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DEVELOPING A SWEDISH BEST PRACTICE GUIDELINE FOR PROPER USE OF CFD-MODELS WHEN PERFORMING ASET-ANALYSIS

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ABSTRACT

During 2012-2013 the Swedish sub-chapter of the Society of Fire Protection Engineers (Chapter 47, BIV) performed a project to develop a Swedish best practice guideline to ensure better use of CFD-modelling when performing available safe egress time analysis (ASET analysis).

The purpose of the project was to increase the knowledge and ability to handle the new requirements given by the Swedish National Board of Housing, Building and Planning and to improve the quality when analysing ASET analysis with advanced fire models.

The purpose of this paper is to spread the knowledge of the working process and to describe how different organisations within Sweden have collaborated to deal with issues concerning CFD-modelling. The paper also presents some of the technical aspects that the work generated to increase the knowledge concerning the use of FDS.

INTRODUCTION

In Sweden there are prefomance based regulations when constructing a buidling. In a performance-based code, compliance with the fire safety regulations can be demonstrated in two ways: either by constructing the building in accordance with pre-accepted solutions (defined by the Swedish National Board of Housing, Building and Planning), or by means of fire safety engineering methods proving that the fire safety is satisfactory according to the societal level of saftey. Fire safety engineering methods are used when pre-accepted solutions are not met due to building-specific conditions (for example if the building is over 16 floors) or if there are specific stakeholder requests (for example large fire compartsments due to occupancy). Performance based regulations was first implemented in Sweden 1994.

During 2012, new fire safety regulations were implemented in Sweden [1] which were the most comprehensive revision of the Swedish building code since the transition to performance-based regulations. In connection to the implementation of the new regulations, the Swedish National Board of Housing, Building and Planning also published general guidelines on the use of fire safety engineering methods [2].

The guidelines presents different analysis methods, what fire scenarios to analyse and what design values to use for different kind of fire safety objectives. The guidelines also defines, in some case, the level of safety to fullfil. The fire safety objectivs presented in the guidelines are about means of egress (ASET-RSET analysis), protection against fire and smoke spread within a building and protection against fire spead between buildings [2]. In the guidelines there are also som guideance according how to work with the desig process when performing an analysis. The main steps presented are:

- indetify the need of verification,
- perform the verification and ensure satisfactory fire safety level,
- control the verificantion,
- document what you have been doing.

But the guidelines from the Swedish National Board of Housing, Building and Planning doesn´t give any guidance on *how* to perfom an analysis and there is limited information about how to ensure the quality of a verification.

The national guidelines for ASET-analysis

In the guidelines from Swedish National Board of Housing, Building and Planning [2], scenario analysis is used to analyze means of egress from a buidling. The approach is based on comparing available safe egress time (ASET) with required safe egress time (RSET). The design process for ASET-analysis is based on pre-defined fire scenarios where parameters such as type of occupancy and available technical systems (for example sprinkler systems) are considered. The prescribed scenarios are chosen to represent a probable worst case scenario and a number of robustness scenarios.

Fire scenarios to be analyzed

The national guidelines [2] specify three required fire scenarios that are generally applicable to the majority of ASET analysis. These scenarios are selected to represent a reasonable stress on the building's fire protection.

Fire scenario 1 is characterized by a severe fire with rapid development, high maximum heat release rate, and a high production of byproducts - *a probable worst case*. The installed technical protection systems are assumed to function as intended and the impact of these may be included in the design fire. Also, fire propagation shall be selected as "*conservative*" (see Table 1 and Table 2). The impact of active systems is also specified in the new regulations. In case the heat release rate is 5.0 MW or less upon activation of an automatic fire extinguishing system, the heat release is kept constant for 1 minute, then reduced to 1/3 during the following minute, and then kept constant at this level. In case the fire's heat release rate at sprinkler activation is greater than 5.0 MW, the heat release should be kept constant after sprinkler activation

In case the building is not equipped with a full automatic fire and evacuation alarm, the analysis should include fire scenario 2. This scenario comprises a fire in an area where there is normally no people, but which is adjacent to an area where there is a large number of people.

Fire scenario 3 is characterized by a fire progression which is expected to have a smaller stress effect on the building's fire protection. On the other hand, in this scenario individual technical systems (such as sprinkler or smoke control systems) are not functioning as intended. The technical systems in the analyzed building should all be made inaccessible separately. In this scenario, the fire progression shall be selected "*non-conservative*" (see Table 1 and Table 2).

Design values to be used

Design values for the required fire scenarios according to growth rate, maximum heat release and heat of combustion should not be less than what is defined in in the national guidelines. The heat release rate should be calculated according to the well-known t-squared fires with defined α-values. In the guidelines there is also design values defined for by-products in the early stage of the fire. The soot yield, CO- and CO_2- production is depending on what fire scenario analyzed.

Table 1 presents the design values according to the different occupancies .Suggested design values for byproducts, are presented in Table 2.

Table 1: Growth rate, HRR, and heat of combustion in the early stage of a fire for different occupancies.

Fire scenario	Occupancy	Growth rate (kW/s^2)	HRR (MW)	Heat of combustion (MJ/kg)
1 & 2	Office school	0.012 *Medium*	5.0*	16
	Dwellings, hotels & healthcare facilities	0.047 *fast*	5.0*	20
	Assembly halls	0.047 *fast*	10.0*	20
3	All occupancies	0.047 *fast*	2.0	20

**In the case where no active extinguishing system is installed in the building, otherwise the heat release rate should be handling according to the impact of an automatic fire extinguishing system described in fire scenario 1.*

Table 2: The design value for byproducts in the early stage of the fire.

Fire scenario	Soot production (g/g)	CO production (g/g)	CO2 production (g/g)
1 & 2	0.10	0.10	2.5
3	0.06	0.06	2.5

The values in Table 2 defined for scenario 3 can also be used for scenario 1 and 2 in case there is no automatic fire extinguishing system in the building.

Tenable conditions

In the national guidelines there are also defined level of tenable conditions to be benchmark against to determine when critical condition occurs. Defined criterions are visibility (or the smoke layer height), heat dose and radiation, temperature and toxicity.
Defined tenability criteria in the national guidelines [2] are presented in Table 3.

Table 3: Criterion for tenability for ASET analysis.

Criterion	Level
1. Smoke layer height	The smoke layer should at least be at the height of 1.6 +0.1 x H (where H is the room height) meter above the floor level
2. Visibility 2,0 m above floor level	10 meter when the building is larger than 100 m^2. 5 m when the building is smaller than 100 m^2 or where people are cueing.
3. Heat exposure criteria	Maximum of 60 kJ/m^2 above the heat radiation energy on a level of 1 kW/m^2.
4. Temperature	Maximum 80°C.
5. Heat radiation	Maximum radiation intensity of 2,5 kW/m^2 or a short dosage of maximum 10 kW/m^2.
6. Toxicity, 2,0 m above floor	CO <2 000 ppm CO_2 5 % O_2 15 %

THE SWEDISH BEST PRACTICE FOR ASET-ANALYSIS WITH CFD-MODELS

Regarding the difficulty to fully understand the defined design process for ASET analysis in the national guidelines [2] and that the Swedish National Board of Housing, Building and Planning don´t give any guidace conmcerning *how* to do the analysis (it is assumed that the enngineer knows how to do it), there was a need for a more into depth guidance. As a result of this, the Swedish sub-chapter of the Society of Fire Protection (BIV) initiated a project 2012 to develop a Swedish best practice to ensure better use of CFD-modelling. The starting point for the project was therefore, to pick up where the national guidelines ended concering ASET-analysis and to give more userfriendly recommendations.

The work in the project was carried out similar to the development of open-source codes, standardizing committees and how the SFPE-organizations work with the development of best practice guidelines. The project was completely non-profit and the project group consisted of 8 members with represents from the consultant industry, academic institutes and research institutes. The project was completed during one year and in all it took about 600 man-hours to complete the project. In order to increase the quality, raise awareness of the project and thus get a wider distribution and legitimacy for the work, the best practice, in a preliminary form, were sent out for referral. All members of the BIV and other relevant organizations within the fire safety community in Sweden were invited to give consultation responses. The received responses were taken into consideration before the final version of the best practice was published.

The overall purpose with the best practice was to be a supporting guide for the practising engineer, reviewers and clients to achieve a sufficient quality level and to increase the understanding for the process when analysing ASET. From this point of view the best practice included both a technical guidance concerning how to work with CFD-models, as to describe a well-functioning working process and to provide suggestions for quality assurance.

Most fire safety engineers in Sweden working with design of buildings use the CFD-model Fire Dynamic Simulation (FDS) [3] when performing advanced ASET-analysis. Based on this, the best practise was developed for FDS version 5.5.3 (SVN 7031), which was the latest official version of the program when the project was initiated. The best practice was limited to only describe aspects concerning the early stage of the fire during well ventilated conditions and to ensure to fulfil the requirements given by the Swedish National Board of Housing, Building and Planning. However, some parts of the best practice guidance can still be used for other CFD-programs or versions of FDS and also for different kind of analysis which doesn't follow the Swedish way of analysing ASET-analysis. Especially the parts concerning the working process and the quality assurance are areas that in some extent are universal for all kinds of CFD-modelling.

The content of the best practice consists of a suggested working process, different technical aspects concerning fire characteristics (based on the national guidelines), and example on parameters to control in a quality assurance. But, the best practice gives also guidance to important aspect concerning verifying and validation of FDS, smoke control management, how to handle input and output data and what sensitivity analysis to perform to ensure reliable results. However the best practice doesn´t give hands-on tips to programing a FDS input file or how to do specific functions in pre-process programs such as Pyrosim. But there are other guidelines developed in Sweden [4]. and Denmark [5] that gives more hands-on tips for that kind of issues.

The working process

One of the essential elements in the best practice is the defined work process. The process is developed to help to identify a problem, define the purpose and the objective with an analysis, to choose a proper calculation method and to ensure reliable results with sufficient quality.

The proposed process is in some extent inspired by the SFPE Engineering Guide to Performance-Based Fire Protection [6]. The process also includes the Swedish National Board of Housing, Building and Planning´s guidelines on how to perform and verify performance based fire protection. [2]

The working process consists of a workflow in eight sequential steps and a parallel process concerning quality assurance within the different steps. The proposed workflow is presented in Figure 1.

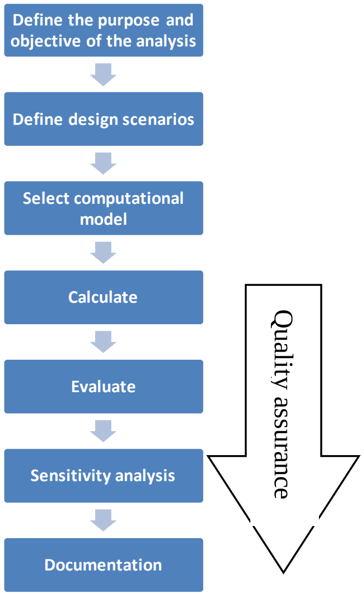

Figure 1: Flowchart for visualisation of the proposed working process.

Define the purpose and objective of the analysis

The purpose and objective of the analysis shall always be defined. The purpose and objective should clearly answer the question *why* the analysis is performed and *what* objectives are to be reached or requirements met.

The objective of the analysis must be expressed in terms that allow for a comparison of the results of the ASET-analysis with applicable acceptance criteria.

Define design scenarios

The purpose of defining fire scenarios is to translate the objectives into an analysable model [7]. According to national guidelines [2], analysis concerning ASET should be by a deterministic scenario analysis.

To identify different critical fire positions, it is recommended to perform an initial risk analysis.

Selecting computational model

To fulfil the purpose and objective, a proper computational model has to be chosen. In general, the selection of computational model should be based on the building's complexity and the objective of the analysis.

It is important that the chosen computational model´s limitations are well-known to ensure that the calculations are accurate and to bear in mind that the need for computational power will increases with the desired level of accuracy of the results. It is also important to ensure that the selected model is sufficiently validated and verified for the issue.

Calculate

During the calculation step, focus is on using reasonable assumptions and input data. Importantly, all assumptions and input data should be documented and traceable, to assure that the analysis is transparent and that the assumptions and input data are available for the sensitivity analysis.

Evaluate

The purpose of the evaluation is to decide if the calculation results are plausible, and to compare the results with established objectives and acceptance criteria. If the acceptance criteria are not met, a new trial fire safety design has to be defined and analysed.

Sensitivity analysis

The sensitivity analysis examines how much impact each parameter has on the outcome of the results from the calculation. If the analysis results do not change significantly, it is assumed that the variable does not need to be further investigated.

When the ASET analysis is performed in accordance to the national guidelines, the following parameters are recommended to control in the sensitivity analysis;

- fire position,
- grid size,
- activation times for different active systems (i.e. sprinkler systems or smoke control systems),
- opening areas used for smoke control management, smoke extraction capacity
- effects of wind.

Documentation

Documentation is important to facilitate control, quality assurance, and traceability [7]. As a minimum, the following elements are recommended to be included in the documentation:

- Initial risk analysis to define critical fire positions, and other important aspects
- Prerequisites and assumptions on which the analysis is based upon
- Description of the methods and models used for the analysis
- The result from the calculations to the extent that the process can be followed.
- Any deviations from the national recommendations from the National Board of Housing, Building and Planning and justification thereof.

Quality assurance

During the analysis quality assurance is recommended to be made within different steps of the working process.

Before the simulation starts, it is strongly recommended that important parameters are controlled to ensure that they are defined correct. The parameters recommended controlling are among others; computational domain, geometry of the model, fire characteristics, surfaces and material, and active systems.

During the evaluation of the results it is also important to ensure that the output data are within reasonable levels and that the quality is good enough for further analysis. It is recommended to control the heat release and growth rate, heat of combustion, flame temperature, mass flow and velocity over mesh boundaries and openings in the model.

TECHNICAL GUIDELINES

The technical guidelines in the BIV´s best practice cover the following parts:

- How the design fires, recommended by the national guidelines [2], could be characterized in the CFD-model
- What aspects of the building geometry that needs to be considered when the model is created
- Which aspects that need to be considered when modelling smoke control ventilation
- How the output data should be evaluated

The main focus of this part of the paper is to summarize the first bullet point. The rest of the contents of the technical guidelines are just briefly summarized in this paper.

Characterizing the fire source and the computational domain

The recommended design fires that are presented in Table 1 can be modelled in a variety of ways with different outcome of the results. In an ASET-analysis is it common that the visibility in the smoke is the parameter that first causing critical conditions. Therefore, is it important to generate the correct amount of soot. The heat release rate needs to grow correctly and reach the correct maximum heat release rate. The flame should be a turbulent diffusion flame, driven by buoyancy, not momentum. Further is it important that the computational domain has a grid resolution fine enough to resolve the fire plume, since the fire plume is the driving force of smoke spread. All these factors influence the soot production and in extension the safe egress time.

Fuel composition

The chemical reaction controlling the combustion process in FDS is defined by the user as a relation between nitrogen, oxygen, hydrogen and carbon in the fuel. FDS can calculate the heat of combustion by using the oxygen consumption in the reaction. The value of the heat of combustion could also be user-specified. The heat of combustion will affect the mass loss rate of the fuel and therefore also the amount of soot being generated. The user should aim for using a chemical composition of the fuel that matches the value of the heat of combustion specified in Table 1. *Table 4* suggests two different fuel compositions that can be used for this purpose. The fuel with a heat of combustion of 20 MJ/kg is composed of 40 mass-% polyurethane and 60 mass-% cellulose. The fuel with a heat of combustion of 16 MJ/kg consists of cellulose only.

Table 4: Fuel composition for the recommended design fires.

Occupancy		Offices, schools	Dwellings, hotels, healthcare facilities and assembly halls
Heat of combustion (MJ/kg) as recommended by the national guidelines		16	20
Composition	C	3.4	4.56
	H	6.2	6.56
	O	2.5	2.34
	N	0	0.4
Heat of combustion (MJ/kg) based on the above composition		17	19.8

Size of the fuel source

The surface area of the fuel source needs to have the right proportion to the heat release rate being developed. A high HRR generated over a small surface area will cause the fire plume being driven by momentum instead of buoyance. The shape of the flame will be similar to a jet flame. Jet flames are more structured than buoyance driven flame which usually occur in building fires, Jet flames are also less affected by surrounding air flows.

If the surface area of the fire source is large with a low HRR the flame will break up into smaller, separate, flames. This will not represent a “real” fire. Cox and Kumar [8] defines that dimensionless HRR, $\dot{Q}^*$, should be in the range 0.3 to 2.5 for natural fires in buildings. Using this range, along with the recommended design fires in the national guidelines, a range of applicable fire diameters can be calculated. With a known fuel surface diameter, the heat release rate per unit area (HRRPUA) can be calculated as well. Values within the applicable range are presented in Table 5. It should, however, be noted that the upper range consist of very high values on the HRRPUA. These values are outside the applicable range given in the Danish technical guidelines [5] which suggests a maximum HRRPUA of 2500 kW/m^2.

In the early stage of the fire, when the heat radiation from the smoke layer to the fuel surface is low, horizontally oriented fuels will develop a HRRPUA in the lower region of the values given in Table 5. E.g. solid wood will roughly have HRRPUA of 100 kW/m^2, PMMA 750 kW/m^2 and a mattress in polyurethane 910 kW/m^2. Some liquid fuels can have a higher HRRPUA, e.g. Heptane with 3300 kW/m^2.

For a given HRR the entrainment of air into the fire plume will be dependent on the fire perimeter. A larger perimeter will cause a larger entrainment resulting in a higher plume mass flow rate and lower plume temperatures.

A fire with a large area is therefore more conservative when modeling smoke spread. It is recommended that the HRRPUA is chosen so it approximately matches the minimum values of $\boldsymbol{\dot{Q}}^*$ in Table 5, e.g. 800 kW/m2 for the high stress design fire in an office.

Heat release rate and growth rate

There are several ways to model the fire growth phase in FDS. E.g. the RAMP-function can be used. However, if the fuel surface area is kept constant during the growth phase the dimensionless HRR will be very low in the early stage of the fire. It is therefore recommended to use the function SPREAD_RATE instead. The function mimics a fire that is growing radially with a constant speed. FDS User's Guide [3] states, however, not to use the function SPREAD_RATE to mimic the alfa-t2 fire. But there are several other guidelines [7] [5] that do recommend the use of the function for the purpose and so do the best practice. The advantage of using the SPREAD_RATE function is that the burning surface is kept small when the HRR is low and therefor it is possible to maintain applicable values of the dimensionless HRR ($\dot{Q}^*$) during the fire growth. The disadvantage of using the function is that the fire source needs to be properly resolved for the HRR to resemble a continuous function.

Figure 2 illustrates how the HRR is non-continuous when the SPREAD_RATE function is being used. The phenomenon is more obvious when larger grid cells are being used.

Table 5: Applicable range of fire size and HRRPUA.

Scenario	Occupancy	HRR (MW)	$\dot{Q}^*$ (-)		Fire surface area (m^2)		HRRPUA (kW/m^2)	
			Min	Max	Max	Min	Min	max
High stress fire scenario 1	Offices, schools	5	0.3	2.5	6.9	1.3	725	3952
	Dwelling, hotels, and healthcare facilities	5			6.9	1.3	725	3952
	Assembly halls	10			12.0	2.2	832	4539
Robustness fire scenario 3	All occupancies	2			3.3	0.6	603	3290

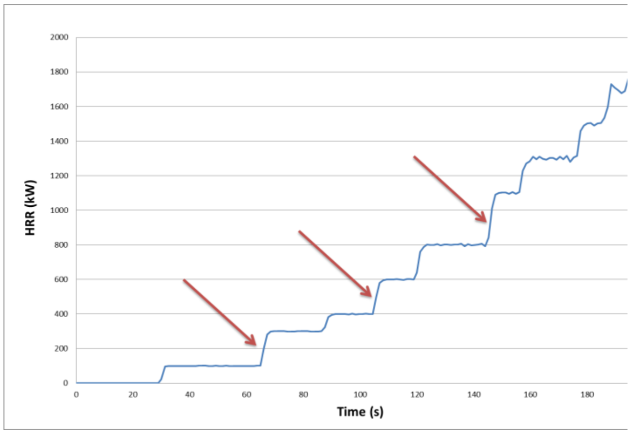

Figure 2: An alfa-t2 growth characterized by the SPREAD_RATE function.

It can also be seen from Figure 2 that there is no fire development during the first 30 seconds of fire. This phenomena origin from fire grid cells being "activated" based on a function that depends on the distance from the point of fire origin (XYZ command) and the grid cell size. The delay in HRR development can be minimized using small grid cells and the point of fire origin being in the center of a grid cell. It is therefore recommended that a square shaped fire source is modeled with an odd number of grid cells covering each side of the fire source.

A fire growth modeled with the SPREAD_RATE function will show a discrepancy with the alfa-t2 function as the fire HRR approach the maximum HRR. Figure 3 illustrates a 10 MW fire with a *fast* growth rate. In the simulation grid cells have a width of 12.5 cm. The discrepancy occurs since the fire source in FDS is square shaped and the fire spread over the fire source surface radially.

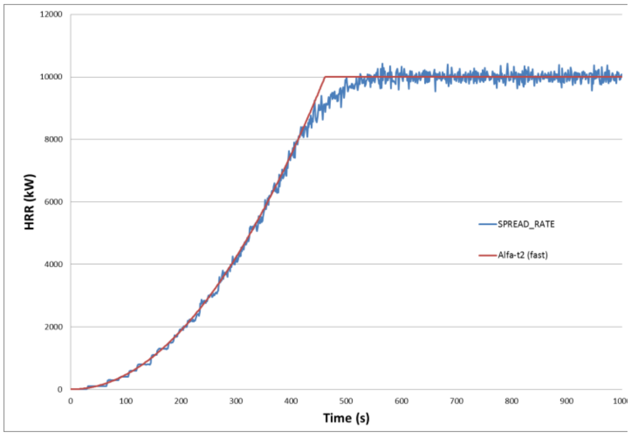

Figure 3: Discrepancy between the SPREAD_RATE function and the alfa-t2 growth.

Since the SPREAD_RATE function underestimates the HRR, any of the following measures should be considered:

- If it can be verified that critical conditions occur before the discrepancy occur, there is no need for any certain measures to be taken.
- The fire is modeled using a higher maximum HRR. If the maximum HRR is increased by 10 %, the discrepancy will occur after the recommended maximum HRR has been reached.
- The SPREAD_RATE value can be increased (using a higher growth rate factor) while maintaining the recommended maximum HRR.
- Instead of using the SPREAD_RATE function the fire source could be modeled using a number of fire cells that are activated at different times to mimic the alfa-t2 growth. The risk of introducing user-errors is larger since the FDS-code becomes more complex. However, the method solves most problems identified concerning growth rate.

To calculate the SPREAD_RATE value, the following equation can be used:

$$SPREAD\_RATE = \sqrt{\frac{\alpha}{\pi} \cdot \frac{1}{HRRPUA}}$$

Where:
SPREAD_RATE=Fire spread rate (m/s)
α = Alfa–t2 growth rate (kW/s^2)
HRRPUA = Heat release rate per unit area (kW/m^2)

Grid resolution

Using a fine grid resolution is important from several aspects; it influences the geometrical shape of the building, how well the SPREAD_RATE function mimics the alfa-t2 growth and the precision in the calculated flows in the fire plume etc.

FDS User's Guide [3] states that, how well resolved the flow field of a buoyancy driven fire plume is, is given by a dimensionless number $D^*/\delta x$. Nystedt [7] states that $D^*/\delta x$ should be in the range of 10-20 in the near-field of the fire. Nystedt also states that at high room heights ($D^*/H<0,5$, where H is the room height in meters) should $D^*/\delta x$ be at least 15. Table 6: The relation between recommended fire scenarios an grid cell sizeTable 6 illustrates how these ranges of values can be applied to the recommended design fires in the national guidelines.

Table 6: The relation between recommended fire scenarios an grid cell size.

Scenario	Occupancy	HRR (MW)	D* (-)	Grid cell size (m)		Critical room height (m)	Max grid cell size at high room heights (m)
				Min	Max		
High stress fire scenario 1	Offices, schools	5	1.8	0.09	0.18	3.7	0.12
	Dwelling, hotels, and healthcare facilities	5	1.8	0.09	0.18	3.7	0.12
	Assembly halls	10	2.4	0.12	0.24	4.8	0.16
Robustness fire scenario 3	All occupancies	2	1.3	0.06	0.13	2.5	0.08

Sprinkler controlled fires develop generally a low HRR. Since D* is depending on the HRR, the demand for fine grid cells will be very high. E.g a sprinkler controlled fire of 700 kW should have grid cells of 4-8 cm to fulfill the criteria of D*/δx. This introduces a practical problem since it would put a very high demand on the calculation capacity (processor speed, RAM etc.). The recommendation is in the best practice is therefor to use the grid cell size of the robustness scenario in order to meet a reasonable simulation time as well as reliable results.

The purpose of the recommended grid cell sizes in the fire grid is to resolve the fire plume properly. However, the best practice does not give any recommendation for size of the volume that the fire grid should cover. Reasonably the plume itself should be covered within the fire grid. However, grid boundaries should not connect where high velocity gradients are expected. Thus, there is no further recommendation given for the size of the fire grid. Though, the best practice group did agree on that if the horizontal dimensions of the fire grid are the same size as the room height, reasonable results should be achieved. In rooms with a higher height this will generate a large, and probably an unreasonable, amount of grid cells in the fire grid. For areas outside the fire grid it is recommended that the grid cells are kept within a multiple of 2 or 3 of the recommended values in Table 6.

Example cases

Example cases based on the recommended fire scenarios and information above are summarized in this chapter. Due to many of the parameters are dependent on each other, e.g. the SPREAD_RATE value must be revised if the HRRPUA is altered.

Table 7 illustrates different examples of how the recommended fire scenarios could be modeled in FDS. Sprinkler controlled fires are not included in the examples since the HRR at sprinkler activation is depending on scenario specific parameters such as RTI value, room height, sprinkler head spacing, activation temperature etc. For the robustness scenario is only a fast growing fire presented.

When creating the example cases, focus have been on fulfilling the applicable relation between the HRR and the fire perimeter ($\dot{Q}^*$). The size of the fire source is dependent on the chosen grid cell size. The fire source side length should also be covered by an odd umber of grid cells. The size of the grid cell has been chosen to fulfill the requirements for rooms with high room height.

Table 7: Examples on how to model the recommended scenarios

Scenario	Occupancy	HRR (MW)	Growth rate (kW/s^2)	Grid cell size (m)	Fire source side length (m)	HRRPUA (kW/m^2	SPREAD_RATE (m/s)
High stress fire scenario 1		5	0.012	0.100	2.500	800	0.002186
	Dwelling, hotels, and healthcare facilities	5	0.047	0.100	2.500	800	0.004326
	Assembly halls	10	0.047	0.125	3.375	878	0.004129
Robustness fire scenario 3	All occupancies	2	0.047	0.075	1.725	672	0.004720

Radiation

The best practice recommends that the radiation model in FDS is not used to evaluate radiant intensity against evacuees. Such a use would require a number of sensitivity analyses on the grid cell size and the number of solid angles in the radiation model. Nevertheless, the recommendation is to keep the radiation model active to resolve the energy balance more correctly. Since the recommended fire scenarios have a rather high soot yield, it is recommended to keep the default value in FDS for the RADIATIVE_FRACTION (i.e. 0.35).

Building geometry

When performing an ASET- analysis with FDS the building´s geometry should be adjusted to fit the grid cells in the computation domain. If an object is not located completely within grid cells, FDS will adjust the location/thickness of the object so it will fit the grid. This recommendation is more evident when creating objects that have a certain and important surface, such as the fire source or a smoke ventilator.

The best practice recommends that the user, as long as possible, should try specifying the material properties of the surrounding surfaces as close to real materials in the building as possible. But in some projects (especially early in the design process), the building components are unknown. In these cases, ADIABATIC or INERT boundaries should be used. Inert means that the boundary is kept at a specified temperature (default 20°C). The heat losses from the smoke layer, to the boundaries, will be high when using this boundary type. Adiabatic means that there are no heat losses to the boundaries.

Smoke ventilation

Natural ventilation

The flow through a smoke ventilator is driven by the buoyancy force and the compression of the airflow when passing through the opening. The compression is a phenomenon called, *vena contracta,* meaning the aerodynamic area is not the same as the geometrical area. to model this contraction properly in FDS, a fine mesh over the opening is required. The phenomenon is visualized in Figure 4. Different mesh sizes as well as different thickness of the slab will also most likely give different results on the mass flow through the opening. Larger grid cell size will generate a larger mass flow through the opening. Furthermore an infinitely thin slab will cause a smaller mass flow through the opening, than a thicker slab S

Since the mass flow through the opening appears to be dependent on the grid cell size, it is recommended that special care should be taken to analyse the required area of the smoke ventilator. Contraction factors of 0.6 for a horizontal and 0.68 for a vertical opening are suggested by Emmons [9] and may act as guidelines for the engineer.

To allow a natural flow through the opening, the computational domain, should be extended outside the opening The required extension of the domain needs, however, to be evaluated for each case. The same considerations should be taken to openings for make-up air.

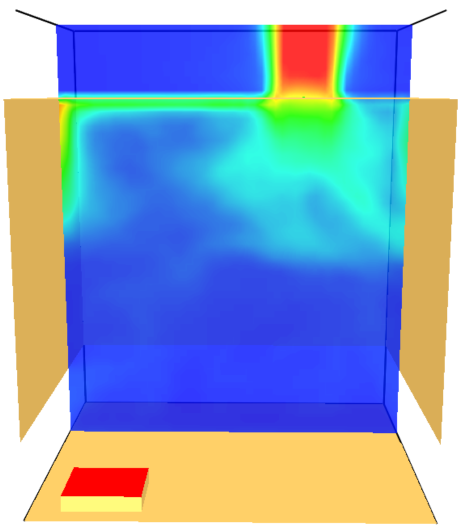

Figure 4: A simple room setup with smoke gas ventilation

Wind effects could have a major impact on the results. However, there are no recommendations on how to deal with wind effects in the guideline. It was just not enough resources in the work group to deal with the issues The user is referred to [10] for a more in-depth reading in this matter.

Mechanical extract

To simulate a mechanical smoke extraction, surface with a positive mass flux or volume flux should be used. The surface needs to be attached to a solid object.

All fans, used for smoke extraction, have a ramp-up time until full capacity is reached. This has to be considered in the ASET-analysis.

If the grid resolution is low, the consequences of plug holing could be missed when reviewing the results. Therefore the risk of plug holing should always be analyzed with hand-calculation methods in connection to a simulation. Example of hand-calculations is presented in [11].

Reviewing output data

Output data from FDS should be evaluated against the criterions for tenability. To meet the acceptable level criterions 1 or 2 and 3-6 have to be met.

Output data could be evaluated in several different ways and the best practice guideline gives certain recommendation on how to do this specific for visibility. The purpose of the recommendations being to minimize subjective estimates should be used when evaluating the data.

Visibility

Visibility could be evaluated by using a slice files, the statistics function in a volume or by point measurements.

The recommendation is that point measurements should not be used since they only measure the visibility in a single grid cell.

Using a time-averaged slice file of visibility 2 meters above the slab will give the user a good understanding when and where tenability occur. But, when presenting the results, the slice will only show the conditions at a single time step. A better way to present the time-dependence is by using the statistics function for a defined volume within the model. The recommendation is to define a volume near each egress route, being two meters high, extending three meters into the room and one meter on each side of the egress route.

Other criterions

Heat exposure will rarely be the critical criterion. Critical levels usually only occur near the fire source. Hand-calculation methods could be used for this analysis.

The temperature criteria could be evaluated using the same method as when evaluating visibility.

Toxicity could be evaluated using point measurements. To analyze this, the measuring points are recommended to be located in vicinity to the egress routes, 2 meters above the slab, and 2 meters into the room.

Other parameters to review

It is also recommended that the user controls and documents that the HRR in the FDS simulation coincide with the desired design HRR. The user should also check that the fire has not become ventilation controlled in the simulation.

Mass flows and velocities should be reviewed over e.g. openings to verify that reasonable values are reached.

To verify that the results are grid independent, a grid sensitivity analysis could be performed. But, if the recommended values of the grid cell sizes presented in this paper are used, the recommendation is that no further analysis of the fire grid is required. A sensitivity analysis may however be appropriate if grid cells larger than 3x the fire grid size is used for the surrounding grids. This statement has, however, not been verified and is only based upon the experience from previous simulations that the members of the best practice group have done.

CONCLUSIONS AND FURTHER WORK

One of the major benefits of the new best practice guidelines is that clients will get more consistent recommendations independent of which fire engineer they choose. It will also simplify the control performed by the authorities and make the entire process more transparent. There is, however, always a disadvantage of publishing guidelines like the one presented in this paper. A user might be able to run the fire model without the proper knowledge and understanding of the models limitations. The user might even be able to fulfil the recommendations given in the guideline. That will, however, not guarantee the right quality of the work. E.g. the results of the simulations are not useful if the design fire is chosen incorrectly.

It is also important to note that the guidelines are not written from the perspective on how to properly model fire. They are written with a designer´s perspective, about how the defined requirements in the building regulations should be met.

There is no current activity in further development of the best practice guide. However, the document should be updated with aspects concerning FDS 6. Such aspects could be how to analyze and evaluate the turbulent resolution in the domain and rework the chapter concerning grid cell sizes and computational domain. Since the new turbulence model, a form of Deardorff model is introduced in FDS 6 the requirement on adequate grid cell size has changed. Grid cells are expected to be able to be coarser while maintaining the precision in the results.

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