In Chapter 9 alternative methods of combining expert opinions such as ranking of experts, conviction weighting of experts, neighborhood consensus and also the Analytical Hierarchy Process (AHP) are discussed.
The different results received here and in the seventh chapter are summarized in Chapter 10. The conclusion made is that the best working vector V´ for the fire safety evaluation scheme is the enhanced perturbed vector (see Chapter 7) obtained utilizing neighborhood consensus data (see Chapter 9) as input to the DSS model (see Chapter 6).

[9] **Criteria for Fire Risk Ranking**

Watts J. M. Jr.

Fire Safety Science **–** Proceedings of the second international symposium, pp 457 - 466, 1991

Watts here summarizes research into the extent, nature and criteria for fire risk ranking methods. A brief explanation is made to fire risk, ranking and fire risk ranking. Three of the most well-documented and most widely used fire risk ranking methods (the Fire Safety Evaluation System, the Gretener Method and the Edinburgh Model) are described. It has been found that a lot of risk ranking methods can be described by three basic components. These components, which are discussed in the text, are a list of parameters, procedures for assigning values to those parameters and relationships, i. e. the mechanism by which the parameter values are combined to produce a measure of risk. Since there are many requirements on a good ranking system the author finally presents ten criteria as an aid in the development and evaluation of fire risk ranking methods.

[12] **Building Firesafety Engineering Method**

Fitzgerald R. W.

Worcester Polytechnic Institute, 1993

This workbook presents the Building Fire Safety Engineering Method (BFSEM), sometimes simply called "The Engineering Method" or "The L-curve Method". By using the BFSEM the author claims that it is possible to reach reasonable and effective solutions for building fire safety. The purpose of the workbook is to provide an extensive guide to the method.
The fire safety in a building is expressed graphically. The inclination of the received curve corresponds to the estimated risk in the building. The flame spread is represented on the x-axis and the probability of flame stop is represented on the y-axis. The L-curve is composed of the T, A and M-curves (representing the probability of self-termination, successful automatic extinguishment and successful fire department extinguishment respectively).
The analysis process is closely described in the handbook. Terms like barriers, established fire, full room involvement etc. are explained. Network diagrams (closely described in the text) are useful tools in facilitating the calculation work. The reliability of the results depends on the input values and therefore they should be based on a combination of knowledge, experiences and statistics.
The author is aware of the limitations of the BFSEM and the method will be revised in the future.

[13] **Evaluation of the L-curve Method** (in Norwegian)

Stenstad V.

Norges byggforskningsinstitutt, nr. N7682, 1997

This report presents results and conclusions from an extensive Norwegian evaluation of the L-curve method. As a part of this evaluation the method has been applied to the new airport Gardermoen in Oslo, Norway.
Chapter 3 is devoted to a description of the L-curve method. The method makes it possible to express the fire safety in a building graphically. Explanations are given to how to create the curve and how to evaluate the results, including terms like established fire, full room involvement, barriers etc.
The evaluation process is closely illustrated in Chapter 4. The advantages and the disadvantages of the method are presented from many different points of view. Some of the major conclusions drawn by the author and the project group in the fourth and fifth chapter are mentioned below.
The graphic presentation makes it very easy to understand the results and to compare these with regulations, other buildings etc. It is possible to use the L-curve method even when the input values are based on rather coarse estimates, but the results can of course be improved by the use of computer simulations etc. The method has proved to be an effective tool for communication between the user of the method and the decision makers. The project group seems to be quite positive to the L-curve method. However, some sections still have to be improved (and therefore the development work is continuing). Above all there is a need for detailed documentation of life safety and external fire spread, which are two parameters the L-curve method pays little regard to.

[15] **An Object-Oriented Simulation (Crisp II) for Fire Risk Assessment**

Fraser-Mitchell J. N.

Fire Safety Science – Proceedings of the fourth international symposium, pp 793 - 804, 1994

The introduction of the performance-based building codes in many countries has led to a growing importance of different risk assessment techniques. In the first chapter the author briefly reviews some of the techniques. Approaches based on event-trees are widely used. However, some important deficiencies have been recognized and attempts have been made to overcome these. To be able to include all interactions between the components, which affect the fire safety, Fraser-Mitchell claims that there is a need for a simulation model.
The Fire Research Station (FRS) in Borehamwood, UK is developing a zone model of the complete fire system called Crisp II. It is written in object-oriented fashion, which means that the system is treated as a collection of objects. The objects, which usually correspond to physical components, interact in a number of ways. The main part of this report consists of a description of the object classes in Crisp II; burning items, hot gas and cold air layers, vents, walls, rooms, smoke detectors, fire brigade and occupants. The behavior of the occupants is the most complex detail to model. The decision process is influenced by a number of parameters such as physiological reactions, sensory perceptions etc.
The final section of the report describes how Crisp II may be used for Monte-Carlo estimates of fire risk in domestic houses. The input conditions are determined randomly and the simulations are repeated many times. The mean number of casualties then gives the relative risk.

[18] **SIA 81 – A Swiss Risk Assessment Method**

Fontana M.

VTT Symposium 179, pp 59 - 69, 1998

This method was originally developed in the early 1960's and first published in 1965. It has since then been revised many times and in 1984 "the Fire Risk Evaluation Method SIA DOC 81" was published. Fontana claims that the method is well accepted in Switzerland, as well as in other countries, and recommended as a rapid assessment to evaluate the fire risk of alternative concepts.
A brief description of the method is presented. SIA DOC 81 is a grading method, i.e. it grades the elements of a building and their performance. Calculated risk is compared with accepted risk, where the first one is a function of the potential danger and the applied fire protection measures, which both are functions of a number of parameters. The author claims that the parameters are based on expert knowledge, a large statistical survey and a wide practical application. As a result of the statistical survey a detailed annex to SIA DOC 81 was obtained, including mobile fire loads of nearly 600 different occupancies. One chapter in the report describes some of the grading parameters used in the method.
Finally two illustrative examples of application of the method are presented - a school building and a furniture company.

[27] **Fire Risk Assessment for Telecommunications Central Offices**

Parks L. L., Kushler B. D., Serapiglia M. J., McKenna L. A. Jr., Budnick E. K., Watts J. M. Jr.

Fire Technology, Vol. 34, No. 2, pp 156 - 176, 1998

This paper describes the development of the Central Office Fire Risk Assessment (COFRA) methodology. The method is designed both to be implemented manually and integrated into a computer-based program. The COFRA methodology systematically assesses the fire risk associated with individual and discrete spaces in telecommunications facilities. The numerical grading system used, based on a hierarchical model, is not unique, similar techniques are used for other types of buildings. The biggest difference is that the life safety risk is very little compared to the business interruption risk. Therefore two different fire risk values are determined, the Life Safety Score and the Network Integrity Score.
Seventeen fire safety parameters were identified and by the use of a Delphi process each parameter was assigned a weight. The grading of parameters is maybe the most complex part of the COFRA methodology. Four different methods were used (and described in the paper) depending on how complex a single attribute was. The methods include the use of survey items, sub-parameters, decision tables, the AHP and the MADM-process.
The Life Safety Score and the Network Integrity Score are then both calculated as scalar products of the parameter weights and the parameter grades.
Finally the authors comment on the computer program COFRA-2.

[28] **Quantifying Fire Risk for Telecommunications Network Integrity**

Budnick E. K., McKenna L. A. Jr., Watts J. M. Jr.

Fire Safety Science – Proceedings of the fifth international symposium, pp 691 - 700, 1997

The authors state that experience has shown that a fire could cause extensive interruption of a telecommunications network. This problem has led to the development of a fire risk ranking method for the assessment of telecommunications network integrity. This methodology uses a multiattribute evaluation model and is in some respects similar to other methods developed for other types of buildings. The development process, described in the report, consisted of four steps: (1) identifying fire safety parameters, (2) calculating parameter weights, (3) establishing methods of grading parameters, and (4) specifying the procedure for calculating the fire risk value.
The hierarchical model used in step 1 and 2 is described in the text. Weights for the identified attributes in each level were determined through a Delphi exercise.
The size of a specific attribute value depends on to which degree this attribute exists in the building. This factor called grade is usually not directly measurable for a parameter and therefore survey items and in some cases sub-parameters had to be used. Decision tables were then used to relate the survey items and the sub-parameters to the parameters, i.e. to assign grades to each parameter. (An example is presented in the text.) Sub-parameter weights were sometimes instead calculated with the Analytic Hierarchy Process. Parameter grades were then calculated as the scalar product of the sub-parameter weights and values.

Finally an additive weighting model was used to produce a relative measure of the fire risk to the integrity of the telecommunications network, called the risk value, V. Each parameter grade was multiplied with its weight and the results were summed to give the risk value.

[31] **An Application of the Hierarchical Approach to Fire Safety**

Shields J., Silcock G.

Fire Safety Journal, 11, pp 235 - 242, 1986

This paper gives a brief introduction to the Analytic Hierarchy Process (AHP) developed by Saaty. The authors have investigated the applicability potential and practicability of the AHP for use in fire safety assessments. A simple mathematical example shows how the method may be used. The difference between the AHP and the points scheme developed by Marchant is elucidated. Shields and Silcock mean that the AHP is better designed to handle interactions between and within the levels of the hierarchy. A considerable limitation, experienced by the authors, is that when more than five components are involved the AHP is not very practical to use.
The conclusion has to be that in many cases the AHP may be an interesting method to estimate fire safety.

[38] **Using Decision Tables to Quantify Fire Risk Parameters**

Watts J. M. Jr., Budnick E. K., Kushler B. D.

Proceedings – International conference on fire research and engineering, pp 241 - 246, 1995

The authors begin with a description of the general fire risk ranking method of today. (A definition is made; ”fire risk ranking is the process of modeling and scoring hazard and exposure parameters to produce a rapid and simple estimate of relative risk”.)
A very important part of fire risk ranking is the grading of fire risk parameters. To simplify grading, the parameters can be divided into measurable constituent parts. These are often directly measurable survey items but in some cases there are also intermediate sub-parameters. The purpose of decision tables is to present a useful logic for translating survey items into parameter- and sub-parameter grades. Every possible combination of attributes which produces a conclusion is represented and referred to as a decision rule. An easy example is presented including a logic tree and a number of decision tables.
Usually a decision table, including survey items, is used to produce a sub-parameter grade. The parameter grade is then received from another decision table, including sub-parameters, or through specific sub-parameter weights. Those weights are usually developed from experienced judgement. The specific weights and the sub-parameter grades received from the decision tables are then multiplied to produce the parameter grade.

Literature survey - wood

[1] **Structural Stability of Timber Structures in Fire – Performance and Requirements**

König J.

COST Action E5 Workshop – Timber frame building systems – Constructional, structural & serviceability aspects of multistorey timber frame buildings, 1998

Many countries have today introduced performance-based building regulations, which have opened the way for new applications for timber-structures. It is, however, necessary to verify that the fire safety (with respect to both life safety and property protection) is as high in timber-frame buildings as in other types of buildings. In order to help the designer in his work this report explains fire safety strategies with respect to the stability of the structure.
In the introduction-chapter König discusses the new regulations. The author's opinion is that parametric/natural fire scenarios are more relevant to the use in the designing process, and also would result in more economic solutions, than the traditional standard fire scenario (ISO 834). However, the problem today is the lack of knowledge of the behavior of timber-structures in natural fires and that there do not exist operational methods for the design of timber-structures exposed to these fires. König suggests four different levels of protection (here presented as failure scenarios) in order to satisfy the requirements with respect to fire resistance. The author discusses how these levels can be achieved, also by paying regard to the interaction of structural performance and fire brigade action. A proposal of design procedure for parametric fires is presented. However, the knowledge about some of the design parameters is still inadequate.
Fire tests have been carried out with load-bearing wall assemblies. The temperature-time relationships of the wall assemblies are presented in figures for both standard fires and natural fires. The results give some solutions of how to achieve adequate fire safety.

[2] **Fire-safe Wooden Houses – a Nordic Wood Project, Final Report - Phase 1**
(in Swedish)

Trätek, Rapport P9702014, 1997

This report briefly summarizes the results of the first phase of the Nordic Wood project ”Fire-safe Wooden Houses”. The purpose of the project has been to consolidate the position of wood as a construction material, especially in multi-storey buildings. The first phase of the project consisted principally of four main areas: (1) Fire technical design of multi-storey wooden houses, (2) Model for determining the load-bearing capacity of wooden structures on fire, (3) High wooden facades and (4) Euro-classes for surface materials.
The report begins with a description of the organization and the objectives of the project. The remaining part is devoted to the results from the four main areas. Some of the results are mentioned below.
Nils E. Forsén at NBI has been responsible for the design-part of the project. Parametric fire scenarios have been introduced to provide a better tool for the verification of the separating and load-bearing functions of structures in the case of fire. An L-curve study and a study of insurance statistics have also been carried out.

Part 2 of the project (Jürgen König at Trätek was responsible) has mostly consisted of an extensive testing program. The purpose has been to find a connection between load-bearing capacity and time, both for parametric and standard fire scenarios. Suggestions to firestops, ventilation of roofs etc. are also presented.
Esko Mikkola at VTT was responsible for the facade-part of the project. Fire tests of wood-facades with different materials, surface treatments and structures were performed on intermediate and large scales. Two different fire scenarios were assumed; flashover of a compartment in an unsprinklered building and a small ignition source outside a sprinklered building. The most efficient way to stop the propagation of flames (in the case of external fire) was by using cantilevers at least 200 mm wide.
Part 4 of the project, Euro-classification of surface linings (Birgit Östman, Trätek and Esko Mikkola, VTT were responsible) has resulted in new testing methodologies for surface products; Single Burning Item (SBI) for wall and ceiling products and Radiant Panel for floor products. However, the European work in this field goes on rather slowly.

[3] **Fire Design of Timber Frame Buildings – Present Knowledge and Research Needs**

Östman B.

VTT Symposium 179, pp 6 - 17, 1998

This report briefly summarizes the knowledge of today in the field of fire design of timber-frame buildings. Östman also discusses what has to be done in the future.
There are two main stages of a fire scenario; the initial and the fully developed fire. The properties of surface linings is an important factor for the initial fire while the load-bearing and separating structures are important for the fully developed fire. The author notices that it is easy to obtain high performance for fire resistance for wood-structures, but more difficult to find a wood-based lining with limited contribution to the initial fire.
One chapter in this report is devoted to fire resistance of wood-structures. Suggestions to firestops and ventilation of roofs are presented together with research needs (to design manuals for fire resistance, to find out if there is a possibility of using timber-frame stairway shafts etc.). Today it is possible to verify the load-bearing and separating functions of the structures by using natural/parametric fire scenarios. The differences between parametric fires and standard fires are elucidated in this chapter.
The next chapter is devoted to the reaction to fire (i.e. the response from materials to an initial fire attack). Research needs for interior linings and facades are discussed. The importance of sprinkler system in a building with wood-based facades and interior linings is emphasized. Östman states that requirements on linings can be partly disregarded since fires will be extinguished at an early stage.

[14] **Risk Analysis of Timber-frame Multi-storey Apartment Buildings** (in Norwegian)

Stenstad V.

Norges byggforskningsinstitutt, nr. O7662, 1997

This report is a part of the Nordic Wood project ”Fire-safe Wooden Houses – Phase 1”. In this report Stenstad presents different statistics and experiences, but he mostly concentrates on an analysis based on the L-curve method. The method gives a graphic presentation of the fire spread in a building.
Chapter 4 presents some general Norwegian fire statistics. The probability of fire in an apartment building is estimated to about 0,001 per year. The author claims that it is very difficult to tell if a timber-frame construction means an increased probability of an established fire compared to a non-combustible frame construction.
The fifth chapter is devoted to the safety of persons. Norwegian statistics indicate no difference in life safety between timber-frame buildings and other types of buildings. Some information is received from an analysis carried out at the National Research Council Canada (NRCC). One conclusion is that active measures have greater influence on life safety than structural measures.
Chapter 6 very closely describes the L-curve method. The method has been applied to a four-storey timber-frame building and a corresponding concrete building. The results indicate that the probability is 3,5 - 12 times bigger of loosing the whole timber-frame building.
Chapter 7 summarizes Swedish experiences from fires in timber-frame buildings. Some conclusions are made and suggestions to future design are presented.
In the last chapter Stenstad summarizes conclusions and presents research needs.

[20] **Fire Tests with Foam Plastic Insulated Timber-frame Roofs** (in Norwegian)

Stenstad V.

Norges byggforskningsinstitutt, nr. O7663, 1997

The most common type of roof-construction today still is the non-insulated roof (i.e. the building is designed with a cold attic). This design is, however, not ideal from a fire point of view. The construction makes it possible for the fire to spread in a space that is hard to reach for the fire brigade. Damp is, however, a big problem with traditionally insulated roofs. As a part of the Nordic Wood project ”Fire-safe Wooden Houses” fire tests with foam plastic insulated roofs have been carried out. (Stenstad claims that with this design the problem of damp is diminishing.)
Chapter 3 closely describes the principal design of the foam plastic insulated roof. The fourth chapter presents the Norwegian regulations for the use of plastic insulation. (The roof has to be divided into areas not bigger than 400 m^2 separated by non-combustible insulation.)
The fire tests are closely described in Chapter 6 and its appendixes. Three different roof assemblies were tested; roof A with rockwool insulation, roof B with foam plastic insulation and roof C with the same design as B but with fibre-glass clothing applied at the upper side. The results are evaluated from many different points of view; smoke production, flame spread, extinction possibilities etc. It is also important to find out if the melting of plastic insulation causes any falling drops and if the fire spreads down through the construction.

Stenstad discusses the results in Chapters 6 and 8. The biggest disadvantages with foam plastic insulation seem to be the fast flame spread (however, the results are better with fibre-glass clothing) and the great smoke production. In Chapter 7 Stenstad discusses alternative design solutions.
The main conclusion made in this report is that it is possible to use foam plastic insulation in roofs if fibre-glass clothing is applied and intersections and other weak parts of the construction are insulated with a non-combustible material.

[23] **A Model for Predicting Heat Transfer through Gypsum-Board/Wood-Stud Walls Exposed to Fire**

Mehaffey J. R., Cuerrier P., Carisse G.

Fire and Materials, Vol. 18, pp 297 - 305, 1994

The authors claim that there is a need of obtaining a simple model in order to calculate fire resistance of wood-frame building assemblies. In this report the development of a two-dimensional computer model is described. The model calculates the heat transfer through gypsum-protected wood-stud walls. It is possible to divide such a wall into three constituent parts; the gypsum-boards, the wood-studs and the cavities. The physical properties and the fire behavior of these parts are closely described in three chapters.
The following chapters describe the heat transfer model. By the introduction of an enthalpy formulation it is possible to express the heat transfer through the wall assembly by a partial differential equation. To solve that equation a computer program has been written in Microsoft FORTRAN. Results from a number of small-scale and full-scale fire resistance tests on wood-stud walls protected by gypsum are presented together with results from the corresponding computer simulations. As the authors emphasize in the conclusion-chapter the model predicts the essential features of the fire test results rather well.
Refinements of the model will be made in the future.

[24] **Fire-resistance and Sound-transmission-class Ratings for Wood-frame Walls**

Richardson L. R., McPhee R. A.

Fire and Materials, Vol. 20, pp 123 - 131, 1996

This report describes a collaborative industry-government research program carried out at the National Research Council Canada (NRC). The purpose of the program was to measure the sound-transmission-class (STC) and fire-resistance (FR) ratings for gypsum-protected wood-frame walls. FR- and STC ratings for approximately 90 different wood-frame wall designs were then included in the 1995 edition of the National Building Code of Canada (NBCC).
In the introduction-chapter the authors state that the program was caused by a revision of the Canadian standard for gypsum-board in 1991. The requirements for minimum density of gypsum-board were then removed causing uncertainty about the changed properties of the boards.
The second chapter describes the acoustical tests and the fire-endurance tests. The latter tests were carried out on both wood-frame and steel-frame wall assemblies, both load-bearing and non-load-bearing assemblies. Small-scale fire-endurance tests were also carried out.

The results received are discussed in the next chapter. Some of the most important conclusions from the fire-endurance tests, presented in this chapter, are the following:
FR ratings are independent of the type of absorptive material in the wall. The FR ratings are lower for load-bearing walls compared to non-load-bearing walls. There is no difference in FR ratings between non-load-bearing wood-stud walls and non-load-bearing steel-stud walls. (Some of the FR ratings are summarized in figures.)

[25] **Revisiting the Component Additive Method for Light-frame Walls Protected by Gypsum Board**

Richardson L. R., Batista M.

Fire and Materials, Vol. 21, pp 107 - 114, 1997

The Component Additive Method (CAM) is a calculation method for assigning fire-resistance (FR) ratings to for example steel-frame and wood-frame wall assemblies. The method was developed in the 1960's, but some sections have recently been revisited thanks to the research program carried out at the National Research Council Canada (NRC). The testing program resulted in new FR ratings for walls protected by gypsum [24]. The results made it possible to revisit the sections of CAM which are applicable to gypsum-protected light-frame walls.
A definition of FR ratings is presented in the introduction-chapter. The development and the revision process of CAM are also described more extensively than above. One chapter briefly describes the testing program.
The main part of this report consists of a discussion about the received results. The CAM calculates the FR rating of a wall by adding different assigned times. These times are assigned for; (1) the membrane on the fire exposed side of the wall, (2) the framing members and (3) any protective measures (insulation etc.). How these times are measured and endpoint criteria for the wall tests are presented in the text.
The report ends with a conclusion-chapter treating limitations and fields of application.

[34] **Modeling the Fire Resistance of Wood-Frame Office Buildings**

Lin C. Y. E., Mehaffey J. R.

Journal of Fire Sciences, Vol. 15, pp 308 - 338, 1997

The authors claim that the purpose of this paper is to demonstrate that it is possible to use computer models to determine the fire resistance of wood-frame buildings. In the undertaken project, three computer models have been employed to calculate the fire resistance of gypsum-protected wood-stud walls. CFAST 2.0 was used to determine the temperature of the upper layer throughout the fire, BREAK 1 was used to simulate cracking of a single-pane window glass and WALL 2D was used to model the thermal and mechanical response of the wall.
The computer models and the modeling process are briefly described in the first chapter.
Chapter 2 describes the building chosen for the study. It is an existing unsprinklered wood-frame building, with two floors and a basement. Six different fire scenarios have been chosen (Chapter 3). Window sizes and door types vary but the ignition source is the same; a wastebasket in an office compartment.

Chapter 4 illustrates the modeling of the temperature in the compartment. Since the temperature depends on a number of variables, which vary in the course of the fire simulations (heat release, size of ventilation opening), the fires have to be divided into different stages. Chapter 5 describes the thermal and mechanical response of the wall assemblies in the fire scenarios. Results from the simulations are presented in a number of figures (heat release- and temperature curves, deflection of the wall assemblies etc.).
The remaining part of this paper is devoted to discussions and conclusions. Some assumptions have, of course, been made and the authors state that there is a need for experimental verification.

[35] **A Review of Formulae for T-equivalent**

Law M.

Fire Safety Science – Proceedings of the fifth international symposium, pp 985 - 996, 1997

In this report Law reviews the different formulae for t-equivalent which have been developed over the years. T-equivalent is here defined as the exposure time in the standard fire resistance test that gives the same heating effect on a structure as a given compartment fire. Law describes the various formulae starting with Ingberg and finishing with the more recently developed Eurocode-formula. The included parameters and the reasoning behind the development of each formula is commentated. In most cases the t-equivalent is a function of such parameters as fire load, compartment and ventilation dimensions.
The different formulae are then compared to experimental data from post flashover fires in full-scale compartments. The conditions for these tests and the results are presented in tables in the report. The formulae developed by Law, Pettersson and Harmathy/Mehaffey give the best correlation (illustrated in a number of figures), but no formula seems to be perfect. According to furnace tests reported by Kirby none of the formulae give satisfactory results for deep well-insulated compartments. Law discusses what the reasons might be, but nothing seems to explain the large discrepancies received in the tests. The author notices that location and insulation both have minor effect on the t-equivalent value.
Finally Law presents some conclusions. She states that t-equivalent is not a useful parameter for design purposes.

Appendix C – Drawings, Orgelbänken

In Chapter 6 the Fire Risk Index Method was applied to a reference object, named Orgelbänken. The object, located in Linköping, Sweden, is a timber-frame multi-storey apartment building, built in 1995/1996.

This appendix contains plans and section drawings showing some essential parts of the building. (Please observe that the scales given in the drawings are not correct.)

Figure C.1 An overview of the multi-storey apartment building Orgelbänken. Orgelbänken consists of a single building with four floors and an attic. Wood-panel is the facade material in access balconies and in stairwells and plaster in the rest of the building. [40]

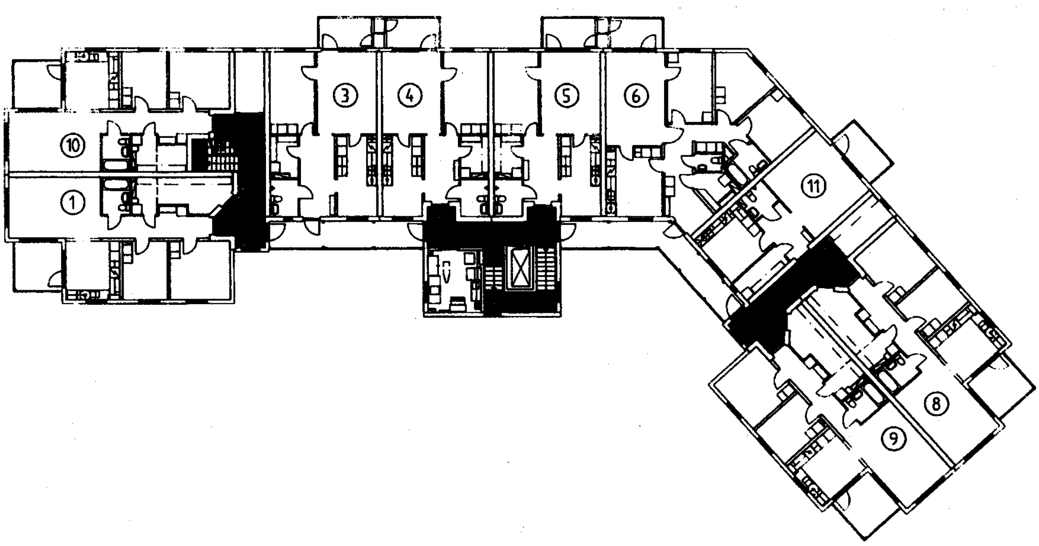


Figure C.2 Plan showing a typical floor. The building is divided into 36 apartments, which are connected to two separate stairwells by access balconies. [40]

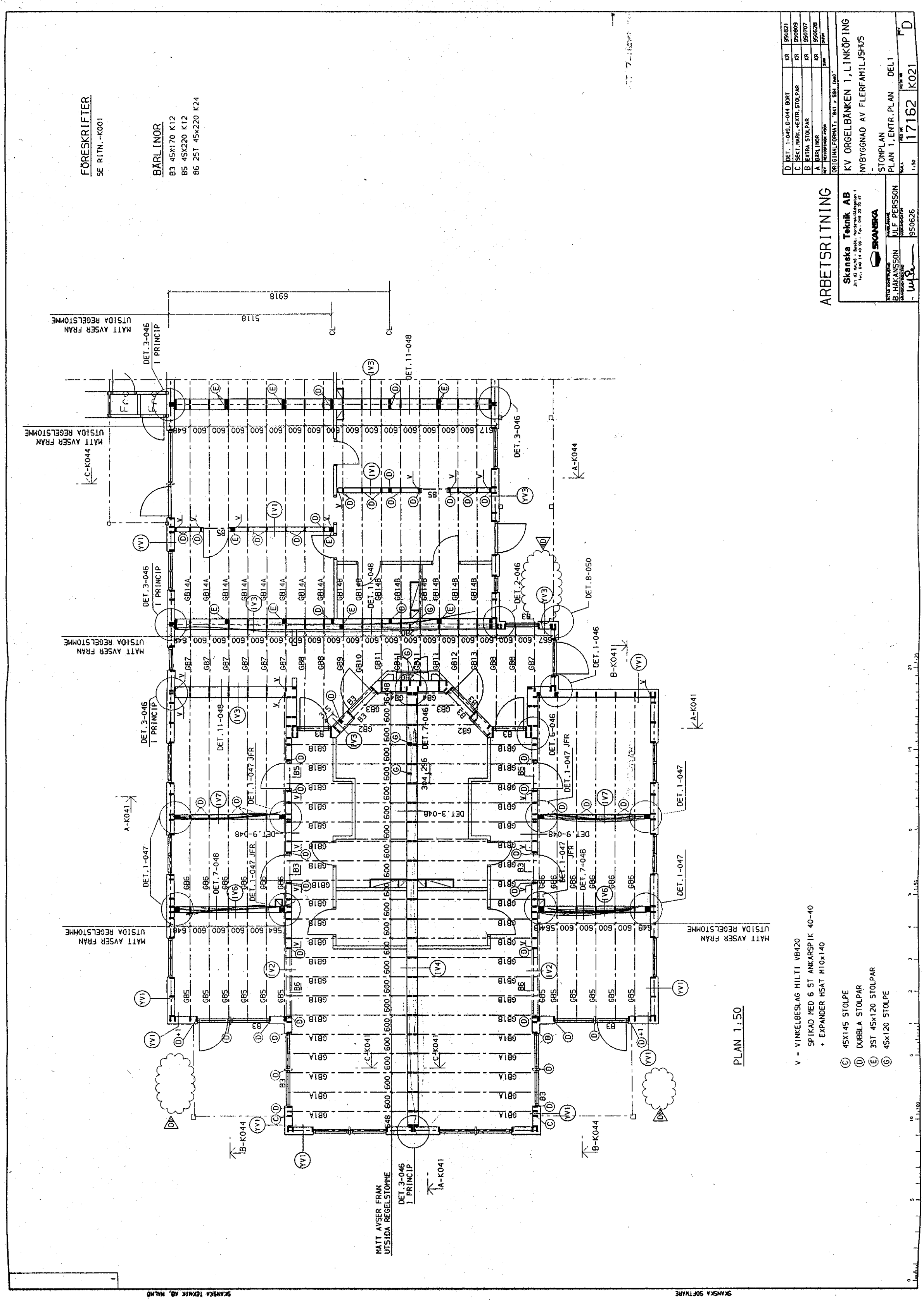


Figure C.3 Plan showing Part 1 of the first floor.

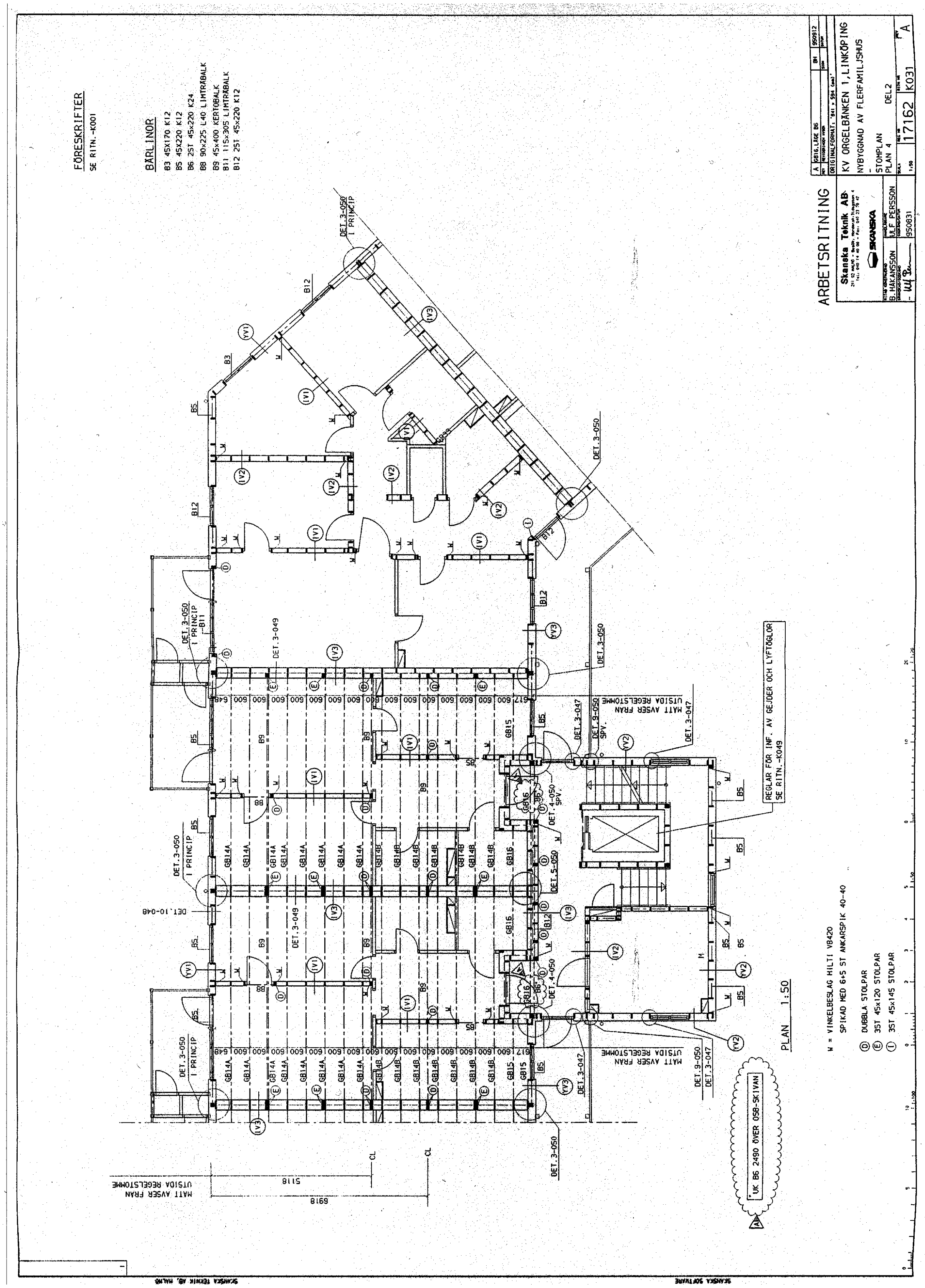


Figure C.4 Plan showing Part 2 of the fourth floor.

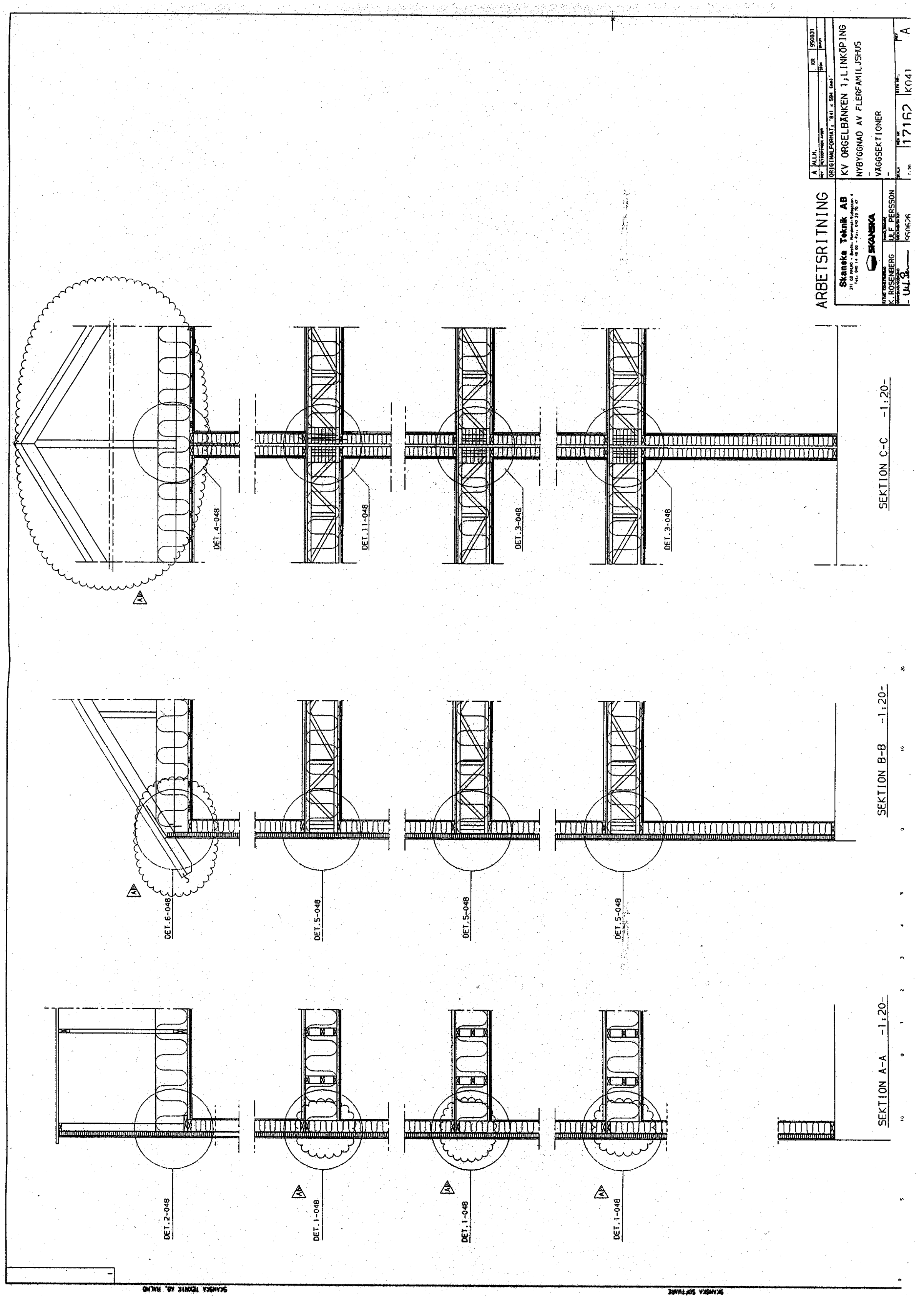


Figure C.5 Sections showing details of wall assemblies. The load-bearing construction is carried out of wood, indoors covered by gypsum boards.

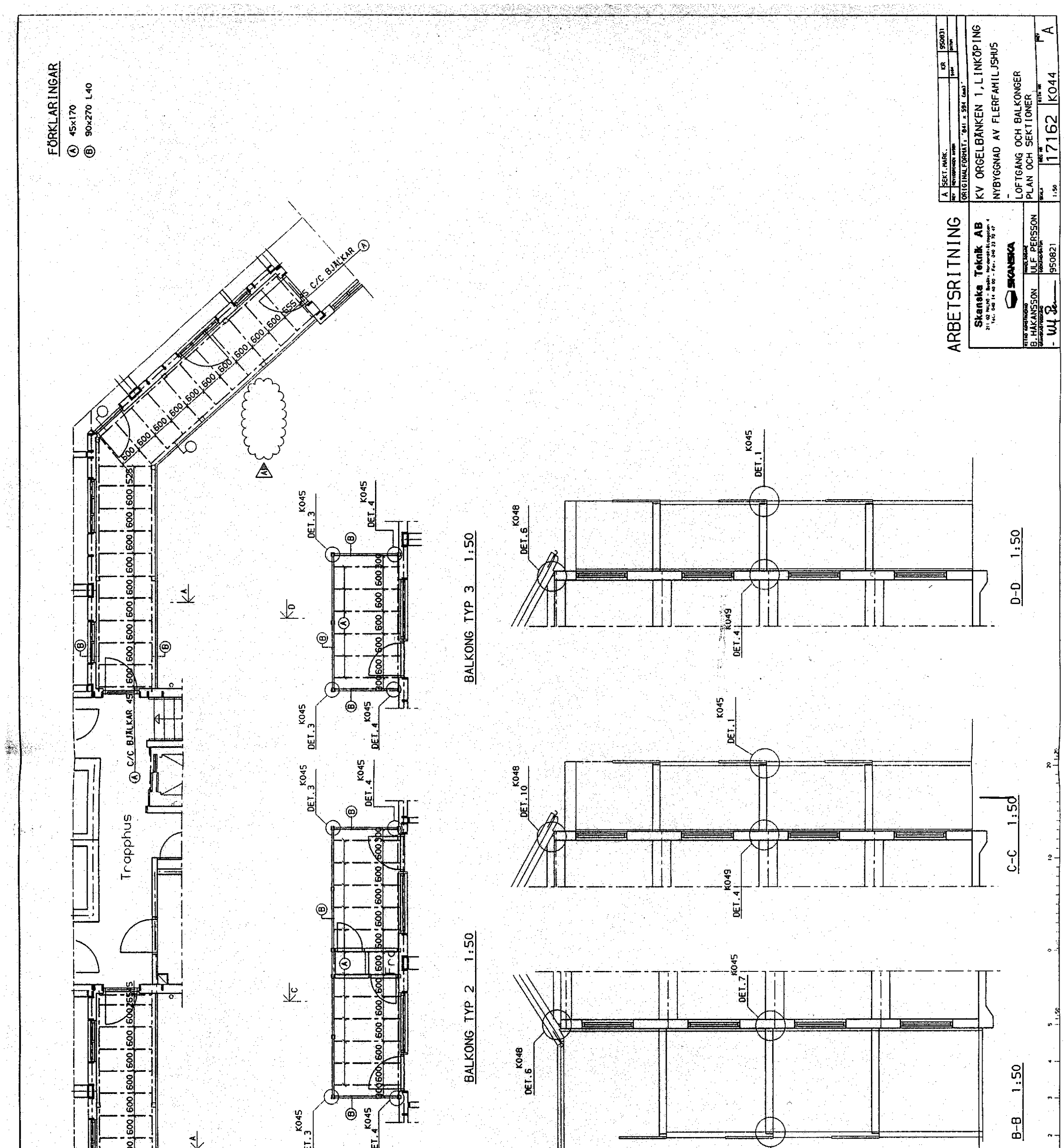


Figure C.6 Plans and sections showing balconies and access balconies.

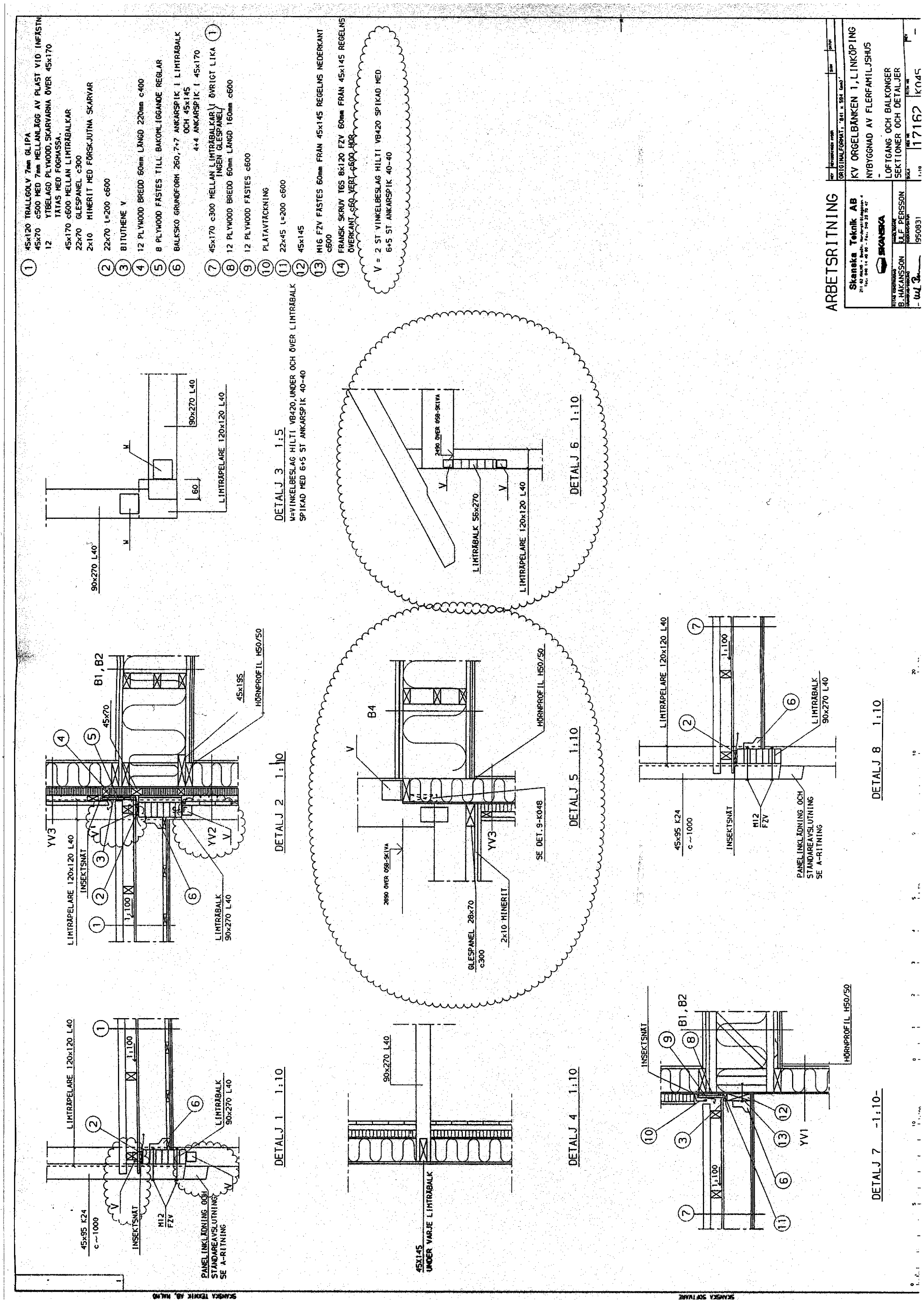


Figure C.7 Sections showing details of balconies and access balconies.

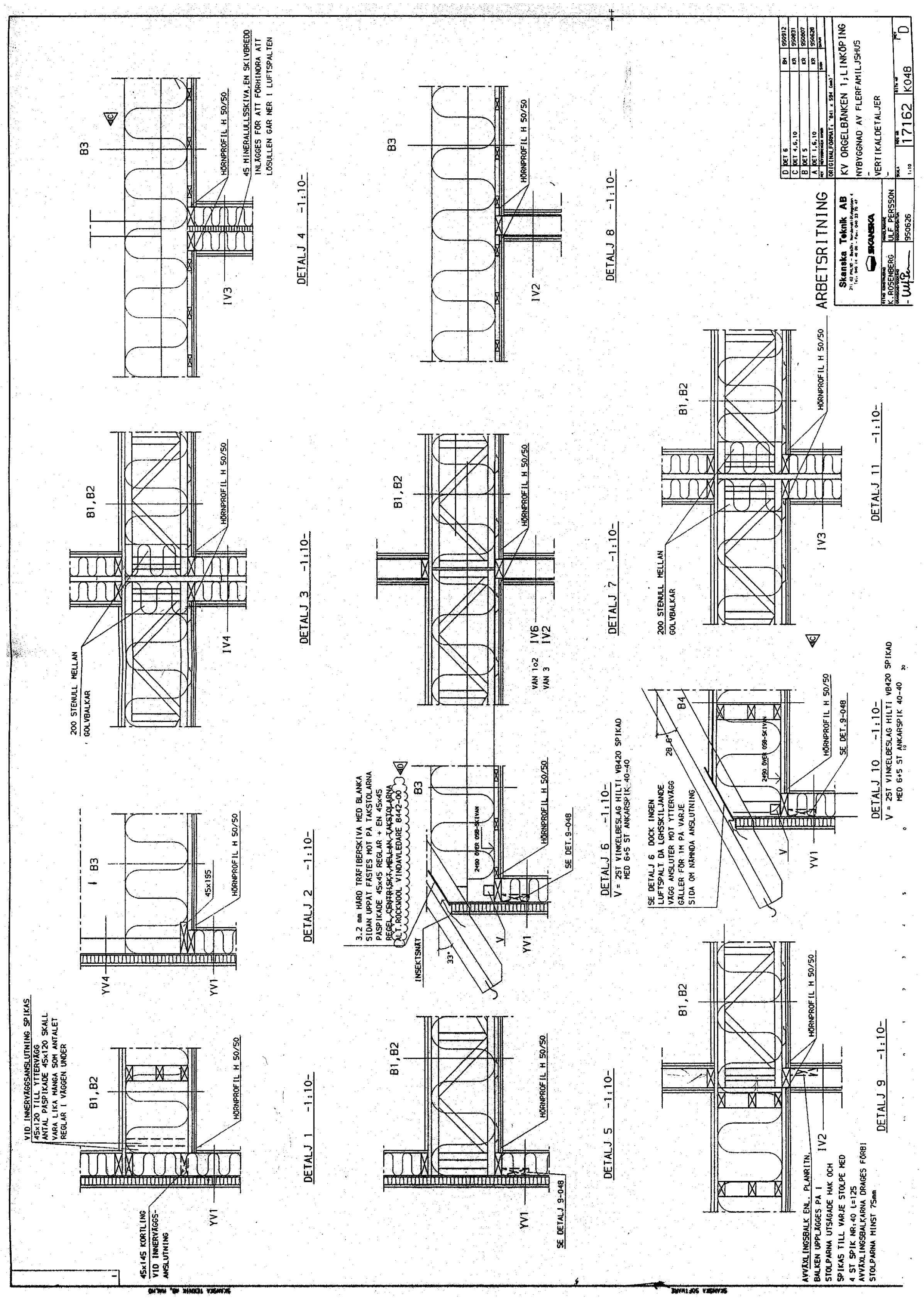


Figure C.8 Sections showing vertical details. Continuous voids in the construction have been avoided if possible.

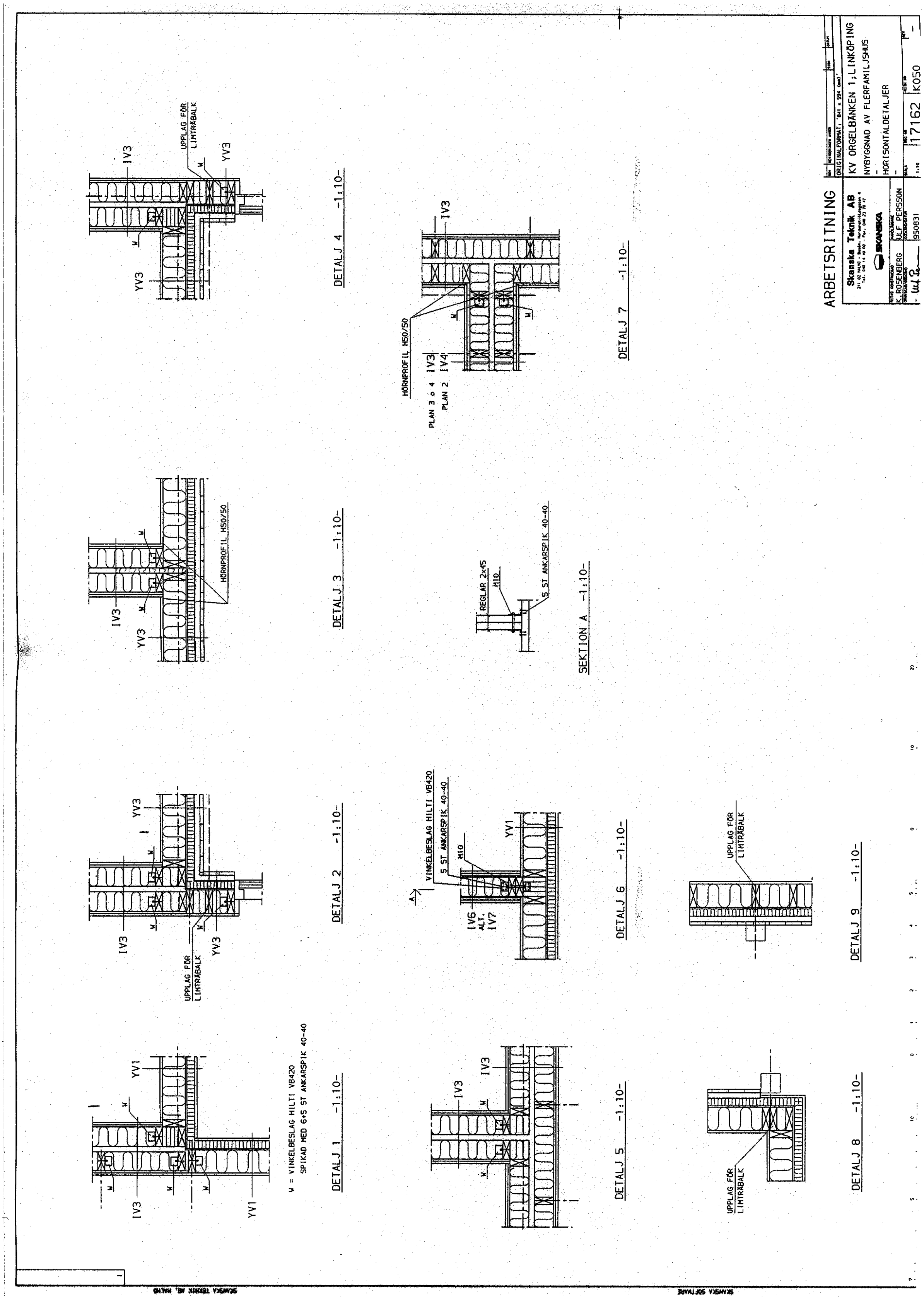


Figure C.9 Sections showing horizontal details.