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Abstract
A need for methods to assess fire risks in timber frame buildings lead to the development of FRIM-MAB, a Fire Risk Index Method for Multi-storey Apartment Buildings. The main objective of this report is to evaluate this method against a different risk analysis method, in this case a standard QRA (quantitative risk analysis) based on an event tree.

Four different multi-storey apartment buildings in the Nordic countries were analysed in this study. The QRA resulted in a certain ranking of the four buildings with respect to fire risk. The Fire Risk Index Method was then used to analyse the same buildings. Three slightly different approaches were used to arrive at a fire risk index for each building. The Index Method results gave exactly the same ranking as the quantitative risk analysis for all three approaches. The conclusion of the analysis is therefore that FRIM-MAB seems to work reasonably well for multi-storey apartment buildings, but further studies are recommended to confirm this.

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Summary

The second phase of the Nordic Wood project "Fire-Safe Wooden Houses" has been running since 1997. The project is divided into three main areas:

i. Strategic knowledge
ii. Technical knowledge and methods
iii. Development of products and systems

The project "Fire Risk Assessment" was formed as a sub-project to "Strategic knowledge". The need for new and better fire risk assessment methods resulted in the work to produce a semi-quantitative index method, the Fire Risk Index Method for Multi-storey Apartment Buildings (FRIM-MAB). In this report FRIM-MAB is referred to simply as the Index Method.

Earlier reports have described the development of the Index Method. The purpose of this report is to get some idea of the validity of the method. Work was therefore carried out to compare it against other risk analysis methods, that have some bases in accepted fire design methods. However, in many cases there are no accepted fire design methods available. For example, firestops at joints, intersections and concealed spaces are very important in timber-frame buildings, but there is no method available to calculate or numerically compare different design solutions in this respect. The evaluation can therefore only result in some indications on validity and is to a considerable extent based on subjective judgement.

The comparative methodology used is a standard quantitative risk analysis (QRA) based on an event tree. The analysis resulted in two rankings of the buildings analysed, one from FRIM-MAB and one from the standard QRA. These rankings were compared and some conclusions drawn on how well FRIM-MAB operates.

The events in the QRA event trees for the analysed buildings were flaming fire, fire detected automatically, occupant suppressing, sprinkler failure, door open, location of occupants, flashover and spread, level and asleep. All or some of these events make up the event trees. The standard QRA resulted in a number of risk profiles and a ranking based on the expected number of people exposed to critical conditions given a fire.

Four existing timber-frame buildings were analysed, one in Sweden (Wälludden), one in Norway (Einmoen), one in Denmark (Casa Nova) and one in Finland (Viikki). The result from FRIM-MAB and from the QRA resulted in the same fire risk ranking, where the Vikki building had the lowest risk and the Casa Nova building the highest.

The main conclusions that can be drawn from this analysis is that the Index Method ranks the buildings analysed in the same order as the very different QRA method. This indicates a certain validity and shows that the Index Method can be a very useful tool, although no proof of validity can be given. More work is recommended, where existing buildings are analysed and the method developed further.

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1 Introduction

1.1 Background

The second phase of the Nordic Wood project "Fire-Safe Wooden Houses" has been running since 1997. The project is divided into three main areas (Larsson, 2000):

i. Strategic knowledge
ii. Technical knowledge and methods
iii. Development of products and systems

The project "Fire Risk Assessment" was formed as a sub-project to "Strategic knowledge". The need for new and better fire risk assessment methods resulted in the work to produce a semi-quantitative index method, the Fire Risk Index Method for Multi-storey Apartment Buildings (FRIM-MAB). The development and design of this semi-quantitative index method is described by Larsson (2000) and the latest version of the index method is presented by Karlsson (2000). In this report FRIM-MAB will simply be referred to as the Index Method.

The purpose of this report is to evaluate the Index Method and to compare it against a quantitative risk analysis (QRA) method. The methodology will be further presented later in the report. Four different buildings, one in each Nordic country, were analysed using the Index Method. This resulted in a ranking between these four buildings. This ranking was then compared to the ranking obtained by the QRA method.

After the analysis of the results some conclusions on the validity of the Index Method are drawn and recommendations on it´s further development and use are discussed.

1.2 Overview of this report

Chapter 2 gives a review of the methodology used in this analysis. First a general description is presented and then the methodology of the standard QRA (Quantitative Risk Analysis) is more closely discussed. Finally a number of remarks regarding the difficulties with the used methodology are given.

Chapter 3 presents information on the analysed buildings. A general QDR (Qualitative Design Review) is given followed by a more detailed description of the analysed buildings.

Chapter 4 explains the events in the event tree and presents the probabilities chosen for all the events.

In Chapter 5 the results from the standard QRA are shown as well as the result from the performed sensitivity analysis.

The results from the Index Method are shown in Chapter 6 together with the QRA ranking of the analysed buildings. Three different Risk Indices are calculated, in order to take account of some of the differences between the QRA methodology and the Risk Index Method.

Chapter 7 gives a graphical comparison between the standard QRA the Index Method.

Last, in Chapter 8, conclusions are drawn from the result and further work discussed.

2 Methodology

2.1 General

A fire risk ranking of buildings can be made in various ways. A first proposal on how the ranking could be achieved in this project was stated in a project plan, accepted by the project group at a meeting in Stockholm (Karlsson, 1999). In short, the plan proposed that time to hazardous conditions be calculated and compared to the time required for evacuation, using the calculation tools HAZARD I (Peacock et. al., 1994) and SIMULEX (Thompson et. al., 1996), for a number of scenarios. This would provide a ranking of the analysed buildings. The ranking could then be compared to the ranking from the Index Method on the same buildings.

A further specification is now needed. The plan only states that the ranking should be based on the time to hazardous conditions and the escape time. Such a ranking can be made in many different ways. Below, a list on some examples on how to achieve this ranking is given:

i. The “reasonably worst case” is studied and time to hazardous conditions is compared to the evacuation time. If the time to hazardous conditions is greater then the evacuation time the fire design solution is deemed acceptable. But many different design solutions can be deemed acceptable. Using this methodology the ranking can only be made against one of many possible design solutions. Further, this method does not take into account failure of e.g. sprinkler or detection systems.

ii. This method is the same as the one above but with the difference that a ranking between e.g. two accepted design solutions can be made by studying the magnitude of the difference between evacuation time and time to hazardous conditions.

iii. A standard quantitative risk analysis (standard QRA) is based on an event tree and produces risk-profiles for different design solutions, showing the results graphically. This method takes into account e.g. sprinkler failure, smoke detector failure, opened or closed apartment doors etc. However, the method does not account for the uncertainties in the parameter values chosen for e.g. sprinkler failure and should therefore be combined with some kind of sensitivity analysis or uncertainty analysis.

iv. The extended quantitative risk analysis (extended QRA) is also based on an event tree as explained above but with the difference that this method deals with the uncertainties of different parameters explicitly.

Methods one and two are the most commonly used by engineers in the fire design process. However, these methods lack with respect to depth of the analysis and can not be said to be an evaluation of risk. Since our objective is not design, but comparison of risk, a wider range of scenarios and parameters have to be taken into account, therefore, at least a standard QRA (i.e. method three) must be carried out.

The project group accepted method three, which will be outlined in the next section.

2.2 Standard QRA

As mentioned above the standard QRA is based on an event tree. This is a very useful technique to identify the outcome of a fire as well as to illustrate the sequence of events involved in ignition, fire development, fire control, evacuation, etc. Figure 2.1 below shows an example of a simple event tree for a fire. The event trees are made with help from the computer program Precision Tree (Palisade Corporation, 1996).

The risk for each sub-scenario is calculated by multiplying the probability of the sub-scenario by its consequence. The total risk is the sum of the risks for all sub-scenarios in the event tree.

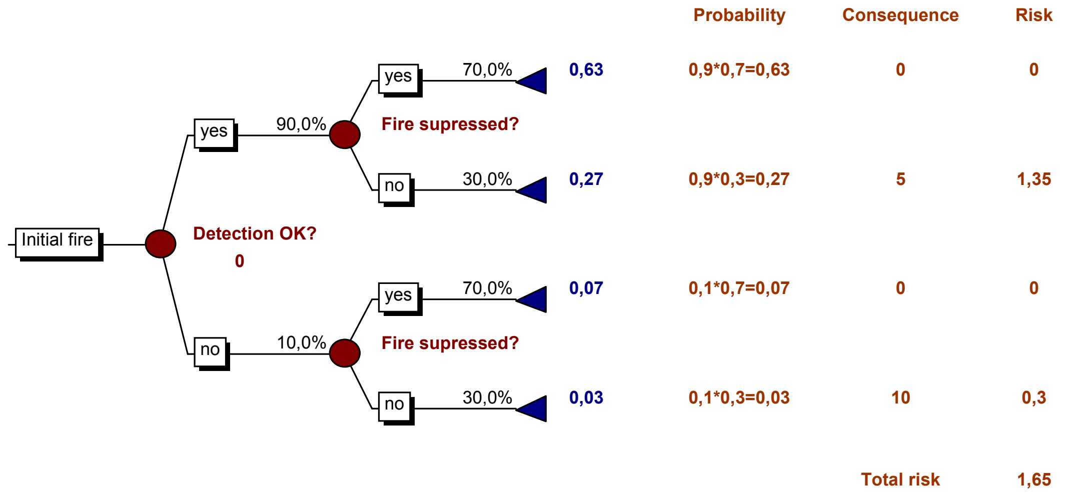

Figure 2.1. Example of an event tree for a fire.

If a definitive measure of the risk is to be produced every combination of fire source, target location and fire scenario has to be considered (Olsson, 1999). However, the amount of computational effort required increases rapidly with the number of sources, scenarios and targets considered. Therefore some limitations and assumptions have to be made to simplify the problem. Performing a qualitative design review, QDR (BSI, 1997), can help limit the problem. In short, the objective of the QDR is to review the architectural design, identify fire hazards and possible consequences and specify fire scenarios for the quantitative analysis.

2.3 Difficulties using suggested tools on a medium-rise apartment building

The project plan suggests that HAZARD I (Peacock et. al., 1994) and SIMULEX (Thompson et. al., 1996) be used as tools for achieving a ranking between the analysed buildings. After an initial round of designing event trees and analysing the suggested method a few problems came up:

i. The time for evacuation is divided into three parts: recognition time, response time and travel time. With help from e.g. SIMULEX (Thompson et. al., 1996) the travel time can be calculated. However, the recognition time and the response time will have to be based on expert judgement. In the case of an apartment building like the ones analysed in this report the recognition- and response time of the occupants in the apartment of fire origin can be fairly well judged based on activation of smoke detectors etc. But, when it comes to the other occupants in the building the judgements will be marred by great uncertainty. As a result of this the quantitative analysis will be less accurate and less trustworthy.

ii. If an occupant is to be exposed to critical conditions this can basically happen in three ways. First, the occupant is inside the apartment of fire origin. Secondly, the staircase is filled with smoke (i.e. not available as an escape route) and the fire spreads along the facade into an apartment above. Third, the occupant is inside the staircase when the door to the apartment of fire origin is opened and smoke spreads to the staircase.

The last of these scenarios is not very likely to occur since it requires that the occupant in the apartment of fire origin decides to evacuate at the same time as an occupant in a second apartment. Since the recognition times for the occupants are different and since the evacuation times are short it is not very probable that the occupants from the apartment of fire origin is inside the staircase at the same time as another occupant. Calculations show; see Appendix A, that the travel time ranges from 20 seconds at level 2 to 50 seconds at level 4 (based on a stairwell with a door leading to the outside at level 1). These calculations were made using SIMULEX (Thompson et. al., 1996). However, as seen in Appendix A, the travel times calculated by hand are almost identical. So, for the travel time, SIMULEX is superfluous in a situation like this, i.e. a medium-rise apartment building with a staircase and a low number of occupants.

As a result of this it was decided that the number of events in the event tree that required expert judgements of the probabilities was to be minimised and that the consequences are based on the assumption that the staircase is either smoke filled or not. It was also decided that hand calculations be used to calculate travel time instead of using SIMULEX.

3 Apartment buildings analysed

3.1 General Qualitative Design Review (QDR)

3.1.1 Occupant characterisation

Since the buildings analysed here are apartment buildings the assumption that most people are at work during the day is made. Thus, between 07.00 and 18.00 there are no occupants in the buildings, i.e. only a fire during the evening and nighttime is considered.

The occupants are assumed to be able to evacuate without any support from other persons and it is assumed that they are free from any physical handicap.

According to Swedish statistics (SCB, 2000) there are 1.5 persons living in each apartment in a high-rise building and according to Finnish statistics (Statistics Finland, 1998) the number is 2 persons per apartment. In this analysis the value 2 persons per apartment will be used.

3.1.2 Fire safety objectives

The main fire safety objectives when structuring the index method were deemed to be:

- Provide life safety
- Provide property protection

For the latter objective, rational methods for evaluating fire risk are scarce and deterministic methods are only available for a small part of the design problem. For example, firestops at joints, intersections and concealed spaces are very important in timber-frame buildings, but there is no method available to calculate or numerically compare different design solutions in this respect. The index method takes account of this in some parameters but the QRA used here will not attempt to quantify risk with respect to property protection.

For the life safety objective, a considerable part of the design problem can be solved using accepted design methods. The QRA will therefore focus on this objective and concentrate on the life safety of occupants. The index method, however, takes account of life safety of fire fighters (which to some degree has to do with structural stability) as well as occupants and a direct comparison of the life safety objective of both methods is therefore questionable.

As a result, a direct comparison between the QRA and the index method is not staright forward. Therefore, three different fire risk indices will be used as a comparison with the QRA, the ordinary Fire Risk Index, an Adjusted Fire Risk Index and an Occupant Escape Fire Risk Index. The way in which these different indices are arrived at is discussed in Section 6. Due to the assumptions made in the QRA methodology and the assumptions made when forming the three different indices, the evaluation can only result in some indications on validity and is to a considerable extent based on subjective judgement.

3.1.3 Evacuation strategy

The strategy for evacuation of an apartment building like these is to evacuate via the balcony or an apartment window, with help from the local fire brigade, or via the staircase. Apart from this, one of the apartment buildings has also been equipped with a permanent evacuation ladder from each balcony.

3.1.4 Potential fire hazards

Statistics collected by the Swedish rescue services (SRV, 1998; SRV, 1999) show that the most frequent causes of fire in an apartment building are soot fire, arson, technical malfunction, forgotten stove and burning candles. This tendency is also shown in the same statistics for the most frequent spaces of fire origin, which are the chimney, the kitchen, the living room and the bedroom. There is also a possibility that the fire starts in e.g. the laundry room or in the rubbish chute. However, the number of fires in these areas is much less frequent than the ones mentioned above. Based on this the analysis is limited to studying a fire with an origin in an apartment.

3.2 Specific on each building

3.2.1 Viikki building characteristics

This is a four-storey apartment building with three apartments on each storey. An open staircase runs from the bottom storey up to the top storey. The size of the apartments is within the range of 55 – 70 m^2, 2.6 meters interior height, each with its own balcony.

Both the horizontal and vertical separation of fire compartments is classed for 60 minutes. All the walls as well as the elevator shaft and the staircase are wood-frame constructions. The apartments and the staircase are separate fire compartments. The apartment doors are of self-closing type.

90% of the facade material is wood. This is allowed since there is a sprinkler system installed in the apartments. There is also a smoke detector (ionising type) in every apartment connected to the domestic electricity net. On each floor the smoke detectors are linked together, thus forming a link-zone. Four storeys result in a total of four link-zones. There are smoke detectors in the corridor and in the staircase. The balcony of each apartment is equipped with a permanent evacuation ladder.

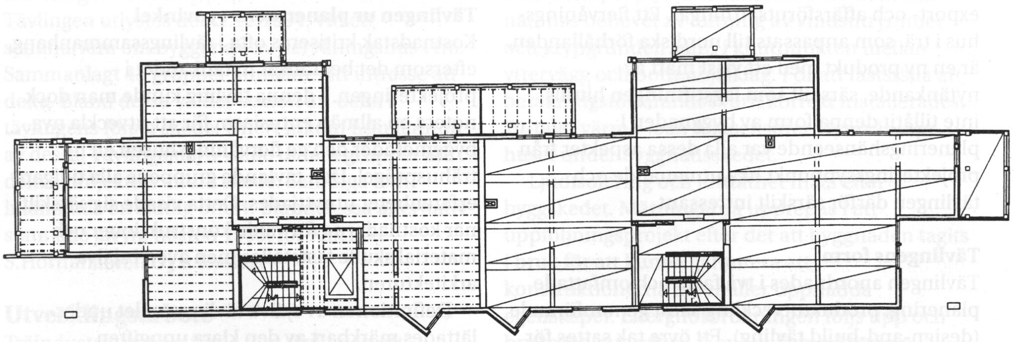

Figure 3.1. Plan of the Vikki building.

3.2.2 Wälludden building characteristics

Wälludden is situated in Växjö, Sweden. This is a four-storey apartment building with four apartments on each storey, ranging from 42 – 84 m^2. The interior height is 2.5 m. All the walls, the staircase and the elevator shaft are wood-frame constructions. Fire compartment separations are classed for 60 minutes. All but the smallest apartments have their own balconies.

There is no sprinkler system installed. Therefore, wood can only be used in a limited amount in the facade. About 20% of the facade is wood, the major part covering the outside of the staircase. This is allowed since the staircase is a single fire compartment.

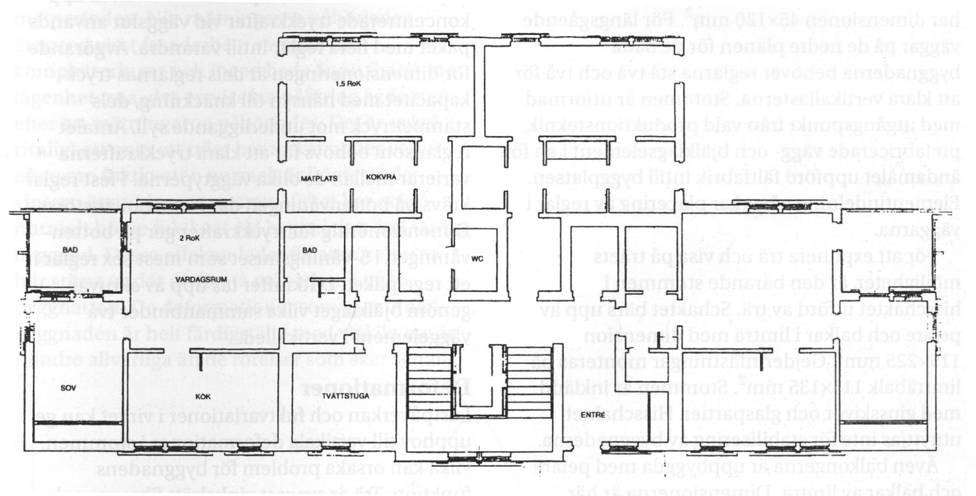

Figure 3.2. Plan of the Wäludden building.

3.2.3 Einmoen building characteristics

This is an apartment building with external galleries. The four stories contain ten apartments per storey. On each end of the external gallery there is an open spiral-stair leading from the top storey down to ground level. The external gallery ceiling is covered by gypsum board. The interior height is 2.4 meters. It is a wood-framed construction.

The apartments are equipped with battery driven smoke detectors and a residential sprinkler system, including the bathroom and the wardrobe. The facade consists of combustible wood-panel.

3.2.4 Casa Nova building characteristics

This is as three-storey building with two apartments per storey. There are four staircases per building. The apartments range from 50 m^2 to 65 m^2 with an interior height of 2.5 meters. It has a timber-frame construction apart from the staircase that is made out of concrete.

The parts in the facade that are made out of fire retardant treated wood is the southern facade, the staircase facade and on the side of the windows. The staircase is equipped with a manually handled smoke-control system.

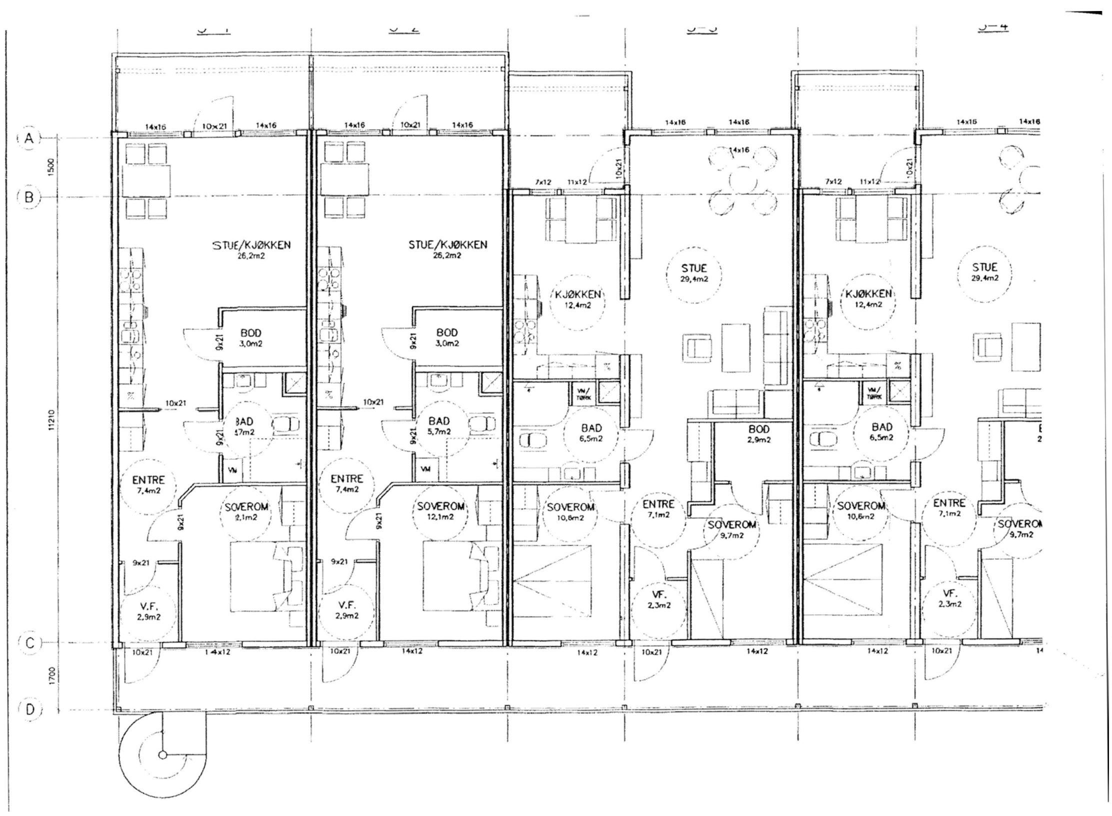

Figure 3.3. Plan of Einmoen building.

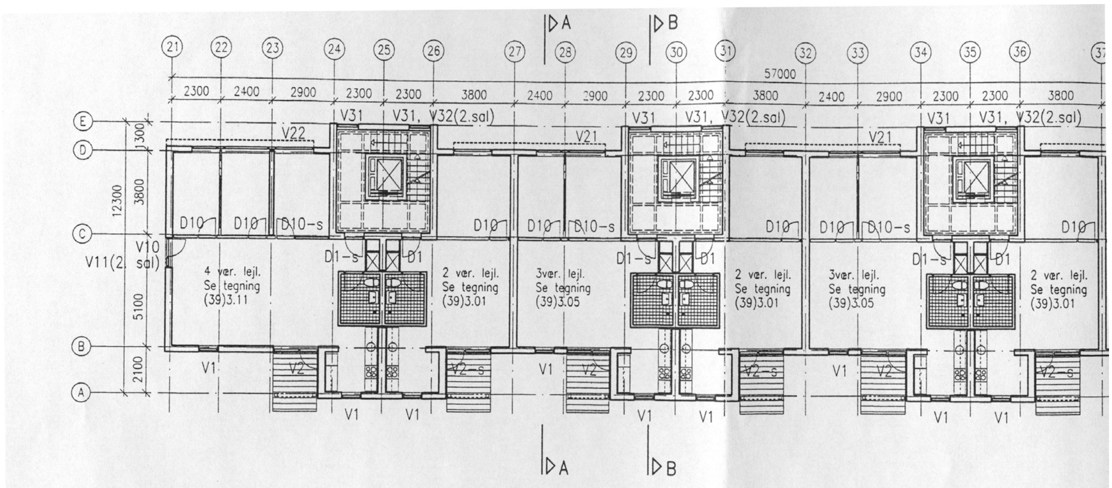

Figure 3.4. Plan of Casa Nova building.

4 Events in the event tree

The event tree is a series of events depending on how the fire safety is designed, where the fire starts, etc. All four buildings analysed in this report have different fire safety designs and depending on the design, all or some of the events listed in this chapter will make up the event tree for these buildings.

4.1 Initial fire location?

The probability of a fire is assumed to be the same for all floors but this analysis has been limited to only studying fire on the first floor since the consequences for this scenario are the worst. If the smoke spreads to the staircase this will no longer be of any use for the occupants above the apartment of fire origin and if the fire spreads on the outside of the building more people above the apartment of fire origin are at risk. The order of smoke spread in the staircase is shown in Table 4.1 below.

The critical conditions are based on the advise in Swedish building regulations (BBR, 1993). The scenario used is described in Appendix B.

Table 4.1. Critical conditions on different levels depending on origin of fire. The numbers 1, 2, 3 and 4 indicate the order in which smoke will spread to each level.

	Critical conditions			
Origin of fire	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Level 1	1	2	3	*
Level 2	No critical conditions	1	2	3
Level 3	No critical conditions	3	1	2
Level 4	No critical conditions	No critical conditions	2	1

* The smoke will spread to this level but will not result in critical conditions on this level. However, since the escape route is blocked on the levels below, no evacuation can be performed from this level via the staircase.

4.2 Flaming fire?

Statistics (SRV, 1997 and Johansson, 1999) show that the probability of a flaming fire in a multi-storey apartment building is 0.72. Both the flaming fire and the non-flaming fire can lead to occupants being exposed to critical conditions but with the difference that the non-flaming fire can expose occupants only in the apartment of fire origin.

4.3 Fire detected automatically?

The probability of successful automatic detection is dependent on how the power supply system is designed. In this analysis two different power supply systems for smoke detectors are used. The first is battery driven smoke detectors and the second is smoke detectors connected to the domestic electricity system. From experience battery driven detectors are more likely to run out of power and quit working. Therefore the probability of successful detection for the battery driven smoke detector is the lower of the two. For the detector connected to the domestic electricity system the probability is set to 0.9 (BSI, 1997). Information on the probability of battery driven detectors is given in (SBF, 2000) as approximately 0.7. This is based on an investigation on how many of the Swedish households that put in new batteries in their smoke detectors. The value used for successful detection in this analysis is 0.7.

4.4 Occupant suppressing?

Statistics (SRV, 1997 and Johansson, 1999) show that the probability that a fire is suppressed is 0.19. The statistics do not indicate how the fire is suppressed but since residential sprinkler is very rare in the Nordic countries the assumption that this probability is associated with occupants is made.

4.5 Sprinkler failure?

There have been several investigations on the probability of successful sprinkler activation; Johansson (1999) gives a summary of some such investigations. The probabilities given range from 0.95 to 0.99. The probability 0.95 is also given in (BSI, 1997). However, there is only one reference (Belles, 1983) that gives the probability for residential sprinklers, this probability is 0.96. The value used in this analysis is 0.96.

4.6 Door open?

This event is divided into three sub-events. The first is that the apartment door is closed and the occupants are still inside. This probability depends on whether or not the fire has been automatically detected. If the fire has not been detected the probability is 0.2 and if the fire is detected automatically the probability is set to 0.1. These values are based on statistics (SRV, 1997 and SRV 1998) that show the probability of being exposed to the fire in a medium-rise apartment building is approximately 0.14. The second sub-event is that the door is closed but the occupants are safe outside and the third sub-event is that the door is open and the occupants are safe outside. The two latter sub-events are assumed to have equal probability if the door is manually handled. Thus, if the fire is not detected these two probabilities are 0.4 and if the fire is detected the probability is 0.45. However, if the door is of self-closing type, the probability of failure is 0.10 (BSI, 1997). Thus, in case of a self-closing door, the probabilities for the second and third sub-events are 0.08 and 0.72 respectively in case the fire has not been detected and 0.09 and 0.81 respectively if the fire has been detected.

4.7 Location of occupants?

To limit the size of the event tree it is assumed to be, in the four storey buildings, four possible locations for the occupants. These locations are: all occupants in their apartments ①, occupants from one level safe outside ②, occupants from two levels safe outside ③ and occupants from three levels safe outside ④. The probability for these sub-events are dependent on if there is a detection system installed or not (remark: detection failure is equivalent to no detection system installed). First, location ① is given a probability depending on detection system and the probabilities for location ② to ④ are then divided on the rest as follows; location ② 0.95, location

③ 0.045 and location ④ 0.005. All the probabilities for these sub-events are listed in Table 4.2 below. In the three-storey building only location ① to ③ are possible.

Table 4.2. Probabilities for sub-events to the event "Location of occupants".

Location	Type of detection system		
	No detection	**Battery driven smoke detector**	**Detectors, connected to domestic electricity system**
①, all occupants in their apartments	0.9*	0.85	0.8
②, occupants from one level safe outside	0.095*	0.1425	0.19
③, occupants from two levels safe outside	0.0045/0.005**	0.00675	0.009
④, occupants from three levels safe outside	0.0005	0.00075	0.001

* Same value for the three-storey building
** Value for the three-storey building

4.8 Level?

Location ② and ③ is further divided into different levels. Location ② can be either level 2, level 3 or level 4 in the staircase. Since the fire is at level 1 the probability of people being safe outside is higher for the level closest to the level of fire origin, i.e. level 2 and after that level 3 etc. In case of the four-storey building the probabilities are set to 0.6 for level 2, 0.3 for level 3 and 0.1 for level 4. In case of the three-storey building the probabilities are set to 0.7 for level 2 and 0.3 for level 3.

Location ③ can be levels 2&3, levels 2&4 or levels 3&4 in the staircase. The probabilities are set to 0.6 for levels 2&3, 0.2 for levels 2&4 and 0.2 for levels 3&4.

4.9 Flashover and spread?

Statistics (SRV, 1997 and Johansson, 1999) show that the probability for flashover given a fire that is not extinguished is 0.4 and given flashover the probability for fire spread to another fire compartment is 0.16. Thus the probability for both these events to occur is approximately 0.06. In these statistics the action of the fire brigade is considered.

When determining the consequences for flashover and fire spread the facade material has to be considered. If the facade is combustible the fire can propagate to a higher level than if the facade is made out of a non-combustible material. In this analysis it is assumed that the fire can propagate one level up if the facade is non-combustible and two levels up if the facade is combustible. These assumptions are based on large-scale test carried out at VTT in Finland (Hakkarainen et. al., 1997). Fire impregnated wood is treated as a combustible material in the sense that in a longer period of time the fire retardant may not be able to prevent fire spread along the facade.

4.10 Asleep?

A non-flaming fire that is not detected can lead to occupants being exposed to critical conditions, if the occupants are asleep. The probability that the occupants are asleep is set to 0.5.

5 Results from the standard QRA

The event trees for all the analysed buildings are shown in Appendix C. As a result of the event tree analysis, risk profiles are obtained. The risk profiles for the analysed buildings are shown in Figure 5.1 below. These should be interpreted as the probability for a given number of people or more to be exposed to critical conditions.

For example:

The probability for one person or more to be exposed in the Viikki building given a fire is approximately 0.05 compared to approximately 0.56 in the Casa Nova building.

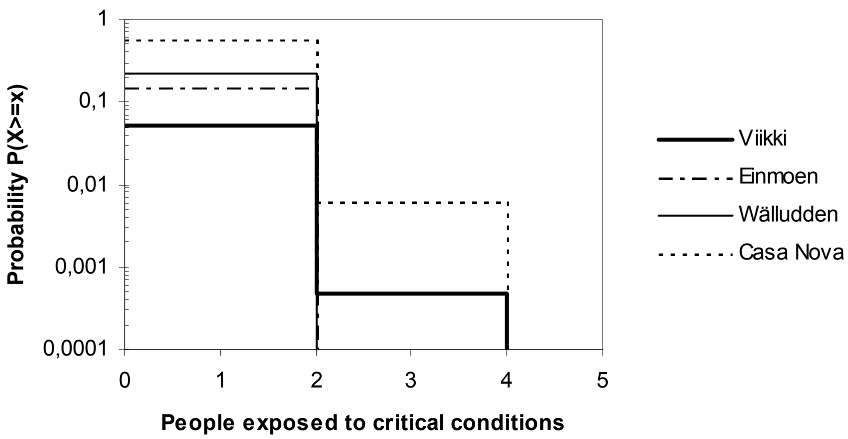

Figure 5.1. Risk profiles for analysed buildings.

Another risk measure is the mean risk. This is the expected number of people exposed to critical conditions per fire. For the analysed buildings the mean risks are shown in Table 5.1.

Table 5.1. Mean risks for analysed buildings

Building	Mean Risk
Viikki	0.11
Wälludden	0.44
Einmoen	0.30
Casa Nova	1.14

If the probability of a consequence is at all times higher for one fire design or building than another there is probabilistic dominance between the two (Johansson et. al., 1999). The ranking is then obvious; the alternative with lower probability for the consequences is of course better, i.e. it has a lower risk. However, if probabilistic dominance is not the case the ranking is more difficult. An evaluation must be made regarding the spread of the risk. For example, one alternative with 1 exposed ten times a year and the other alternative with 10 exposed once a year. The mean risk is the same but alternative two involves a higher consequence. Society tends to evaluate situations with high possible consequences more risky, despite that they are less frequent.

In this analysis there is no probabilistic dominance. However, the magnitude of the consequences is small and the difference between the buildings is also small, a maximum of four people exposed in Casa Nova and Viikki compared to a maximum of two exposed people in Einmoen and Wälludden. Therefore, the ranking will be based solely on the mean risk, as shown in Table 5.2 below.

Table 5.2. Ranking for analysed buildings based on mean risk

Ranking	Mean Risk
1. Viikki	0.11
2. Einmoen	0.30
3. Wälludden	0.44
4. Casa Nova	1.14

5.1 Sensitivity analysis

As mentioned in Chapter 2.1 a sensitivity analysis has to be carried out. The events that are included in this analysis are the ones that are not based on statistics, but on judgements. These events are:

Occupant in apartment
Location if occupants
Asleep
Door open
Level/levels

The consequence is also included in the sensitivity analysis. The scenarios where the fire can spread three storeys up if the facade is made of combustible material and two storeys in case of a non-combustible facade are also analysed.

The results from the sensitivity analysis are shown in Table 5.3 below. Only the changes that are greater than 10% at a 50% variation of the event probability are shown.

Table 5.3. Results from sensitivity analysis, event probability varied 6 50%.

Viikki	Einmoen	Wälludden	Casa Nova
Asleep: 647%	Asleep: 650%	Asleep: 630% Door open: 613%	Asleep: 638%

As seen from the results, the event "Asleep" has a great impact on the final value of the risk. However, the variations do not have any effect on the ranking of the four buildings, neither does the variation of the event "Door open" or any of the other events as well. So, the chosen values for the event probabilities can be used without any changes.

6 Index Method version 1.2

6.1 General

Since the development and the design of the latest version of the Index Method have been discussed in other reports (Larsson, 2000; Karlsson et. al., 1999), only a short presentation will be given here. An explanation of the parameters in the Index Method is shown in Table 6.1 below and a full version of the Index Method is given in Appendix D. A more detailed definition of all the parameters is shown in Appendix E.

Table 6.1. Parameters in Index Method version 1.2.

Parameter			
P1	Linings in apartment	**P10**	Adjacent buildings
P2	Suppression system	**P11**	Smoke control system
P3	Fire service	**P12**	Detection system
P4	Compartmentation	**P13**	Signal system
P5	Structure – separating	**P14**	Escape routes
P6	Doors	**P15**	Structure – load-bearing
P7	Windows	**P16**	Maintenance and information
P8	Facade	**P17**	Ventilation system
P9	Attic		

In short, each of the parameters are given a grade according to the grading schemes presented in Appendix D. A Dephi panel has given each parameter a weight. The parameter grade is multiplied by the weight and all the weighted grades are added to give a final grade, where the highest attainable final grade is 5.0. The Risk Index is then given as 5 minus the final grade (see results table in Appendix D).

6.2 Three different Risk Indices

The Index Method is divided into seventeen sub-parameters, as shown in Table 6.1 above. It is impossible to take some of these parameters into consideration when performing the quantitative risk analysis, as was discussed in Section 3.1.2. A quantitative risk analysis can only take account of life safety of the occupants. The Index Method, however, takes account of life safety of occupants and fire fighters as well as property protection. In order to compare the two methods, the grades from the Index Method must be adapted in some way.

Three different Risk Indices were therefore formed for the comparison; the original Risk Index, an Adjusted Risk Index and an Occupant Escape Risk Index. The two latter are discussed briefly below.

6.2.1 The Adjusted Risk Index

The Adjusted Risk Index was formed by ignoring some parameters that have to do with property protection. This grade is made up by the parameters listed in Table 6.2 below. The reason for creating the Adjusted Risk Index is to obtain a more closely related comparison to the quantitative risk analysis.

Parameters P5 and P15 are excluded since the analysis is focused on the early stage in the fire and that the fire is assumed to spread to another fire compartment through the window (P7). Also, parameter P17 is excluded since the fire is said not to spread via the ventilation system, parameter P10 is excluded because the fire is said to start in an apartment and not by fire-spread from an adjacent building. Finally, parameter P9 is excluded since it is uncommon that occupants are present in the attic for a longer period of time. Also, the fire is said to start at ground level and the fire-spread to the attic and then on to another fire compartment is conceivable later on in the fire.

Table 6.2. Parameters in Adjusted Risk Index marked in bold.

Parameter			
P1	**Linings in apartment**	P10	Adjacent buildings
P2	**Suppression system**	**P11**	**Smoke control system**
P3	**Fire service**	**P12**	**Detection system**
P4	**Compartmentation**	**P13**	**Signal system**
P5	Structure – separating	**P14**	**Escape routes**
P6	**Doors**	P15	Structure – load-bearing
P7	**Windows**	**P16**	**Maintenance and information**
P8	**Facade**	P17	Ventilation system
P9	Attic		

The Adjusted Risk Index was obtained by taking the grades for the parameters marked in bold letters in Table 6.2, multiplying these by their weights and summing up. Subtracting this sum from the maximum value of 5 resulted in the Adjusted Risk Index.

6.2.2 Occupant Escape Risk Index

Since the quantitative risk analysis only takes account of occupant life safety, an attempt was made to form a Risk Index that only reflected this. The original Index Method Grades were given by a Delphi panel, where weights were given to Objectives such as "Life safety" and "Property protection" as well as different Strategies. The weights were then combined through matrix multiplication to form a single, final weight for each Parameter.

The Occupant Escape Risk Index (OE Risk Index for short) was formed by changing the Delphi panel weights, such that the Property protection Objective was given a zero grade, as well as Strategies that did not have to do with Occupant Escape. The matrix multiplication was performed and resulted in Parameter weights that only have to do with Occupant Escape.

Figure 6.1 shows the difference in the weights between the Full Index Method and an index where Occupant Escape is only taken into account. The numbers show that even though some parameters may seem to be only associated with Property protection, the Delphi panel still feels that they are in some way linked to Occupant safety. For example, Parameter 9 (Attic) has a weight of 5.2% of the total fire safety while it gets a value of 3.2% with respect to Occupant safety. This reflects the intuition of the Delphi panel members with respect to the attics and the difference between different objectives and strategies.

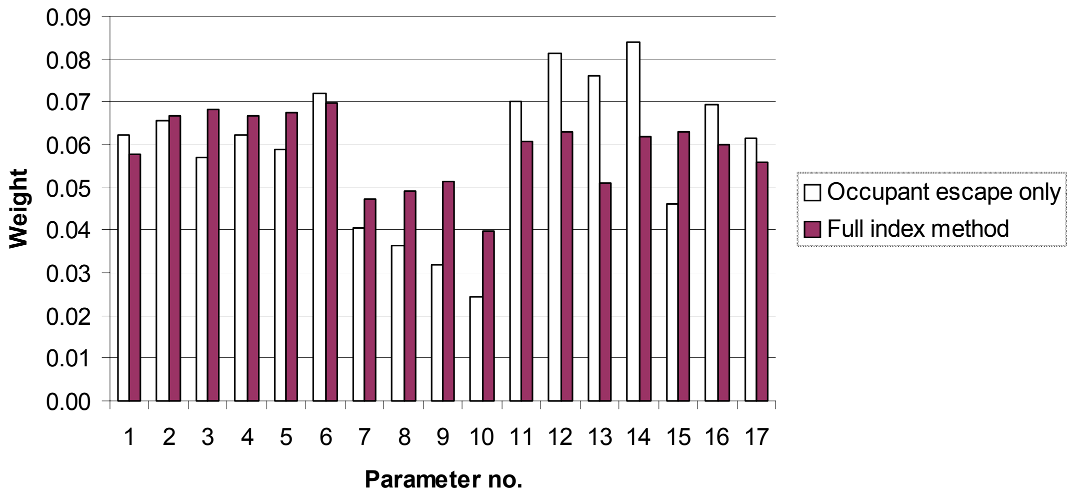

Figure 6.1. Parameter weights for Full Index Method and Index Method for Occupant escape only.

6.3 Results

The values for all the parameters and all the analysed buildings are shown in Appendix F. The Ordinary Risk Index, Adjusted Risk Index and Occupant Escape Risk Index are listed in Table 6.3 below.

Table 6.3. Results from the QRA ranking and three Index Method rankings, all four methods give the same ranking.

Building	QRA Ranking	Ordinary Risk Index	Ranking	Adjusted Risk Index	Ranking	Occupant Escape Risk Index	Ranking
Viikki	1	2.11	1	2.73	1	2.06	1
Einmoen	2	2.16	2	3.00	2	2.11	2
Wälludden	3	2.20	3	3.22	3	2.22	3
Casa Nova	4	2.39	4	3.62	4	2.58	4

As seen in Table 6.3 above, the QRA ranking gives exactly the same ranking as the three index method grades. It should be mentioned that the QRA work was carried out separately and results from the index method were not available when this work was carried out. Similarly, the index method grades were given by four independent engineers in four different Nordic countries. Since the index method and the QRA are based on very different methodologies, the results must be seen to be quite encouraging and indicate that both methods seem to evaluate risk in a similar manner.

When the Index Method was sent out to the engineers who would perform the calculations they were asked to comment on the difficulties they encountered using it. These comments are summarised in Appendix G and were partly used to form comments from users which are listed in the main risk index scheme document (Karlsson, 2000)

Additionally, it is of some interest to compare results from a wood-frame building with those of a similar concrete building. This has been done for all four buildings in this analysis. The results can be seen in Appendix H.

7 Comparison between Index Method and standard QRA

Table 6.3 showed that all three risk indices ranked the four buildings in the same order as the quantitative risk analysis did. A further comparison can be shown graphically in the following figures.

Figure 7.1 shows how the ordinary Risk Index and the Adjusted Risk Index ranking compare to the Expected Risk ranking calculated from the quantitative risk analysis. Observe that there is no direct link between the two scales on the left and right hand side of the diagram, so the values can not be compared numerically. Only the relative ranking can be compared.

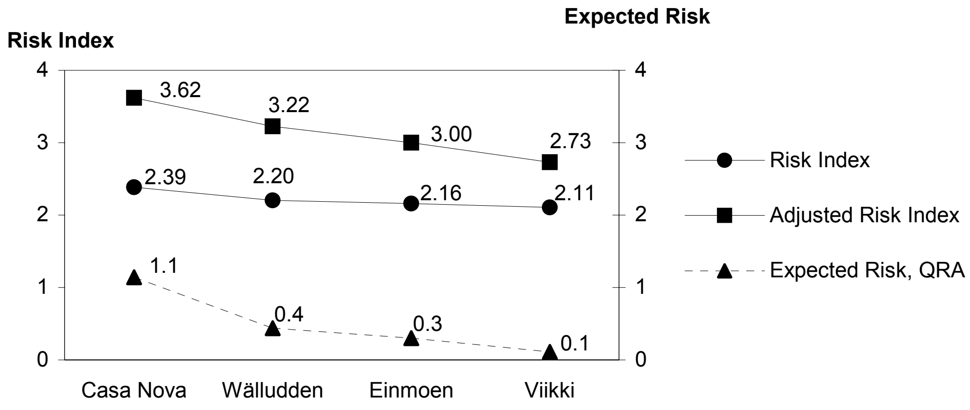

Figure 7.1. The diagram shows how the Risk Index and Adjusted Risk Index rank the 4 buildings compared to the Expected risk ranking from the quantitative risk analysis.

A second comparison was also made, using the Occupant Escape Risk Index. Figure 7.2 shows how the ordinary Risk Index and the Occupant Escape Risk Index ranking compare to the Expected Risk ranking calculated from the quantitative risk analysis.

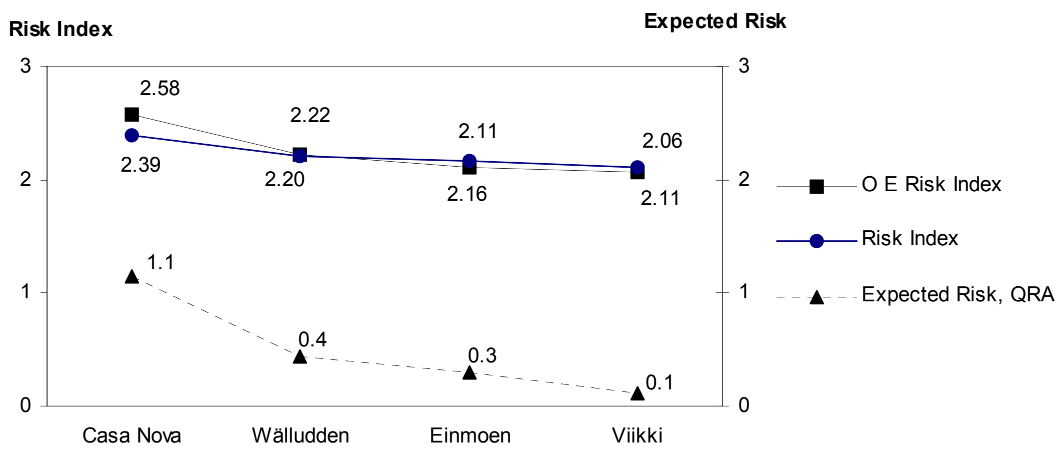

Figure 7.2. The diagram shows how the Risk Index and Occupant Escape Risk Index rank the 4 buildings compared to the Expected risk ranking from the quantitative risk analysis.

The Occupant Escape Risk Index is based on other weights than the ordinary Risk Index, as is seen in Figure 6.1. These new weights are achieved by setting the weights arrived at by the Delphi panel for Property Protection and for strategies other than Occupant Escape to zero. The Occupant Escape Risk Index should therefore show a closer ranking than the ordinary Risk Index to the QRA ranking, since the QRA ranking is basically a measure of the risk for failed occupant escape. This is quite apparent in Figure 7.2, where both the QRA and the Occupant Escape Risk Index show that the Casa Nova building has considerably higher risk in this respect than the other buildings.

8 Conclusions

The results from the Fire Risk Index method presented in earlier work has been compared to a standard QRA (quantitative risk analysis) based on an event tree. Four different multi-storey apartment buildings in the Nordic countries were analysed. The QRA resulted in a certain ranking of the four buildings with respect to fire risk. The Fire Risk Index Method was then used to analyse the same buildings. Three slightly different approaches were used to arrive at a fire risk index for each building. The Index Method results gave exactly the same ranking as the quantitative risk analysis for all three approaches, see Figures 7.1 and 7.2.

It should be carefully noted that the QRA methodology and the Risk Index methodology are very different with respect to the assumptions made along the way. When using the QRA methodology, very rough assumptions must be made regarding the course of events, human behaviour and the fire induced environment. Similarly, there are extreme simplifications embedded in the Risk Index method, but these simplifications are of a different nature than the assumptions made in the QRA method.

It must therefore be seen as a very good sign that these very different methods rank the 4 buildings the same with regards to fire risk. Due to the complexity of the phenomena that the QRA and the Risk Index method try to address, it is impossible to directly validate either methodology against experiments. Nevertheless, the results presented above must be considered to have shown some degree of validation.

We conclude that the Fire Risk Index method presented has considerable promise, but since only 4 buildings were analysed it is clear that further work is needed to evaluate the method and to make adjustments to it.

During the work it has also become clear that the method can be misused, if an engineer consciously wishes to misuse it. It is quite possible achieve a good index rating by giving some parameters a very bad rating and other parameters extremely good rating. In spite of the good index rating, the resulting building design may be totally unacceptable or absurd from a fire safety point of view. But this is only possible if the engineer really wishes to misuse the method. The building design and the use of the method must therefore be based on common sense, as is true for most methods in all engineering disciplines.

In the near future the index method will by tried out by a number of engineers and applied to a number of buildings. Improvements to the method will then be made, including measures to diminish any intentional misuse of the method.

Acknowledgements

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Appendix A Evacuation calculations

The SIMULEX calculations are varied for one, two, four and six persons on levels two, three and four. The results are shown in Table A.1 below.

Table A.1. Evacuation times, results from SIMULEX calculations.

Level	Number of occupants evacuating				
	1	2	4	6	Mean value
2	20 s	21 s	25 s	26 s	**23** s
3	35 s	36 s	37 s	37 s	**36** s
4	46 s	48 s	52 s	52 s	**50** s

As the results show, there is a very small difference between the evacuation time for one occupant and the evacuation time for six occupants. Thus, we conclude that no queues will form.

The hand calculations that where carried out are based on the following travel speeds and distances:

Travel distance per stair level = **7** meters
Travel distance per corridor = **7** meters
Travel speed in stair = **0.6** m/s (Frantzich, 1994)
Travel speed in corridor = **1.2** m/s (Frantzich, 1994)

The total evacuation time is then calculated as follows:

$$\text{Evacuation time} = (L-1)\times\frac{\text{Travel distance stair}}{\text{Travel speed stair}} + 2\times\frac{\text{Travel distance corridor}}{\text{Travel speed corridor}}$$

where L is the level number.

The results from the hand calculations are shown in Table A.2 below. These calculations are based on one occupant evacuating, but since there are no queue formations the evacuation time can be compared directly with the results from SIMULEX. This comparison is also shown in Table A.2.

Table A.2. Results from hand calculations and comparison with SIMULEX.

Level	Hand calculation	Comparison with SIMULEX results
2	23 s	**23** s vs. **23** s
3	35 s	**35** s vs. **36** s
4	47 s	**47** s vs. **50** s

Appendix B HAZARD scenario

This appendix will give a short presentation on the scenario that Table 4.1 is based on. In Figure B.1 a schematic design of the geometry is shown.

The apartment of fire origin is approximately 56 m^2. The apartment door is assumed to be opened after 200 s and the apartment windows break after 400 s.

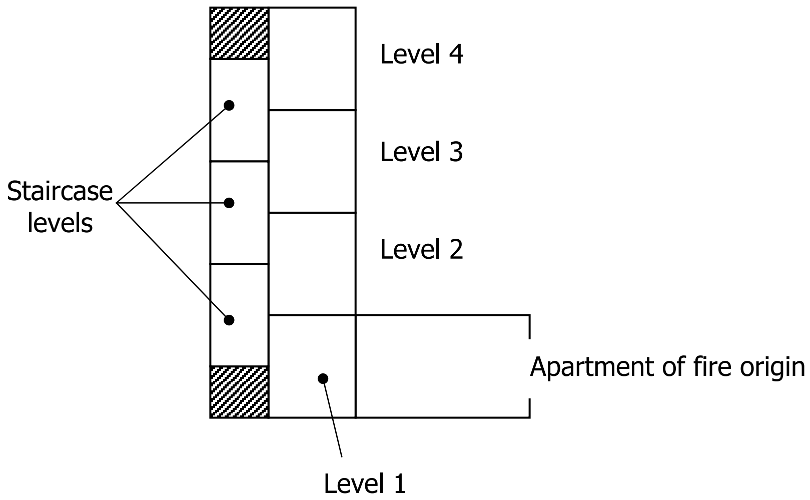

Figure B.1. Schematic design of the geometry, in this case fire at level 1.

The fire specifications are (SFPE, 1995):

ΔH_c	**18** MJ/kg	Corresponds to a mix of wooden materials and plastics
H/C	**0.14** kg/kg	
CO/CO_2	**0.004** kg/kg	
C/CO_2	**0.012** kg/kg	

The fire growth is assumed to be a αt^2 fire with **medium** growth rate. The maximum heat release rate is **2** MW. The design fire is shown is Figure B.2.

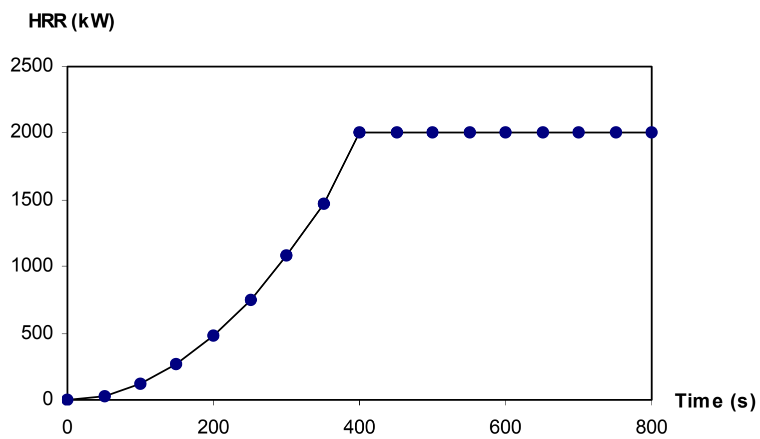

Figure B.2. Design fire

Appendix C Event trees for analysed buildings

NOTE! THE EVENT TREES ARE NOT AVAILABLE IN THIS DIGITAL VERSION, ONLY IN THE ORIGINAL PAPER VERSION!!

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Appendix D Full version of Index Method

Note that a separate publication, Karlsson, 2000, gives the Index Method with comments from users. The comments can be a useful guidance when evaluating some of the parameters.

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 **(P_{3a})**

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 (ie. number of windows (or balconies) that are accessible by the fire service ladder trucks) **(P_{3c})**

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 (P_{5a})

INTEG.RITY 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 (P_{5b})

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 are specially designed for preventing fire spread and deemed by engineers to have adequate performance.	**2**
Joints, intersections and concealed spaces have been tested and shown to have endurance in accordance with the EI of other parts of the construction.	**3**
Homogenous construction with no voids	**5**

(Minimum grade = 0 and maximum grade = 5)

Penetrations (P_{5c})
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 (P_{5d})
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 separating function of doors between fire compartments

SUB-PARAMETERS:

Doors leading to escape route (P_{6a})
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 (P_{6b})
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)

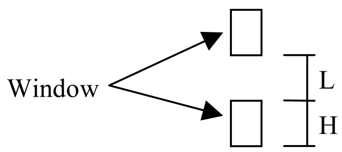
Resulting grade:

P_7. WINDOWS

DEFINITION: Windows (and other facade openings) and protection of these, ie. 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 (P_{8a})

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

(Minimum grade = 0 and maximum grade = 5)

Combustible material above windows (P_{8b})

COMBUSTIBLE MATERIAL ABOVE WINDOWS?	GRADE
Yes	**0**
No	**5**

(Minimum grade = 0 and maximum grade = 5)

Void (P_{8c})
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 (eg. 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 (ie. 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	N

(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**
$6 \leq D < 8$ m	**1**
$8 \leq D < 12$ m	**2**
$12 \leq D < 20$ m	**3**
$D \geq 20$ 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	Pressurisation and natural ventilation for exiting smoke
PM	Pressurisation 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 (P_{14a})
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 (P_{14b})
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 (P_{14c})
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 (P_{14d})

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 (P_{15a})

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 (P_{15b})
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 ie. detection, alarm, suppression and smoke control system **(P_{16a})**

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 (P_{16b})

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 **(P_{16c})**

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

(Risk Index – Timber frame Buildings: Version 1.2)

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 ⇒	
		Risk Index (= 5 - Score)	

Maximum individual grade is 5.00. Minimum Risk Index is 0, which means maximum fire safety level.

Appendix E Detailed parameter definitions

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 protection of windows, ie. 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 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.

Appendix F Index Method results

This appendix gives all the values on the sub-parameters in the Index Method for all the analysed buildings. Four consultant engineers carried out the work, one from each Nordic country (Finland, Sweden, Norway and Denmark). Tables F.1 - F.4 show the results.

Table F.1. Parameter grades, weights and three different grades for Viikki apartment building.

Parameter	Grade	Ordinary Weight	Occupant Escape Weight	Index method Grade	Adjusted Grade	Occupant Escape Grade
P1	5	0,0576	0.0623	0.2880	0.2880	0.3115
P2	5	0,0668	0.0658	0.3340	0.3340	0.3290
P3	5	0,0681	0.0571	0.3405	0.3405	0.2855
P4	3	0,0666	0.0623	0.1998	0.1998	0.1869
P5	2.5	0,0675	0.0588	0.1687	-	0.1488
P6	2.3	0,0698	0.0718	0.1605	0.1605	0.1666
P7	0	0,0473	0.0407	0	-	0
P8	0.9	0,0492	0.0363	0.0443	0.0443	0.0316
P9	3	0,0515	0.0320	0.1545	-	0.0960
P10	2	0,0396	0.0242	0.0792	-	0.0484
P11	2	0,0609	0.0701	0.1218	0.1218	0.1402
P12	5	0,0630	0.0814	0.3150	0.3150	0.4070
P13	3	0,0512	0.0762	0.1536	0.1536	0.2286
P14	2.8	0,0620	0.0839	0.1736	0.1736	0.2383
P15	3.5	0,0630	0.0463	0.2205	-	0.1611
P16	2.3	0,0601	0.0692	0.1382	0.1382	0.1564
P17	0	0,0558	0.0614	0	-	0
			Score ►	**2.89**	**2.27**	**2.94**
			Risk Index (= 5.0 - Score) ►	**2.11**	**2.73**	**2.06**

Table F.2. Parameter grades, weights and three different grades for Wälludden apartment building.

Parameter	Grade	Ordinary Weight	Occupant Escape Weight	Index method Grade	Adjusted Grade	Occupant Escape Grade
P1	5	0,0576	0.0623	0.2880	0.2880	0.3115
P2	0	0,0668	0.0658	0	0	0
P3	4.06	0,0681	0.0571	0.2765	0.2765	0.2318
P4	3	0,0666	0.0623	0.1998	0,1998	0.1869
P5	3.46	0,0675	0.0588	0.2336	-	0.2034
P6	2.99	0,0698	0.0718	0.2087	0.2087	0.2147
P7	0	0,0473	0.0407	0	-	0
P8	2.68	0,0492	0.0363	0.1319	0.1319	0.0973
P9	3	0,0515	0.0320	0.1545	-	0.0960
P10	3	0,0396	0.0242	0.1188	-	0.0726
P11	2	0,0609	0.0701	0.1218	0.1218	0.1402
P12	2	0,0630	0.0814	0.1260	0.1260	0.1628
P13	3	0,0512	0.0762	0.1536	0.1536	0.2286
P14	3.32	0,0620	0.0839	0.2058	0.2058	0.2785
P15	3.74	0,0630	0.0463	0.2356	-	0.1732
P16	1.07	0,0601	0.0692	0.0643	0.0643	0.0740
P17	5	0,0558	0.0614	0.2790	-	0.3070
			Score ►	**2.80**	**1.78**	**2.78**
			Risk Index (= 5.0 - Score) ►	**2.20**	**3.22**	**2.22**

Table F.3. Parameter grades, weights and three different grades for Einmoen apartment building.

Parameter	Grade	Ordinary Weight	Occupant Escape Weight	Index method Grade	Adjusted Grade	Occupant Escape Grade
P1	5	0,0576	0.0623	0.2880	0.2880	0.3115
P2	4	0,0668	0.0658	0.2672	0,2672	0.2632
P3	3.15	0,0681	0.0571	0.2145	0,2145	0.1799
P4	3	0,0666	0.0623	0.1998	0,1998	0.1869
P5	3.18	0,0675	0.0588	0.2146	-	0.187
P6	2.32	0,0698	0.0718	0.1619	0,1619	0.1666
P7	2	0,0473	0.0407	0.0946	-	0.0814
P8	0.87	0,0492	0.0363	0.0428	0.0428	0.0316
P9	2	0,0515	0.0320	0.1030	-	0.064
P10	2	0,0396	0.0242	0.0792	-	0.0484
P11	4	0,0609	0.0701	0.2436	0.2436	0.2804
P12	2	0,0630	0.0814	0.1260	0,1260	0.1628
P13	3	0,0512	0.0762	0.1536	0,1536	0.2286
P14	3.84	0,0620	0.0839	0.2381	0.2381	0.3222
P15	3.74	0,0630	0.0463	0.2356	-	0.1732
P16	1.13	0,0601	0.0692	0.0679	0,0679	0.0782
P17	2	0,0558	0.0614	0.1116	-	0.1228
			Score ►	**2.84**	**2.00**	**2.89**
			Risk Index (= 5.0 - Score) ►	**2.16**	**3.00**	**2.11**

Table F.4. Parameter grades, weights and three different grades for Casa Nova apartment building.

Parameter	Grade	Ordinary Weight	Occupant Escape Weight	Index method Grade	Adjusted Grade	Occupant Escape Grade
P1	5	0,0576	0.0623	0.2880	0.2880	0.3115
P2	0	0,0668	0.0658	0	0	0
P3	4.06	0,0681	0.0571	0.2765	0.2765	0.2318
P4	3	0,0666	0.0623	0.1998	0,1998	0.1869
P5	3.7	0,0675	0.0588	0.2498	-	0.2187
P6	2.99	0,0698	0.0718	0.2087	0.2087	0.2147
P7	2	0,0473	0.0407	0.0946	-	0.0814
P8	1.5	0,0492	0.0363	0.0738	0.0738	0.0545
P9	5	0,0515	0.0320	0.2575	-	0.1600
P10	3	0,0396	0.0242	0.1188	-	0.0726
P11	2	0,0609	0.0701	0.1218	0.1218	0.1402
P12	0	0,0630	0.0814	0	0	0
P13	0	0,0512	0.0762	0	0	0
P14	3.5	0,0620	0.0839	0.2170	0.2170	0.2953
P15	4.5	0,0630	0.0463	0.2835	-	0.2074
P16	0	0,0601	0.0692	0	0	0
P17	4	0,0558	0.0614	0.2232	-	0.2456
			Score ►	**2.61**	**1.38**	**2.42**
			Risk Index (= 5.0 - Score) ►	**2.39**	**3.62**	**2.58**

Observe that the Adjusted Risk Index value is much higher than the other Risk Index values. This is since not all parameters are given a value when evaluating the Adjusted Risk Index.

Appendix G Comments given on using the Index Method

The parameters that are not listed below didn't receive any comments by the engineers. Remark: These are not the same exact words used by the engineers, i.e. no direct quotes.

P1, Lining in apartments – In some cases there is a possibility that there are different lining materials in the apartments due to options given to the occupant. It may be hard to estimate in what degree this has been done and if this is the case, how should it be dealt with in the Index Method?

P2, Suppression system – The residential sprinkler systems can be different in different countries. Maybe a separation regarding this?

P5 d, Structure - separating - combustibility – If the separating constructions is made out of timber studs, insulation and gypsum boards, how should the separating structure be interpreted?

i. Only as the gypsum board or
ii. The whole separating structure

P6, Doors – Should the open external galleries be treated as a fire compartment?

P6 b, doors in escape route – Why is the grade related to the national requirements for doors in escape routes? The Index Method states that if no doors are needed in the escape route the highest grade is given. Is this design really comparable to the design including doors with the highest integrity and insulation as well as a self-closing mechanism (which also is given the highest grade)?

Is the lift-door counted as a door in the escape route?

P7, Windows – Is this referred to windows in separate fire compartments or within a single fire compartment?

If there are different relative vertical distances, should the highest, the lowest or the mean-value be used?

Maybe a sub-parameter regarding if the window, or another facade opening, is allowed to be open or not? If it's open in a fire situation it doesn't matter if the window is classed or not.

P8 a, Facades - combustible part of facade – How can different materials be treated in this sub-parameter? Should e.g. fire- impregnated wood be treated the same as non-impregnated wood?

The combustible part of the facade might differ on a building, e.g. one of the facades have >40% combustible material while another facade has <20%. How should this be dealt with? Worst case or the average value?

P8 b, Facades - combustible material over windows – What grade should be given if the distance between the windows is not entirely covered with combustible material?

If the major part of the windows also have a balcony above, can a higher grade be given? The fire spread along the facade is limited due to the cantilever.

P9, Attic – The sub-parameter *fire separation in attic* might be differentiated, giving grades if the attic is separated at each apartment or not, i.e. only one apartment adjacent to each fire compartment in the attic.

P11, Smoke control system – If the Index Method is used, a building with external galleries will receive the resulting grade zero. This is a bit misleading since the possibility of smoke blocking an escape route is quite small. Should the design with external galleries be given the same grade as a staircase with no smoke control system?

P12, Detection system – Shouldn't a combined detector (heat and smoke) be an option?

P14, Escape routes – This parameter is clearly developed for buildings with staircases. How should a building with external galleries be valued? Either another option is added or guidance on how external galleries should be treated should be given.

P14 c, equipment – There might be motion detectors that turn on the general light. Should this be treated as a manually switched or always on?

P14 d, linings and floorings – How is a floor material in class G, e.g. wood, handled?

Appendix H Comparison with concrete building

A Risk Index was obtained for the 4 buildings analysed in this report, where the building frame is assumed to be of concrete instead of timber. This new index was to reflect the minimum requirements in the building codes in the four Nordic countries for multi-storey apartment buildings with a concrete frame. In order to evaluate this index, the grades for a few parameters had to be changed. These parameters were:

P1 Lining materials
P2 Suppression system
P5 Structure – separating
P8 Facade
P9 Attic
P15 Structure – load-bearing
P16 Maintenance and information

P1 was changed according to the minimum requirements in the four Nordic countries. P2 was set to zero in all four buildings, since sprinkler is not required for these in the building codes. P5 and P15 changed since the load-bearing and separating structure changed. P8 changed for the Einmoen and Casa Nova buildings since the minimum requirements in Norway and Denmark with regards to facades are slightly different from those in Sweden and Finland. P9 was changed for the Einmoen and Wäludden buildings since requirements for attics in the Norwegian and Swedish building codes allowed such changes.

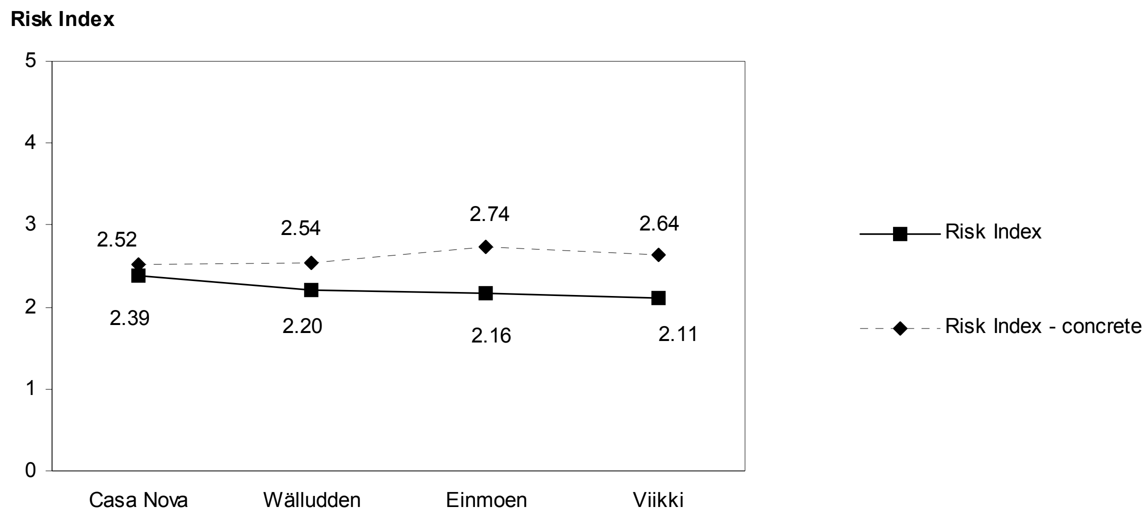


Figure H.1. Comparison between wood-frame building and concrete building.

The result is shown in Figure H.1. The figure shows that the concrete-frame buildings indicate a higher fire risk than the timber-frame buildings; this is natural since the evaluation for the concrete buildings was made in terms of reasonable minimum code requirements in each country. The figure also shows that the increase in risk is greatest for the Vikki and Einmoen buildings. This is mainly due to the fact that the concrete buildings are not equipped with a sprinkler system but Viikki and Einmoen are equipped with a residential sprinkler system in the timber-framed cases.

It would be advantageous to arrive at some measure of a maximum Fire Risk Index value for concrete-frame buildings allowed by the building codes in each country. This maximum Fire Risk Index value could then be used as some measure of the minimum requirements and could be used as a basis for comparisons. However, this is difficult to achieve here, mainly for the following reasons:

- The four buildings analysed in this report are all different. One can arrive at a maximum Fire Risk Index for the specific building, but a slightly differently designed building, in the same country, may receive a different Fire Risk Index. The maximum Fire Risk Index allowed, with respect to minimum requirements in building codes, can therefore vary between slightly different building designs.

- Building codes can be quite complex and sometimes authorities allow that lesser requirements than the minimum be used, given that this is compensated by higher requirements in other parameters. There is a considerable difference in how this is treated in the different countries but there are also differences in treatment within each country. For example, the building authorities in Stockholm may treat such compensations very differently than the building authorities in Malmö.

Therefore, no single generally valid maximum allowable Fire Risk Index value can be arrived at. However, systematic studies using the Index Method in the Nordic countries, can lead to recommendations for such a value. This requires considerable work on a Nordic scale.